TASK
1

MUNICIPAL SOLID WASTE TO LIQUID FUELS STUDY

Port of Seattle + King County Solid Waste Division

Report Name:
Task 1 – Conversion Technologies Evaluation

2023-06-30

prepared by

EXP
451 Montgomery Street, Suite 300 | San Francisco, CA 94104
Principal, Marcos Souza: marcos.souza@exp.com
Project Manager, Joseph Gale: joseph.gale@exp.com

TABLE OF CONTENTS

TABLE OF CONTENTS

CONTINUED

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

- **AMA** – Advanced Methanol Amsterdam
- **ASTM** – American Society for Testing and Materials
- **ATJ** – Alcohol-to-jet
- **ATJ-SPK** – Alcohol to Jet Synthetic Paraffinic Kerosene
- **BHS** – Bulk Handling Systems
- **bpd** – Barrels per day
- **BTL** – Biomass to Liquid
- **CCS** – Carbon Capture and Storage
- **CEPCI** – Chemical Engineering Plant Cost Index
- **CO** – Carbon monoxide
- **CO_2** – Carbon Dioxide
- **FT** – Fischer-Tropsch
- **FT-SPK** – Fischer-Tropsch Synthetic Paraffinic
- **FT-SPK/A** – Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics
- **GHG** – Greenhouse gas
- **GTL** – Gas-to-liquids
- **H_2** - Hydrogen
- **HEFA** – Hydro-processed Esters and Fatty Acids
- **HTW** – High Temperature Winkler
- **HVO** - Hydrotreated Vegetable Oil
- **ICAO** – International Civil Aviation Organization
- **KC** – King County
- **kWh** – Kilowatt Hours
- **LCFS** – Low Carbon Fuel Standard
- **MIT** – Massachusetts Institute of Technology
- **mm** – Millions
- **mmgpa** – Million Gallons per Annum
- **MRF** – Material Recovery Facility
- **MSW** – Municipal Solid Waste
- **mt** – Metric Ton
- **mtpa** – Metric Tons per Annum
- **OLCV** – Oxy Low Carbon Ventures, LLC
- **PEM** – Polymer-electrolyte Membrane
- **PNW** – Pacific Northwest
- **POS** – Port of Seattle
- **PPI** – Proton Power, Inc.
- **RDF** – Refuse Derived Fuel
- **RFS** – Renewable Fuel Standard
- **RINs** – Renewable Identification Numbers
- **RNG** – Renewable Natural Gas
- **RSB** – Roundtable on Sustainable Biomaterials
- **RWGS** – Reverse Water Gas Shift
- **SAF** – Sustainable Aviation Fuel
- **SEA** – Seattle-Tacoma International Airport
- **SFW** – Sumitomo SHI FW
- **SMDS** – Shell Middle Distillate Synthesis
- **Syncrude** – Synthetic crude
- **Syngas** – Synthetic gas
- **TIC** – Total Investment Cost
- **TRL** - Technology Readiness Level
- **USEPA** – United States Environmental Protection
- **WSU** – Washington State University

exp.

1

TASK 1 – CONVERSION TECHNOLOGIES EVALUATION

1. Task 1 - Conversion Technologies Evaluation

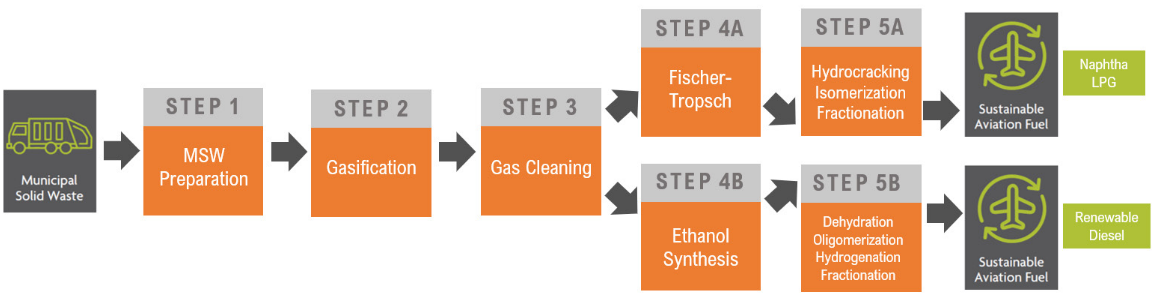
1.1. Executive Summary

Task 1 evaluates commercially viable technologies for the conversion of solid waste to liquid fuels, with an emphasis on Sustainable Aviation Fuels (SAF). Throughout this task, various technologies were evaluated to determine applicable Technology Readiness Levels (TRL), the suitability of the Municipal Solid Waste (MSW) feedstock that can be provided, technology and relevant infrastructure space requirements, performance parameters, potential products and by-products, and associated effluents and emissions.

The ASTM International's D7566 "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons" has approved three applicable pathways for solid waste to fuel conversion: Annex 1 (FT-SPK), Annex 4 (FT-SPK/A) and Annex 5 (ATJ-SPK.

Suitability of MSW Feedstock

To determine the feasibility of MSW for SAF production, it is necessary to understand its composition and processes for conversion. MSW is a heterogeneous mixture of materials. The two-dimensional character of plastic films and textiles makes grinding into dust-size particles almost impossible, limiting the commercially available gasification technologies to fluidized bed gasifiers. Two conversion technologies for MSW to jet fuel include the Fischer-Tropsch (FT) technology and Alcohol-to-Jet (ATJ) fuel process.



Commercial-Readiness

The Fischer-Tropsch technology for fuel production is well-established when receiving feedgas from natural gas reforming or coal gasification, however; the pathway for feedgas from MSW gasification has not yet reached a commercially viable maturity level. Fulcrum is the first commercial plant using MSW as feedstock for the Fischer-Tropsch process. In 2022, the plant was commissioned. The long-term operational results are not yet available, regarding the flexibility of the FT catalyst for fluctuations in MSW and subsequent feedgas composition. Other MSW-to-fuel plants either produce syngas only or convert syngas into methanol (GIDARA) or ethanol (Enerkem), avoiding the complex Fischer-Tropsch process.

Axens and LanzaJet have developed ethanol-to-jet fuel conversion technologies; all process steps have proven successful in the demonstration, as well as in commercial plants. In the summer of 2022, ExxonMobil applied for approval of methanol as feedstock for the ATJ pathway. Enerkem is also working on a methanol-to-jet fuel process. Fermentation as an alternative to catalytic conversion of syngas into alcohols is also gaining attraction. Both Axens and LanzaTech have developed microbes that process syngas and produce ethanol; however, most applications in demonstration or large-scale plants for processing of syngas derived from MSW are still outstanding.

A commercial application for processing MSW-to-jet fuel should focus on the robustness of the chosen pathway, technologies, and vendors with relevant operational and maintenance experience. Improvements in first operational plants may lead to significant energy savings and yield increases.

Currently, a fluidized bed gasifier followed by Fischer-Tropsch synthesis and hydrocracking is the most mature process covering the full chain from MSW to SAF. Enerkem demonstrated the robustness of the catalytic syngas to ethanol route in its Edmonton, Canada plant. Syngas fermentation has only been demonstrated for steel plant off-gases. The first pre-commercial and commercial units for the ATJ route, converting ethanol into SAF, are expected to start up in the 2023/2024 timeframe.

The MSW to alcohol conversion followed by the ATJ process seems to be a promising alternative to the Fischer-Tropsch route for large-scale plants soon and allows for increased flexibility regarding split locations.

The technology-readiness of the different pathways can be summarized as follows:

- **Commercially proven and ready:**
  - Fluidized bed gasifier followed by Fischer-Tropsch synthesis and hydrocracking.
  - Fluidized bed gasifier followed by catalytic conversion of syngas into alcohols.
- **Most promising, with a commercially viable option in five years:**
  - Hydroprocessing of alcohols to SAF (ATJ).
- **Long-term development (5-10 years):**
  - Fermentation of syngas into alcohols.

1.2. Introduction

The United States Environmental Protection Agency (EPA) determined the transportation sector to be one of the largest contributors to national greenhouse gas (GHG) emissions. As a leader in the mission to decarbonize the transportation sector, the Port of Seattle (POS) established a goal for all flights at Seattle-Tacoma International Airport (SEA) to have a blend of 10 percent sustainable aviation fuel (SAF) by 2028.[1]

To evaluate potential paths for renewable fuel production, a study was performed by Washington State University (WSU) in 2020. The study assessed Pacific Northwest (PNW) regional feedstock availability and quality, compared cost of various conversion methodologies, and performed a siting analysis. It concluded MSW is an abundant and viable feedstock option for liquid fuel conversion. The International Civil Aviation Organization's (ICAO) predicted 4.3% annual growth of jet fuel demand, the estimated demand for sustainable aviation fuel at Seattle-Tacoma airport in 2028 will be 75 million gallons per annum (mmgpa) or 250,000 metric tons per annum (mtpa). This demand can be covered by a facility with an SAF production capacity of approximately 5,400 barrels per day (bpd).[2]

The Port of Seattle and King County Solid Waste Division are now furthering this research with an emphasis on elements considered in the WSU study to include:

- Evaluation of feasible technologies for conversion of municipal solid waste and other solid waste into liquid fuels, in particular sustainable aviation fuel.
- Evaluation of existing waste feedstocks from the Cedar Hills Regional Landfill and populated regions of western Washington and Oregon.
- Identification and evaluation of potential facility siting locations.
- Identification and evaluation of models for project financing.
- Identification and evaluation of financial and logistical partnerships.
- Delivery of final recommendations.

The use of MSW as a feedstock for fuel production can reduce the amount of methane formed through decomposition of landfill waste, reduce the further expansion of landfill sites, and provides a steady stream of feedstock supply. This report evaluates the feasibility of directing municipal solid waste and other material received in King County and other regional (western WA and OR) solid waste facilities to a potential sustainable fuel production facility. This joint initiative funded by the Port of Seattle and King County Solid Waste Division intends to achieve both entities' goals of greenhouse gas emission reduction, economic vitality, and waste reduction. The study provides insights into the potential costs and benefits from building and operating a renewable fuel production facility that uses regionally generated MSW.

1 USEPA (2023, April 28). US Environmental Protection Agency, Sources of Greenhouse Gas Emissions. Retrieved from: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#:~:text=Greenhouse%20gas%20emissions%20from%20transportation,ships%2C%20trains%2C%20and%20planes.

2 Port of Seattle and WSU (2020, February). Port of Seattle and Washington State University, Potential Northwest Regional Feedstock and Production of Sustainable Aviation Fuel. Retrieved from: https://www.portseattle.org/sites/default/files/2020-08/PofSeattleWSU2019updated_appendix.pdf.

1.3. SAF Production

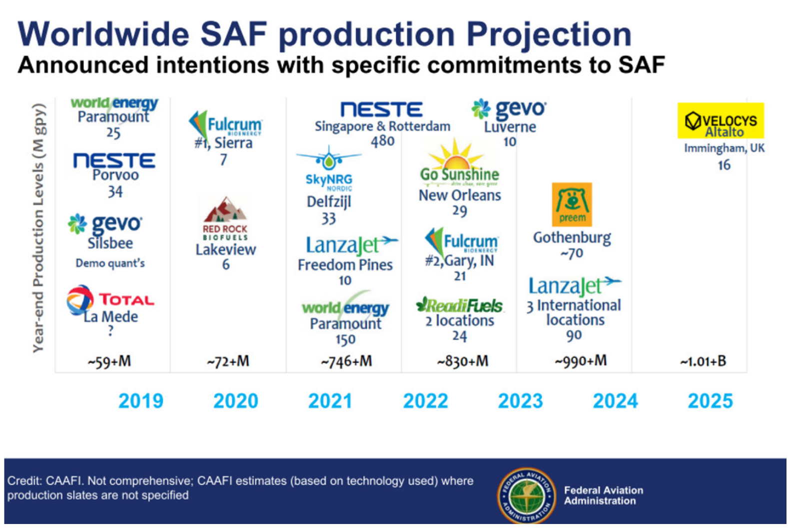
The ASTM International approved seven conversion processes for SAF production as of June 2023.[3] This section evaluates commercially viable technologies for the conversion of solid waste to liquid fuels. Vendor technologies were assessed to determine applicable Technology Readiness Levels (TRL), the suitability of the MSW feedstock, technology, and relevant infrastructure space requirements, performance parameters, potential products and by-products, and associated effluents and emissions. Task 1's findings involve the comparison and recommendation of vendor technologies for the creation of a sustainable fuel production plant that uses sustainable resources in the Pacific Northwest region.

The ASTM D7566 *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons* has approved production pathways for SAF as a drop-in fuel and blending limitations.

This section reviews commercially viable conversion technologies for SAF production. Most renewable fuel production plants utilize vegetable oils from crops such as canola, sunflower, or soybeans as feedstock that compete against usage as food. The growth of these feedstocks requires valuable resources such as water and land, with negative externalities linked to carbon intensity using agricultural equipment and additional fertilizers. Consequently, many countries have prohibited the use of feedstocks that fall under the 'fuel versus food' debate as a source for fuel production. The industry has shifted to recycling and reuse of materials that otherwise would end up in landfills or simply decompose e.g., MSW, wood residues, used cooking oils, tallow, or forestry waste, etc. Based on IATA's research, over 130 relevant renewable fuel projects have been announced publicly by more than 85 producers across 30 countries. Importantly, each of these projects have either announced the intent or commitment to produce SAF within their wider product slate of renewable fuels.

The announced capacity of 69 billion liters is equivalent to 182,280 million gallons per year. Table 1.1: Worldwide SAF Production Projection[4]

Table 1.1. Tracking Renewable Fuel Capacity



1.4. Waste to Biofuels Conversion Technologies

The ASTM D7566 approved three pathways suitable for solid waste to fuel conversion: Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK), Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics (FT-SPK/A), and Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK). Each pathway has a blending limitation of up to 50 percent, as shown in **Table 1.2.**

3 ICAO (2023, April 9). International Civil Aviation Organization, Environmental Protection, GFAAF, Conversion Processes. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx#:~:text=Annex%2016%20Vol%20IV%20defines,approved%20by%20the%20ASTM%20International.

4 IATA (2023). International Air Transport Association, Media Briefing Update on Sustainable Aviation Fuels (SAF), Annual General Meeting 2023. Retrieved from: https://www.iata.org/en/iata-repository/pressroom/presentations/sustainable-aviation-fuel-agm-2023/.

FT-SPK and FT-SPK/A are both based on Fischer-Tropsch synthesis using syngas from MSW gasification followed by hydro-processing into jet fuel, diesel, and naphtha. ATJ-SPK consists of hydro-processing alcohols from renewable sources to create SAF and diesel.

Table 1.2: Overview of Pathways Incorporated as Annexes of D7566[5]

Annex	Code	Technology	Feedstock	Max. Blend
A1	FT-SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene of syngas generated from gasification of MSW or biomass	Biomass, MSW	50%
A2	HEFA-SPK	Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene	Plant and animal fats, oils, and greases	50%
A3	HFS-SIP	Hydroprocessed Fermented Sugars to Synthetic Isoparaffins	Sugars	10%
A4	FT-SPK/A	Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics, alkylation of light aromatics after FT synthesis	Biomass, MSW	50%
A5	ATJ-SPK	Alcohol (usually ethanol or iso-butanol) to Jet Synthetic Paraffinic Kerosene by dehydration followed by oligomerization, hydrogenation and fractionation	Alcohols derived from cellulosic biomass, starch/sugar, waste streams or circular economy byproducts	50%
A6	CH-SK, or CHJ	Catalytic Hydrothermolysis Synthesized Kerosene	Fatty acids, lipids coming from plant and animal fats, oils, and greases	50%
A7	HC-HEFA-SPK	Synthesized paraffinic kerosene from bio-derived hydrocarbon-hydroprocessed esters and fatty acids	Oils produced by the Botryococcus braunii algae	10%

1.4.1. Fischer-Tropsch Pathways

MSW to jet fuel production using Fischer-Tropsch (FT) technology, as shown in Figure 1.1, is based on the following process steps:

→ **Step 1 – MSW Preparation:** MSW arriving at a landfill is sorted to extract the usable portion for fuel production, which is mainly organic material such as wood, paper, non-recyclable plastics, rubber, and textiles. An automated Material Recovery Facility (MRF) is recommended for best sorting results as it also allows for the recovery of valuable materials such as glass, metals, or plastics that can be recycled, and food residues for composting. Pursuant to Renewable Fuel Standard (RFS) regulations, MSW-derived feedstock may qualify as renewable biomass and be used in renewable fuel production pathways authorized for the generation of Renewable Identification Numbers (RINs).

The remaining portion of MSW that is suitable for fuel production, Refuse Derived Fuel (RDF), will either be shredded, pelletized, or milled into fine particles, depending on the type of gasification.

→ **Step 2 – Gasification:** Gasification is a process that converts organic or fossil-based carbonaceous materials into synthesis gas, which mainly consists of carbon monoxide, hydrogen, and carbon dioxide, at high temperatures, without combustion, using a controlled amount of oxygen and/or steam. The two most common types of gasifiers for solid waste and biomass gasification are fluidized bed and entrained flow reactors. Fixed bed reactors and plasma gasification are not yet commercially viable for this application, in part due to scaling issues.

→ **Step 3 – Gas Cleaning and Conditioning:** The synthesis gas (syngas) leaving the gasifier is cleaned of ash, tar, and other impurities which would otherwise act as catalyst poison for downstream processes. These impurities are catalytically converted or washed out. The synthesis gas leaving the gasifier is then conditioned to meet the required hydrogen to carbon monoxide ratio for FT synthesis.

5 USDOE (2023). US Department of Energy, Alternative Fuels Data Center, Sustainable Aviation Fuel, SAF Production Pathways. Retrieved from: https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html.

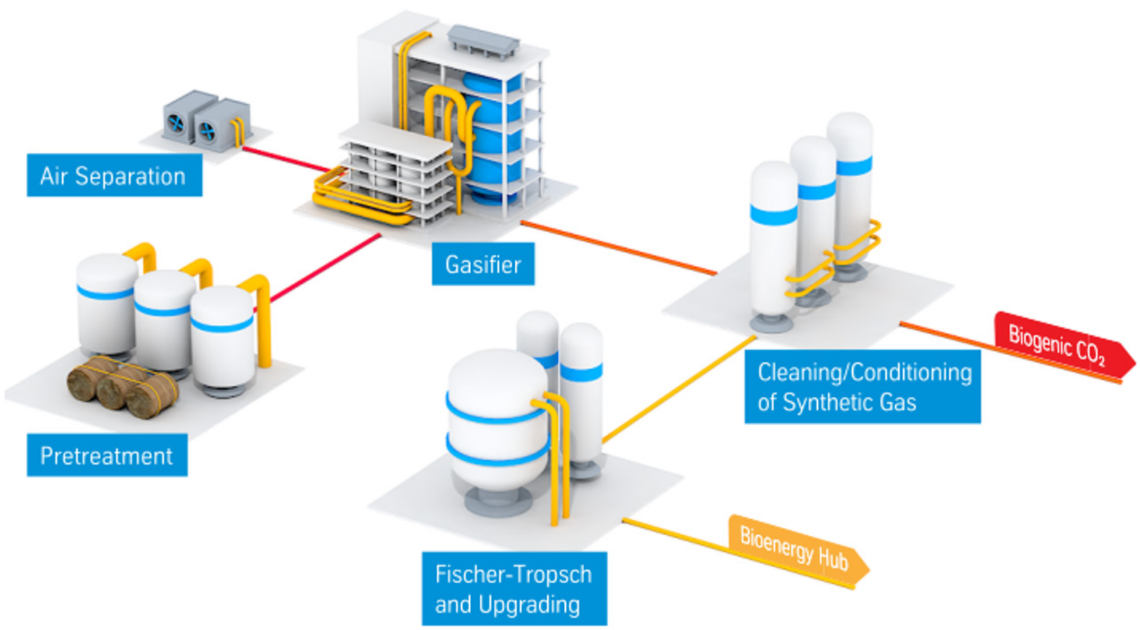
→ **Step 4 – Fischer-Tropsch Synthesis:** The FT process is a catalytic conversion of light hydrocarbons and hydrogen into longer chain hydrocarbons which can be utilized as synthetic crude (syncrude) and further processed into renewable fuel as described in Step 5 below. These FT reactions occur in the presence of metal catalysts (i.e., cobalt and iron-based), typically at temperatures between 150–300 °C (302–572 °F) and pressures of one to several tens of atmospheres. Recently, this process has been modified by several developers to better meet the requirements for diesel and jet fuel production.

Since the FT process is highly exothermic, heat removal is an important factor in technology design. The three types of reactors developed for commercial scale operations are:

- Fixed bed reactor
- Fluidized bed reactor
- Slurry bed reactor

→ **Step 5 – Hydrocracking, Isomerization, and Fractionation:** The Syncrude generated in the FT process is upgraded in a hydrocracker/isomerization unit and separated in a fractionator into the final products. Typical product split for FT Syncrude, designed for maximum diesel and/or jet fuel output, is 80% diesel or SAF, 15% naphtha, and 5% liquid.

Figure 1.1: Waste-to-Fuel Pathway via FT Synthesis[6]



1.4.2. Alcohol-to-Jet Fuel Pathway

An alternate approach to SAF production is the Alcohol-to-jet (ATJ) pathway. In 2018, the ASTM approved ASTM D7566 Annex A5, adding ethanol as a qualified feedstock for ATJ pathways. The qualification was determined by 'fit for purpose' data submitted by LanzaJet™, formerly LanzaTech, and is now considered the Alcohol-to-jet process. The ATJ pathway is applicable to all sources of ethanol, whether first-generation (sugarcane, corn, typically low carbon intensity preferred) or waste-based ethanol (produced from a variety of materials including MSW, forest residues, agricultural residues, wood waste, industrial off-gases, and CO_2 from industrial sources or direct air capture).

The ATJ process converts MSW to ethanol and then Sustainable Aviation Fuel using catalytic steps. After MSW sorting and gasification as the first process steps, the syngas can either be biologically fermented (e.g.-LanzaTechTM Gas fermentation) or catalytically converted into ethanol or other alcohols (e.g., Enerkem). The ATJ pathway in ASTM D7566 Annex A5 currently only allows ethanol (LanzaJet Inc. and others) or iso-butanol (Gevo Inc.) as inputs, whereas the application for methanol is still unapproved and ongoing.

6 Thyssenkrupp (2020). Uhde Entrained Flow Gasification Brochure.

The ATJ annex does not limit the source or technology used to produce the ethanol or iso-butanol feedstocks for SAF.

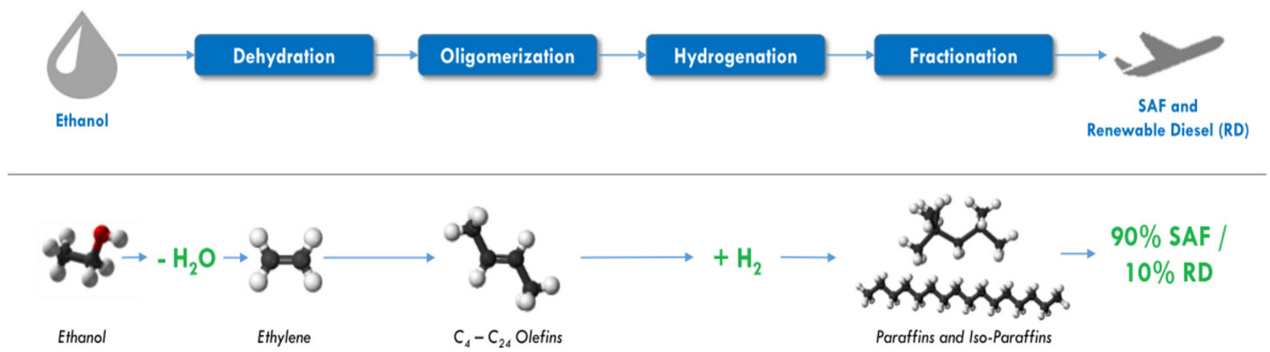
The benefits of this pathway are a possible split of the process into ethanol production and ethanol-to-SAF production at different locations using a hub and spoke model. This allows multiple waste to ethanol production units located near waste sources to feed larger ATJ units processing a variety of ethanol sources to attain a larger economy of scale and avoids the transport of waste feedstocks.

The ATJ fuel pathway consists of a four-stage catalytic process, illustrated in **Figure 1.2**:

- **Stage 1:** Dehydration of ethanol into ethylene
- **Stage 2:** Oligomerization of ethylene into jet-range and other olefins
- **Stage 3:** Hydrogenation of olefins into paraffins and iso-paraffins
- **Stage 4:** Fractionation into SAF (SPK or synthetic paraffinic kerosene) and renewable diesel (SPD or synthetic paraffinic diesel)

Plant design may be configured for production purposes. For example, if maximum SAF output is desired, the plant may be designed for a resulting product slate of up to 90% SAF and 10% renewable diesel. Certain ATJ technologies produce other by-products such as Naphtha, Propane, etc.

Figure 1.2: Alcohol to Jet Fuel Process[7]



1.5. Critical Components

The Fischer-Tropsch (FT) synthesis and ATJ fuel pathway processes as described above include several critical components which require more detail to understand the evaluation criteria for the various technologies and vendors:

- MSW Sorting and Preparation
- Gasifier
- FT Reactor
- Fermentation Reactor
- Hydro-processing

1.5.1. MSW Sorting and Preparation

The FT and ATJ processes require feedstock suitable for gasification. The gasification process consists of the conversion of hydrocarbons into carbon oxides and hydrogen. This is enabled by using the organic portion of the MSW.

7 LanzaJet (n.d.). LanzaJet Presentation, *Company Overview.*

Mechanical sorting of the solid waste arriving at a landfill into RDF and the remaining waste is the first step followed by a drying and shredding or grinding of the RDF. The moisture content of MSW typically ranges between 40 and 50%, and the mechanically sorted RDF still has a moisture content of up to 30%. To avoid energy losses in gasification, RDF should be dried to a moisture content of 10-15%.

Gasifier technology vendors recommend that less than 1.5% of the MSW feedstock consist of non-organic materials. High-production MRFs are best suited for this task, as shown in **Figure 1.3.**

Figure 1.3: High Production Single Stream MRF[8]

1.5.2. Gasifier

This section provides an overview of fluidized bed and entrained gasifiers and discusses the special design of the gasifier supplied by ThermoChem Recovery International (TRI).

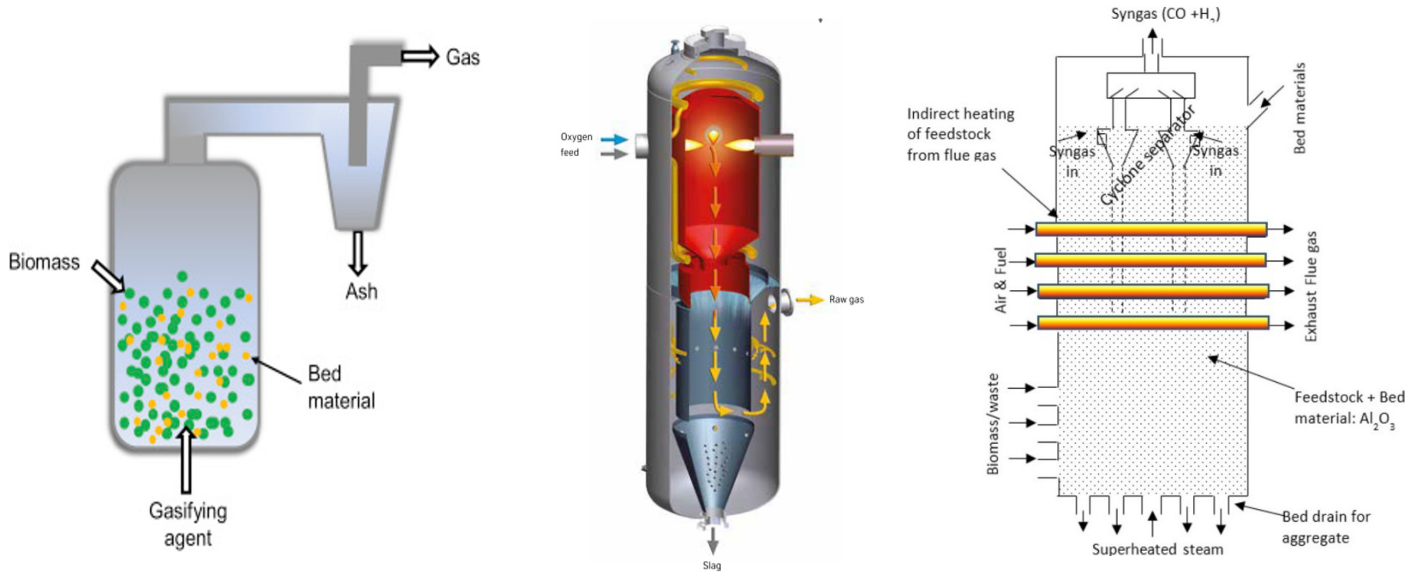
Fluidized bed and entrained flow gasifiers are most frequently used for solid waste gasification, as shown in **Figure 1.4.** According to a report published by the Massachusetts Institute of Technology (MIT), a fluidized bed gasifier has a lower cost than entrained flow gasification. The lower operating temperatures of a fluidized bed gasifier (ranging between 650 - 950° C) compared to an entrained flow gasifier triggers tar formation in the former. As a result, tar removal is a required process. A thermochemical removal is more costly than scrubbing but is better suited to obtaining the low tar levels required for FT synthesis.[9] Biomass and MSW can be conditioned and fed into a fluidized bed reactor as the residence times are sufficient for complete gasification.

The second-generation fluidized bed gasifiers have a second process step either integrated into the gasification reactor itself or as a separate partial oxidation reactor. In the second step, oxygen is blown into the reactor to increase the temperature to above 1100° C, converting tar and methane into carbon oxides and achieving a significant increase in overall carbon conversion and efficiency. This step elevates the efficiency and minimizes the process performance disadvantages compared to the entrained flow gasification. The fluidized bed gasifier produces ash that is separated from the syngas by cyclones and can later be used for industrial purposes or dumped. The non-organic and non-volatile portion of the feedstock is separated simultaneously.

An entrained flow gasifier operates at higher temperatures of 1300 – 1600° C and produces only slag. Slag is non-bleachable and can be sold and used in construction. Feedstock entering this type of gasifier must be pulverized to 0.1 mm, otherwise it will not be fully gasified due to the short residence time in the gasifier. Biomass/wood waste can be milled after torrefaction. MSW preparation for feeding into an entrained flow gasifier is not available and requires further research and development – one vendor sees cryogenic milling as the only currently available but costly technique.

8 MRF Economics (2018). Presentation at 36th Annual Conference of Michigan Recycling Coalition.
9 Barrett, S., Field, R., Herzog, H., Lu, X., Malina, R., Seifkar, N., & Withers, M. (2015). *Biomass to Liquid Fuels Pathway:* A Techno-Economic Environmental Evaluation. Cambridge: MIT. Retrieved from: https://sequestration.mit.edu/bibliography/BTL%20final%20compiled.pdf

Figure 1.4: Fluidized Bed, Entrained Flow, and TRI Gasifiers



Bubbling fluidized bed gasifier[10] Entrained-flow gasifier[11] TRI Gasifier[12]

The TRI gasifier is a type of fluidized bed gasifier that uses aluminum oxide bed material with utilized steam as the fluidization agent. The recycled aluminum oxide already has pyrolysis temperature when the feedstock is introduced, accelerating the pyrolysis process significantly. The bed moves upwards and is indirectly heated by hot flue gas. During this second step of the reaction, almost all carbon is converted into syngas. Cyclones in the upper reactor area separate non-converted material and aluminum oxide from the syngas and return solids back to the bottom. Solids recycling in the reactor leads to high carbon conversion and utilization rates of materials, even those regarded as difficult to convert. A lock hopper system at the bottom discharges ash, metals, and other non-carbon materials.

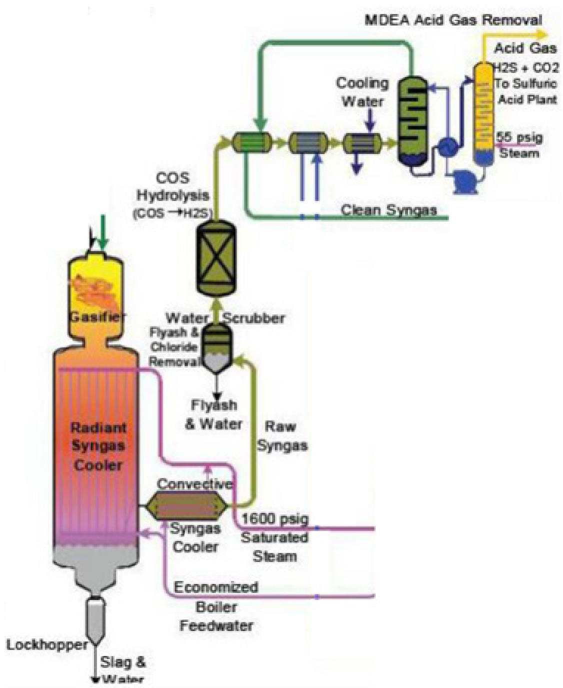
1.5.3. Gas Treatment and Conditioning

FT catalysts are highly sensitive to catalyst poisons and therefore, catalyst lifetime may be shortened significantly when contaminated. Sulfur and other catalyst poisons such as chlorine or mercury must be removed from the syngas before entering FT synthesis. The cleaning steps depend largely on the MSW composition and the expected concentration of impurities in the syngas. A detailed analysis of the MSW is required prior to the commencement of design work. Design contingencies should be sufficient to cover fluctuations in the feedstock composition. A typical gas treatment after gasification is shown in **Figure 1.5.**

Acidic gases like CO_2 are typically washed out by physical or chemical absorption solutions and recovered in concentrations of 99+% for further processing (i.e., compression or liquefaction) and use or released into the atmosphere. For higher sulfur levels, a combined sulfur and CO_2 absorption system can be designed with separate sulfur and CO_2 recovery. Sulfur, in lower concentrations and more common in MSW, and other impurities are typically removed catalytically. The loaded catalysts are either sent for recovery or dumped.

10 Bermudez, J.M., & Fidalgo, B. (2016). *Handbook of Biofuels Production* (2nd ed.). Woodhead Publishing.
11 Thyssenkrupp (2020). Uhde Entrained Flow Gasification Brochure.
12 Bhaskar, T., Krishna, B., Perkins, G., Shahabuddin, M., Tanvir Alam, Md. (2020). *A review of the production of renewable fuel from the gasification of biomass and residual waste.* Bioresour Technol. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7255753/.

Figure 1.5: Typical Gas Cleaning Configuration (Modified for this Report)[13]



Technology providers and engineers for gas processing such as Linde, Air Liquide, Axens, UOP, etc., should be consulted for the gas cleaning steps if the FT licensor does not include it in their package. This process section is tailor made for each application.

The Fischer-Tropsch reaction requires a syngas with an H_2:CO ratio of approximately 2.0. The typical syngas from a gasification unit has a lower ratio of 0.6 to 1.0. The missing hydrogen can either be produced by a water shift reaction where steam reacts with carbon monoxide to form hydrogen and carbon dioxide, or hydrogen can be added separately, either by hydrogen delivery over the fence from adjacent refineries or from gas suppliers, from conventional hydrogen production by autothermal reforming or by steam reforming, or preferably producing renewable hydrogen to avoid negative carbon intensity effects. Depending on the selected gasifier technology, the oxygen by-product produced in a water electrolysis plant may be sufficient to cover the oxygen demand of the gasification process. The syngas conditioning via hydrogen generated from renewable sources reduces the CO_2 emissions significantly. Produced CO_2 can either be captured for utilization or sequestration, or it can be converted into carbon monoxide in a reverse water gas shift (RWGS) reaction.

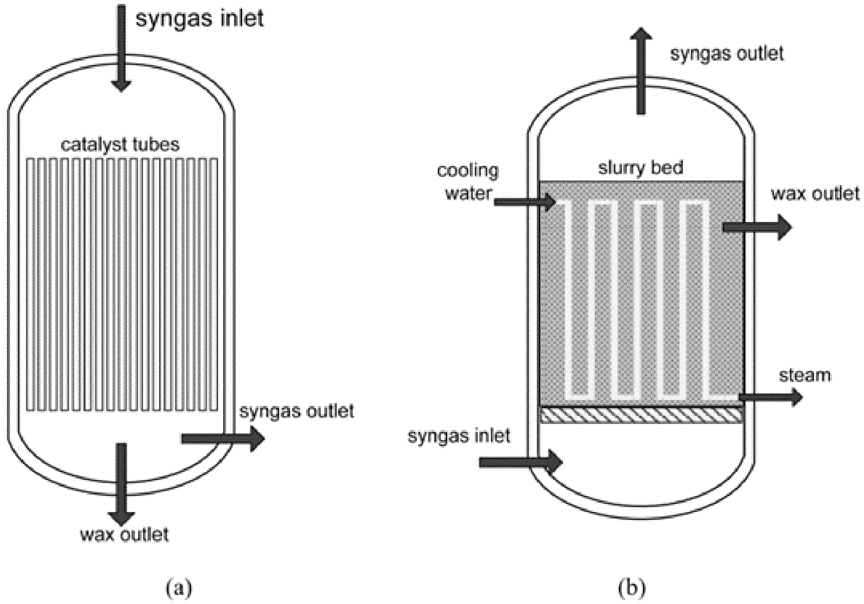
Similar gas cleaning steps are required in the ATJ pathway for the catalytical syngas-to-alcohol process. The vendors for syngas to ethanol fermentation plants claim that the microbes are more robust towards impurities than catalysts and require a simpler gas treatment prior to feeding the syngas into the fermenter. The microbes can handle a wide range of H_2-CO-CO_2 ratios. The carbon utilization rate increases with higher hydrogen content in the syngas or by adding external hydrogen.

1.5.4. Fischer-Tropsch Reactor

The most common reactor types in commercial operations for FT synthesis are fixed bed and slurry bed reactors. Slurry bed reactors are the preferred reactor type for low-temperature FT processes as required for SAF production; they offer better temperature control and higher conversion rates. Based on fixed-bed technology, vendors of new reactor developments promise to reach similar or better performance than a slurry bed reactor. These reactor types have been applied in new projects and are also discussed in this section. Proof of their performance is expected in the near future once the plants are fully commissioned and have operated for a while.

13 NETL (n.d.). National Energy Technology Laboratory, Commercial Technologies for Syngas Cleanup, Section 6.1. Retrieved from: https://netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/syngas.

Figure 1.6: Fischer-Tropsch Reactor Types, (a) Fixed Bed and (b) Slurry Bed Reactor[14]



Velocys developed a proprietary Microchannel FT Synthesis Reactor to reduce reaction volume to 1/10 compared to conventional technology. The process removes the reaction heat with integrated microchannels by boiling the water, and accelerating the reaction time with a highly active catalyst. The FT synthesis reactor and the associated facility can be downsized and easily modularized, shortening the construction period.[15]

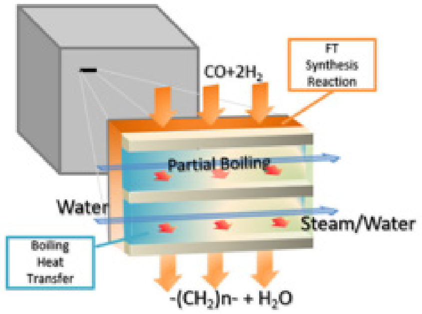


Figure 1.7 – Velocys Microchannel FT Synthesis

Johnson Matthey developed a novel catalyst carrier device to fit inside a tubular reactor for the use of smaller catalyst particles. A reactor tube contains 60–80 CANS catalyst carriers and creates mini-adiabatic radial flow reactors with intercooling. The radial flow through each catalyst carrier enables the use of smaller catalyst particles which provide improved selectivity and activity.

The modular design of a CANS catalyst carrier enables greater flexibility in commercial applications. It can also be loaded with different catalysts at the top or the bottom to address any performance deficiency.[16]

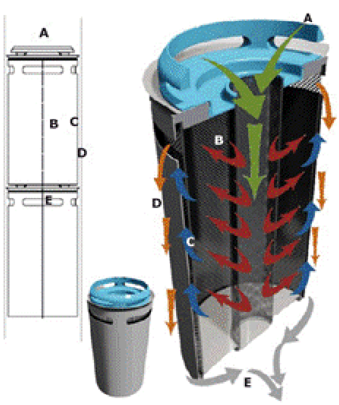


Figure 1.8: Johnson Matthey CANS® Reactor[17]

1.5.5. FT Catalysts

Several different catalysts have been developed for Fischer-Tropsch synthesis. A cobalt catalyst and a slurry reactor are preferred for maximum diesel or SAF production. If maximizing the gasoline product fraction, an iron catalyst at a high temperature in a fixed

14 Brown, R., Hsu, D., Platon, A., Satrio, J., & Swanson, R. (2010). *Techno-Economic Analysis of Biofuels Production Based on Gasification*. NREL/TP-6A20-46587. Retrieved from: https://www.nrel.gov/docs/fy11osti/46587.pdf.

15 Kojima. Y. (2022, March 28 – 30) *Production of Sustainable Aviation Fuel from woody biomass by gasification – FT synthesis technology – successful demonstration to fly a commercial flight.* Nitrogen + Syngas 2022 International Conference & Exhibition in Berlin, Germany.

16 Carter, S., Clarkson, J., Coe, A., Davies, S., Paterson, J., Peacock, M., Reed, L. 2020. Innovation in Fischer-Tropsch: Developing Fundamental Understanding to Support Commercial Opportunities. Top Catal 63, 328-339. Retrieved from: https://doi.org/10.1007/s11244-020-01239-6.

17 Coe, A., & Pearson, R. (2021). Innovation in Fischer-Tropsch: A Sustainable Approach to Fuels Production. *Johnson Matthey Technology Review*, 395-403. Retrieved from: https://technology.matthey.com/article/65/3/395-403/.

bed reactor is best.[18] Recently, new catalyst developments have led to reduced reactor volumes and improved activity.

1.5.6. Hydro-processing

1.5.6.1. Fischer-Tropsch Syncrude

FT products contain significant amounts of high-molecular weight wax. Hydrogen is required to crack these high-molecular-weight paraffins to low-molecular-weight hydrocarbons.[19] The typical hydro-processing steps for Fischer-Tropsch Syncrude include:

- **Step 1:** Hydrocracking/isomerization
- **Step 2:** Distillation/fractionation.

Hydrocracking/isomerization is a combination of two successive reaction steps: isomerization and cracking. Hydrocracking is the cracking of high-molecular-weight paraffins into low-molecular-weight hydrocarbons. Isomerization is the chemical process by which a compound is transformed into any of its isomeric forms, i.e., forms with the same chemical composition but with different structure or configuration and, hence, generally with different physical and chemical properties.[20] The degree of isomerization determines the cold flow properties of the fuel.

The catalysts used for the hydrocracking/isomerization step are typically noble metals combined with zeolites. The fuel leaving the hydrocracking/isomerization consists of a mixture of jet fuel, naphtha, and LPG. A distillation or fractionation finally separates the mixture into the final products. In the case of maximum SAF production, the split is about 80% jet fuel, 15% naphtha, and 5% LPG.

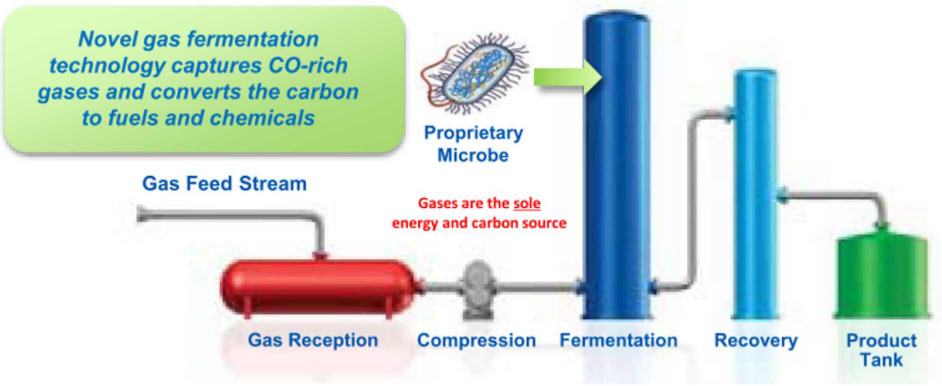
1.5.6.2. ATJ

The four-step hydro-processing for the alcohol-to-jet fuel pathway is explained in **Section 1.4.2**. These processes, a combination of catalytical steps, and a final distillation as thermal separation step, are well known refinery processes. The dehydration and oligomerization steps require special attention to avoid formation of unwanted hydrocarbon chain lengths.

1.5.6.3. Fermentation Reactor

LanzaTech and Axens have developed gas fermentation processes which convert hydrogen and carbon oxides containing syngas into ethanol. Microbes convert the syngas directly into ethanol and the used microbes are a good protein source for animal food and can be sold to market. The required syngas purification steps depend on the robustness of the microbes and are determined by the licensors but are generally less complex than for catalytical processes. Easy scale-up of the fermentation reactor is achievable.

Figure 1.9: LanzaTech Fermentation[21]



18 NETL (n.d.). National Energy Technology Laboratory, Fischer-Tropsch Synthesis, Section 10.2. Retrieved from: https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/ftsynthesis.

19 Brown, R., Hsu, D., Platon, A., Satrio, J., & Swanson, R. (2010). *Techno-Economic Analysis of Biofuels Production Based on Gasification*. NREL/TP-6A20-46587. Retrieved from: https://www.nrel.gov/docs/fy11osti/46587.pdf.

20 Britannica (n.d.). Britannica, Isomerization. Retrieved from: https://www.britannica.com/science/isomerization.

21 Simpson. (2017). LanzaTech Workshop.

1.6. Active Waste to Sustainable Fuels Projects

Renewable fuel projects developed in the early 2000's focused on ethanol production for blending into gasoline to decarbonize the ground transport sector. Renewable diesel projects were less attractive due to low oil prices and lack of subsidies or tax incentives. Second generation renewable fuels projects, mostly based on used cooking oil and tallow or animal fat (which is deoxygenated and hydrocracked), have been developed over the last ten years. The fuel is finally distilled and separated into renewable diesel, jet fuel, and LPG. This process is approved according to ASTM D7566, Annex A2 HEFA-SPK.

As discussed in **Section 1.4**, the conversion of municipal solid waste into renewable fuels following the Fischer-Tropsch process route is capital intensive and not competitive to the Hydro-processed Esters and Fatty Acids (HEFA) pathway without the appropriate regulatory framework and financial support. As a result, very few plants have been developed or are still in development utilizing either forestry and other woody waste or MSW as feedstock.

Another evolving process route is the conversion of solid waste into alcohols via gasification and fermentation or catalytic ethanol production followed by the conversion of alcohols into jet fuel. The ATJ route is ASTM D7566 approved as per Annex A5, ATJ-SPK for ethanol and iso-butanol. ExxonMobil recently applied for approval of a methanol-to-SAF process to be added to Annex A5.[22]

The following section describes projects with a full solid waste to SAF or renewable diesel chain, projects for the front end only, converting solid waste into syngas, hydrogen, or alcohols, and a project list for the ATJ route. Additionally, this section identifies SAF projects based on other processes with most based on HEFA processes according to Annex A2 of ASTM D7566.

1.6.1. Solid Waste to Sustainable Fuel Projects

1.6.1.1. Velocys

Velocys has roots in technology spin-offs developed at Oxford University and the Pacific Northwest National Laboratory, allowing the organization to license its technology to commercial projects.[23] Two projects are currently under development: Altalto, located in Immingham (the UK) in partnership with British Airways, and Bayou, an American project in Mississippi. Project Bayou targets biomass forest residue and enjoys additional environmental benefits through Carbon Capture and Storage (CCS) arising from an agreement with Oxy Low Carbon Ventures, LLC (OLCV). As a result, the Bayou facility will create net negative carbon intensity fuels.

Table 1.3: An Overview of SAF Production at Velocys

COMPANY	Velocys
General overview	Velocys developed its own FT catalyst and FT reactor. They license their technology and are developing their own projects together with partners. The FT catalyst and reactor have been proven in demonstration plants.
Production line	Gasification, FT, Hydro-processing
Feedstock type and quantity	MSW, 600,000 tpa Wood chips
Product type and quantity	SAF + naphtha: 20 mmgpa
Technologies used or announced	TRI gasifier Air Liquide gas treatment Velocys FT Haldor Topsoe hydro-processing
ASTM D7566 compliant, Annex:	Annex-1 compliant

22 Businesswire (2022, June 20). Businesswire, ExxonMobil Methanol to Jet Technology to Provide New Route for Sustainable Aviation Fuel Production. Retrieved from: https://www.businesswire.com/news/home/20220620005021/en/ExxonMobil-Methanol-to-Jet-Technology-to-Provide-New-Route-for-Sustainable-Aviation-Fuel-Production.

23 Velocys (n.d.). Velocys, Bringing sustainable fuels to life. Retrieved from: https://www.velocys.com/projects/.

COMPANY	Velocys
References / experience / ongoing projects	a. Toyo / Velocys Demo plant – 700 kg/d woody biomass – 80 litre per day SAF + diesel + naphtha – Five months of operation incl. 30 days of uninterrupted operation b. Altalto, Immingham, U.K. – 20 mmgpa / 1360 bpd / 60 mio. litres (SAF + naphtha) – MSW as feedstock, 600,000 tpa, – 60-acre site – Financial close in 2024, plant in operation in 2027. – No technology details provided c. Bayou Fuels, Natchez, MS – 35 mmgpa / 2380 bpd (SAF 25 mmgpa + naphtha 10 mmgpa) – Feedstock: Forestry and paper waste – Federal loan guarantee application in progress – Financial close in 2023 – Start-up in 2026 – RIN qualified

1.6.1.2. Fulcrum Bioenergy

Fulcrum Bioenergy is a fuel-from-landfill pioneer striving to produce hundreds of millions of gallons of clean fuel annually through a network of production facilities.[24] In 2022 the first commercial-scale fuel plant of its type Fulcrum's Sierra BioFuels Plant commenced operations to convert MSW into syngas. Over ten locations across the US have been identified for future plants and offtake agreements have already been secured. International opportunities in locations such as Australia, the UK, South Korea, Japan, and Mexico are on the horizon.

Table 1.4: An Overview of SAF Production at Fulcrum Bioenergy

COMPANY	Fulcrum Bioenergy
General overview	The project developer aims to produce renewable, drop-in transportation fuels at scale from an abundant and low-cost source that does not need to be grown or pulled from a well, i.e., household garbage.[25]
Production line	Gasification, Fischer-Tropsch synthesis FT Syncrude hydro-processed by Marathon at separate location
Feedstock type and quantity	MSW, 30,000 tpa in first phase, 175,000 tpa in final phase
Product type and quantity	Renewable syncrude, 11 mmgpa Marathon will produce renewable diesel first, SAF in later stage
Technologies used or announced	TRI gasifier for MSW Johnson Matthey / BP Fischer-Tropsch
ASTM D7566 compliant, Annex:	N/A for current plant but approved as per Annex 1 FT-SPK for future projects.

24 Fulcrum Bioenergy (n.d.). Fulcrum Bioenergy, Turning garbage into net-zero carbon jet fuel. Retrieved from: https://www.fulcrum-bioenergy.com/.
25 Fulcrum Bioenergy (n.d.). Fulcrum Bioenergy, Shaping the Waste-to-Jet Fuel Future. Retrieved from: https://www.fulcrum-bioenergy.com/our-story.

COMPANY	Fulcrum Bioenergy
References / experience / ongoing projects	a. Sierra Biofuels Plant, Storey County, Nevada – Plant commissioning in 2022, first product in late 2022 b. Nikiski, Alaska – Commercial demonstration plant for Johnson Matthey / BP FT and renewable fuel production, 2002 - 2009. c. Centerpoint Biofuels Plant, Gary, IN – 700,000 mtpa solid waste, 31 mmgpa SAF, estimated completion in 2025 d. Trinity Guels Plant – 700,000 mtpa solid waste, 31 mmgpa SAF, estimated completion in 2025 e. 2 more plants in early development

1.6.1.3. Red Rock Biofuels

Red Rock Biofuels addresses two problems by producing biofuel from waste woody biomass at its Lakeview plant since its founding in 2011: catastrophic wildfires and emissions.[26] Instead of following the annual winter forest management tradition of burning slash piles (generating CO_2), Red Rock produces jet fuel from the forest harvesting waste through FT and hydro-processing technologies.

Table 1.5: An Overview of SAF Production at Red Rock Biofuels

COMPANY	Red Rock
General overview	Project announced to produce renewable fuels from woody forestry biomass. Project seems to be on hold.
Production line	Gasification, FT, hydrocracking, distillation
Feedstock type and quantity	Forestry and sawmill waste, 136,000 tpa
Product type and quantity	6 mmgpa SAF + 9 mmgpa diesel + naphtha
Technologies used or announced	Gasification: TCG Global Fischer-Tropsch: Velocys Gas treatment and hydrocracking: Shell
ASTM D7566 compliant, Annex:	Annex 1
References / experience / ongoing projects	a. Red Rock, Lakeview, OR – Groundbreaking event in 2019 – No further progress reports or other information, project most likely stalled.

1.6.2. Solid Waste to Syngas, Synfuel or Alcohol

1.6.2.1. Proton Power

Proton Power, Inc (PPI) developed technology to produce synthetic fuel from biomass feedstock.[27] Despite systems operating on a small scale, PPI made it financially viable. As a result, PPI systems can be near the feedstock supply.

26 Red Rock Biofuels (n.d.). Red Rock Biofuels, Healthy Forests Healthy Fuels. Retrieved from: https://www.redrockbio.com/.
27 Proton Power (n.d.). Proton Power. Retrieved from: http://www.protonpower.com/.

Table 1.6: An Overview of SAF Production at Proton Power

COMPANY	Proton Power
General overview	Project developer uses pyrolysis of solid waste. Graphene is a valuable by-product. Only suitable for small capacities. No clear pathway for SAF.
Production line	Pyrolysis, syngas treatment
Feedstock type and quantity	Forestry waste MSW
Product type and quantity	Syngas Graphene Diesel, meets ASTM D6751 requirements
Technologies used or announced	Proton CHyP® pyrolysis
ASTM D7566 compliant, Annex:	N/A
References / experience / ongoing projects	Project in Canada's Maritimes in development.

1.6.2.2. Enerkem

Enerkem is a Canadian organization with an MSW-to-ethanol facility in Edmonton and have an Innovation Center in Westbury.[28] The organization follows circular economy principles and became the first company to transform non-compostable and non-recyclable waste into renewable ethanol and methanol.

Table 1.7: An Overview of SAF Production at Enerkem

COMPANY	Enerkem
General overview	Enerkem has developed its own process to convert MSW into methanol and ethanol. Enerkem has one commercial plant operating and several others in development.
Production line	Gasification, gas treatment, catalytic synthesis
Feedstock type and quantity	MSW, 100,000 tpa dry MSW
Product type and quantity	Ethanol, 10 mmgpa
Technologies used or announced	Enerkem fluidized bed gasifier Enerkem gas treatment and ethanol synthesis
ASTM D7566 compliant, Annex:	N/A
References / experience / ongoing projects	a. Edmonton, AB, Canada: Commercial plant – 30,000 mtpa ethanol capacity. Plant commissioned in 2015. b. Varennes, QC, Canada: Plant under construction – 100,000 mtpa biofuels and renewable chemicals capacity – Commissioning scheduled for 2024 c. Tarragona, Spain: Plant construction to start soon – 200,000 mtpa methanol capacity – Commercial operation in 2025

28 Enerkem (n.d.). Retrieved from About Us: https://enerkem.com/company/about-us/.

1.6.2.3. Protos Biofuels

This commercial scale project in the UK, developed by Advanced Biofuel Solutions Ltd and Greenergy, will transform household waste into syngas when completed in 2025.[29] The Protos plant will allow for the annual diversion of 150,000 tons of household waste from incineration, avoiding 160,000 tons of CO2 emissions annually (the equivalent emissions produced by 107,000 cars).

Table 1.8: An Overview of SAF Production at Protos Biofuels

COMPANY	Protos Biofuels
General overview	Project development by Advanced Biofuel Solutions Ltd. and Greenergy.
Production line	Gasification, gas cleaning, catalytic conversion to methane and hydrogen
Feedstock type and quantity	MSW, 150,000 tpa
Product type and quantity	Hydrogen and methane
Technologies used or announced	Sumitomo SHI FW (SFW) fluidized bed gasifier ABSL RadGas Proval direct current plasma arc furnace for gas cleaning Wood VESTA process for syngas to CH4 and H2 conversion
ASTM D7566 compliant, Annex:	N/A
References / experience / ongoing projects	a. Protos Biofuels, Ellesmere Port, U.K. – FEED by Petrofac, complete by Q3 2022, completion in 2025
Remarks	Sumitomo has not responded to our request for information. They are operating a fluidized bed gasifier on basis of High Temperature Winkler (HTW) which is now licensed by GIDARA.

1.6.2.4. GIDARA

GIDARA is a Dutch company converting non-recyclable waste into syngas to enhance The Netherland's recycling rate from the current 80% to 100%.[30] The organization has owned the High-Temperature Winkler (HTW) gasification technology since 2019 and is developing production facilities in Amsterdam and Rotterdam that will be fully operational in 2024 and 2025.

Table 1.9: An Overview of SAF Production at GIDARA Energy

COMPANY	GIDARA Energy
General overview	Project developer and owner of the HTW gasification technology. GIDARA designs, builds, and operates waste-to-liquid plants.
Production line	Gasification, methanol synthesis
Feedstock type and quantity	Non-recyclable waste, 175,000 tpa
Product type and quantity	Methanol, 87,500 tpa
Technologies used or announced	HTW gasification Linde gas cleaning (Rectisol)
ASTM D7566 compliant, Annex:	N/A

29 Green Energy (2022, May 11). Green Energy, Protos Biofuels' first commercial scale municipal waste to biofuels plant progresses to FEED stage. Retrieved from: https://www.greenergy.com/protos-biofuels-first-commercial-scale-municipal-waste-to-bi.

30 GIDARA Energy (n.d.). GIDARA Energy, Environment. Retrieved from: https://www.gidara-energy.com/advanced-methanol-amsterdam.

References / experience / ongoing projects	a. Berrenrath HTW gasification. – 15,000 hours of RDF processing, 10 years total. b. Advanced Methanol Amsterdam (AMA). – The production facility and pilot plant should be operational in 2024.

1.6.2.5. LanzaTech

LanzaTech developed technology to convert air pollution (aka industrial emissions) to fuels (ethanol) by feeding carbon emissions to carbon-hungry microbes.[31] As an alternative to ethanol for ground transport, the technology can be used to produce other chemicals for use in a range of products, such as sustainable fashion, fragrances, and packaging. Further the organization launched LanzaJet in 2020 to enable the aviation industry to meet environmental targets by converting ethanol to SAF via the Alcohol to Jet pathway. LanzaJet has set an ambitious target to produce 1 billion gallons of SAF by 2030.

Table 1.10: An Overview of Ethanol Production by LanzaTech Gas Fermentation Process

COMPANY	LanzaTech
General overview	Process developed for fermentation of waste gases and syngas to ethanol.
Production line	Gasification, fermentation
Feedstock type and quantitya)	MSW, 20 tpd (7000 tpa)
Product type and quantitya)	Ethanol, 1000 to 2000 litres per day
Technologies used or announced	Gasification: technology neutral but have preferred vendors Gas cleaning: Proprietary LanzaTech process Fermentation: LanzaTech
ASTM D7566 compliant, Annex:	N/A
References / experience / ongoing projects	a. Three Shougang LanzaTech commercial operating units, China: – Steel mill off gas, 58M lpy, commissioned 2018 – Ferroalloy mill off gas, 58M lpy, 2021 – Ferroalloy mill off gas, 76M lpy, 2022 b. Commercial units in construction: – Indian Oil Corp, refinery off gas, 40-50M lpy (expected 2022) – SGLT, ferroalloy mill off gas, 76M lpy ethanol (expected 2022) – ArcelorMittal, steel mill off gas, 80M lpy ethanol, Belgium (expected 2023) c. Sekisui Demo Plant, Japan – Gasification, MHI – Gas refining: Sekisui Chemical – Fermentation LanzaTech – Commissioning in 2022 d. Baosteel Demo Plant, Shanghai – Pre-commercial facility – Steel mill waste gas, 100,000 gpa ethanol – Commissioned in 2012 e. Shougang Demo Plant, steel mill off gas, China f. Sekisui Pilot Plant, syngas from unsorted MSW – Suncor Demo Plant, syngas from biomass

Note a): Refers to Sekisui demo plant as the only MSW to ethanol plant.

31 LanzaTech (2021). LanzaTech, 2021 Annual Report. Retrieved from: https://lanzatech.com/wp-content/uploads/2022/08/LanzaTech_2021_Annual_Report.pdf.

1.6.2.6. BioTfuel

BioTfuel, pronounced "beautiful," is a project developed through partnerships between multiple companies, including Thyssenkrupp, Total, Axens, CEA, Avril, and IFPEN.[32] The process chain produces biomass to liquids (BTL) fuel from biomass sources such as green waste, straw, natural waste, and wood residues.

Table 1.11: An Overview of SAF Production at BioTFuel

COMPANY	Bionext (Cooperation of Total, Axens, Thyssenkrupp, Air Liquide and others)
General overview	Process developed for converting biomass into biodiesel and SAF.
Production line	Torrefaction, gasification, Fischer-Tropsch
Feedstock type and quantity	Wood waste, 50 mtpd torrefied. Plastics tested limited time for suitability in gasifier.
Product type and quantity	FT Syncrude. Axens is operating another demonstration plant for FT crude to fuel processing, this plant should only test the suitability of the syngas for the FT process.
Technologies used or announced	Prenflo® gasification (TK Uhde process), Axens for gas cleaning, and for Fischer-Tropsch synthesis
ASTM D7566 compliant, Annex:	Annex 1
References / experience / ongoing projects	a. Prenflo® gasifier, Coal gasification in Puertollano, Spain – Capacity: 3,500 mtpd solid waste equivalent b. Axens FT demonstration plant in San Nazarro, Italy

1.6.3. Alcohol-to-Jet

The ATJ pathway is independent of the conversion from MSW to alcohols. As the first step, MSW is gasified, and the syngas is either fermented or catalytically converted into ethanol or methanol. In the use-case of biomass or lignocellulosic materials, they may be gasified and converted to alcohols in the same fashion as MSW. So far only ethanol and iso-butanol are approved alcohols under ASTM D7566 Annex A5. In summer 2022, ExxonMobil announced the development of a methanol to jet fuel process which is currently in the ASTM process for the ATJ-SPK pathway.[33]

1.6.3.1. LanzaJet

Table 1.12: An Overview of ATJ SAF Production by LanzaJet ATJ Technology

COMPANY	LanzaJet
General overview	Project developer and technology licensor. ATJ route can be combined with LanzaTech's MSW syngas fermentation process or with any other ethanol production route.
Production line	Catalytic conversion, distillation
Feedstock type and quantity	Ethanol, 50 to 1,500,000 tpa
Product type and quantity	10 - 300 mmgpa SAF + RD

32 Thyssenkrupp (n.d.). BioTfuel, The biofuel of the future is made from waste. Retrieved from: https://www.thyssenkrupp.com/en/stories/sustainability-and-climate-protection/biotfuel-the-biofuel-of-the-future-is-made-from-waste.
33 Businesswire (2022, June 20). Businesswire, ExxonMobil Methanol to Jet Technology to Provide New Route for Sustainable Aviation Fuel Production. Retrieved from: https://www.businesswire.com/news/home/20220620005021/en/ExxonMobil-Methanol-to-Jet-Technology-to-Provide-New-Route-for-Sustainable-Aviation-Fuel-Production.

Technologies used or announced	LanzaJet Alcohol to Jet Process
ASTM D7566 compliant, Annex:	Annex 5 ATJ-SPK
References / experience / ongoing projects	a. Freedom Pines, Soperton, Georgia – Pilot Plant 2014 – 2017 – Demo Plant start-up 2023 b. Marquis Sustainable Aviation Fuels, Hennepin, Illinois, USA – Commercial Plant – Capacity: 120 mmgpa sustainable fuel – Commissioning not before 2026 c. FLITE, UK, 30mmgpa, 2024 d. Dragon (LanzaTech), UK, 30mmgpa, 2025 e. Speedbird (British Airways), UK, 30mmgpa, 2025 f. Vattenfall, Sweden, 30mmgpa, 2025 g. Suncor, North America, 60mmgpa, 2025 h. Mitsui- Cosmo Oil, Japan, 60mmgpa, 2027

1.6.3.2. Gevo/Axens

Gevo developed energy-dense liquid hydrocarbons from renewable resource-based carbohydrates. Sustainably grown corn from Minnesota is used as feedstock and converted into ethanol.[34]

Table 1.13: An Overview of ATJ SAF Production at Gevo/Axens

COMPANY	Gevo
General overview	Gevo has partnerships with technology providers and has various offtake agreements in place but is not building a plant yet. Alliance with Axens for ATJ fuel production in USA. Gevo is tracking and accounting for carbon, emissions, and sustainability.
Production line	Biomass fermentation to ethanol, catalytic conversion, distillation
Feedstock type and quantity	Biomass, lignocellulosic (rice straw, sugar cane waste, forestry waste)
Product type and quantity	SAF, 10 mmgpa Isooctane, 5 mmgpa
Technologies used or announced	Axens alcohol to jet fuel
ASTM D7566 compliant, Annex:	Annex A5 ATJ-SPK
References / experience / ongoing projects	No commercial projects yet.

1.6.4. Other Renewables to Sustainable Fuel Projects

Biofuel production processes are based on crops and vegetable oils, animal fats, oils, and greases. The projects below are exemplary for producing renewable diesel or SAF from sources other than solid waste.

1.6.4.1. Neste

After more than ten years of SAF production experience, Neste earned the title of the world's largest producer of SAF and renewable diesel produced from hydrotreated vegetable oil (HVO), animal fat, vegetable and palm oils, and vegetable oil residues

34 Gevo (2020). The Circular Economy. Retrieved from: https://gevo.com/wp-content/uploads/2020/05/Gevo-Whitepaper-The-Circular-Economy.pdf.

through the NEXBTL process. To meet increasing industry demand, Neste aims to scale-up SAF production from 34 mmgpa to 515 mmgpa by the close of 2023.[35] Neste boasts three renewable fuel production facilities utilizing the HEFA process located in Porvoo, Finland, Rotterdam, The Netherlands, and Singapore.

1.6.4.2. TotalEnergies

TotalEnergies is best described as a broad energy company supplying natural gas, electricity, and fuel across more than 130 countries[36]. Its La Mede Refinery in France has the capacity to produce up to 500,000 mtpa, specializing in HVO-type biofuels produced from oils meeting the European Union's sustainability criteria.[37] TotalEnergies has demonstrated the ability to process raw materials (e.g., vegetable and palm oils) as well as waste (e.g., animal fats) aligned with the circular economy.

1.6.4.3. World Energy

World Energy advanced biofuels across North America, with seven production and eleven distribution sites across Canada and the US. Its Paramount, California location is the only commercial scale SAF production facility in America and gained recent attention after a partnership was announced with Air Products to scale up SAF production to 340 mmgpa by 2025 (increasing the biofuel output by 700%).[38] This is achieved by constructing the most technologically advanced SAF hub in the world. World Energy uses vegetable oils and beef tallow to produce renewable diesel, naphtha, SAF, and fuel gas through the HEFA process.

1.6.4.4. SkyNRG

SkyNRG is a Dutch SAF leader that has sourced, blended, and distributed SAF to over 40 airlines worldwide since 2009. The organization prides itself on its Roundtable on Sustainable Biomaterials (RSB) certification and Independent Sustainability Board which guide SkyNRG's actions.[39]

In 2021, SkyNRG identified the opportunity to develop a SAF production facility in the United States after the Biden administration set an ambitious SAF production target for the country, i.e., 3 billion gallons by 2030 and 35 billion gallons by 2035. The PNW region was identified as an ideal location to tap into the West Coast market already benefiting from Low Carbon Fuel Standard (LCFS) policies. Several offtake agreements have already been secured and SkyNRG set an ambitious target to produce 30 million gallons (90,000 tons) annually by 2027 from green hydrogen and renewable natural gas (RNG). The process is based on syngas fermentation to alcohol, followed by the ATJ pathway.

The Synkero factory constructed at the Port of Amsterdam will be completed in 2027 with an annual production capacity of 50,000 tons and the ability to capitalize on the existing kerosene pipeline to Schiphol airport. The SAF is produced as e-fuel, made by synthesizing captured CO2 emissions and hydrogen produced using renewable or CO2-free electricity. SkyNRG is also constructing a second Dutch facility in Delfzijl with an annual SAF capacity of 100,000 tons when it opens in 2025, produced from the HEFA process. 35,000 tons of sustainable by-products will also be produced at the facility.

1.6.4.5. Twelve

Twelve, formerly known as Opus 12, is a carbon transformation company that developed a polymer-electrolyte membrane (PEM) CO_2 electrolyzer that uses CO_2, water, and electricity as inputs and produces carbon monoxide (CO) and syngas as outputs.[40] Twelve's syngas can be refined into a carbon neutral drop-in jet fuel called E-Jet(R).

The company has fostered two important partnerships. In 2021, it partnered with the U.S. Air Force to produce and test the world's first jet fuel made via CO2 electrolysis, proving that it is drop-in ready. In March 2022, Twelve partnered with Lanzatech to convert CO produced from Twelve's electrolysis into ethanol using Lanzatech's reactor technology. The ethanol can then be used to make jet fuel.

35 Ahlgren, L. (2022, June 17). Simple Flying. Which Producers Are Leading the Sustainable Aviation Fuel Race? Retrieved from: https://simpleflying.com/producers-leading-sustainable-aviation-fuel/.
36 TotalEnergies (n.d.). TotalEnergies, Our Identities. Retrieved from: https://totalenergies.com/company/identity.
37 TotalEnergies (2019, March 7). TotalEnergies, Total Starts Up the La Mède Biorefinery. Retrieved from: https://totalenergies.com/media/news/press-releases/total-starts-la-mede-biorefinery.
38 Kotrba, R. (2022, April 25). World Energy Secures Permits to Greatly Expand SAF Production in Southern California. Retrieved from World Energy: https://www.worldenergy.net/newsroom/world-energy-secures-permits-to-greatly-expand-saf-production-in-southern-c/.
39 SkyNRG (n.d.). SkyNRG, Fueling a new era of progress in aviation. Retrieved from: https://skynrg.com/.
40 Twelve (n.d.). Twelve. Retrieved from: https://www.twelve.co/.

It should be noted that E-fuels generate methane and NOx as by-products which negatively impacts the carbon footprint reduction.

1.7. Technologies for Pre-Processing, Gasification/Pyrolysis, FT, Hydro-processing

A MSW to SAF production facility consists of multiple process steps. Major vendors for the most relevant processes are listed below in **Table 1.14.**

Table 1.14: Major Vendors and Applicable Processes for a MSW to SAF Production Facility

Process	Vendors
MRFs	BHS (Bulk Handling Systems) CP Manufacturing Sparta Machinex Green Machine Van Dyk Krause Manufacturing (part of the CP Group)
Gasification	**Fluidized bed gasifier Manufacturers:** • Enerkem • GIDARA (HTW) • TRI • Sumitomo SHI FW (SFW) **Entrained flow gasifier Manufacturers:** • MHI atmospheric entrained flow biomass gasifier • TKIS Prenflo (Thyssenkrupp Industrial Solutions, Uhde) • JFE Engineering (cooperation with NextChem), gasification and direct melting. Plant capacity 1 – 13 tons/hour available.
Pyrolysis	Proton Power
Fischer-Tropsch	Velocys Axens Johnson-Matthey / BP Sasol
Hydro-processing	Johnson Matthey Axens Haldor Topsoe UOP
Syngas to ethanol	LanzaTech Enerkem
Alcohol to jet fuel	LanzaJet Axens

1.8. Failed Pathways

The production of jet fuel and diesel from renewable sources has gained attraction in recent years. While multiple pathways are under development, not all have proven successful. This section identifies a handful of failed technologies to serve as cautionary tales about pursuing SAF production opportunities from certain feedstocks and processes, and to acquire knowledge to enhance the success rate of a new facility.

A list below indicates failed pathways. These pathways are not conducive to establishing a steady stream of SAF.

1.8.1. Algae

Microalgae is a popular material for large-scale biofuel production. While investment into algae biofuels is significant, numerous logistical and technological issues persist. For example, cultivation, harvesting, and oil extraction technologies are still inefficient and/or capital and resource intensive. When coupled with prohibitions toward environmental impacts, commercialization is blocked. There have been a number of trial and pilot microalgae production plants, and demonstration flights run on algal-derived jet fuel but to date there is still no economically feasible production.[41]

1.8.2. Ineos Bio

An Ineos Bio demonstration plant for waste fermentation into ethanol was built in Florida but several severe issues forced the owners to shut down the plant. Reasons for failure included too much water in feed, hydrogen cyanide that killed bacteria, various equipment and power failures, and scale-up issues with the fermenter.[42]

1.8.3. Choren

Choren developed a proprietary biomass entrained flow gasification technology called Carbo-V. The technology was sold to Linde Engineering in 2010 but no further development has been reported since then.

1.8.4. AlterNRG

AlterNRG commercialized the Westinghouse Plasma Gasification Technology for gasification of solid waste, biomass, coal, petroleum coke, and tires. The process failed when scaling up to a large-scale commercial plant (Air Products Teesside, U.K.). AlterNRG is currently in receivership.

Plama gasification technology is used for small scale applications such as hazardous waste gasification; however, plasma gasification technology is not economically viable for MSW. The large investment costs, high operational costs, and high energy demand (net negative) are the main disadvantages for plasma gasification.

1.9. Determine Technology Readiness Levels

Technology Readiness Levels assess the maturity of a type of technology according to a ten-level measurement system indicated in **Figure 1.10**. This serves as guidance on the level of maturity of multiple SAF technologies. Information from this figure has been used to assess the most sustainable option for SAF.

Figure 1.10 – The Technology Readiness Levels (TRL) Scale

41 Doliente, S., Narayan, A., Samsatli, N., Samsatli, S., Tapia, J., & Zhao, Y. (2020). Bio-aviation Fuel: A Comprehensive Review and Analysis of the Supply Chain Components. Frontiers in Energy Research Volume 8, 1-38. Retrieved from: https://www.frontiersin.org/articles/10.3389/fenrg.2020.00110/full.

42 Daprile, L. (2017, January 17). TC Palm. Investigation: INEOS failed despite $129 million in taxpayer subsidies. Retrieved from: https://www.tcpalm.com/story/news/2017/01/17/ineos-closes-vero-beach-biofuel-plant/96412616/.

Table 1.15: TRL of a Variety of Producers and Processes

Process Step	Vendor	TRL	Comments
MSW Sorting	Multiple	9	Single train units up to 1,200 mtpd MSW
Fluidized bed gasifier	Enerkem	8-9	250 mtpd MSWdry unit built, 360 mtpd MSWdry unit under construction, 700 mtpd MSWdry (two gasifiers) construction to start soon
	Gidara	9	500 mtpd MSW built
	TRI	7-8	500 mtpd MSW built
Entrained flow gasifier	TKIS	5 / 9	TRL 5 for MSW (select plastics), TRL 9 for biomass and coal
Gas cleaning	Air Liquide	9	Gas cleaning processes well established in multiple applications
	Axens	9	Gas cleaning processes well established in multiple applications
	Linde	9	Gas cleaning processes well established in multiple applications
	UOP	9	Gas cleaning processes well established in multiple applications
Fischer-Tropsch	Axens	5-6	Prototype plant
	Johnson-Matthey	7-8	Fulcrum to be watched closely to verify assessment
	Sasol	7	TRL 7 for next generation catalysts, TRL 9 for FT process
	Velocys	6-7	Demo plant in operation
Hydrocracking / Isomerization	Axens	9	Well established refinery processes
	Haldor Topsoe	9	Well established refinery processes
	Johnson-Matthey	9	Well established refinery processes
	UOP	9	Well established refinery processes
Conversion of syngas to alcohol	Enerkem	8-9	Catalytic conversion of syngas to alcohols
	LanzaTech	9[1)]	Fermentation of syngas and industrial offgases to ethanol via biological process
Alcohol to Jet (ATJ)	Axens	6	Dehydration of ethanol determining TRL. The other hydro-processing steps are TRL 9.
	LanzaJet	7	Commercial demonstration plant used for ASTM pathway certification in 2018., Commercial plant in construction for 2023 start up at Freedom Pines Fuels, Georgia, USA

Remark: [1)] No commercial experience with syngas from MSW

The process steps for the Fischer-Tropsch route already reach TRL's of 7 and above, whereas only the MSW to ethanol portion in the ATJ route for MSW processing has reached production level.

1.10.Performance and Design Data

Per the Port of Seattle's Century Agenda goals of 10 percent SAF used at SEA by 2028, initial SAF demand is approximately 75 mmgpa, equivalent to 227,000 gpd (i.e., 5400 bpd) based on 330 stream days per year. Currently, the largest announced MSW based renewable fuels projects have an MSW capacity of up to 700,000 mtpa and a biofuel production capacity of up to 31 mmgpa.

1.10.1. Overall Conversion Rates

1.10.1.1. Fischer-Tropsch Pathway

When maximizing SAF production with the Fischer-Tropsch pathway, the product slate is in the range of:

- SAF **80%**
- Naphtha **15%**
- LPG **5%**

Based on this product slate, the MSW demand for a 75 mmgpa SAF production facility would be as follows:

- The demand for RDF used as feedstock, presorted and dried to 10 to 15% moisture content, is about 8.33 tons per ton of SAF or 1.92 million mtpa for 75 mmgpa SAF.
- Previous studies regarding the suitability of MSW for gasification show that about 40 to 50% of all MSW can be used as RDF and fed into a gasifier, the balance is food and yard waste (too high moisture content), metals, glass, and other non-organics.
- The moisture content of RDF before drying is about 25 to 30%.
- This results in a total expected unsorted MSW demand at the source of 5 to 6 million mtpa and
- 2 to 2.5 million mtpa of mechanically sorted MSW before drying.

1.10.1.2. ATJ Pathway

The SAF yield through the ATJ route is comparable to or slightly higher than that produced through the Fischer-Tropsch route. Vendor provided data shows SAF content in the product slate of up to 90% with the balance being renewable diesel. However, commercial size plants demonstrating the carbon utilization have not been built. Both process pathways show potential for process optimization and further yield increases.

1.10.2. MSW Requirements for Gasification

1.10.2.1. General

The main gasification process is the conversion of hydrocarbons into carbon oxides and hydrogen allowing all organic material to be gasified. The typical moisture content of pre-sorted MSW is in the range of 25 – 30%. However, the MSW should be dried to 10 to 15% to minimize energy losses in the gasifier. Gasifier vendors recommend non-organics in the feed to be less than 1.5%.

1.10.2.2. Sorting and Pre-treatment

MSW requirements for the gasification process make sorting and pre-treatment unavoidable. Non-organic material should be removed to the maximum extent possible. Compostable materials, such as food, have an extremely high moisture content which make them also more suitable for separate processing / composting and possible biogas capturing.

1.10.2.3. TRI

Due to the special design of the TRI gasifier, the RDF can be loose fluff. This eliminates the need to pelletize. The feeder system consists of six feeders for equal distribution of feedstock in the reactor and has sufficient redundancy to take a feeder offline for maintenance.

1.10.2.4. GIDARA

The GIDARA HTW reactor requires pellets, and a lock hopper system is used to feed the reactor.

1.10.2.5. Enerkem

The Enerkem gasifier is quite robust regarding the mechanical conditions of the feedstock and has a redundant feeder system. The RDF needs to be crushed to a certain size but can be loose fluff.

1.10.2.6. Thyssenkrupp

The Thyssenkrupp Prenflo® gasification is an entrained flow system. Particles of 0.1 mm are preferred since larger particles might not fully gasify due to the short residence time. Feedstock enters the reactor through a lock hopper system and pneumatic transport preferably using CO2 as carrier gas. Cryogenic grinding is required. However, Thyssenkrupp is confident about the development of a new feeder system within the next years that can handle MSW and makes an entrained flow gasifier competitive.

1.10.3. Gasification

Gasifiers need steam and oxygen for the conversion of MSW into syngas. Data from literature confirms information received from vendors that the oxygen demand in the gasifier for MSW as feedstock is around 0.65 to 0.8 tons per ton of dry MSW. The gasification process also requires steam that is generated by utilizing the waste heat of the syngas leaving the gasification unit. Typical steam demand is about 0.5 tons per ton of RDF.

1.10.4. Gas Cleaning and Conditioning

1.10.4.1. Fischer-Tropsch

Sulfur, chlorine, and other catalyst poisons found in the syngas must be removed to ppm or ppb levels before entering the Fischer-Tropsch synthesis. Specific consumption figures for acid gas removal solvents, regeneration heat, and lifetime of adsorbents depend strongly on the gas contaminants. Internal heat recovery can provide the regeneration heat for the solvent system.

Adding hydrogen to the process can improve the product yield by moving the syngas composition from the hydrogen-to-carbon ration of 0.6 to 1.0 as achieved in the gasification to the required ratio of around 2.0 for the Fischer-Tropsch synthesis without consuming valuable carbon monoxide to convert it in a CO shift to hydrogen.

1.10.4.2. Syngas to Alcohol

The gas treatment prior to feeding the syngas into the fermenter depends on the microbes used for this process step and must be determined by the vendor. The vendors for syngas to ethanol fermentation plants claim that the microbes are more robust towards impurities than catalysts and require a simpler gas treatment prior to feeding the syngas into the fermenter. The produced ethanol is of fuel grade quality without further processing.

The requirements for gas cleaning in the catalytical syngas to alcohol route are similar as for other catalytical processes as catalyst poisons need to be removed.

1.10.5. Fischer-Tropsch and Hydro-processing

Fischer-Tropsch and hydro-processing are offered as a package by most technology providers who select their catalysts tuned for both units. The Fischer-Tropsch reactions are highly exothermic, generating heat that is typically used to generate steam for other process purposes or for electric power generation. Typical steam production rates are around 0.6 to 0.7 tons per one barrel of SAF produced. The hydrocracking and isomerization process requires additional hydrogen which can either be recovered from the syngas or produced separately in a small hydrogen generation unit. The hydrogen demand is about 18 to 19 Nm3 per barrel of produced SAF.

1.10.6. ATJ

The vendors of the ATJ pathways are reluctant to provide any detailed design and performance data, production and consumption figures are based on publicly available information only.

1.10.7. Production and Consumption Figures

Production facility consumption and production figures can be categorized as follows:

- Process related
- Plant specific

Process related data are applicable for a specific process whereas plant specific data depends on the plant location, available infrastructure, degree of recycling / recovery of water or steam, grid power versus own power generation, etc. The data below are typical specific numbers for 1 metric ton (mt) of dried RDF fed into a gasifier. They may vary depending on the selected vendor or technology and the project specific design and should only serve as a guideline.

1.10.7.1. Fischer-Tropsch Plant

For a Fischer-Tropsch based MSW-to-SAF plant, typical process related demand and production figures per metric ton of dry MSW are given in **Table 1.16**.

Table 1.16: Specific Production and Consumption Figures per Metric Ton of Dried RDF Based on the Fischer-Tropsch Pathway

RDF_{dried}	1.00	mt
SAF production	0.16	mt
Naphtha production	0.03	mt
LPG production	0.01	mt
Steam demand (internal production)	0.5	mt
Oxygen demand	0.65 – 0.8	mt
Hydrogen demand	0.0016	mt
Natural Gas demand	0.25 – 0.4	mt (for start-up or abnormal operation, quantity and duration depending on gasifier)
BFW demand	0.97	mt
Sulfur production	0.0003	mt (highly dependent on MSW)
CO2 production	1.24	mt
Steam production	0.5 – 0.7	mt
Ash (incl. metals, unconverted carbon)	0.05 – 0.1	mt
Electric power demand for ASU	260 – 320	kWh
Electric power demand for FT + HP	26	kWh

1.10.7.2. Alcohol-to-Jet Pathway

For the ATJ pathway, a gasification and catalytic conversion of syngas to ethanol with an overall mass yield of 0.30 to 0.35 tons of ethanol per ton of dry RDF has been assumed. Higher yields based on syngas fermentation may be possible. The main production and consumption figures for the conversion of ethanol into SAF are given in **Table 1.17**.

Table 1.17: Specific Production and Consumption Figures per Metric Ton of Dried RDF Based on the ATJ Pathway

RDF_{dried}	1.00	mt
Ethanol production	0.30 – 0.35	mt
SAF production	0.16 – 0.19	mt
Hydrogen demand	0.002 – 0.004	mt
Renewable diesel production	0.017 – 0.02	mt
Sulfur production	0.0003	mt
CO2 production	1.25 – 1.30	mt

Natural gas demand	0.004	mt (for normal operation)
	0.25 – 0.4	mt (for start-up or abnormal operation, quantity and duration depending on gasifier)
Process water production	0.10 – 0.15	mt

1.10.7.3. Process Optimization

To date, solid waste to renewable diesel and jet fuel projects have focused on combining suitable technologies to achieve the desired products. The next steps will include optimization of product yields and energy consumption as well as the reduction of CO_2 production. The reverse CO shift conversion (RWGS) gains attraction as it catalytically converts surplus CO_2 with the help of H2 into CO which can be further converted into fuel. If the hydrogen needed for this process step will be produced from renewable energy e.g., water electrolysis, this green hydrogen has a carbon neutral footprint, improves the SAF yield and reduces the overall carbon intensity of SAF. Furthermore, the oxygen produced in the water electrolyzer can be used for the gasification process and reduces the size and energy demand of the ASU or can even avoid an additional ASU. Product yield improvements of up to 100% may be possible utilizing all available process optimization steps. On the other hand, the energy demand for these yield improvement steps is significant, and a benefit depends on the availability of sufficient and cheap renewable energy.

Table 1.18 shows specific production and consumption figures based on utilization of all above-described improvement measures based on the ATJ pathway but are in the same way applicable to FT based projects, i.e.

- MSW to Ethanol (Enerkem catalytic conversion) and ATJ pathway
- Increase of product yield by adding hydrogen
- Reverse water gas shift process to convert CO2 into CO
- Water electrolysis to produce green hydrogen and oxygen

These figures are derived from process calculations for existing processes and plants in development, but still have to prove the performance in operations.

Table 1.18: Specific Production and Consumption Figures per Metric Ton of Dry RDF for Maximum Yield Configuration

RDF_{dried}	1.00	mt
SAF	0.34	mt
Renewable diesel	0.04	mt
Natural Gas demand	0.008 0.25 – 0.4	mt (for normal operation) mt (for start-up or abnormal operation, quantity and duration depending on gasifier)
Sulfur production	0.0003	mt (highly dependent on MSW)
CO2 production	0.7	mt
Ash (incl. metals, unconverted carbon)	0.05 – 0.1	mt
Electric power for electrolyzer and process equipment	5500	kWh
Water demand for process	0.8	mt
Water demand for electrolysis	1.1	mt
Oxygen demand	(0.65 – 0.8)*	mt
Hydrogen demand	(0.11)*	mt

*) produced by electrolyzer, no additional import required

1.10.8. Design Capacities

The MSW-to-fuel pathways are partly mature technologies, but several processes and pathways are still in development phase. For an overall assessment, it is important to know what the design capacities for the various process steps are. This section analyzes existing and future capacities to better understand the capacity limitations with surveyed vendor technologies design capacities shown in **Figures 1.11 and 1.12.**

1.10.8.1. Gasification

The capacities of fluidized bed gasifiers are lower than those of entrained flow gasifiers caused mainly by the longer residence time of the feed and mechanical design limitations of the reactor system. GIDARA's HTW gasifier is designed for 500 mtpd of RDF and TRI's gasifier at Fulcrum has the same capacity of 500 mtpd. TRI has completed designs for 1000 mtpd and 2000 mtpd but wants to wait for operating results from Fulcrum's plant before implementing scaling up. Enerkem's plant capacities for new projects are for up to 150,000 mtpa ethanol production. This design consists of two gasifiers and a single train syngas to ethanol unit. The ethanol capacity may vary depending on the specific process design such as water gas shift, possible CO_2 export, hydrogen import, and other considerations.

1.10.8.2. Fischer-Tropsch Process and Hydrocracking

Large scale Fischer-Tropsch reactors have been built by Sasol and Shell for their gas-to-liquids (GTL) plants in Qatar, Nigeria, and Kazakhstan. Whereas Shell's SMDS (Shell Middle Distillate Synthesis) process is only suitable for a middle distillate mix with up to 50% kerosene and proven for natural gas as feedstock, Sasol has also developed catalysts specifically for diesel and jet fuel production from gasification syngas. Topsoe / Sasol's FT reactor and Johnson Matthey's CANS® reactor can be designed for single train capacities equal to or even exceeding the demand for the POS project. Axens has a similar reactor design than Sasol and can handle similar capacities.

Velocys has not provided any design information. Their largest reference plant at Immingham, U.K. is designed for 20 mmgpa of renewable fuel which requires approximately 1,450 mtpd of MSW.

Hydrocracking and isomerization units are typical refinery units and can be designed for even larger single train capacities than what is required for this project.

1.10.8.3. Fermentation

Fermentation of syngas follows an MSW gasification and gas cleaning unit. The size of LanzaTech's demonstration plant is about 10 to 20 mtpd of MSW for up to 1.6 tons per day of ethanol. Future commercial scale plants will meet the design capacities of fluidized bed gasifiers and can process 500 to 550 mtpd of MSW in a single train. Multiple trains can be utilized to process larger amounts.

1.10.8.4. Catalytic Ethanol Production

Enerkem's plant capacities for new projects are for up to 150,000 mtpa ethanol production. This design consists of two gasifiers and a single train syngas to ethanol unit. The ethanol capacity may vary depending on the specific process design such as water gas shift / hydrogen import, and other considerations.

1.10.8.5. ATJ

The alcohol to jet fuel (ATJ) pathway consists of several catalytic refinery type process steps which can be designed for capacities exceeding 300 mmgpa and are often limited by feedstock availability, particularly waste-based ethanol. The scale-up to large scale commercial plants is still outstanding, with LanzaJet's Freedom Pines Fuels commercial plant coming on stream in 2023.

1.10.8.6. Capacity limitations

The single stream capacity of the FT pathway for MSW processing is determined by the MSW preparation and the gasification processes whereas gas cleaning, FT synthesis and downstream processing can be built in a single train for all required capacities. MSW processing units are neither cost nor plot space relevant compared to the main process units and can easily be built in multiple parallel trains. The gasification is the single most expensive unit (see 1.10.9 below), latest project developments include two parallel gasification trains followed by single train downstream units resulting in processing up to 1000 mtpd of RDF.

The MSW-to-alcohol pathway is also limited by the gasification unit. Enerkem is the only operator of a commercial catalytic ethanol synthesis unit, and their offering of commercial MSW-to-ethanol plants is for processing 720 mtpd of RDF. The demo plants for the downstream ATJ pathway are already in same or larger size than the Enerkem ethanol production plants, and it can be expected that much larger commercial size plants will come into operation in the next years.

Figure 1.11: Vendor Design Capacities Single Train for Fischer-Tropsch Pathway

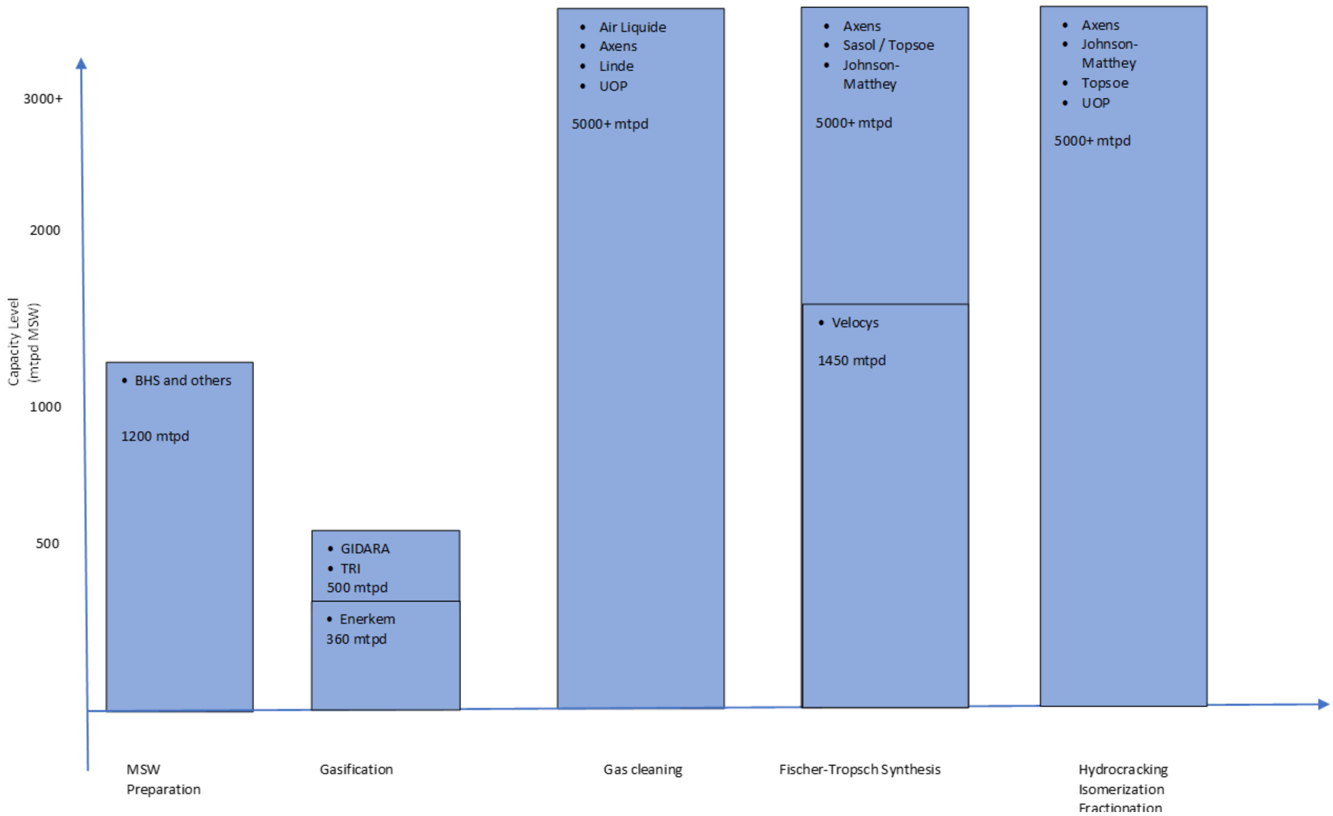
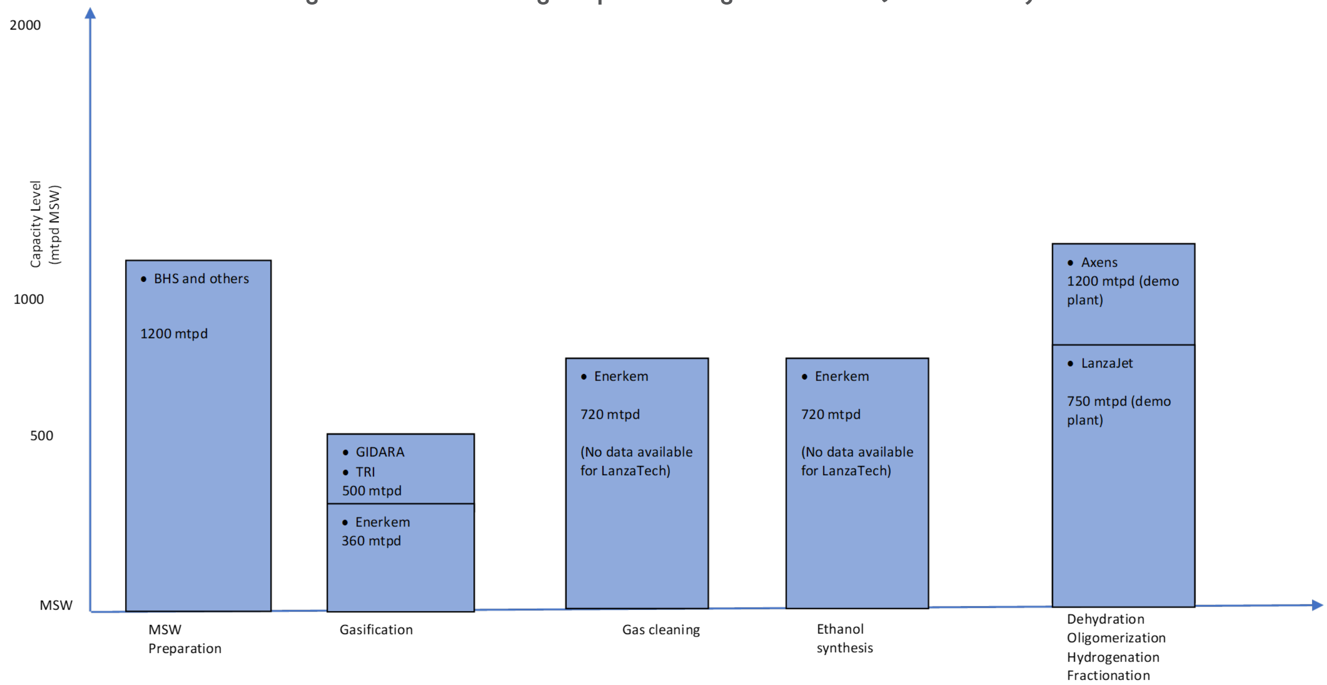


Figure 1.12: Vendor Design Capacities Single Train for ATJ Fuel Pathway



1.10.9. Design Scenarios

The study evaluates two scenarios which take into consideration the minimum feasible design capacities of the individual process units for the FT and ATJ pathway, and two scenarios for FT and ATJ pathways to produce 25 mmgpa of SAF. The authors have chosen 25 mmgpa SAF product capacity as this capacityis a viable size for this application with MSW as feedstock.

Scenario 1: Process plant with MSW preparation (sorting, drying, pelletizing), gasifier, gas cleaning, FT synthesis, hydrocracking / isomerization and fractionation for processing 500 mtpd of RDF and producing 8.6 mmgpa of SAF.

OSBL units include water treatment, wastewater handling, air separation unit, maintenance and office building, final product storage.

Scenario 2: Process plant with MSW preparation (sorting, drying, pelletizing), two gasifiers, common gas cleaning, ethanol synthesis, and hydro-processing units for processing 720 mtpd of RDF into 24 mmgpa of ethanol as intermediate product and 12.7 mmgpa of SAF as final product.

OSBL units include an air separation unit, water treatment, wastewater handling, other utility units, maintenance and office building, intermediate ethanol and final product storage.

Scenario 3: Process plant with MSW preparation (sorting, drying, pelletizing), three gasifiers, gas cleaning, FT synthesis, hydrocracking / isomerization and fractionation for processing 1,450 mtpd of RDF and producing 25 mmgpa of SAF.

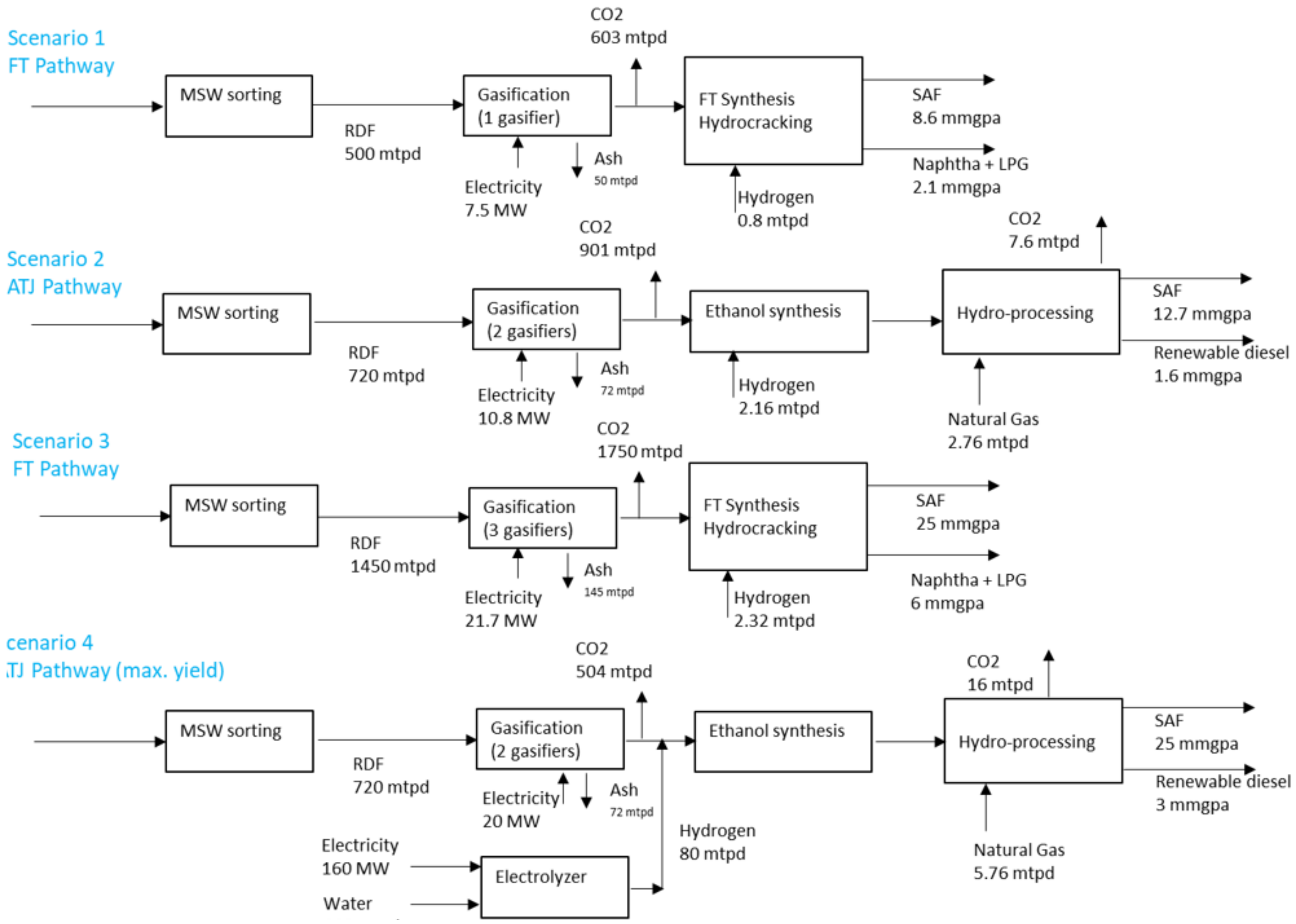
OSBL units include water treatment, wastewater handling, air separation unit, maintenance and office building, final product storage.

Scenario 4: Process plant with MSW preparation (sorting, drying, pelletizing), two gasifiers, gas cleaning, CO_2 into CO conversion (reverse water gas shift reaction), ethanol synthesis, and hydro-processing units for processing 720 mtpd of RDF and 80 mtpd of additional hydrogen into 25 mmgpa of SAF.

OSBL units include a water electrolyzer, water treatment, wastewater handling, other utility units, maintenance and office building, final product storage.

The discussed scenarios include an onsite air separation and onsite water electrolyzer. Technical gases like oxygen, nitrogen, or hydrogen might also be available for a supply over the fence which would shift some of the costs from the capital to the operating side.

Figure 1.13: Scenarios 1 to 4 and Key Data



1.10.10. Facility Footprint

Facility footprints are based on collected vendor information, publicly available information, and author determinations.

Table 1.19 provides indicative plot sizes for the process plants and the OSBL units for the four (4) scenarios, as defined in **Section 1.10.9.** Additional plot space for laydown and prefabrication areas near the future plant site are not included.

Table 1.19: Indicative Plot Sizes for Process Plants and OSBL Plants

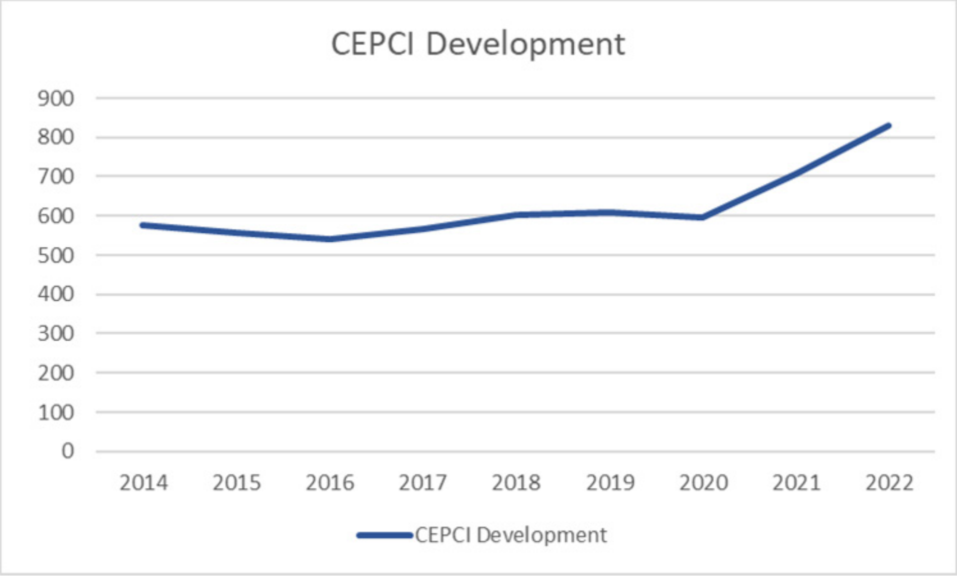
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Key data	FT pathway RDF: 500 mtpd SAF: 8.6 mmgpa Naphtha + LPG: 2.1 mmgpa	ATJ pathway RDF: 720 mtpd SAF: 12.7 mmgpa Renewable diesel: 1.6 mmgpa	FT pathway RDF: 1450 mtpd SAF: 25 mmgpa Naphtha + LPG: 6 mmgpa	ATJ pathway RDF: 720 mtpd Hydrogen: 80 mtpd SAF: 25 mmgpa Renewable diesel: 3 mmgpa
Plot size				
Process plant	25 acres	25 - 30 acres	70 acres	30 - 40 acres
OSBL	15 acres	15 - 20 acres	30 acres	20 - 25 acres
TOTAL	40 acres	40 - 50 acres	100 acres	50 - 65 acres

1.10.11. Capital Cost Estimates

1.10.11.1. General

Various factors have led to a very volatile market with resulting high-cost fluctuations during recent years. Covid-19, supply chain issues, and labor limitations may be considered as the most relevant reasons. This volatility has been further increased by the war in Ukraine in 2022. **Figure 1.14** shows the development of the Chemical Engineering Plant Cost Index (CEPCI) for the last eight years and the extreme volatility during the last two years compared to the years before.

Figure 1.14: Development of the Chemical Engineering Plant Cost Index[43]



These cost estimates have been developed for the different pathways and capacities as defined in Section 1.10.9. Due to the low level of project definition, a top-down approach with capacity factoring and parametric modeling has been chosen.

The comparison shows similar costs per gallon of fuel produced for the ATJ and the FT pathways. The economy of scale makes a design for higher yields more attractive however, the gasifiers are responsible for up to a half of the total investment costs (TIC), and the need for multiple gasifiers for higher capacities reduces this advantage.

43 Chemical Engineering (2022, November). Chemical Engineering. Retrieved from https://www.chemengonline.com/issues/2022-11.

The impacts of a possible utilization and income from CO_2 export and the availability and cost of renewable energy for green hydrogen production change the economics and may further reduce the total costs per gallon as can be seen in Scenario 4. Logistics and transportation costs may also play a role in the overall economics, and finally the carbon footprint, potential cost for carbon emissions and tax incentives are important factors under cost and ESG aspects. See **Task Report 3**.

Tables 1.20 and 1.21 provide cost breakdowns and the TICs for the four scenarios previously described.

Table 1.20: Capital Cost Breakdown for FT Pathway-Based Plants

	Scenario 1	Scenario 3
Key data	FT pathway RDF: 500 mtpd SAF: 8.6 mmgpa Naphtha + LPG: 2.1 mmgpa	FT pathway RDF: 1,450 mtpd SAF: 25 mmgpa Naphtha + LPG: 6 mmgpa
Capital cost estimate	million US-Dollar	million US-Dollar
Feed preparation	35	75
Gasification + Gas cleaning	220	593
Fischer-Tropsch + Hydrocracking	90	194
ASU	50	108
Balance of Plant	60	130
TIC	455	1,100
Cost in USD per mmgpa fuel capacity	42.5	35.5

Table 1.21: Capital Cost Breakdown for ATJ Pathway-Based Plants

	Scenario 2	Scenario 4
Key data	ATJ pathway RDF: 720 mtpd SAF: 13 mmgpa Ren. diesel: 1.6 mmgpa	ATJ pathway RDF: 720 mtpd Hydrogen: 80 mtpd SAF: 25 mmgpa Ren. diesel: 3 mmgpa
Capital cost estimate	million US-Dollar	million US-Dollar
Feed preparation (gasifier specific)	50	50
Gasification + Ethanol synthesis + ATJ	400	520
ASU	70	0
Electrolyzer		185
Balance of Plant	75	125
TIC	595	880
Cost in USD per mmgpa fuel capacity	40.8	31.4

1.10.11.2. Cost-Basis

The cost estimates in this study are based on budgetary cost information received from vendors, on publicly available cost information and the author's own estimates. The obtained data were based on different years and for different capacities. In this study, the data was equalized onto a 2022 cost basis using the cost index as per CEPCI. Due to the high volatility in the last few years, the accuracy is AACE Class 5 in a range of -50%/+100%.[44]

44 AACE (2020). AACE, International Recommended Practice No. 18R-97, Cost Estimate Classification System – As Applied in Engineering, Procurement and Construction for the Process Industries.

The Total Investment Costs (TIC) include project management, license and technology fees, infrastructure, engineering, procurement services, supplies of equipment and materials, civil works, construction, commissioning, and start-up. Not included in the TIC are owner's cost, legal fees, insurances, cost for land purchase and development, and other non-plant related costs.

Table 1.22: Cost Estimate Classification Matrix

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology, availability of applicable reference cost data, and many other risks affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

1.10.12. Maintenance Requirements

Production facilities require regular maintenance. It is highly recommended to design a facility with a strong focus on maintenance and reliability, i.e., on the robustness of a plant, and not only on efficiency or lowest capital cost. Due to their harsh process conditions, gasification units typically have the lowest availability with 80 to 85% and require a bi-annual or annual turnaround. Critical parts are the feeder system, the burners, and the refractory lining. Slag and ash removal can also cause operational disturbances. As most gasifiers only have limited operational experience processing MSW, the next years will reveal their true reliability. Redundancies of the critical components, e.g., multiple feeder lines or multiple burners, help improve reliability.

Most process steps in the MSW-to-fuel production line are catalytical processes. The lifetime of adsorbent materials in the gas cleaning phase (e.g., for sulfur or other contaminants) depends on the degree of contamination and the selected adsorbent volume/vessel size. Onstream time can either be increased by selecting larger vessels, allowing for a higher volume of adsorbent material, or by installing redundancies using stand-by vessels or a lead-lag-configuration allowing for a catalyst or adsorbent material exchange during operations. Catalysts for Fischer-Tropsch and for other hydro-processing units have a limited lifetime as they lose activity over time. FT catalysts in a slurry bed reactor can be exchanged continuously during operation, which keeps the activity steady. Catalysts in fixed bed reactors need to be exchanged after a certain period. Typical catalyst lifetimes for gas cleaning and for hydro-processing are in the range of three to four years.

Scrubbing solutions do not need a dedicated change after a certain period since lost or degraded solutions are replaced on a permanent basis. The adsorption processes (e.g., for sulfur or chlorine) should be designed with reactor volumes that are sufficient to have the same onstream time as catalysts to avoid additional shutdowns or to have a stand-by or lead-lag configuration which allows to exchange adsorbent material during normal operations. Rotating equipment such as compressors has onstream times of between one and four years, depending on the service. Pumps are commonly designed with stand-by items and can be maintained or repaired during normal operation.

Maintenance costs of 2 to 3 percent of the TIC can be assumed for this type of plant.

1.11. Conclusion

ASTM D7566 defines approved pathways for the production of SAF from solid waste: Annex A1 and Annex A4 with gasification followed by Fischer-Tropsch synthesis and further hydro-processing, and Annex A5 with conversion of alcohols to jet fuel (ATJ). However, Annex A5 does not define a pathway to alcohol production, which offers a diversity of choices, whether fermentation of sugars, or gasification followed by catalytic conversion or fermentation of solid waste.

For the ASTM-approved pathways reviewed in this chapter there is reliance on gasification of the dry organic fraction of the MSW waste stream. MSW is a heterogeneous mixture of materials. The two-dimensional character of plastic film and textiles makes grinding into dust size particles almost impossible, limiting the commercially available gasification technologies to fluidized bed gasifiers.

The Fischer-Tropsch technology for fuel production is well established. Fulcrum is the first plant to utilize the FT process for the conversion of MSW to renewable fuels. Although the plant was commissioned in 2022, long-term results detailing operational success will not be available for several years. Other currently operating MSW processing plants produce either methanol (GIDARA) or ethanol (Enerkem), but do not have the conversion of alcohols into SAF as the final step.

The conversion of ethanol to jet fuel has been approved in Annex A5 of ASTM D7566. Axens and LanzaJet have developed relevant technologies and all process steps are proven in demonstration and some even in commercial plants. In the summer of 2022, ExxonMobil applied for approval of methanol as feedstock for the ATJ pathway. Enerkem and others are also working on a methanol-to-jet fuel process.

A comparison of the two pathways FT and ATJ is provided in **Table 1.23**. With this comparison, the authors intend to show qualitative strengths or weaknesses of major aspects of the processes.

Table 1.23: Comparison of FT and ATJ pathways

Pathway	FT	ATJ
MSW requirements	0	0
Yield [mt SAF per mt RDF]	0	0
Plot size		+
TRL (maturity)	+	
Capital cost	0	0
Design allows process split		+

Fermentation as an alternative to catalytic conversion of syngas into alcohols is gaining attraction. Both Axens and LanzaTech have developed microbes that process syngas and produce ethanol but applications in demonstration or larger scale plants for processing of syngas derived from MSW are still outstanding.

A commercial application for processing MSW to jet fuel should focus on the robustness of the chosen pathway and on technologies and vendors with solid experience working with these applications. Rules for tax incentives and carbon credits require significant carbon conversion and energy efficiency rates, which can be found in recent, but not mature, developments.

Currently, a fluidized bed gasifier followed by Fischer-Tropsch synthesis and hydrocracking is the most mature process. Enerkem has demonstrated the robustness of the catalytic syngas to ethanol route in their Edmonton plant. Syngas fermentation has only been demonstrated for steel plant off-gases, however, commercial units for MSW and for refinery off-gases are expected to start up in the 2023/2024 timeframe. The MSW to alcohol conversion followed by the ATJ process seems to be a promising alternative to the Fischer-Tropsch route for large scale plants, requires less plot space, and allows for increased flexibility regarding split locations.

1.12. References

AACE (2020). AACE, International Recommended Practice No. 18R-97, Cost Estimate Classification System – As Applied in Engineering, Procurement and Construction for the Process Industries.

Ahlgren, L. (2022, June 17). *Simple Flying.* Which Producers Are Leading the Sustainable Aviation Fuel Race? Retrieved from: https://simpleflying.com/producers-leading-sustainable-aviation-fuel/.

Barrett, S., Field, R., Herzog, H., Lu, X., Malina, R., Seifkar, N., & Withers, M. (2015). *Biomass to Liquid Fuels Pathway:* A Techno-Economic Environmental Evaluation. Cambridge: MIT. Retrieved from: https://sequestration.mit.edu/bibliography/BTL%20final%20compiled.pdf.

Bhaskar, T., Krishna, B., Perkins, G., Shahabuddin, M., Tanvir Alam, Md. (2020). *A review of the production of renewable fuel from the gasification of biomass and residual waste.* Bioresour Technol. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7255753/.

Bermudez, J.M., & Fidalgo, B. (2016). *Handbook of Biofuels Production* (2nd ed.). Woodhead Publishing.

Britannica (n.d.). Britannica, Isomerization. Retrieved from: https://www.britannica.com/science/isomerization.

Brown, R., Hsu, D., Platon, A., Satrio, J., & Swanson, R. (2010). *Techno-Economic Analysis of Biofuels Production Based on Gasification*. NREL/TP-6A20-46587. Retrieved from: https://www.nrel.gov/docs/fy11osti/46587.pdf.

Businesswire (2022, June 20). Businesswire, ExxonMobil Methanol to Jet Technology to Provide New Route for Sustainable Aviation Fuel Production. Retrieved from: https://www.businesswire.com/news/home/20220620005021/en/ExxonMobil-Methanol-to-Jet-Technology-to-Provide-New-Route-for-Sustainable-Aviation-Fuel-Production.

Carter, S., Clarkson, J., Coe, A., Davies, S., Paterson, J., Peacock, M., Reed, L. 2020. Innovation in Fischer-Tropsch: Developing Fundamental Understanding to Support Commercial Opportunities. *Top Catal 63*, 328-339. Retrieved from: https://doi.org/10.1007/s11244-020-01239-6.

Chemical Engineering (2022, November). Chemical Engineering. Retrieved from https://www.chemengonline.com/issues/2022-11.

Coe, A., & Pearson, R. (2021). Innovation in Fischer-Tropsch: A Sustainable Approach to Fuels Production. *Johnson Matthey Technology Review*, 395-403. Retrieved from: https://technology.matthey.com/article/65/3/395-403/.

Daprile, L. (2017, January 17). *TC Palm*. Investigation: INEOS failed despite $129 million in taxpayer subsidies. Retrieved from: https://www.tcpalm.com/story/news/2017/01/17/ineos-closes-vero-beach-biofuel-plant/96412616/.

Doliente, S., Narayan, A., Samsatli, N., Samsatli, S., Tapia, J., & Zhao, Y. (2020). Bio-aviation Fuel: A Comprehensive Review and Analysis of the Supply Chain Components. *Frontiers in Energy Research Volume 8*, 1-38. Retrieved from: https://www.frontiersin.org/articles/10.3389/fenrg.2020.00110/full.

Enerkem (n.d.). Retrieved from About Us: https://enerkem.com/company/about-us/.

FAA (2021, March). Federal Aviation Administration, Research, Engineering and Development Advisory Committee (REDAC). Retrieved from: https://www.faa.gov/about/office_org/headquarters_offices/ang/redac#environmentEnergy.

Fulcrum Bioenergy (n.d.). Fulcrum Bioenergy, Shaping the Waste-to-Jet Fuel Future. Retrieved from: https://www.fulcrum-bioenergy.com/our-story.

Fulcrum Bioenergy (n.d.). Fulcrum Bioenergy, Turning garbage into net-zero carbon jet fuel. Retrieved from: https://www.fulcrum-bioenergy.com/.

Gevo (2020). *The Circular Economy*. Retrieved from: https://gevo.com/wp-content/uploads/2020/05/Gevo-Whitepaper-The-Circular-Economy.pdf.

GIDARA Energy (n.d.). GIDARA Energy, Environment. Retrieved from: https://www.gidara-energy.com/advanced-methanol-amsterdam.

Green Energy (2022, May 11). Green Energy, Protos Biofuels' first commercial scale municipal waste to biofuels plant progresses to FEED stage. Retrieved from: https://www.greenergy.com/protos-biofuels-first-commercial-scale-municipal-waste-to-bi.

IATA (2023). International Air Transport Association, Media Briefing Update on Sustainable Aviation Fuels (SAF), Annual General Meeting 2023. Retrieved from: https://www.iata.org/en/iata-repository/pressroom/presentations/sustainable-aviation-fuel-agm-2023/.

ICAO (2023, April 9). International Civil Aviation Organization, Environmental Protection, GFAAF, Conversion Processes. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx#:~:text=Annex%2016%20Vol%20IV%20defines,approved%20by%20the%20ASTM%20International.

Kojima. Y. (2022, March 28 – 30) *Production of Sustainable Aviation Fuel from woody biomass by gasification – FT synthesis technology – successful demonstration to fly a commercial flight*. Nitrogen + Syngas 2022 International Conference & Exhibition in Berlin, Germany.

Kotrba, R. (2022, April 25). *World Energy Secures Permits to Greatly Expand SAF Production in Southern California*. Retrieved from World Energy: https://www.worldenergy.net/newsroom/world-energy-secures-permits-to-greatly-expand-saf-production-in-southern-c/.

LanzaJet (n.d.). LanzaJet Presentation, *Company Overview*.

LanzaTech (2021). LanzaTech, 2021 Annual Report. Retrieved from: https://lanzatech.com/wp-content/uploads/2022/08/LanzaTech_2021_Annual_Report.pdf.

MRF Economics (2018). Presentation at 36th Annual Conference of Michigan Recycling Coalition.

NETL (n.d.). National Energy Technology Laboratory, Commercial Technologies for Syngas Cleanup, Section 6.1. Retrieved from: https://netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/syngas.

NETL (n.d.). National Energy Technology Laboratory, Fischer-Tropsch Synthesis, Section 10.2. Retrieved from: https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/ftsynthesis.

Port of Seattle and WSU (2020, February). Port of Seattle and Washington State University, Potential Northwest Regional Feedstock and Production of Sustainable Aviation Fuel. Retrieved from: https://www.portseattle.org/sites/default/files/2020-08/PofSeattleWSU2019updated_appendix.pdf.

Proton Power (n.d.). Proton Power. Retrieved from: http://www.protonpower.com/.

Red Rock Biofuels (n.d.). Red Rock Biofuels, Healthy Forests Healthy Fuels. Retrieved from: https://www.redrockbio.com/.

Simpson. (2017). LanzaTech Workshop.

SkyNRG (n.d.). SkyNRG, Fueling a new era of progress in aviation. Retrieved from: https://skynrg.com/.

Thyssenkrupp (2020). Uhde Entrained Flow Gasification Brochure.

Thyssenkrupp (n.d.). BioTfuel, The biofuel of the future is made from waste. Retrieved from: https://www.thyssenkrupp.com/en/stories/sustainability-and-climate-protection/biotfuel-the-biofuel-of-the-future-is-made-from-waste.

TotalEnergies (2019, March 7). TotalEnergies, Total Starts Up the La Mède Biorefinery. Retrieved from: https://totalenergies.com/media/news/press-releases/total-starts-la-mede-biorefinery.

TotalEnergies (n.d.). TotalEnergies, Our Identities. Retrieved from: https://totalenergies.com/company/identity.

Twelve (n.d.). Twelve. Retrieved from: https://www.twelve.co/.

USDOE (2023). US Department of Energy, Alternative Fuels Data Center, Sustainable Aviation Fuel, SAF Production Pathways. Retrieved from: https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html.

USEPA (2023, April 28). US Environmental Protection Agency, Sources of Greenhouse Gas Emissions. Retrieved from: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#:~:text=Greenhouse%20gas%20emissions%20from%20transportation,ships%2C%20trains%2C%20and%20planes.

Velocys (n.d.). Velocys, Bringing sustainable fuels to life. Retrieved from: https://www.velocys.com/projects/.

EXP | 451 Montgomery Street, Suite 300 | San Francisco, CA 94104
t: +1. 954.999.8292

exp.com

TASK 2

MUNICIPAL SOLID WASTE TO LIQUID FUELS STUDY

Port of Seattle + King County Solid Waste Division

Report Name:

Task 2 – Evaluate Existing Feedstocks

2023-06-30

prepared by

EXP

451 Montgomery Street, Suite 300 | San Francisco, CA 94104

Principal, Marcos Souza: marcos.souza@exp.com

Project Manager, Joseph Gale: joseph.gale@exp.com

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

2

TASK 2 – EVALUATE EXISTING FEEDSTOCKS

2. Task 2 - Evaluate Existing Feedstocks

2.1. Executive Summary

Washington State produces more than 5 million tons of municipal solid waste (MSW) per year which arrives at landfills. About half of this non-recyclable MSW can be used as feedstock for fuel production. While waste generation per capita has remained constant over the last several years, population growth increases waste generation.

This report analyses the waste and its flow from origin to landfill, the amount of waste and waste composition, waste contracts, landfill capacities, and discusses laws and regulations applicable to waste management and renewable fuel production facilities.

The sustainability of utilizing non-recyclable MSW as a feedstock is influenced by the heterogeneity of its material composition. In particular, the fossil carbon content of plastics in waste has a significant impact on the carbon intensity (CI) of fuels produced from MSW. This report analyses the current MSW feedstock composition and organic content, as well as models a future MSW feedstock composition where more plastics will be diverted into a circular economy, i.e., plastics recycling and reuse, and not available for fuel production. This report analyses the impact of future changes in MSW feedstock composition on refuse-derived fuels (RDF) properties.

EXP has developed a model to determine the impact of future changes in recycling behavior and recycling and reuse options on the quantity and composition of RDF as feedstock for SAF production. An expected reduction of the plastics content in MSW leads to a lower SAF yield per ton of RDF resulting in approximately 50% more landfill waste that would be needed compared to the waste demand calculated for today, to produce the same amount of SAF. The combination of plastics diversion and higher MSW demand for fuel production significantly reduces waste generation in landfills.

Five landfills in Washington State and northern Oregon receive sufficient MSW, currently and in the future, for a stand-alone SAF production plant. These include:

- Roosevelt Regional Landfill in Washington,
- Columbia Ridge Landfill in Oregon,
- Finley Buttes in Oregon,
- Cedar Hills Landfill in Washington, and
- LRI Landfill in Washington.

Cedar Hills and LRI Landfill receive MSW from the counties in which they are located (i.e., from within a radius of 50 miles). The other three landfills are located near the Columbia River and the Washington/Oregon border and collect waste from all over Washington State and parts of Oregon, with the waste traveling up to more than 500 miles from origin to landfill.

An analysis of waste hauler contracts revealed that the counties with the largest waste production have contracts that expire before 2028 and would allow the counties to divert their waste to a waste sorting and SAF production plant.

Tipping fees are above $100 per ton of waste in most counties with a significant increase over the last several years. Multiple federal, state, and municipal laws and regulations are in place related to waste management, renewable fuel production, and tax incentives. Earlier laws and incentives for renewable fuel production focused on pure biomass such as crops, vegetable oil, or animal fat and did not consider MSW as a renewable source; this has changed in recent years and MSW has been added as feedstock for renewable fuel production.

2.2. Introduction

MSW is a permanent feedstock stream arriving at landfills. MSW contains organic and carbon-containing material which can be further processed for energy production or for chemicals and fuel production. The subject of this study is the conversion of MSW to fuel. This section defines the basic requirements of MSW to be a suitable fuel source, identifies the MSW sources and flows from sources to landfills in the Pacific Northwest (PNW) region, assesses the MSW regarding the requirements for fuel production, and assesses U.S. requirements for renewable fuel incentives and the minimization of plastics in the fuel feedstock.

2.3. MSW Requirements for SAF Production

ASTM D7566 has defined three pathways to produce SAF from MSW. All three pathways utilize MSW gasification as a first step to produce syngas that will either be processed in a Fischer-Tropsch synthesis or converted to alcohol (ethanol or iso-butanol) and then hydro-processed to SAF in the ATJ process.

2.3.1. MSW Properties and Composition

MSW, shipped to a landfill, consists of materials such as food waste, paper, glass, rigid plastics (3-dimensional), yard waste, metals, wood, demolition materials, textiles, and plastic film, e.g., plastic wrap, plastic bags. The composition depends on recycling programs, seasonality, industrial collection, and residential structures. MSW suitable for gasification is called Refuse Derived Fuel (RDF) and consists mainly of paper, demolition wood, cardboard, plastic film, plastics, and textiles. Only small amounts of food waste and yard waste may be mixed into the RDF as they typically contain more than 50% moisture and must first be dried. Glass, metals, and other non-combustibles should be sorted out to keep their content below 1.5% as they would reduce energy efficiency and increase ash processing and handling. Manual sorting is not an efficient process, and it is strongly recommended a materials recovery facility (MRF) for the pre-sorting task. **Table 2.1** shows the properties of RDF components.

Table 2.1: Properties of Refuse Derived Fuel (RDF)[1,2]

Material	Calorific value (BTU/lb)	Calorific value (kJ/kg)	Ash content (wt.%)	Moisture content (wt.%)
Soft wood	6,330	14,724	0.1	19
Fiberboard, 90% paper	7,600	17,678	4.6	7.5
Damp wood	5,690	13,235	1.2	27.5
Leather trimmings	7,670	17,840	5.2	10.4
Cotton seed hulls	10,600	24,656	2.47	8.9
Sludge material (steel mill)	9,150	21,283	24.5	1.9
Nitrile rubber	15,240	35,448	3.4	
Cardboard, granulated	8,592	19,985	12.3	6.4
Wood waste, sawdust	7,500	17,445	0.8	14
Nut shells	7,980	18,561	1.75	11.85
Paper	5,765	13,410	6	6
Plastic Film	18,856	43,860	10	2
Rigid Plastic (3-dimensional)	14,433	33,570	10	2
Textile	8,500	19,770	4	4
Food waste	2,580	6,000	0.2	70
Yard waste	3,010	7,000	6.3	60

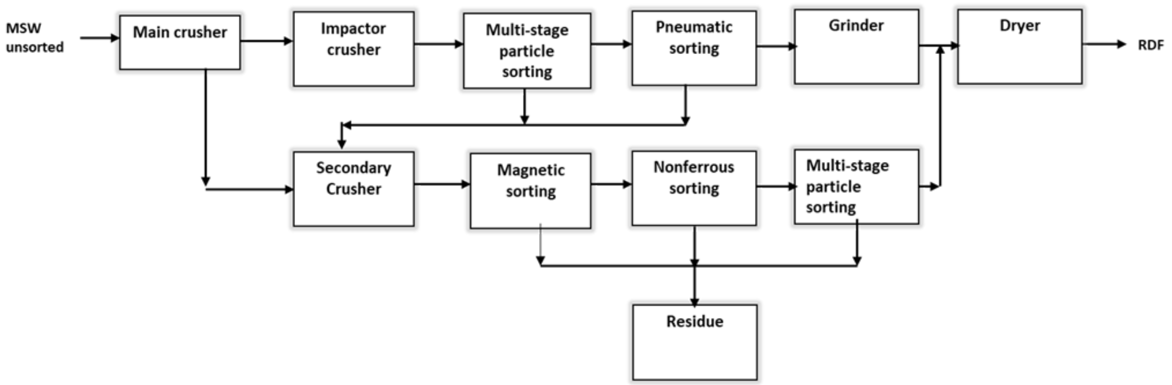
1 Haydary, J. (2016). Gasification of Refuse-Derived Fuel (RDF). Retrieved from *GeoScience Engineering*, 37-44: https://www.researchgate.net/publication/306085514_Gasification_of_Refuse-Derived_Fuel_RDF

2 Yong-Chil,S., Md Tanvir, A., Won-Seok, Y.(2018). Retrieved from Gasification of Municipal Solid Waste: https://www.intechopen.com/chapters/59269#B4, DOI: 10.5772/intechopen.73685

2.3.2. MSW Pre-processing

Task 1 discussed the requirements of solid material to feed into a gasifier. The material is crushed, pelletized, or milled to a certain size. As discussed above, certain materials should be removed from the MSW and delivered to a landfill with the remaining portion dried. Waste heat from the MSW to liquid fuel process is a good energy source for the drying process. The process of typical MSW preparation is shown in **Figure 2.1.**

Figure 2.1: MSW Preparation



2.4. MSW in the Pacific Northwest

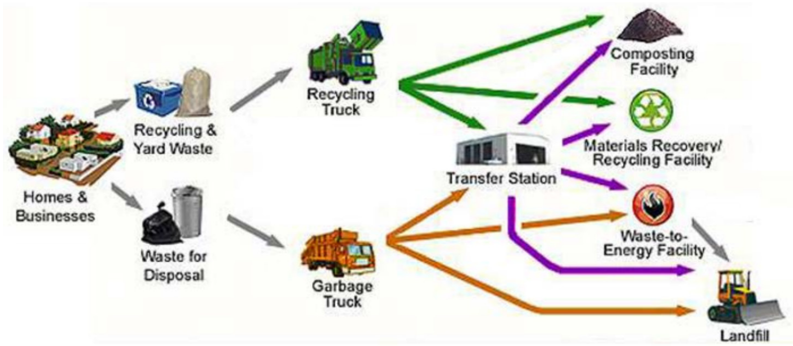
This section assesses MSW originating in the PNW region for quantity and quality to determine the availability for SAF production including:

- Recycling/sorting programs at the source (i.e., within the various municipalities and at transfer stations).
- Sorting and other usage at landfills (e.g., RNG production, composting, and energy production).
- Composition and amount of RDF components at landfills and major transfer stations.

2.4.1. Waste from Generation to Landfill

Waste originates in households and businesses. The various paths of this waste, collection, recycling programs at municipalities, and further processing are visible in **Figure 2.2**. This section of the study identifies the quantities and compositions at their source and follows the path to recycling stations and landfills. The analysis of this data is required to determine the quantity of available RDF at each landfill and assesses the potential for a renewable fuels production plant at a specific site and/or the requirement to ship either the MSW or the RDF to another potential renewable fuels production plant site.

Figure 2.2 Waste Destinations between Generation and Disposal[3]



3 Barrett, S., Field, R., Herzog, H., Lu, X., Malina, R., Seifkar, N., & Withers, M. (2015). *Biomass to Liquid Fuels Pathway: A Techno-Economic Environmental Evaluation.* Cambridge: MIT. Retrieved from: https://sequestration.mit.edu/bibliography/BTL%20final%20compiled.pdf

Industry trends suggest that developers of waste-to-chemicals or waste-to-fuel plants are increasingly focused on minimizing technological and financial risks by opting for smaller facility sizes. Rather than investing in larger-scale operations, these developers are dedicating their resources to optimizing the quality of feedstock to maximize the technical performance and economic viability of their plants. Consequently, significant endeavors have been undertaken to enhance and optimize waste sorting and material recovery practices. The objective is to generate uniform waste-derived feed streams with low moisture content and acceptable heating value. Such standardized feedstock is ideal for utilization in waste-to-energy and waste-to-liquid (WTL) conversion plants[4].

2.4.2. Waste Classification

EXP combined data from various sources to assess the MSW and its properties for the potential use as feedstock to produce SAF. [5],[6] This assessment addresses MSW derived from households and commercial sources in Washington State. Other waste delivered to landfills such as contaminated soil, asphalt, brick, soil, rock, gravel, construction and demolition debris, or special and toxic waste are excluded. These excluded materials are not suitable or there was not enough information available on the composition of the materials to qualify them.

The composition of MSW arriving at landfills varies depending on the region. The following criteria were considered for this evaluation:

- Usable portion of MSW arriving at a landfill (i.e., the RDF content)
- Lower heating value of the RDF
- Moisture content of the RDF

The materials included in RDF are:

- Wood debris
- Paper and cardboard
- Rigid plastics and plastic film
- Rubber
- Textiles and leather
- Food and yard waste (10% portion of total food and yard waste)

The study assumed a certain portion of food and yard waste cannot be sorted and will be part of the RDF. The available data are not consistent and differ by up to 10% depending on the source. The study uses the lowest of the available numbers for the MSW arriving at each landfill.

Table 2.2 compares the compositions for King County and the average for Washington State. The composition of the RDF from each region is satisfactory as feedstock, and the differences between the regions are within the overall accuracy of the data pool.

4 Barrett, S., Field, R., Herzog, H., Lu, X., Malina, R., Seifkar, N., & Withers, M. (2015). *Biomass to Liquid Fuels Pathway: A Techno-Economic Environmental Evaluation.* Cambridge: MIT. Retrieved from: https://sequestration.mit.edu/bibliography/BTL%20final%20compiled.pdf

5 Solid Waste & Recycling Data. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Research-Data/Data-resources/Solid-waste-recycling-data

6 Washington Statewide Waste Characterization Study. (2020-2021). Published in August 2021, Department of Ecology and Cascadia Consulting Group

Table 2.2: Comparison of RDF and MSW in King County and Average of Washington State

	WASHINGTON OVERALL		KING COUNTY	
	thousand mtpa MSW	per cent	thousand mtpa MSW	per cent
Wood	710	13.7	106	12.2
Paper and cardboard	880	16.9	153	17.7
Rigid plastics and plastic film	692	13.3	122	14.0
Rubber	23	0.4	9	1.1
Textiles and leather	190	3.7	36	4.2
10% of food and yard waste	120	2.3	35	4.0
Total RDF	2,615	50.3	462	53.2
Non-usable	2,585	49.7	40.6	46.8
Total MSW	5,200	100.0	868	100.0
Moisture content of RDF		13.5		14.5
Calorific value of RDF [MJ/kg]	19.5		21.2	

The MSW in King County has a higher portion of usable material and an almost 10% higher calorific value than the average for the state which would result in a slightly better product yield. The moisture content of RDF in all regions of Washington state is between 11 and 15% and within the acceptable range for further processing. The RDF portion varies between 46% in the Puget Sound area and 56% in Washington's southwest region with 50% as the state-wide average.

2.4.3. Municipal Waste Collection

2.4.3.1. Kitsap County

Seven facilities in the county receive and transfer waste:[7]

- Bainbridge Island Transfer Station
- City of Poulsbo Transfer Station
- Hansville RAGF
- Olalla RAGF
- Silverdale RAGF
- Poulsbo Recycle Center (PRC)
- Olympic View Transfer Station (OVTS)

Poulsbo Recycle Center does not collect garbage. Hansville, Olalla, and Silverdale are drop-off facilities for self-haulers, called recycling and garbage facilities (RAGFs). At the RAGFs', customers place their waste into open roll-off containers. A contractor then hauls the containers to OVTS. At OVTS, the self-hauler's waste is tipped onto the floor and combined with the waste delivered from a curbside collection by commercial vehicles. Once on the floor, the waste goes into an automated compactor that compacts it into containers. The containers travel via rail to the Columbia Ridge Landfill.[8]

At the Bainbridge Island Transfer Station, MSW and recyclables delivered by self-haulers and small commercial vehicles are dumped into roll-off containers and hauled to OVTS. Recyclables go to multiple locations. MSW arriving at the City of Poulsbo are delivered to OVTS.

7 Kitsap County Solid and Hazardous Waste Management Plan. (2018). Chapter 8, Transfer Systems for Waste and Recyclables. Retrieved from Kitsap County Department of Public Works: https://www.kitsapgov.com/pw/Documents/2018_SHWMP_Web.pdf.
8 Ibid.

Table 2.3: A Summary of the Type of Waste Accepted at Six Facilities in Kitsap County[9]

Material	Bainbridge Island Transfer Station	Hansville RAGF	Olalla RAGF	Silverdale RAGF	Poulsbo Recycle Center	OVTS
Commercial Waste	✓					✓
Self-Haul Waste	✓	✓	✓	✓		✓
Tires	✓*					✓
Electronics	✓					✓
Household Recyclables	✓	✓	✓	✓	✓	✓
Yard Debris	✓					✓
Wood Debris	✓					✓
Scrap Metal	✓			✓	✓	✓
SharpsW	✓	✓	✓	✓	✓	✓
Used Oil	✓	✓	✓	✓	✓	✓
Used Antifreeze	✓	✓	✓	✓	✓	✓
Household Batteries	✓	✓	✓	✓	✓	✓
Vehicle Batteries	✓	✓	✓	✓		
White Goods	✓	✓	✓	✓	✓	✓
Compact Fluorescent Lights	✓	✓	✓	✓	✓	✓
Used Oil Filters	✓	✓	✓	✓	✓	✓

*Limited number and size collected.

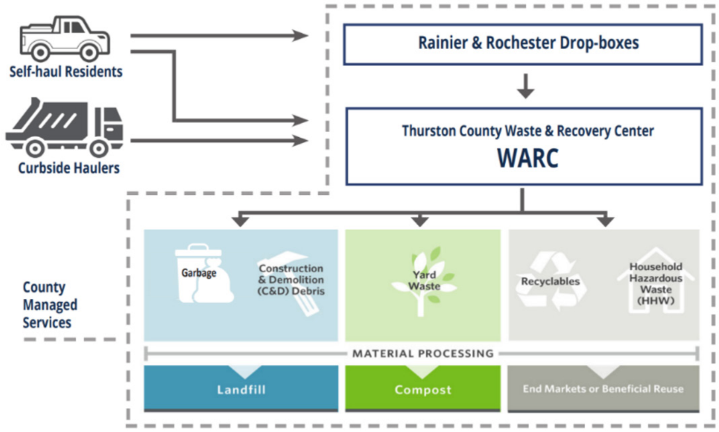
2.4.3.2. Clark County

Curbside collection is delivered to three transfer stations. All transfer stations are operated by Columbia Resource Company (CRC), which is owned by Waste Connections.[10] Central Transfer and Recycling (CTR) and West Vancouver Materials and Recovery Center (West Van) are the largest transfer stations,[11] and West Van is the only of the three transfer stations with MRFs activities to recover resources such as plastic containers, glass bottles, office paper, cardboard, aluminum and ferrous metals, and oil.[12] After recyclable materials are recovered at West Van and CTR, the remaining MSW is compacted, placed in shipping containers (each able to hold approximately 30 tons of MSW), and hauled to the Tidewater M-5 barge loading facility.[13] At this facility, the containers are loaded onto barges and shipped, under the responsibility of Tidewater Barge Lines, upriver to the Port of Morrow (Morrow County, OR) - a 180-mile journey. Large barges accommodate up to 80 containers and smaller barges carry a maximum of 36; the monthly average of containers shipped is 800. Finally, trucks transport the containers from the port to Finley Buttes Landfill, a 12-mile journey. After disposing of the MSW at the landfill, the trucks return the containers to the Port of Morrow and are shipped back to the transfer stations for reuse.

Washougal Transfer Station (WTS) is the third station, and MSW passing through is ultimately disposed of at Wasco County Landfill after transportation via truck. The route is as follows: from WTS, the trucks travel east on Highway 14. After passing over the Dalles Bridge to Oregon, the trucks travel south on Highway 197 to the landfill.[14]

9 Kitsap County Solid and Hazardous Waste Management Plan. (2018). Chapter 8, Transfer Systems for Waste and Recyclables. Retrieved from Kitsap County Department of Public Works: https://www.kitsapgov.com/pw/Documents/2018_SHWMP_Web.pdf.
10 Drop-off Services. (n.d.). Retrieved from Waste Connections of Washington, Inc: https://wcnorthwest.com/dropoff.
11 County, C. (2015). Chapter 10, Landfill Disposal. In Clark County Solid Waste Management Plan 2015 (pp. 10-1 – 10-6). Vancouver
12 Materials Recovery Facility or MRF. (n.d.). Retrieved from Columbia Resource Company: https://www.columbiaresourcecompany.com/materials-recovery-facility
13 County, C. (2015). Chapter 10, Landfill Disposal. In Clark County Solid Waste Management Plan 2015 (pp. 10-1 – 10-6). Vancouver
14 Ibid.

Figure 2.3: The Flow of Waste in Thurston County[15]



2.4.3.3. Thurston County

From the curbside, garbage is sent to the Thurston County Waste & Recovery Center (WARC). Alternatively, self-haulers deliver their own garbage to the WARC, Rainier Drop-Box, or Rochester Drop-Box.[16] Since the drop-boxes are being operated above capacity, the county is considering a new transfer station for the south.[17] At the WARC, garbage is compacted and loaded into shipping containers. Trucks deliver the containers to Centralia, WA, from where it is sent 200 miles via rail to Roosevelt.[18] Finally, trucks deliver the containers to Roosevelt Landfill.

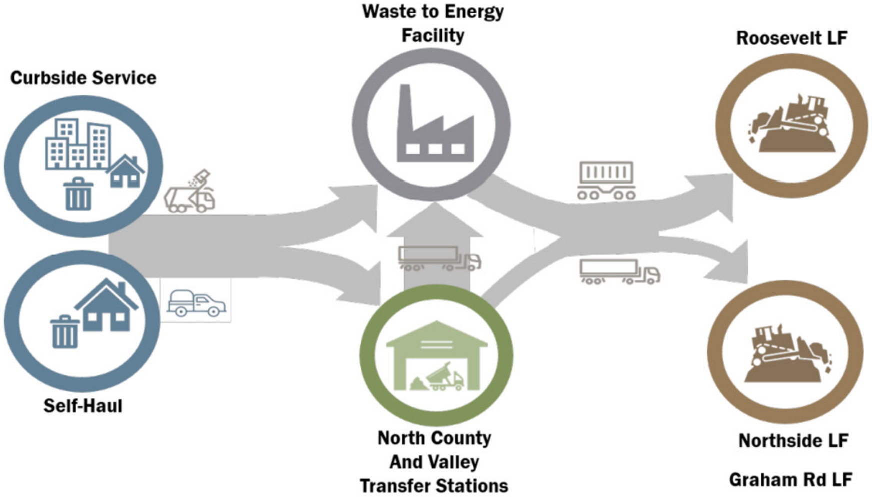
2.4.3.4. Spokane County

Curbside collectors pick up waste in five service areas and transport the waste to the Spokane Waste to Energy Facility (WTE Facility) or two transfer stations - the North County Transfer Station and Valley Transfer Station, owned by Spokane County.[19] The WTE facility is the primary facility in the county and has an onsite transfer facility to handle waste unsuitable for incineration. Waste received at the remaining two transfer stations is transported via truck to the WTE facility for incineration. WTE can only process roughly 800 tons daily (292,000 tons annually). If the capacity exceeds this amount, or if the WTE facility is undergoing maintenance, the waste is occasionally packed into containers at each facility and trucked to the Yardley intermodal railroad facility and sent to Roosevelt Landfill by rail. If rail transport and the WTE facility are unavailable, MSW is trucked to the Northside Landfill and C&D and inert material is delivered to the Graham Road Recycling and Disposal Facility. A summary of the transfer process is in **Figure 2.4**.

In 2021, North County received 76,208 tons of waste, Valley received0 79,257 tons, and the WTE Facility received 274,416 tons. Roosevelt Landfill received 68,650 tons that same year.

15 Solid Waste Services Contract FAQs. (2022, March 22). Retrieved from Thurston County Public Works: https://www.thurstoncountywa.gov/tchome/SiteAssets/Pages/publicmeetings/Contract%20FAQs.pdf
16 Public Works. (n.d.). Thurston County Washington: https://www.thurstoncountywa.gov/pw/sw-grhome/Pages/sw-Garbage.aspx
17 Thurston County Solid Waste Advisory Committee. (2022, March 2). Retrieved from *Meeting Minutes*: https://www.co.thurston.wa.us/solidwaste/swac/2022/SWAC%20March%20Minutes.pdf
18 Solid Waste Services Contract FAQs. (2022, March 22). Retrieved from Thurston County Public Works: https://www.thurstoncountywa.gov/tchome/SiteAssets/Pages/publicmeetings/Contract%20FAQs.pdf
19 Comprehensive Solid Waste and Moderate Risk Waste Management Plan for Spokane County 2022 through 2027. (2022, July). *Great West Engineering.* Retrieved from Spokane County Regional Solid Waste System: https://www.spokanecounty.org/DocumentCenter/View/44215/Spokane-County-SWMP?bidId=

Figure 2.4: A Summary of the Transfer of Waste in Spokane County[20]



2.4.3.5. City of Seattle

The City of Seattle owns and operates the North and South Transfer Stations. The North Transfer Station is located in the Wallingford neighborhood and South Transfer Station located south of the First Avenue South Bridge. In 2022, the North Transfer Station received a total of 99,831 tons of annual waste (86,796 tons of garbage, 10,376 tons of organics, 206 tons of wood waste, 553 tons of recyclables, 1,697 tons of appliances, 204 tons of tires). Similarly, the South Transfer Station received 269,433 tons of waste in 2022 (200,336 tons of garbage, 66,770 tons of organics, 338 tons of wood waste, 827 tons of recyclables, 900 tons of appliances, 262 tons of tires).[21]

After passing through transfer stations, waste is transported onto the Union Pacific Railroad Argo Rail Yard. Finally, a contract between Seattle and Washington Waste Systems, Inc. (WWS) directs the MSW via rail to the Columbia Ridge Landfill in Gilliam County, Oregon. A Garbage Report for Quarter 4 published by Seattle Public Utilities (SPU) in 2019 indicated the Columbia Ridge Landfill received 361,762 tons of waste.

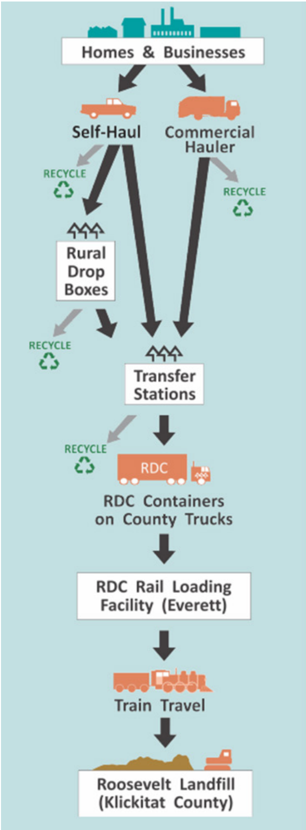


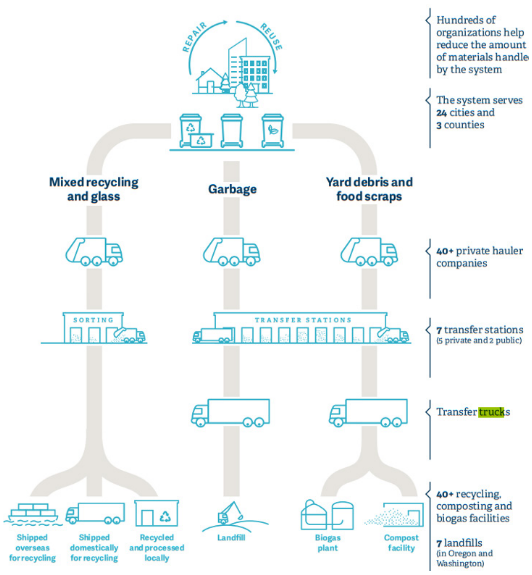
Figure 2.5: The Transfer of Waste Through Snohomish County[22] >

2.4.3.6. Snohomish County

MSW generated by the 18 cities, two towns, and 49 census-designated places in Snohomish County is picked up from the curbside in garbage trucks by private haulers and sent to one of three transfer stations: Airport Road Recycling and Transfer Station (ARTS), in South Everett; North County Recycling and Transfer Station (NCRTS), in Arlington; or Southwest Recycling and Transfer Station (SWRTS) in Mountlake Terrace. At the station, MSW is compacted into cubes – each with a weight of 29 tons – and then packed into shipping containers and transported via truck to the Everett Intermodal Facility. Thereafter, the waste travels 360 miles by rail (a roughly 12hr journey) to Roosevelt. Finally, trucks transport the containers to the Roosevelt Regional Landfill, WA (which receives over 95% of the waste), and the Columbia Ridge Landfill, OR, and the containers are returned so the process can continue.[23]

20 Comprehensive Solid Waste and Moderate Risk Waste Management Plan for Spokane County 2022 through 2027. (2022, July). *Great West Engineering.* Retrieved from Spokane County Regional Solid Waste System: https://www.spokanecounty.org/DocumentCenter/View/44215/Spokane-County-SWMP?bidId=
21 *Seattle Public Utilities Station Monthly Tons 2022 Year End Summary Monthly Tons Report*. Seattle Public Utilities, 01 November. 2022: https://www.seattle.gov/documents/Departments/SPU/Services/Garbage/Station%20Monthly%20Trips_Landscape%202022-combined.pdf
22 Snohomish County Public Works. (n.d.). Getting down to Basics: Where does our Garbage go? Retrieved from: https://www.snohomishcountywa.gov/DocumentCenter/View/44630/Where-Does-Our-Garbage-Go--English?bidId=
23 Ibid.

Figure 2.6: A Summary of the Waste Flow in Metro[24]



2.4.3.7. Oregon Metro

Over 40 private haulers collect garbage from the curb and deliver waste to the seven transfer stations and recyclable materials to sorting stations.[25] Of the seven stations, five are privately owned and two owned by Metro, the Metro Central facility (Portland) and Metro South facility, OR.[26] After passing through the transfer stations, waste is trucked to seven landfills, as indicated in Figure 2.6. The two stations owned by Metro always dispose of waste at the Columbia Ridge Landfill since 2020 and jointly receive over 500,000 tons of garbage annually.[27]

2.4.3.8. Pierce County

Waste haulers deliver curbside collection to the six transfer stations. Four transfer stations are operated by LRI but owned by the county. The city of Tacoma operates and owns one, and LRI owns and operates the final station. From the transfer stations, all waste is disposed of at the LRI Landfill.

2.4.3.9. King County

Curbside waste is delivered to eight transfer stations: Shoreline, Houghton, Factoria, Renton, Bow Lake, Cedar Falls, Algona, and Enumclaw. Self-haulers have the option of delivering waste to the transfer stations or to two drop-boxes. At the transfer stations, garbage is compacted into trailers, loaded onto trucks, and delivered to the Cedar Hills Regional Landfill.[28]

2.4.3.10. Skagit County

All MSW in the county passes through a transfer station called Skagit County Transfer and Recycling Station (TRS) or two rural drop box sites, namely Sauk Transfer Station and Clear Lake Recycling and Compactor Site. Waste Management collects waste in the county and delivers it to TRS (located five miles west of Mount Vernon), where self-haulers add their waste. TRS received 99,189 tons of MSW in 2014. Sauk transfer station accepts self-hauler deliveries. In 2014, Sauk received 1,550 tons of solid waste (1.7% of the waste produced in the county). Similarly, Clear Lake received 136 tons of waste from self-haulers in 2014 (approximately 0.2% of the waste produced in the county). All county waste is disposed of at Roosevelt Regional Landfill.[29]

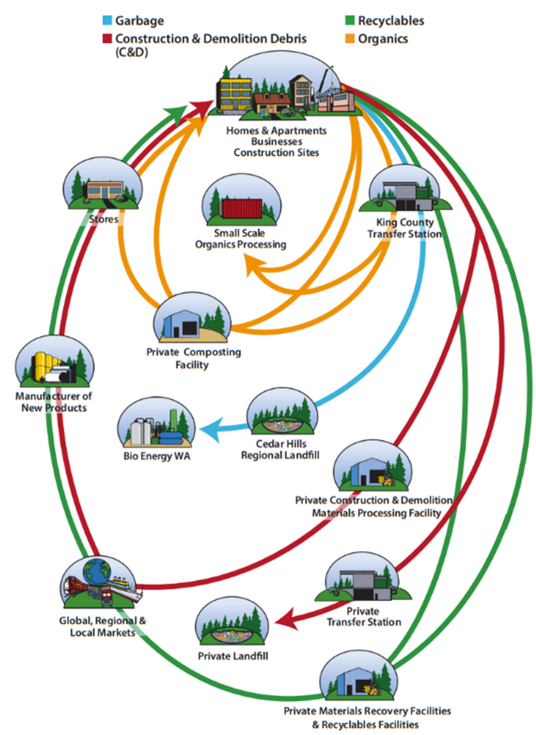


Figure 2.7: King County Waste Flow[30]

24 2030 Regional Waste Plan, Equity, health and the environment. (2019, March 7). Metro, Portland: https://www.oregonmetro.gov/sites/default/files/2019/03/22/2030Regional-WastePlan_03222019_1.pdf
25 2030 Regional Waste Plan, Equity, health and the environment. (2019, March 7). Metro, Portland: https://www.oregonmetro.gov/sites/default/files/2019/03/22/2030RegionalWastePlan_03222019_1.pdf
26 Ibid
27 Landfills and waste transport. (n.d.). Metro: https://www.oregonmetro.gov/landfills-and-waste-transport
28 2019 Comprehensive Solid Waste Management Plan. (2019, November). Retrieved from King County Solid Waste Division, Seattle: https://your.kingcounty.gov/dnrp/library/solid-waste/about/planning/2019-comp-plan.pdf
29 Skagit County Solid Waste Management Plan. (2017, September). Retrieved from Green Solutions, South Prairie: https://www.skagitcounty.net/PublicWorks-SolidWaste/Documents/SCSWMP%202018-2023.pdf
30 Ibid

2.4.3.11. Whatcom County

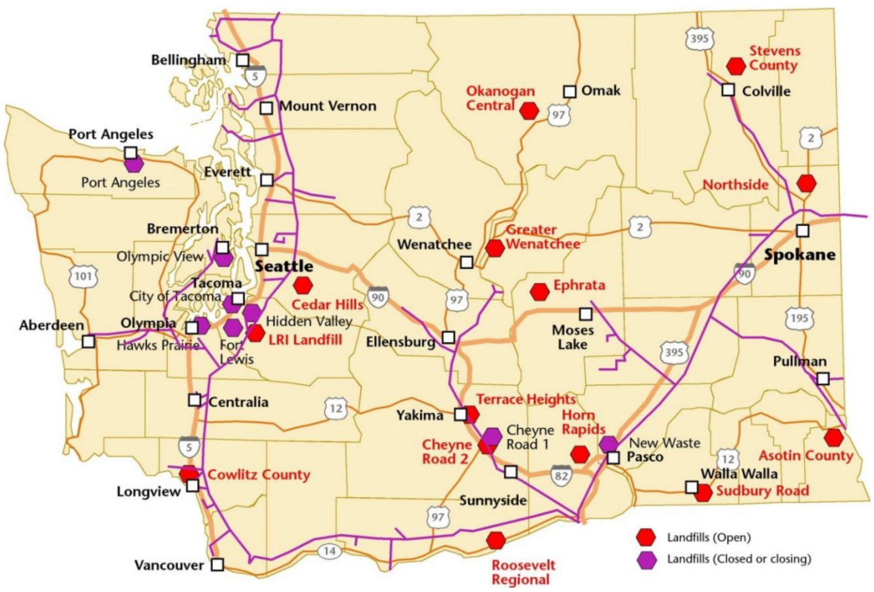
Curbside collectors and self-haulers dispose of waste at three transfer stations: Regional Disposal Contract (RDC) Transfer Station, Recycling and Disposal Services (RDS) Transfer Station (which houses an MRF), and Cando Recycling Transfer Station. In addition, self-haulers may deliver waste to the following four drop-boxes: SSC Birch Bay-Lynden Drop Box Facility, SSC Cedarville Drop Box Facility, SSC Roeder Avenue Drop Box Facility, and NVD Drop Box Facility. RDC and RDS are the two primary stations. Waste from RDC is delivered to the Roosevelt Regional Landfill by rail. A total of 50,422 tons of waste was processed at RDC in 2013. Waste from RDS is sent to the Columbia Ridge Landfill by truck where recyclable materials are resold, and wood is shipped to Canada and Washington State. A total of 105,788 tons of waste was processed at RDS in 2013. Finally, waste from the Cando Recycling and Transfer Station is trucked to the Cowlitz County Headquarters Landfill and recyclable materials are sold in British Columbia, Canada.[31]

2.4.4. Landfills

2.4.4.1. Landfills in Washington

The study assesses Washington and Oregon landfills and pre-selects suitable landfills in regard to quantity of MSW and distance from SEA. **Figure 2.8** provides an overview of active landfills and their proximity to natural gas pipelines. Natural gas is required for operations of the gasification units and close proximity to a major natural gas pipeline is beneficial.

Figure 2.8: Washington Landfills and Major Natural Gas Pipelines[32]



Counties in Washington State send MSW to 17 different landfill sites. For this study, this section introduces the five most relevant landfills.

For a technically and economically viable SAF plant, approximately 500 mtpd of RDF is required. This equates to approximately 330,000 tons per year of incoming MSW. The following landfills meet the minimum capacity requirements and will be further evaluated for size, location, and flow of MSW:

- Roosevelt Regional Landfill in Washington State, Columbia Ridge Landfill, and Finley Buttes in Oregon as landfills with mostly *inter-county waste shipments*. All three landfills are in the Columbia River region. A total waste stream of more than 1.5 million tons annually flows from Puget Sound and counties in northwestern Washington and 290,000 tons from counties in southwestern Washington to landfills in the Columbia River area.

31 Comprehensive Solid and Hazardous Waste Management Plan. (2016, June 14). Whatcom County, Washington: https://www.whatcomcounty.us/DocumentCenter/View/6723/Whatcom-County-Comprehensive-Solid-and-Hazardous-Waste-Management-Plan

32 Washington State University Energy Program. (2017, December). *Harnessing Renewable Natural Gas for Low-Carbon Fuel: A Roadmap for Washington State.* Retrieved from: https://www.commerce.wa.gov/wp-content/uploads/2018/02/Energy-RNG-Roadmap-for-Washington-Jan-2018.pdf

- Cedar Hills Landfill, LRI Landfill, and Cowlitz County Landfill receive regionally sourced waste, with Cedar Hills Landfill and LRI Landfill receiving enough for delivery to stand-alone SAF plants. Cowlitz County would need additional import of waste but is logistically well located.
- Spokane Regional collects waste from the region and utilizes its own waste-to-energy facility.

2.4.4.2. Cedar Hills Landfill

Cedar Hills Landfill, owned by King County, receives between 800,000 and one million tons of solid waste each year from residential and non-residential sources.[33] It commenced operations in 1965 and held 42,929,254 tons of waste on site in 2020. The exact closure date is currently unknown and depends on site development and waste prevention efforts. It is anticipated that capacity could be extended to as late as 2040. A waste-to-liquid fuel production facility could help extend the life of the landfill.[34]

2.4.4.3. Roosevelt Regional MSW Landfill

Roosevelt Regional MSW Landfill, owned by Republic Services, Inc, is another potential long-term partner for a future fuel production facility; with a life span from 1990-2085. The site hosts 60,551,072 tons of waste.[35] Approximately 60% of the waste onsite is MSW, 20% special waste (e.g., asbestos and soils), and 20% C&D.[36] The landfill is fed with more than 480,000 tons of MSW from Snohomish County, 180,000 tons from Thurston County and more than 100,000 tons from Skagit County. In 2017, the landfill reported incoming municipal waste to be in the region of approximately 1.15 million tons of material annually.[37]

2.4.4.4. Land Recovery, Incorporated (LRI) Landfill

In 2020, this landfill had 20,300,558 tons of waste on site. The remaining site capacity to accommodate more waste is 29.2 million cubic yards, or approximately 20 years of service.[38] LRI Landfill received 680,000 tons per year of MSW.

2.4.4.5. Columbia Ridge

The Columbia Ridge Landfill receives more than 300,000 tons per year from the City of Seattle, more than 200,000 tons from Kitsap County and more than 100,000 tons per year from Whatcom County. As of 2022, the landfill anticipates continuing operation for the next 143 years if it continues to receive approximately 1.5 million tons of MSW annually.[39]

2.4.4.6. Finley Buttes

Finley Buttes' main sources from Washington state are Clark County with around 290,000 tons per year and Franklin County in eastern Washington with around 100,000 tons per year. In 2015, it was anticipated that the site would remain open for another 300 years.[40] Finley Buttes currently accepts MSW, C&D waste, and special wastes.[41]

2.4.5. Waste Quantities and Flows

The State of Washington produced around 5 million tons of municipal waste in 2016 that landed in landfills. **Figure 2.9** identifies the amount of MSW produced by each county and the amount that each landfill received.[42]

---

33 Draft Environmental Impact Statement, Cedar Hills Regional Landfill 2020 Site Development Plan and Facility Relocation

34 Cedar Hills Regional Landfill. (2022, September 28). King County Solid Waste Division Fall 2022 Community Meeting: Sept. 28, 2022 - Cedar Hills Regional Landfill Community Meeting Notes - King County Solid Waste Division

35 USEPA. (2022, August). *Washington State-Level Project and Landfill Totals from the LMOP Databse.* Retrieved from United States Environmental Protection Agency: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.epa.gov%2Fsystem%2Ffiles%2Fdocuments%2F2022-08%2Flmopdatawa.xlsx&wd-Origin=BROWSELINK

36 Lopez, L., Pitzler, D., & Wallace, B. (2017, May 9). *Memorandum: Transportation and Disposal Evaluation– Phase 1 Results.* Retrieved from Metro: https://www.oregonmetro.gov/sites/default/files/2017/05/09/Transport_Disposal_Procurement_Technical_Memo_20170509.pdf

37 DeMent. (2017, November 7). Revisiting Roosevelt: the landfill of a truly epic scale. Retrieved from The Goldendale Sentinel: Revisiting Roosevelt: the landfill of a truly epic scale | News | goldendalesentinel.com

38 LRI Landfill. (n.d.). Retrieved from: https://www.lriservices.com/lri-landfill

39 Chapter 7, Solid Waste Transfer, Processing, Disposal, and Emergency Management. (2022, April). Retrieved from Draft for Public Review: https://www.seattle.gov/documents/departments/spu/documents/plans/2022solidwastedraftch7.pdf

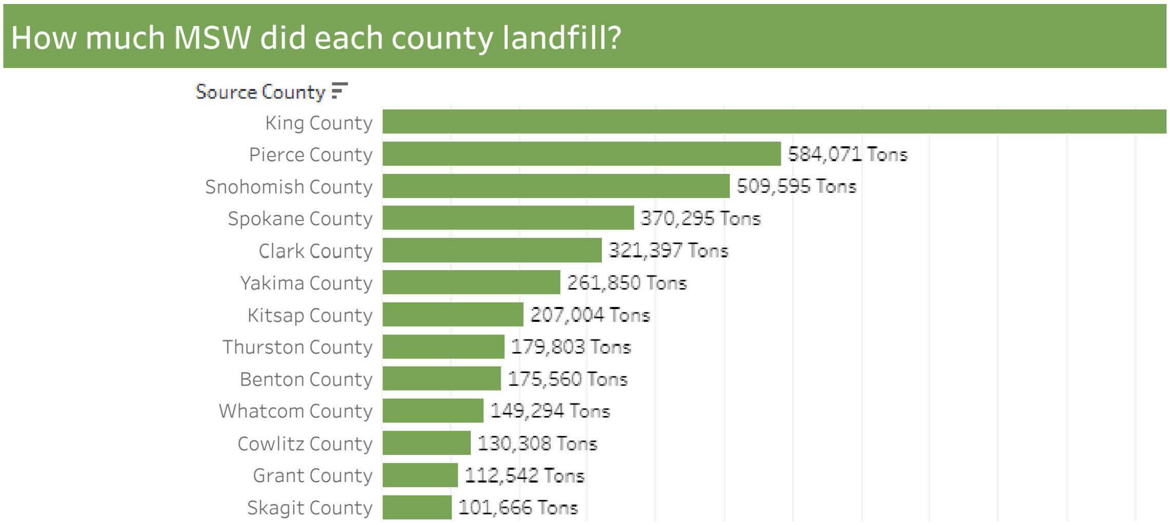
40 Clark County. (2015). Chapter 10, Landfill Disposal. In Clark County Solid Waste Management Plan 2015 (pp. 10-1 – 10-6). Vancouver

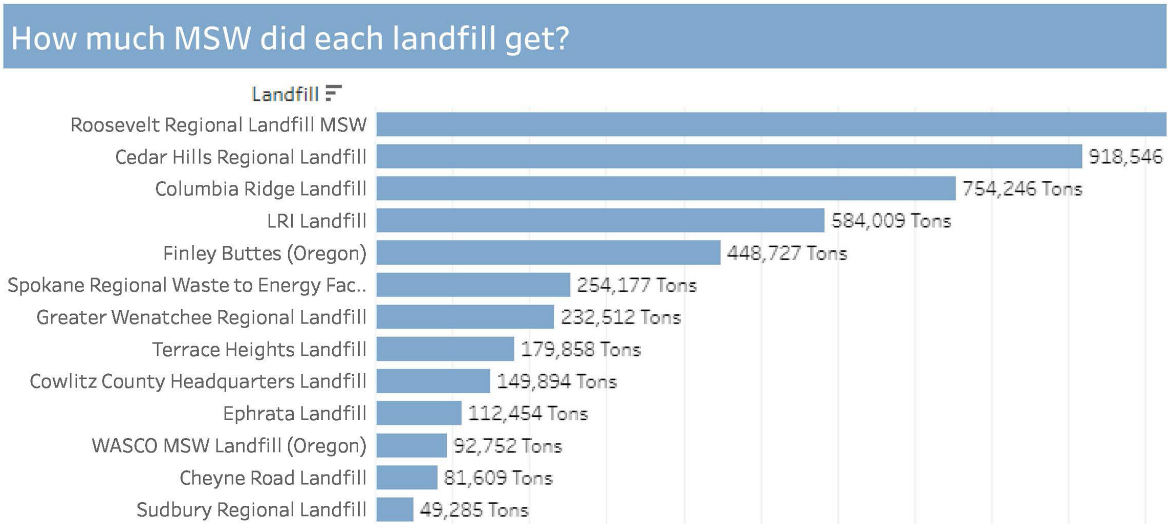
41 Waste Connections. (n.d.). Retrieved from Finley Buttes Landfill: https://www.wasteconnections.com/finley-buttes-landfill/

42 Municipal Solid Waste Flow. (2016). Retrieved from Department of Ecology State of Washington: https://public.tableau.com/app/profile/solidwastemgmt/viz/MunicipalSolidWasteFlow2016/Dashboard1

The main inter-county waste streams are summarized below. Significant amounts of waste flow from Puget Sound and southwest Washington areas to landfills in the Columbia River area. The Columbia Ridge Landfill receives more than 300,000 tons per year from King County, more than 200,000 tons from Kitsap County and more than 100,000 tons per year from Whatcom County. Roosevelt Regional Landfill is fed with more than 480,000 tons from Snohomish County, 180,000 tons from Thurston County and more than 100,000 tons from Skagit County. Finley Buttes' main sources from Washington state are Clark County with around 290,000 tons per year and Franklin County in eastern Washington with around 100,000 tons per year. A total waste stream of more than 1.5 million tons annually flows from Puget Sound and the Northwest to landfills in the Columbia River area and 290,000 tons from Clark County to Finley Buttes.

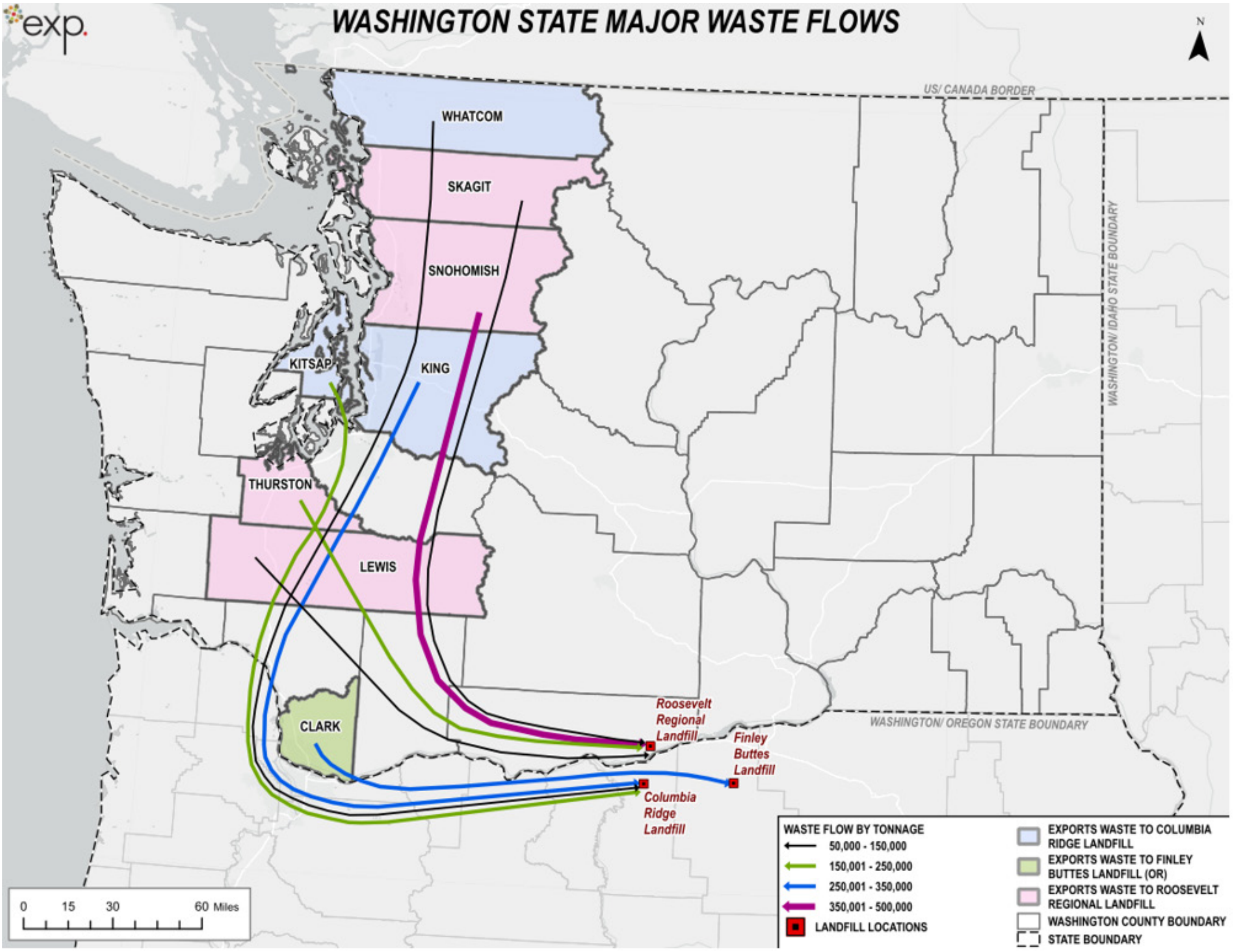
Figure 2.9 Waste Producer and Receiver[43]





43 Municipal Solid Waste Flow. (2016). Retrieved from Department of Ecology State of Washington: https://public.tableau.com/app/profile/solidwastemgmt/viz/MunicipalSolidWasteFlow2016/Dashboard1

Figure 2.10: Major Waste Streams in Washington State and Columbia River Area



2.5. Current and Future Waste Composition, Impact on SAF

2.5.1. EXP Model

EXP analyzed and identified trends in population growth, waste generation and recycling behavior between 2000 to 2018. This period does not include disruptors including the COVID-19 pandemic, as these could cause misinterpretations of long-term trends.

Waste produced from households and commercial sources has increased significantly over the last two decades. Recycling programs during this period reduced the growth rate of waste sent to landfill but did increase waste quantities. The dip in the 2008 to 2012 time period may rather be caused by the economic dip and a slowdown in population growth during this time but not be seen as a general trend change.

Figure 2.11 compares the growth in population, produced waste and MSW sent to landfills. The amount of generated MSW as well as MSW arriving at landfills is expected to further increase. This pattern could change, and the amount of waste be reduced by the introduction of additional recycling and reuse programs and policies such as a zero-waste policy. Cascadia Consulting Group developed a forecast model assuming three waste diversion scenarios. The model confirms changes in recycling programs and behavior modification could help limit the growth of landfilled waste.

Figure 2.11: Growth Trends in Washington State for Population, Produced, and Landfilled Waste

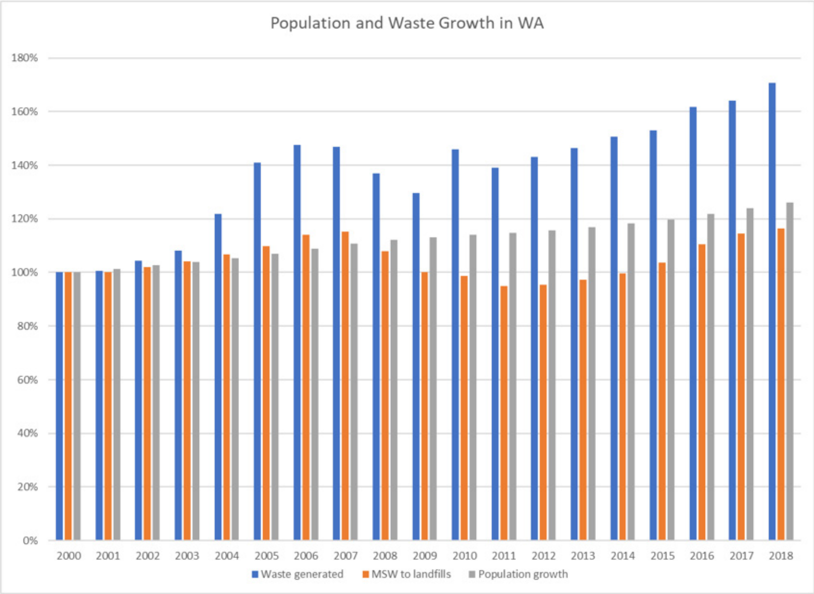
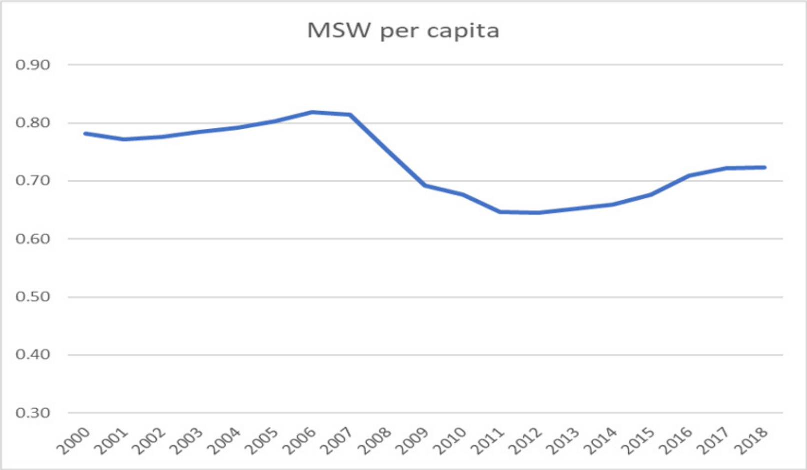


Figure 2.12: MSW to Landfills per Capita for WA State



Another trend curve shown indicates a reduction in waste to landfills cannot be expected with current recycling programs. The MSW per capita could be stabilized; however, the population in Washington is still growing.

Table 2.4 shows changes in absolute quantities and changes in the waste mix for landfilled MSW in WA between 2009, 2015, and 2021. Wood waste, nitrile rubber, textiles and plastics increased between 2009 and 2021, whereas paper and organics see a reduction in landfilled quantities.[44,45,46]

44 Washington Statewide Waste Characterization Study. (2009). Published in June 2010, Department of Ecology and Cascadia Consulting Group.
45 Washington Statewide Waste Characterization Study. (2015). Published in October 2016, Department of Ecology and Cascadia Consulting Group.
46 Washington Statewide Waste Characterization Study. (2020-2021). Published in August 2021, Department of Ecology and Cascadia Consulting Group.

Table 2.4: Average MSW Quantities and Composition in Washington State in the Years 2009, 2015, and 2021.
Only materials that can be used as RDF for SAF production are listed.

Material	2009		2015		2021	
	mtpa of usable MSW	portion	mtpa of usable MSW	portion	mtpa of usable MSW	portion
Cardboard	469,574	20.8%	332,543	16.3%	514,406	19.7%
Wood waste	438,174	19.4%	562,462	27.6%	710,919	27.2%
Nitrile rubber	15,216	0.7%	30,118	1.5%	23,594	0.9%
Paper	490,049	21.7%	351,210	17.2%	365,485	14.0%
Plastics, rigid and film	568,145	25.2%	466,749	22.9%	692,798	26.5%
Textile	136,340	6.1%	167,357	8.2%	188,132	7.2%
Organic[1]	135,625	6.0%	130,614	6.4%	120,192	4.6%
Usable for SAF Production	2,253,123	100%	2,041,053	100%	2,615,526	100%
Total MSW	4,978,496		4,589,537		5,275,514	
usable portion	45.3%		44.5%		49.6%	
Calorific value [MJ/kg]	19.0		18.6		19.5	

Note 1: A portion of 10% of organics has been assumed for SAF production.

A future outlook requires the assumption of possible changes in behavior and in recycling programs. Paper, fiberboard, plastics and possibly textiles are the materials with the highest probability for changes in the coming years.

Future MSW flows and compositions have been modeled for higher degrees of recycling or reuse to determine the impact on RDF and fuel production. The model assumes an approximate 25% reduction of total waste per capita ending in landfills with reductions in plastics of 50%, paper of 40%, cardboard of 30% and textiles of 20%. A second scenario assumes the avoidance of plastics entirely to determine the impact of maximum plastics recycling or plastics ban for renewable fuels.

Cascadia's forecast model exhibits similar trends. The "Zero Plastics" model is a more theoretical contemplation to examine the impact on MSW regarding suitability for fuel production as it could result from additional sorting requirements or establishing a full circular economy for plastics.

The RDF compositions for future waste recycling options are compared in **Table 2.5.**

Table 2.5: Modeling the Impact of Waste Reduction on Future RDF Composition

Material	Future	Zero Plastics
Cardboard	18.9%	31.8%
Wood waste	37.5%	42.7%
Nitrile rubber	1.2%	2.1%
Paper	11.6%	10.1%
Plastics, rigid and film	18.2%	0%
Textile	7.9%	13.3%
Organic[1]	4.7%	0%
Usable for SAF Production	100%	100%
Calorific Value [MJ/kg]	17.9	16.0

Cascadia's future waste model for low, medium, and high diversion rates confirms that enough RDF will be available even in the high diversion scenario. The identified landfills are large enough to deliver sufficient RDF for a fuels production plant under the modified future conditions and could even do so if the total waste flow were to decrease over the next decade and beyond.

2.5.2. Cascadia Modeling and Parameters

Cascadia Consulting Group estimated the current quantity and composition of MSW at each landfill in Washington and Oregon as well as the future quantity and composition. The following parameters were used in this modeling exercise:

- Only waste reported by landfills as MSW was included in the modeling. Many landfills receive non-MSW waste including asbestos, tires, sewage sludge, industrial waste, contaminated soils, diseased livestock, and other items. These categories were excluded from the analysis.
- The modeling focused on materials with value in the MSW-liquid fuel conversion pathway.
- The model assumes that changes in the commercial and residential waste tonnage over the last twenty years will be maintained for the next twenty years.
- Washington and Oregon export a considerable amount of waste to each other, i.e., waste generated in the State of Washington is not necessarily landfilled in the State of Washington. No special procedures are necessary to account for this waste, but it is noteworthy.
- Future tonnage and composition estimates are projected for 2041, 20 years from the most recent available data[47].
- The model does not account for the complex interdependence of goals and changes to commercial sector employment that may increase or decrease the quantity and suitability of waste for conversion.
- Three future scenarios are modeled – high diversion, medium diversion, and low diversion – which equates to feedstock availability.
  - High diversion (low feedstock) – 70% diversion of traditional recyclables and currently passed legislation meets its legislative requirements.
  - Low diversion (high feedstock) – no change to current diversion and currently passed legislation does not meet its legislative requirements.
  - Medium diversion (medium feedstock) – the midpoint between high and low diversion estimates.
- Numerous counties dispose of waste at multiple landfill locations. In the absence of any data to determine otherwise, the model assumes that there is no difference in the composition of the waste sent to different landfills by county.[48]

2.5.3. Constraints

Many landfills and self-haulers consider information about quantity of material and corresponding source of the material confidential. The sharing of information is often limited. When shared, details necessary for modeling, including tonnage, waste type, or waste sector, may be excluded. Cascadia's strong relationships with private haulers and facilities yielded collection of to public and non-public data. However, incomplete data from all private entities places limitations on the value of this information.

Oftentimes, public entities less granular tonnage data than private entities. For example, waste tonnage data is available by county through public entities while private entities often have data at the city level. However, many public agencies are currently staff and budget constrained. Many public entities require completing a public disclosure request with the caveat that responding to the request would require an extended period.

The data public entities have is often reliant on reporting from private entities with permissive deadlines for filing reports; COVID frequently extended those deadlines. In some cases, the most recent data available is from 2018. The model is built on the best publicly available data and any data private entities were willing to share during the project period.

47 Current results are presented with 2018 tonnage data, the most recent year currently available. Washington Department of Ecology anticipates having 2021 data available in early 2023; estimates will be updated with 2021 data when made available.

48 Oregon waste is reported for wastesheds instead of by county. In most cases a wasteshed is equivalent to a county, however, in a few cases a wasteshed may be smaller than a county (Milton-Freewater is its own wasteshed separate from Umatilla County where it is located) or a wasteshed may span counties (the Metro wasteshed includes the greater Portland metropolitan area which spans Clackamas, Washington, and Multnomah counties). The terms county and wasteshed are used synonymously throughout this report.

Many facilities receive tons from outside of the two-state study area. These facilities often report this as simply out of state tonnage with no further detail as to the source. The model as currently built excludes these tons due to a lack of visibility into the origin of these tons. These tons will be incorporated into future revisions of this model as additional information becomes available.

2.5.4. Approach to Current Composition and Quantity

All tables referenced in this section are included in Appendix A: Reference Tables.

2.5.4.1. Current Composition and Quantity (2018 Baseline)

The modeling proceeded according to the following ten steps:

Step 1 – Acquire 2018 waste tonnage data detailing the MSW received by each landfill in Washington and Oregon and the county of waste origin. Tonnage data by county is shown in Appendix A, Table 1, and Table 2.

- The Washington Department of Ecology (WDOE) and the Oregon Department of Environmental Quality (ODEQ) provided this data. WDOE data is readily available and ODEQ data required public records requests.

Step 2 – Determine the 2018 population for each county in Washington and Oregon. Population data by county is summarized in Appendix A, Table 1, and Table 2.

Step 3 – Define three residential waste generator groups.

- Group one: Residents with only a garbage container for their curbside waste management (one bin service).
- Group two: Residents with a garbage container and a recycle container for their curbside waste management (two bin service).
- Group three: Residents with a garbage container, a recycle container, and an organics container for their curbside waste management (three bin service).

Step 4 – Define nine commercial waste generator groups based on the types of waste service available (one, two, or three bins) and the predominate industry subgroups in the commercial sector (e.g., professional services, personal services, or truck/manufacturing/natural resources). The groups are further defined in Appendix A, Table 7, Table 8, and Table 9.

Step 5 – Develop three residential disposal rates in tons per person per year. These rates were developed using data from recent studies in Seattle, King County, Washington State, Oregon State, Cupertino (CA), San Francisco, Los Angeles County, New York City, and Houston, TX.

- Rate one-residents with one bin service – 0.3485 tons per person per year.
- Rate two-residents with two bin service – 0.3205 tons per person per year.
- Rate three-residents with three bin service – 0.2045 tons per person per year.

Step 6 – Develop waste composition profiles for each of the three residential and nine commercial generator groups.

- Waste composition data from recent studies (the proxies) that characterized waste from all three bins (garbage, recycle, organics) were used to develop these profiles.
- For one bin service profiles, the proxy data from all three containers was combined under the assumption that if a location has one bin service, the material in the recycle and organics containers in the proxy study is all displaced to the garbage container.
- For two bin service profiles, the proxy data from the garbage container and the organics container was combined under the assumption that if a location has two bin service, the material in the organics containers in the proxy study is all displaced to the garbage container.
- For three bin service profiles, the individual container proxy data are not combined.

Step 7 – Assign a residential waste generator group and commercial waste generator group to each county. The assignments by county are shown in Appendix A, Table 1, and Table 2.

Step 8 – Estimate the residential tonnage disposed from each county by multiplying the residential disposal rate (Step 5) by the county population (Step 2). The residential tonnage by county is shown in Appendix A, Table 1, and Table 2.

Step 9 – Estimate the commercial tonnage disposed from each county by subtracting the residential tonnage (Step 9) from the total tonnage (Step 1). The commercial tonnage by county is shown in Appendix A, Table 1, and Table 2.

Step 10 – Apply the designated residential and commercial waste profiles (Step 6) the residential tonnage (Step 8) and commercial tonnage (Step 9) for each county to estimate the quantity by material type for each county. The commercial tonnage by county is shown in Appendix A, Table 1, and Table 2.

Step 11 – Sum quantities in Step 10 by each county assigned to each landfill (assigned in Step 1) to estimate the quantity by material type for each landfill.

2.5.4.2. Future Composition and Quantity

Low Diversion Scenario

The authors used the following five steps to model the low diversion scenarios future composition and quantity data. Note that this scenario assumes no changes to programs or behavior, the only difference between this scenario and the 2018 baseline is a growing population and its associated increase in disposal. Summary data used in these calculations are included in Appendix A, along with data tables for the current composition and quantities.

Step 1 – Collect 2035 population estimates by county from the Washington State Office of Financial Management and Portland State University population research center.

Step 2 – Determine the percent increase in population from 2018 to 2035 for each county.

Step 3 – Multiply the percent increase in population and the 2018 tonnage to estimate 2035 tonnage.

Step 4 – Apply the residential and commercial profiles developed in Step 3 through Step 7 of the current composition and quantities projects to each county.

Step 5 – Apply Step 8 through Step 11 from **Section 2.5.4.1** of the current composition and quantities projects to the 2035 population and tonnage estimates.

High Diversion Scenario

The Project Team used the following five steps to model the high diversion scenario future composition and quantity data. Summary data used in these calculations are included in Appendix A, along with the data tables for current composition and quantities.

Step 1 – Collect 2035 population estimates by county from the Washington State Office of Financial Management and Portland State University population research center.

Step 2 – Develop a generation rate and composition profile for residential generators based on composition data from Seattle (generally considered to be on the highest performing cities in the United States).

Step 3 – Develop a generation rate and composition profile for each of the three commercial waste generator groups defined in the 2018 baseline model. The profiles assume commercial generators divert:

- 70% of their traditional recyclables
- 75% of their organics are in compliance with currently passed statewide diversion legislation.

Step 4 – Multiply the population (Step 1) by the residential generation rate and composition to estimate the residential quantity by material type.

Step 5 – Use the 2035 low diversion commercial quantity data and low diversion commercial generation rate data to estimate 2035 employment by county.

Step 6 – Multiply the employment by county (Step 5) by the high diversion generation rate and composition profile (Step 3) for each county to estimate the commercial quantity by material type.

Step 7 – Sum quantities in Step 6 by each county assigned to each landfill (assigned in Step 1 of the current composition and quantities projections) to estimate the quantity by material type for each landfill.

Mid Diversion Scenario

The mid diversion scenario is the mid-point between the low diversion and high diversion scenarios. This scenario was calculated by averaging the low diversion and high diversion quantity by material type, by landfill.

2.5.5. Results

2.5.5.1. Current Composition and Quantity

There are 45 landfills in Washington and Oregon that received MSW from Washington and Oregon. Those landfills received 8,637,216 tons of MSW in 2018. The three landfills that received the greatest quantity of MSW were the Columbia Ridge Landfill (1,467,163 tons), Roosevelt Regional Landfill (1,129,009 tons), and Cedar Hills Regional Landfill (879,224 tons). These three landfills received approximately 3.475 million tons of MSW which is slightly more than 40% of the total MSW received at Washington and Oregon landfills. Paper (2 million tons), food (1.8 million tons), and yard debris (0.8 million tons) are the three most prevalent material types in the MSW received at Washington and Oregon landfills.

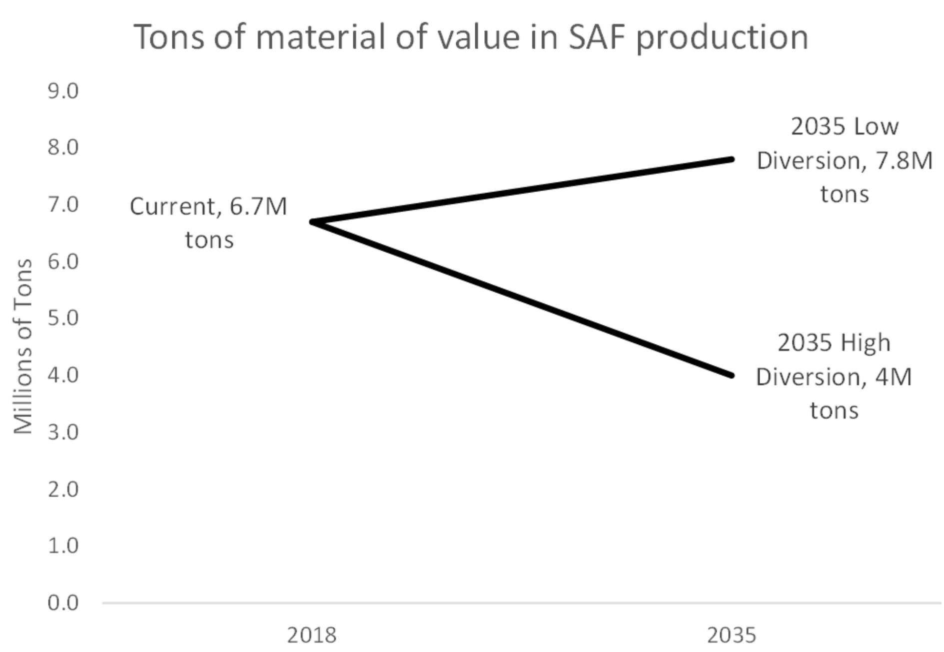
An estimated 6.7 million tons of material of value in SAF production were disposed of in Oregon and Washington in 2018.

2.5.5.2. Future Composition and Quantity

The largest facilities in 2018 will remain the largest facilities in 2035 and will account for approximately the same proportion of disposed waste, assuming no major changes to the current waste management landscape. The quantity of material being disposed in those landfills will change, increasing to between 6 million tons (high diversion scenario) and 10 million tons (low diversion scenario) by 2035. Total disposed tons in 2035 under a high diversion scenario are less than the total 2018 baseline disposal tonnage, despite a 16% population increase.

An estimated 4 million to 7.8 million tons of material of value in SAF production will be disposed in Oregon and Washington in 2035.

Figure 2.13: Tons of Material of Value in SAF Production, Low and High Diversion Scenario Estimates



2.6. Feedstock Supply Agreements and Tipping Fees

2.6.1. Supply Agreements

This section analyses the waste disposal supply agreements for Kitsap County, Clark County, Thurston County, Spokane County, City of Seattle, Snohomish County, Oregon Metro, Pierce County, King County, and Whatcom County. Each jurisdiction is presented in chronological order according to the date of termination of each contract. Contracts that are already expired or that will expire shortly are favored over those expiring closer to the anticipated date of construction of a liquid fuel production facility.

2.6.1.1. Kitsap County

The county entered into a fixed-term 20-year agreement in 2000 with Waste Management, taking effect in 2002 and terminating in 2022, to develop and operate a solid waste transfer station, intermodal services, rail transport of solid waste, and disposal of the waste from the Olympic View Transfer Station (OVTS) to Columbia Ridge Landfill. On June 1, 2022, a new agreement between the same parties came into effect.[49]

2.6.1.2. Skagit County

The county entered into a 10-year contract in October 1993 with Regional Disposal Company (RDC) (now Republic Services) to deliver waste from the Resource Recovery Facility (RRF) to a landfill owned by RDC Klickitat County. After the RRF closed in 1994, Skagit County's entire solid waste stream was disposed through this waste export and landfill disposal system. A Transfer and Recycling Station (TRS) commenced operations on the site in 2012. The contract was extended in 1998 through Supplemental Agreement #2 with a termination date of September 30, 2013. Thereafter, two more renewals, each for a duration of five years, was executed with a final termination date in 2023. It was stated that the county would start the process of preparing RFPs in 2021. [50] No updated information is available.

2.6.1.3. Spokane County

In 1988, Spokane County and the City of Spokane created an interlocal agreement to operate disposal, recycling, and MRW facilities, provide for effective implementation of regional solid waste policies, and to develop solutions to regional and solid waste management needs. Over the next two decades, the agreement was amended to include additional cities (e.g., City of Spokane Valley and City of Liberty Lake). Since the agreement was set to expire in 2014, a new agreement for a seven-year period between Spokane County and the City of Spokane was entered into that same year. The new agreement transferred ownership of two transfer stations (North County and Valley) to Spokane County. The County is now responsible for ensuring that the waste arriving at the transfer stations is delivered to the waste-to-energy facility for incineration. The city still maintains the waste-to-energy facility and Northside Landfill.

The City of Spokane contracted Republic Services for disposal services, which terminated on September 1, 2022. On November 17, 2014[51], the County entered into a fixed-term 10-year agreement with Waste Connections of Washington, Inc to provide operations, maintenance, transport, and disposal services.[52] Since this contract ends in 2024, it does not impact SAF production. The County is currently participating in discussions to extend and/or amend the contract before the expiration date. Simultaneously, the county will evaluate alternative disposal possibilities (e.g., a liquid fuels production facility).[53]

2.6.1.4. Clark County

A fixed-term and renewable contract exists between the county and a subsidiary of Waste Connections, Inc (WCW) called Columbia Resource Company (CRC). CRC is contracted for solid waste collection, transfer, and disposal. The original contract expired on December 31, 2021. There was an option to extend from January 1, 2022, to December 31, 2026, if the county provided

49 Kitsap County Board of Commissioners. (2000). Contract Amendment KC-479-00 with Waste Management of Washington, Inc: https://www.kitsap.gov/das/Documents/OVTS%20Operations%20Plan%20for%20RFP%202020-125%20Addendum%205.pdf

50 Skagit County Solid Waste Management Plan. (2017, September). Retrieved from Green Solutions, South Prairie: https://www.skagitcounty.net/PublicWorksSolidWaste/Documents/SCSWMP%202018-2023.pdf

51 Spokane County and Waste Connections of Washington, Inc. (2014, September 9). Service Contract For Transfer Station Operation And Maintenance And Solid Waste Transportation And Disposal Services

52 City of Spokane and Spokane County. (2017, August 15). Interlocal Agreement Between the City of Spokane and Spokane County

53 Comprehensive Solid Waste and Moderate Risk Waste Management Plan for Spokane County 2022 through 2027. (2022, July). Great West Engineering. Retrieved from Spokane County Regional Solid Waste System: https://www.spokanecounty.org/DocumentCenter/View/44215/Spokane-County-SWMP?bidId=

notice by December 31, 2020.[54] Since the 2022 disposal rates for all three transfer stations states that the rates "are governed by (a) contract between Clark County and Columbia Resource Company[55]," it is reasonable to assume that the contract was extended to expire in 2026. When the contract terminates, the county will have the option to purchase the transfer facilities for $1 per station[56] and was already considering the possibility in 2020, before extending the contract termination to 2026.[57] Since the contract expires in 2026 at the latest, it does not hinder the development of a liquid fuel production facility.

2.6.1.5. City of Seattle

The City of Seattle holds contracts with Waste Management Inc. (WM) and Recology for the transportation and disposal of waste. Both contracts are fixed term and renewable with a duration of 10 years. The WM contract was initiated on April 1, 2019 and Recology contract initiated on April 30, 2019; both contracts are in place through March 31, 2029. Both can be extended twice, with the opportunity to review and make amendments. Each extension is for a two-year period (therefore, terminating on March 30, 2031, or April 3, 2033) and notice to extend must be provided by June 30, 2028, and June 30, 2030.[58]

Both contracts include language that suggest amendment opportunities to redirect waste to a point of Seattle's choosing (e.g., a different transfer station that will direct MSW to a liquid fuels production facility): "The City may designate an alternate transfer station for the tipping of Garbage, Compostables, or Recyclables. The designation may be temporary or permanent." In addition, language in another section allows for the creation of pilot tests (e.g., transferring MSW to a liquid fuels production facility): "[the] City may require the Contractor to conduct pilot tests that temporarily change one or more provisions of this Contract."[59]

2.6.1.6. Snohomish County

From the transfer station, Rabanco Ltd (operating as Republic Services) is contracted to transport and dispose of MSW at the end disposal facility. The contract is for a fixed term, but it is renewable; commencing on April 5, 2018, and expires after a ten-year agreement on April 5, 2028. The County may renew the contract for up to two five-year terms.[60] According to the contract, MSW may be disposed of at an alternative location (e.g., a liquid fuels production facility), without restrictions on the tonnage. Snohomish County also has the right to transfer the contract to new ownership at its sole discretion.

2.6.1.7. Oregon Metro

Metro entered a contract with Waste Management Disposal Services to dispose of waste at the Columbia Ridge Landfill. The contract expires December 31, 2029, and may be extended for a maximum of two terms of five years each.[61] Waste Management provides exclusive disposal services from the Metro Central and Metro South transfer stations (the only public transfer stations, whereas the five other transfer stations are private) and no waste is recycled from those two stations.

Waste Management owns Columbia Ridge Landfill. As such, Waste Management can decide to build a SAF facility on the landfill site and has experience as a SAF feedstock supplier to Fulcrum Bioenergy.[62] Unless Metro is willing to pay arbitration fees and damages, the existing Landfill Disposal Agreement cannot be discontinued. However, Metro does favor recycling so both parties could be incentivized to partner on a SAF facility at the landfill site.

54 L.P. Clark County. (2006, January 1). Contract Regarding Solid Waste Recycling, Transfer, Transport and Out-Of-County Disposal Between Clark County, Washington and Columbia Resource Company

55 Columbia Resource Company Rate Schedule, Effective January 1, 2022. (n.d.). Retrieved From: https://cdn.wasteconnections.com/cms/columbia-resource-company/CRC%20-%20Rate%20Card%202022.pdf

56 L.P. Clark County. (2006, January 1). Contract Regarding Solid Waste Recycling, Transfer, Transport and Out-Of-County Disposal Between Clark County, Washington and Columbia Resource Company

57 Clark County RFP #788. (November 9, 2020). Solid Waste Contract Negotiations Questions and Answers

58 Seattle Public Utilities. (2018, May 14). Solid Waste Collection and Transfer Contract between City of Seattle and Waste Management of Washington, Inc. Seattle Public Utilities

59 Ibid

60 Breault, C. & Lim, Fay. (2018, April 5). Retrieved from Snohomish County Executive Approves Contract for Solid Waste Services: https://snohomishcountywa.gov/DocumentCenter/View/50841/Snohomish-County-Executive-Approves-Contract-for-Solid-Waste-Services-PDF?bidId=

61 Landfill Disposal Agreement. (2018, December 3). Metro, an Oregon Metropolitan Service District and Waste Management Disposal Services of Oregon, Inc.

62 Abu-Hakima, A., Farley, S., Flores, A., Hyatt, R., Massana, L., Rohleder, N., . . . Valenti, A. (2020). Can Municipal Solid Waste Power Airplanes in Washington State? . New York : Columbia Uiniersity.

2.6.1.8. Thurston County

In 1998, Republic Services was contracted for two ten-year contracts.[63] Republic Services subcontracts Waste Connections to operate the transfer station. In 2020, the contract was renewed again for a fixed-term and will terminate in May 2023. In 2022, the County held a public hearing for a proposed new contract that would come into effect May 1, 2023.[64] It was mentioned that the existing agreement is outdated, and the new contract would save the county $1 million annually. The contract between the County and Republic Services was approved and is for a 10-year duration, ending 2033.[65] The contract language suggests that an alternative disposal destination may only be selected after agreement from both parties if the existing destination proves insufficient.[66] If this is proven, waste could be diverted to a liquid fuel production facility.

2.6.1.9. Pierce County

In 2008, LRI and the County entered into a Waste Handling Agreement (WHA) that expires on December 31, 2036. The county is contractually obliged to dispose of all system waste at LRI, without a set volume of waste, with the exception that third parties may be contracted that recycle materials. In fact, the WHA and SWMP encourage a circular waste management process since minimizing the total amount of waste that reaches the landfill will increase its lifespan (e.g., using waste to create fuel instead of disposing of the waste at LRI). Pierce County and LRI jointly and equally fund a Research and Development (R&D) Program (with an annual maximum contribution of $75,000) for multiple pursuits, including diverting waste from the LRI landfill.[67] This indicates a strong interest in supporting alternative disposal initiatives.

LRI partnered with Waste Connections and BioFuels Washington in 2013 through an agreement to produce compressed natural gas by capturing methane. Puget Sound Energy (PSE) purchases gas to power 10,000 households annually. No further information concerning this contract was obtained.

2.6.1.10. King County

King County produces 900,000 tons of waste annually,[68] with an average of 2,550 tons of waste arriving at the Cedar Hills landfill daily[69] - a landfill owned by the County.[70] The Cedar Hills Landfill remains the sole operational waste facility in the county. Despite previous projections that anticipated the end of its lifespan as early as 2028, the county is currently developing a project aimed at guaranteeing waste capacity beyond 2028, potentially extending until 2040. Waste collection in the county is primarily conducted by four private companies: Recology CleanScapes, Inc., Republic Services, Inc, Waste Connections, Inc., and Waste Management, Inc. Since the end of the life is rapidly approaching, the next disposal method must be identified. Alternative disposal solutions, such as the conversion of waste into fuel could be a viable solution. The county has a contract with Bio Energy Washington to produce pipeline-quality natural gas from landfill gas.[71]

2.6.1.11. Whatcom County

Waste Management is contracted to dispose of MSW passing through the RDC Transfer Station at Roosevelt Regional Landfill.[72]

---

63 Department of Water and Waste Management. (2016, November 14). Thurston County Waste Export and Transportation Agreement. First Amendment.

64 Solid Waste Services Contract FAQs. (2022, March 22). Retrieved from Thurston County Public Works: https://www.thurstoncountywa.gov/tchome/SiteAssets/Pages/publicmeetings/Contract%20FAQs.pdf

65 Leigh, April. (2022, April 5). Thurston County News Release. Retrieved from Thurston County: https://www.thurstoncountywa.gov/tchome/pages/newsrelease-detail.aspx?List-ID=2253

66 Abu-Hakima, A., Farley, S., Flores, A., Hyatt, R., Massana, L., Rohleder, N., . . . Valenti, A. (2020). Can Municipal Solid Waste Power Airplanes in Washington State? . New York : Columbia Uniersity.

67 Pierce County. (2008). PCRCD dba LRI Waste Handling Agreement

68 Gillmore. Waste Tonnage Volumes. Received in email dated 06 July 2022.

69 King County Solid Waste Division. (2019). Comprehensive Solid Waste Management Plan . Seattle : King County. Retrieved from: https://your.kingcounty.gov/dnrp/library/solid-waste/about/planning/2019-comp-plan.pdf

70 Cedar Hills Regional Landfill. (2022, September 28). King County Solid Waste Division Fall 2022 Community Meeting: Sept. 28, 2022 - Cedar Hills Regional Landfill Community Meeting Notes - King County Solid Waste Division

71 King County (n.d.). Cedar Hills Regional Landfill Development. Retrieved from: https://kingcounty.gov/en/dept/dnrp/waste-services/garbage-recycling-compost/solid-waste-facilities/cedar-hills-development.

72 Comprehensive Solid and Hazardous Waste Management Plan. (2016, June 14). Whatcom County, Washington: https://www.whatcomcounty.us/DocumentCenter/View/6723/Whatcom-County-Comprehensive-Solid-and-Hazardous-Waste-Management-Plan

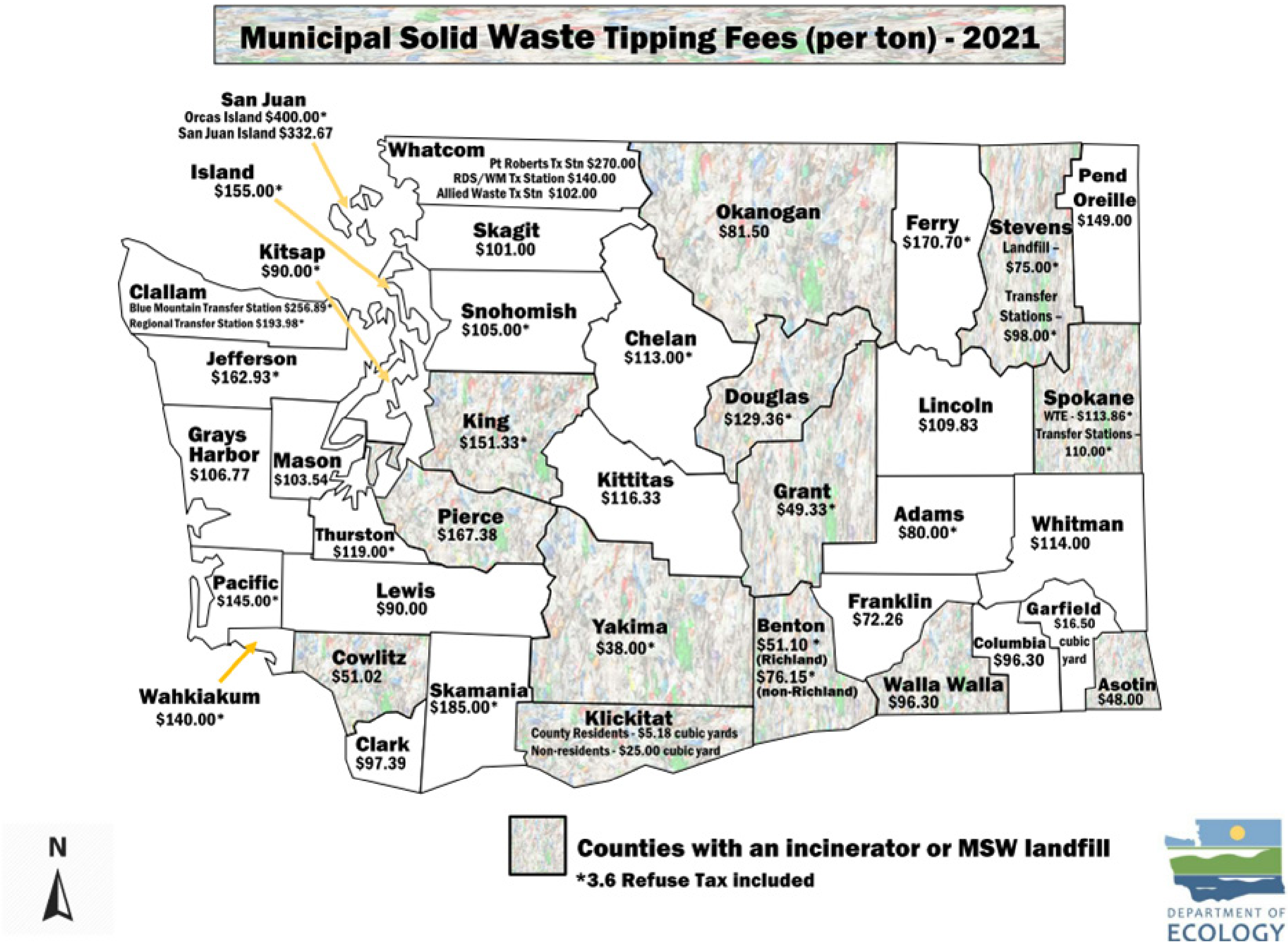
Table 2.6: A Summary of Supply Agreements of Various Jurisdictions to Determine the Availability of Feedstock for a Future SAF Facility

Rank	Jurisdiction	Primary Disposal Destination(s)	Disposal Contractor(s)	Contract Type	Contract Duration + Termination Date	Contract Extension Opportunities	Ability to Terminate Contract Early	Contract Provisions Supporting Liquid Fuel Facility
1	Kitsap County	Columbia Ridge Landfill *(Owned and operated by Waste Management, Inc.)*	Waste Management, Inc.	Fixed-Term	20 years 2002 - 2022	No	Unknown	Unknown, but irrelevant since the contract terminated in 2022.
2	Skagit County	Roosevelt Regional Landfill *(Owned and operated by Republic Services)*	Republic Services	Fixed-Term	5 years 2018 - 2023	The county was supposed to start preparing RFPs in 2021. No further information available.	N/A	Unknown, but irrelevant since the contract terminates in 2023.
3	Spokane County	Waste to Energy Facility (Spokane County)	Waste Connections of Washington, Inc.	Fixed-Term	10 years November 17, 2014 - 2024		Unknown	Contract terminates in 2024, so it doesn't impact the SAF facility. In addition, the county will evaluate alternative disposal possibilities (e.g., a liquid fuels production facility.)
4	Clark County	Finley Buttes & Wasco County Landfills *(Owned and operated by Waste Connections, Inc.)*	Columbia Resource Company (CRC) (Subsidiary of Waste Connections, Inc.)	Fixed-Term	5 years January 1, 2022 - December 31, 2026	No	Unknown	Unknown, but irrelevant since the contract terminates in 2026.
5	City of Seattle	Columbia Ridge Landfill, OR *(Owned and operated by Waste Management, Inc.)*	Waste Management, Inc. Recology	Fixed-Term Renewable	10 years April 1, 2019 - March 31, 2029	Up to 2 extensions 2-year terms	No	To redirected to an alternative transfer station A pilot test may be conducted
			Washington Waste Systems, Inc. (WWS)	Fixed-Term	38 years April 11, 1990 - March 31, 2028	No	Yes, may terminate without cause by March 31, 2024	A minimum amount of waste may be diverted for a short period of time for experimental purposes
6	Snohomish County	Roosevelt Regional Landfill *(Owned and operated by Republic Services)*	Rabanco Ltd (operating as Republic Services)	Fixed-Term and renewable	10 years April 5, 2018 - April 5, 2028	Up to 2 extensions 5-year terms	Unknown	MSW may be disposed of at an alternative location No restrictions on the tonnage that may be diverted
7	Oregon Metro	Columbia Ridge Landfill *(Owned and operated by Waste Management, Inc.)*	Waste Management, Inc.	Fixed-Term and renewable	Terminates December 31, 2029	Up to 2 extensions 5-year terms	No, unless willing to pay for arbitration	WM owns Columbia Ridge Landfill. As such, Waste Management can decide to build a SAF facility on the landfill site
8	Thurston County	Roosevelt Reional Landfill *(Owned and operated by Republic Services)*	Republic Services	Fixed-Term	10 years May 1, 2023 - 2033	No	Unknown	An alternative disposal destination (e.g., to a liquid fuel facility) may only be selected if the existing destination proves insufficient.
9	Pierce County	LRI Landfill *(Owned and operated by Pierce County)*	Land Recovery, Inc.	Fixed-Term	Terminates December 31, 2036	No	No	Third parties that recycle waste may be contracted
10	King County	Cedar Hills Landfill *(Owned by King County)*	Recology, CleanScapes, Inc., Republic Services, Inc., Waste Connections Inc., and Waste Management	Unknown	Unknown	Unknown	Unknown	Unknown
11	Whatcom County	Roosevelt Regional Landfill, Columbia Ridge Landfill and Cowlitz County Headquarters Landfill (Owned by Cowlitz County)	Waste Management	Unknown	Unknown	Unknown	Unknown	Unknown

2.6.2. Tipping Fees

The tipping fees for each county are summarized in **Figure 2.14**. An analysis of the tipping fees for each county reveals an annual increase and it is reasonable to expect this trend to continue. **Table 2.7** summarizes the annual increase in tipping fees in a few counties to support the statement.

Figure 2.14: The MSW Tipping Fees for all Counties in Washington State[73]



73 Solid Waste & Recycling Data. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Research-Data/Data-resources/Solid-waste-recycling-data

Table 2.7: A Table to Indicate the Development of 'Typical' Annual Tipping Fees over the Years in Multiple Counties

County	First Year + Tipping Fee	Second Year + Tipping Fee
Pierce County [74]	Year: 2015 Tipping Fee: $144.97	Year: 2016 Tipping Fee: $145.84
Clark County	Year: 2021 Tipping Fee: $97.39[75]	Year: 2022 Tipping Fee: $99.88[76]
Spokane County	Year 2021 Tipping Fee: $113.86 (WTE Transfer Station)[77]	Year 2022 Tipping Fee: $117.16 (WTE Transfer Station)[78]
King County	Year: 2022 Tipping Fee: $154.02[79]	Year: 2023 Tipping Fee: $168.68[80]

2.7. Current Waste Laws and Regulations

2.7.1. Laws and Regulations

2.7.1.1. Federal Regulations

The U.S. Environmental Protection Agency (EPA) is the main contributor to creating, guiding, and enforcing the federal regulations regarding waste management. The EPA is responsible for creating policies to ensure the safe handling and cleanup of solid and hazardous waste. They developed programs to encourage not only proper disposal but source reduction and beneficial reuse of material.

The EPA's Universal Waste Program serves as a regulator for commonly generated hazardous waste. Promoting their collection and recycling, easing the burden for waste generators and transporters, and encouraging the development of local programs to reduce the waste quantity going into municipal solid waste landfills. While states may adopt the Universal Waste's Federal Program, states can also adopt a State-Specific Universal Waste Program catered to other forms of hazardous material common to that region.[81]

Resource Conservation and Recovery Act (RCRA)
The Resource Conservation and Recovery Act is the framework for a national system of municipal solid waste control. Under the RCRA, the US Environmental Protection Agency (EPA) is given the authority to develop policies over the generation, transportation, treatment, storage, and disposal stages of waste.

Congress has amended the RCRA on several occasions, using "Subtitles" (Table 2.8) to develop regulations setting a minimum standard for how waste facilities should be designed and operated. The State plays a major role in implementing disposal programs under such Subtitles. For example, under Subtitle C, the EPA may grant states the capability to implement key provisions of

74 2016 Supplement to the Tacoma-Pierce County Solid Waste Management Plan. (2016). Retrieved from Pierce County Department of Public Works and Utilities: https://co.pierce.wa.us/DocumentCenter/View/38769/2015_SupplementFULL_2016-08-10?bidId=
75 Columbia Resource Company Rate Schedule, Effective January 1, 2021. (n.d.). Retrieved From: https://cdn.wasteconnections.com/cms/columbia-resource-company/CRC%20-%20Rate%20Card%202021.pdf
76 Ibid.
77 Solid Waste & Recycling Data. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Research-Data/Data-resources/Solid-waste-recycling-data
78 Disposal. (n.d.). Retrieved from Solid Waste Services: https://my.spokanecity.org/solidwaste/locations/#:~:text=2022%20Trash%20Disposal%20Rates%20%E2%80%93%20a,and%20North%20County%20transfer%20stations
79 Disposal Fees – Solid waste, recycling, unsecured loads, and Cleanup LIFT Discount. (2022, January 1). Retrieved from King County: https://kingcounty.gov/depts/dnrp/solid-waste/facilities/disposal-fees.aspx
80 New King County Solid Waste Disposal Rates for 2023. (2022, September 30). Retrieved from King County: https://content.govdelivery.com/accounts/WAKING/bulletins/32dc4fd
81 Universal Waste . (2022, January 22). Retrieved from United States EPA: https://www.epa.gov/hw/universal-waste

hazardous waste requirements in lieu of the federal government. Whereas in Subtitle D, in the absence of an approved state program, the federal requirements delegated by the EPA through Congress must be met by waste disposal facilities.[82]

According to Subtitle E – Duties of the Secretary of Commerce in Resource and Recovery – the Secretary of Commerce is tasked with promoting technology with proven success and developing markets for materials recovered.[83] This allows for the commercialization of projects.

Table 2.8: A Summary of the RCRA Subtitles.[84]

Subtitle	Provision
A	General Provisions
B	Office of Solid Waste; Authorities of the Administrator and Interagency Coordinating Committee
C	Hazardous Waste
D	Non-hazardous Waste
E	Duties of the Secretary of Commerce in Resource and Recovery
F	Federal Responsibilities
G	Miscellaneous Provisions
H	Research, Development, Demonstration and Information
I	Regulation of Underground Storage Tanks
J	Standards for the Tracking and Management of Medical Waste

Note: Subtitle E is relevant to a future liquid fuels production facility.

Regulated Waste Management
An Order by the U.S. General Services Administration (GSA), 1095.9 PBS Regulated Waste Management establishes the policy for managing regulated waste. Regulated waste is defined as: "hazardous wastes, commercial chemicals, and used oil as defined by RCRA; listed and unlisted elements and compounds and hazardous wastes appearing in the table in 40 CFR Part 302.4; used personal-use sharps; batteries; Ozone Depleting Substances (ODS); asbestos or ACM wastes, PCB wastes and lead-based paint subject to the waste management requirements of the CAA or TSCA; and jurisdictionally-regulated wastes." The Order is applicable to all facilities under GSA's jurisdiction under the authorities of many federal Chapters, Titles, Associations and Acts, including the comprehensive law of RCRA.

The policy itself is simple. "Facilities and tenant agencies subject to this Order shall comply with all applicable Federal, State, and local regulations for the management of regulated waste, and the procedures set forth herein. Where differences among requirements exist, the more stringent requirement shall be applied." This Order is to ensure compliance with the above regulations as of June 2019 through June 2026.[85]

2.7.1.2. State Regulations

The Washington State Department of Ecology is the agency responsible for administering the state regulations for solid waste management, maintaining compliance with federal and local regulations.

Contract Laws
There are two main Washington State laws guiding the contracts for waste transfer stations and landfills.

82 Resource Conservation and Recovery Act (RCRA) Overview. (2022, June 29). Retrieved from United States EPA : https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview

83 Resource Conservation and Recovery Act of 1976. Public Law 94-580-Oct. 21, 1976: https://www.govinfo.gov/content/pkg/STATUTE-90/pdf/STATUTE-90-Pg2795.pdf

84 Resource Conservation and Recovery Act (RCRA) Overview. (2022, June 29). Retrieved from United States EPA : https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview

85 1095.9 PBS Regulated Waste Management. (2019, June 14). Retrieved from U.S. General Services Administration: https://www.gsa.gov/directive/regulated-waste-management

- **RCW 70A.205.045, Solid Waste Management – Reduction and Recycling**

  Under RCW 70A.205.045, all cities and counties are required to prepare a six-year comprehensive solid waste management plan as well as a long-term 20-year plan that projects solid waste collection needs. The Washington State Department of Ecology is required to approve each plan. This law indicates that each contract (between a transfer station and a landfill) aligns with a solid waste management plan and RCW 70A.205.045. The Department of Ecology also encourages the development of a regional solid waste management plan across multiple jurisdictions if appropriate for that region. A regional solid waste management plan could be used to consolidate the waste stream of several counties and divert waste towards a specific disposal site, such as an SAF facility.[86]

- **RCW 36.58.040, Solid Waste Handling Systems Authorized**

  The second law, RCW 36.58.040, stipulates that counties are permitted to "construct, lease, purchase, acquire, add to, alter, or extend solid waste handling systems, plants, sites, or other facilities and shall have full jurisdiction and authority to manage, regulate, maintain, utilize, operate, control, and establish the rates and charges for those solid waste handling systems, plants, sites, or other facilities." This law provides counties the ability to redirect the flow of waste, indicating that it is legally possible to amend an existing contract to redirect MSW to an SAF facility from a landfill. There is no existing law that determines waste collection prices. All waste fees and pricing for collection from customers is regulated by the Washington Utilities and Transportation Commission (WUTC).[87]

Organics Management Law
Washington state set an ambitious target to reduce the amount of organic material disposed of in landfills by 75%, compared to a 2015 baseline. To achieve this, a 20% reduction must be achieved by 2025. House Bill 1799: Organic Materials Management was passed in 2022 to mandate the diversion of organic materials away from landfill disposal and towards food rescue programs and organics management facilities.[88] This includes using organic waste for emerging technologies.

Landfills
All landfills listed in this study reside within the United States and therefore must comply with the U.S. EPA standards for waste handling.

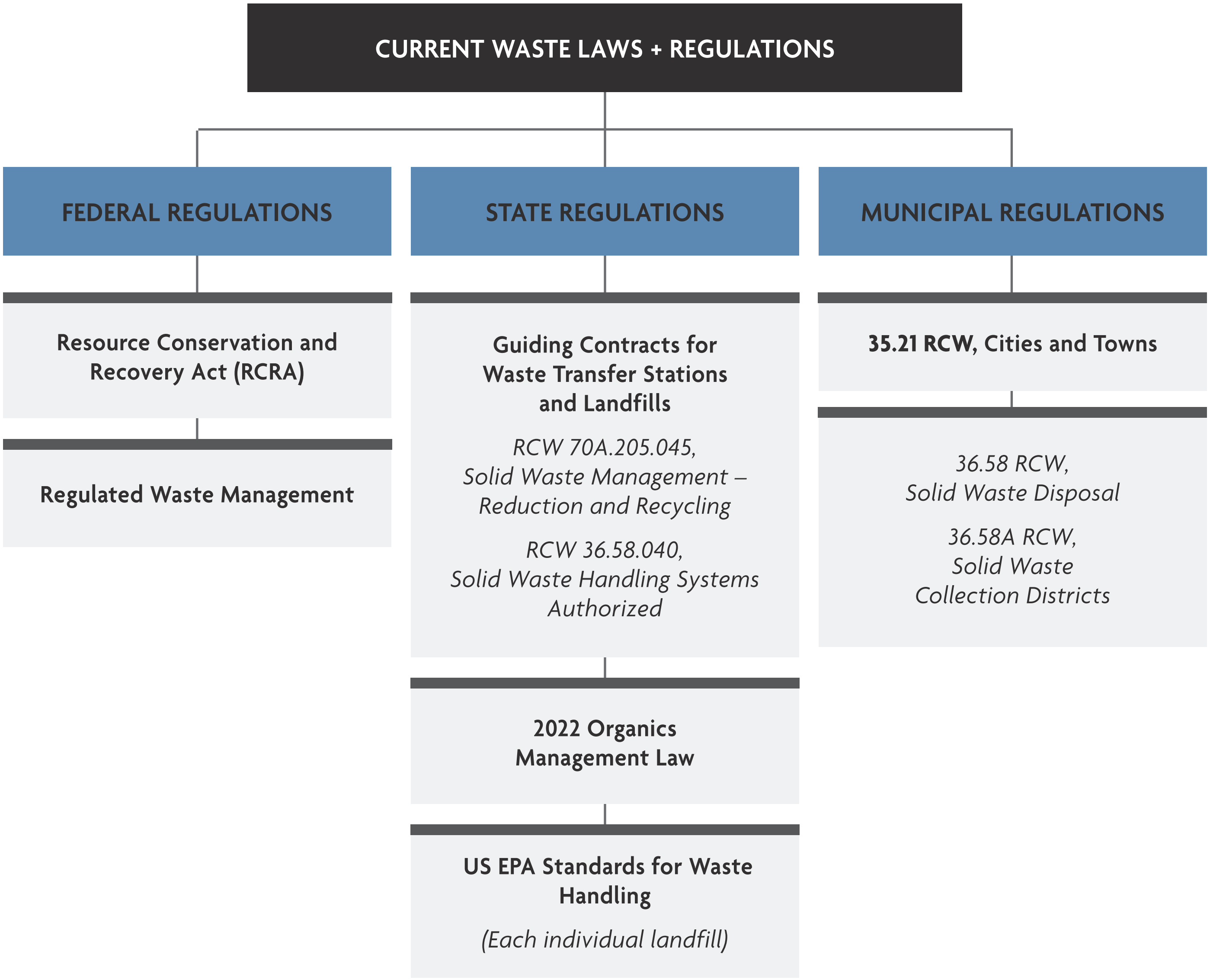
2.7.1.3. Municipal Regulations

Chapter 35.21 RCW, Cities and Towns: RCW 35.21.120 states that "(a) city or town may by ordinance provide for the establishment of a system or systems of solid waste handling for the entire city or town or for portions thereof. A city or town may provide for solid waste handling by or under the direction of officials and employees of the city or town or may award contracts for any service related to solid waste handling.[89] This authorizes towns and cities for solid waste and lists compliance standards and procedures.

Chapter 36.58 RCW, Solid Waste Disposal, and 36.58A RCW, Solid Waste Collection Districts: Chapter 36.58A RCW authorizes counties to form a collection district that would enable the adoption of mandatory waste collection. Chapter 36.58 RCW primarily addresses disposal activities, including the ability to form a solid waste disposal district, but one section (RCW 36.58.045) authorizes counties to "impose a fee upon ... a solid waste collection company" to fund planning and administrative expenses that may be incurred by the county.[90]

86 Abu-Hakima, A., Farley, S., Flores, A., Hyatt, R., Massana, L., Rohleder, N., . . . Valenti, A. (2020). Can Municipal Solid Waste Power Airplanes in Washington State? . New York : Columbia Uniersity.
87 Ibid
88 2022 Organics Management Law. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Waste-Toxics/Reducing-recycling-waste/Waste-reduction-programs/Organic-materials/2022-organics-management-law
89 Skagit County Solid Waste Management Plan. (2017, September). Retrieved from Green Solutions, South Prairie: https://www.skagitcounty.net/PublicWorksSolidWaste/Documents/SCSWMP%202018-2023.pdf
90 Ibid.

Figure 2.15: A Summary the Current Waste Laws and Regulations Applicable to a Liquid Fuel Production Facility



2.7.2. MSW to SAF Incentives and Restrictions

The incentives for creating SAF from MSW mainly concern the reduction of waste from landfills and the reduction of fossil fuels within the aviation industry. There are additional incentives regarding various beneficial programs, as well as fiscal and monetary incentives defined at the international, national, state, and local levels.

Risks of the process for municipal solid waste to transition to sustainable aviation fuel generally revolve around the lack of participation and pressure to revise the current waste processes. To mitigate these risks, policies and incentives need to be enacted at the local and regional levels to strengthen waste diversion efforts and encourage participation towards a cleaner fuel standard. The restrictions of MSW to SAF are also broken down across the same international, national, state, and local levels.

2.7.2.1. International

Incentives

The Carbon Offset and Reduction Scheme for International Aviation (CORSIA)
CORSIA is a global market-based measure that allows ICAO Member States (which includes the US) to offset emissions that cannot be combatted through technological improvements, operational efficiency, and SAF. CORSIA is divided into three phases. Participation in the pilot phase (2021-2023) and first phase (2024-2026) are voluntary[91] and the US is one of 107 Member States committed to these phases.[92] Phase two (2027-2035) participation is determined by 2018 Revenue-Ton-Kilometers (RTK)* data. Operators using CORSIA eligible fuels (CEF) may reduce their offset requirements, which serves as a financial incentive. CEF include CORSIA certified SAFs and low carbon fuel.[93]

SAF produced from MSW may benefit from two credits under the CORSIA Life Cycle Assessment (LCA): Avoided Landfill Emissions Credit (LEC) and a Recycling Emissions Credit (REC).[94] However, one of the key differences in the lifecycle GHG emissions of MSW derived SAF is that CO_2 emissions from fuel combustion cannot be considered climate neutral, as it is for the biomass derived SAF. CO_2 from biogenic carbon is supposed to be sequestered in biomass growth; that is not the case of the non-biogenic fractions of MSW feedstock. Therefore, some proportion of the CO_2 from MSW-derived SAF combustion is not entitled to be CO_2 neutral. For example, carbon in the plastic and rubber components of MSW feedstock is derived from fossil fuels, and therefore, CO_2 emissions from this part of the feedstock during fuel production and combustion should be counted against lifecycle GHG emissions. The default CORSIA supporting document — Life cycle assessment methodology - 18 - core LCA emissions of SAF produced from MSW are calculated as a function of the non-biogenic content (NBC) of the MSW derived feedstock to account for this.[95]

Restrictions

None.

2.7.2.2. Federal

Within the U.S., the implementation of SAF can extend the useful lifespan of our aging aircraft supply. The utilization of existing fuel infrastructure and blending SAF with conventional fuel should ensure a seamless transition to alternative fuel at a national standard. There are feedstock supplies available to produce SAF within the U.S. to eliminate external dependence.

Incentives

Energy Policy Act of 2005 - RFS
The RFS falls under the Energy Policy Act of 2005 and is detailed in the Energy Independence and Security Act of 2007. This national program allows producers of renewable fuel, such as biofuel, to receive credits for fuel generated. These credits are known as RINs and are in the form of unique numbers attributed to the equivalent of one gallon of ethanol produced (fuel dependent as 1 gallon of fuel can produce more than 1 RIN). RINs are classified in four ways, advanced biofuel (D-code 5), biomass-based diesel (D-Code 4), cellulosic biofuel (D-Code 3 or D-Code 7), and renewable fuel (D-Code 6). The two types of RIN classifications that are most relevant to this project are advanced biofuels (derived from all biomass barring corn starch ethanol) and bio-mass based diesel. Both RIN classifications are required to lower 50% or greater lifecycle GHG emissions, from petroleum and diesel respectively.

While airlines are not mandated to participate in the RFS, producers of road fuels are required to produce a certain volume of renewable fuel production or purchase the equivalent in the form of RIN credits. RIN credits can be generated by several different fuels including SAF, which conventional on-road fuel producers can purchase to meet renewable fuel obligations. Similar to LCFS credits, an SAF developer can generate RIN credits. After RINs are produced, SAF developers would have the option to buy, sell,

91 ICAO Environment. (n.d.). Retrieved from Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) : https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx
92 ICAO. (2021). CORSIA States for Chapter 3 State Pairs. Retrieved from International Civil Aviation Organization: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_States_for_Chapter3_State_Pairs_Sept2020.pdf
93 CORSIA Eligible Fuels. (n.d.). Retrieved from ICAO Environment: https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx
94 CORSIA Methodology for Calculating Actual Life Cycle Emissions Values. (2022). ICAO. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf
95 CORSIA Supporting Document . (2019). CORSIA Eligible Fuels - Life Cycle Assessment Methodology. ICAO. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20Supporting%20Document_CORSIA%20Eligible%20Fuels_LCA%20Methodology.pdf

or trade, or retire RINs via an assigned RIN or a separated RIN. An assigned RIN is when both the fuel and RIN are traded jointly. A separated RIN is when the RIN is purchased, but the fuel is not. By selling RINs, SAF developers would generate additional revenue that would help to lower development costs and as mentioned above, lower risk and increase ease of business. As more developers have incentives to participate in the SAF market, the price of SAF would eventually become more economical for potential fuel buyers.[96]

Renewable Identification Number (RIN)

Alternative transportation fuel policies can lead to financial incentives under the RIN generation of the Renewable Fuel Standard (RFS2). The RFS2 is a program created to expand the renewable fuels sector within the United States. Credits from these programs can in turn provide additional revenue to SAF producers. It is important to note that the present SAF volumes will continue to be eligible for RINs, and state LCFS credits in California, Oregon, and Washington state to encourage investment and production.

RINs, being the currency of the RFS Program, are also used to confirm compliance with the program. To qualify, a fuel shall be produced from the approved feedstock through an approved pathway. For any approved feedstock there may be several approved conversion processes. RINs are generated through production of a predetermined quantity of renewable fuel gallons. Obligated parties should blend the renewable fuel into fuel derived from petrol or purchase RIN credits to meet their specified annual volume obligation.[97]

Furthermore, the registration for RIN credits must ensure the below RFS qualifications are met. Producers must provide evidence of all actions taken towards addressing recyclable materials. The EPA reviews the registrations individually, thoroughly evaluating the provided documentation.

§80.1401 - Definitions of renewable fuel and renewable biomass

§80.1426 - Approved fuel pathways

§80.1450 - Registration requirements

§80.1451 - Reporting requirements

§80.1454 - Recordkeeping requirements

§80.1464 - Attest engagement requirements

Inflation Reduction Act

The Inflation Reduction Act supports the rapid scale-up of domestic SAF production in the nascent SAF industry to close the price gap between SAF and Jet A by building on the foundations set in the 2021 Aviation Grand Fuel Challenge. The Challenge aimed to achieve an annual domestic production of a minimum of 3 billion gallons by 2030, reducing aviation emissions by 20% during the same period. In addition, the Challenge pledged to invest up to $4.3 billion in SAF projects and producers.

The IRA applies to SAF sold by registered producers manufacturing SAF in the US, or SAF used by entering an aircraft's fuel tank in the US, after December 31, 2021, and until December 31, 2024. To qualify as SAF, the fuel must meet the ASTM International Standard D7566 or the Fischer Tropsch provisions of ASTM International Standard D1655, Annex A1. It must also have a lifecycle GHG reduction percentage of at least 50 percent compared to petroleum-based jet fuel, certified in accordance with CORSIA or any similar methodology which satisfies the criteria under section 211(o)(1)(H) of the Clean Air Act (42 U.S.C. 7545(o)(1)(H)). The base amount of $1.25 per gallon can be increased to a maximum of $1.75, since $0.01 is awarded for each percentage point by which the lifecycle GHG reduction percentage with respect to such fuel exceeds 50 percent, up to a maximum of 50%. In other words, a SAF with a 100% lifecycle GHG reduction is eligible for the $1.75 credit per gallon.

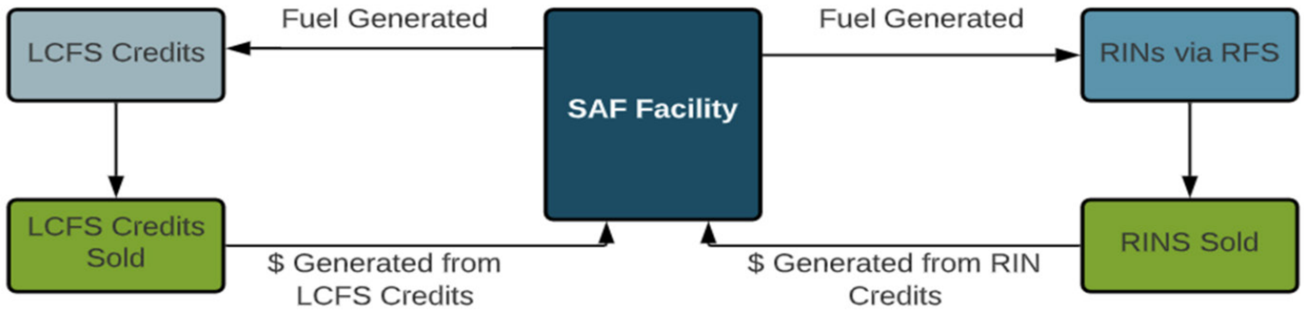
More specifically, the Inflation Reduction Act (IRA) of 2022 incentivizes the domestic production of clean energy technologies. Organized into phases, the first phase is anticipated for 2023-2024: the Biomass-based Diesel Blenders Tax Credit (BTC), which includes a separate "per-gallon" incentive for SAF. The second phase is predicted for 2025-2027, under the Clean Fuel Production

96 Abu-Hakima, A., Farley, S., Flores, A., Hyatt, R., Massana, L., Rohleder, N., Valenti, A. (2020). Can Municipal Solid Waste Power Airplanes in Washington State? . New York : Columbia Uniersity

97 Feedstock for RINs Credits. Celianis Biomass Analysis Laboratory, Celignis Analytical. Retrieved from: https://celignis.com/RINs-credits.php.

Credit (CFPC) which is now enhanced to include renewable fuels such as SAF.[98] There is speculation that the IRA support will continue past 2027. If this occurs, IRA support will benefit a future liquid fuel production facility.

Figure 2.16: Financial Incentives for SAF Production Through LCFS and RFS[99]



Restrictions

Renewable Fuel Standard (RFS)
The RFS is a volume mandate and requires fuels to be produced from renewable biomass. The RFS does not include fuels produced by other sources that claim to be clean by other stakeholders, such as: hydrogen, natural gas, nuclear, wind and solar. Some consider the RFS to exclude sources of clean energy which ultimately limits the adoption of alternative means for transportation.[100]

Renewable Energy Credits (REC)
Another monetary incentive unlikely to become available to Washington is Renewable Energy Credits (REC). Generally, SAF facilities do not utilize renewable processes to generate electricity.

2.7.2.3. State

Incentives

Clean Fuel Standard
The Clean Fuel Standard intends to reduce carbon pollution from transportation in Washington. Transportation accounts for about 45% of statewide GHG emissions. Followed by residential, commercial, and industrial heating responsible for almost 24% of GHG emissions, electricity accounting for approximately 16% and then other miscellaneous sources are responsible for the remaining 15% of GHG emissions statewide.[101] The Clean Fuel Standard in Washington is equivalent to the Low Carbon Fuel Standard (LCFS) implemented in California and Oregon.

The Clean Fuel Standard has legally enforced suppliers to reduce the magnitude of carbon in transportation fuels. Suppliers are looking into various paths to achieve this reduction:

- Improving the efficiency of their fuel production processes.
- Producing and/or blending low-carbon biofuels into the fuel they sell.
- Purchasing credits generated by low-carbon fuel providers, including electric vehicle charging providers.

Feedstocks derived from MSW qualify for CFS credits in the same way as other LCFS programs by calculating the lifecycle emission reductions using the WA GREET model (a WA state specific version of the GREET model). While it doesn't prohibit particular

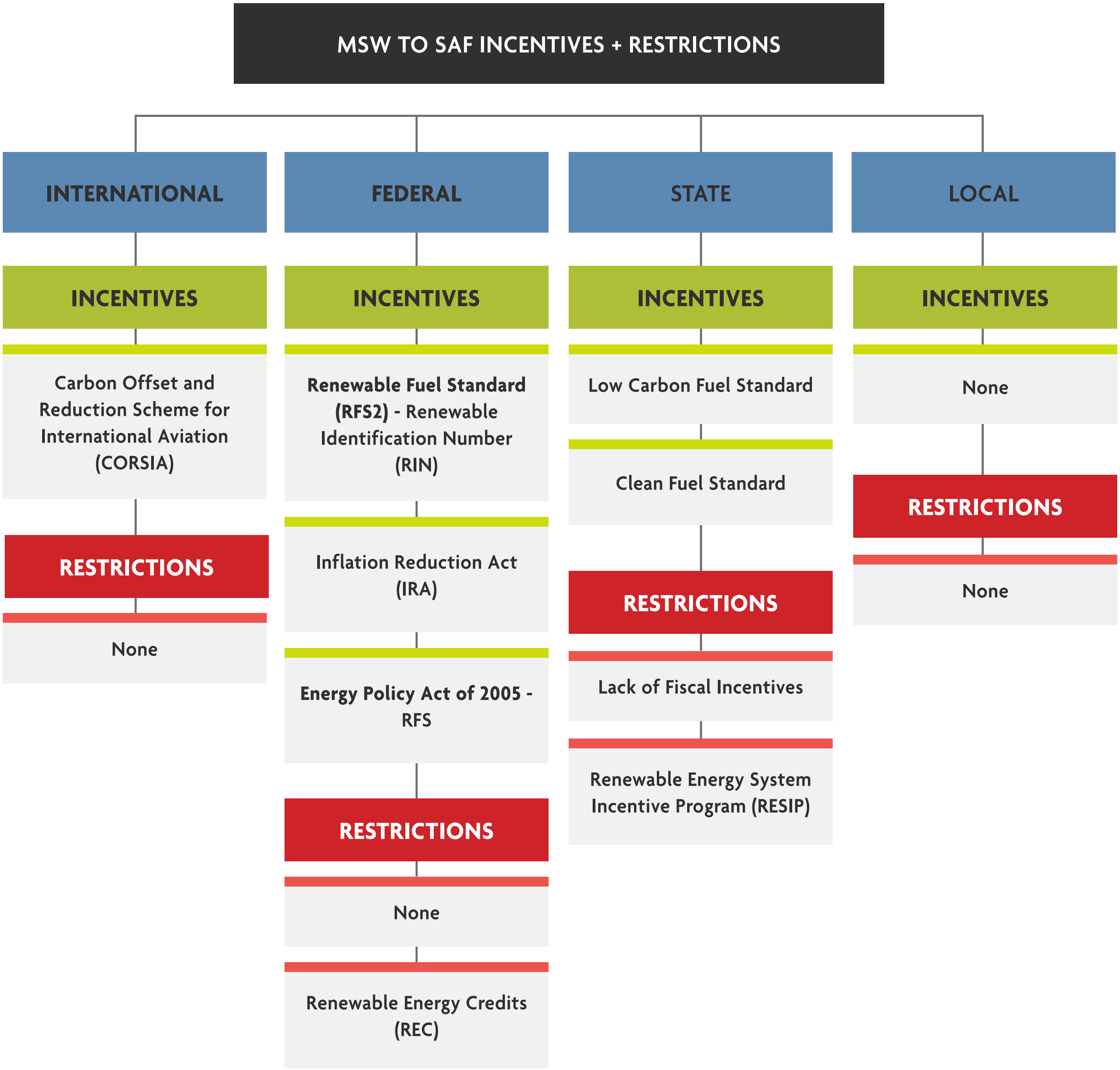
98 Boutwell, M. (2022, September 07). Inflation Reduction Act Sustainable Aviation Fuel Credit. Retrieved from Stillwater Associates: https://stillwaterassociates.com/inflation-reduction-act-sustainable-aviation-fuel-credit-carbon-intensity-matters/#:~:text=Among%20the%20many%20incentives%20for%20renewable%20fuel%20production,of%20SAF%20in%20the%20U.S.%20by%202030.%20
99 Ibid.
100 Bracmort, K. (2021). A Low Carbon Fuel Standard: In Brief. Congressional Research Service. Retrieved from https://sgp.fas.org/crs/misc/R46835.pdf
101 Clean Fuel Standard. (n.d.). Retrieved from Department of Ecology State of Washingston: https://ecology.wa.gov/Air-Climate/Climate-change/Reducing-greenhouse-gases/Clean-Fuel-Standard

MSW waste streams, the higher the nonrenewable (e.g., plastics) content of the SAF, the worse the lifecycle emissions reductions performance of the fuel, directly impacting the financial viability of the SAF.

2.7.2.4. Local

There are currently no local incentives in place for SAF production from MSW feedstock.

Figure 2.17: A Summary of MSW to SAF Incentives and Restrictions



2.8. Conclusion

The State of Washington produces more than 5 million tons of MSW per year ending up in landfills with a growing population resulting in even more waste production.

An assessment of the current waste composition performed by Cascadia Consulting Group reveals that close to half of the waste arriving at the Washington and northern Oregon landfills can be used as feedstock for future liquid fuel facilities. A multi-step sorting process is required to separate the RDF, which contains the components that can be converted into fuel, from non-convertibles like glass, metals, electronics, or hazardous waste.

Incentive programs at the international, federal, and state level require the RDF to be composed of as much biogenic content as possible and to demonstrate that sorting and diversion programs have been maximized before conversion to liquid fuels. Therefore, the data used from the Task 2 outputs will consider scenarios that range in their plastics diversion from low to high in subsequent SAF production scenarios.

The waste composition varies from county to county caused by various reasons such as different waste collection programs (no recycling, recycling only, or recycling and compostable), rural or urban, or socio-demographic differences. However, the mixed waste at the landfills levelized these differences, and the compositions between the landfills do not differ significantly.

Five landfills in Washington State and northern Oregon receive sufficient MSW, currently and in the future, for a stand-alone SAF production plant. These include:

- Roosevelt Regional Landfill in Washington,
- Columbia Ridge Landfill in Oregon,
- Finley Buttes in Oregon,
- Cedar Hills Landfill in Washington, and
- LRI Landfill in Washington.

The three large landfills: Roosevelt Regional, Columbia Ridge and Finley Buttes are located in the Columbia River region and collect waste from all over Washington state and parts of Oregon, with the waste traveling up to 500 miles from origin to landfill.

Most contracts between waste haulers and counties expire between now and 2028. A waste-to-fuel conversion facility needs four to five years to be built and therefore, would not be commissioned before 2028 which provides sufficient flexibility to renegotiate contracts and divert collected waste from landfills to SAF production.

Future waste production and changes in recycling programs have been fed into a model to understand the impact on MSW quality and quantity for a waste conversion project. The model confirms that the five large landfills receive sufficient MSW even with a future change in composition of MSW and would be a good RDF source for a future SAF facility.

Multiple federal, state, and municipal laws and regulations are in place related to waste management, renewable fuel production, and tax incentives. Whereas earlier laws and incentives focused on pure biomass such as crops, vegetable oil, or animal fat and did not consider municipal waste as renewable source, this has changed in the last several years and municipal waste has been added as feedstock for renewable fuel production.

2.9. References

Abu-Hakima, A., Farley, S., Flores, A., Hyatt, R., Massana, L., Rohleder, N., Valenti, A. (2020). *Can Municipal Solid Waste Power Airplanes in Washington State?* . New York : Columbia Uniersity.

Barrett, S., Field, R., Herzog, H., Lu, X., Malina, R., Seifkar, N., & Withers, M. (2015). *Biomass to Liquid Fuels Pathway:* A Techno-Economic Environmental Evaluation. Cambridge: MIT. Retrieved from: https://sequestration.mit.edu/bibliography/BTL%20final%20compiled.pdf.

Boutwell, M. (2022, September 07). *Inflation Reduction Act Sustainable Aviation Fuel Credit.* Retrieved from Stillwater Associates: https://stillwaterassociates.com/inflation-reduction-act-sustainable-aviation-fuel-credit-carbon-intensity-matters/#:~:text=Among%20the%20many%20incentives%20for%20renewable%20fuel%20production,of%20SAF%20in%20the%20U.S.%20by%202030.%20.

Bracmort, K. (2021). *A Low Carbon Fuel Standard: In Brief.* Congressional Research Service. Retrieved from https://sgp.fas.org/crs/misc/R46835.pdf.

Breault, C. & Lim, Fay. (2018, April 5). Retrieved from Snohomish County Executive Approves Contract for Solid Waste Services: https://snohomishcountywa.gov/DocumentCenter/View/50841/Snohomish-County-Executive-Approves-Contract-for-Solid-Waste-Services-PDF?bidId=.

Cedar Hills Regional Landfill. (2022, September 28). King County Solid Waste Division Fall 2022 Community Meeting: Sept. 28, 2022 - Cedar Hills Regional Landfill Community Meeting Notes - King County Solid Waste Division.

Chapter 7, Solid Waste Transfer, Processing, Disposal, and Emergency Management. (2022, April). Retrieved from Draft for Public Review: https://www.seattle.gov/documents/departments/spu/documents/plans/2022solidwastedraftch7.pdf.

City of Spokane and Spokane County. (2017, August 15). *Interlocal Agreement Between the City of Spokane and Spokane County.*

Clark County. (2015). Chapter 10, Landfill Disposal. In Clark County Solid Waste Management Plan 2015 (pp. 10-1 – 10-6). Vancouver.

Clark County RFP #788. (November 9, 2020). *Solid Waste Contract Negotiations Questions and Answers.*

Clean Fuel Standard. (n.d.). Retrieved from Department of Ecology State of Washingston: https://ecology.wa.gov/Air-Climate/Climate-change/Reducing-greenhouse-gases/Clean-Fuel-Standard.

Climate Commitment Act (CCA). (n.d.). Retrieved from Department of Ecology: https://ecology.wa.gov/Air-Climate/Climate-Commitment-Act.

Columbia Resource Company Rate Schedule, Effective January 1, 2022. (n.d.). Retrieved From: https://cdn.wasteconnections.com/cms/columbia-resource-company/CRC%20-%20Rate%20Card%202022.pdf.

County, C. (2015). Chapter 10, Landfill Disposal. In Clark County Solid Waste Management Plan 2015 (pp. 10-1 – 10-6). Vancouver.

Comprehensive Solid Waste and Moderate Risk Waste Management Plan for Spokane County 2022 through 2027. (2022, July). Great West Engineering. Retrieved from Spokane County Regional Solid Waste System: https://www.spokanecounty.org/DocumentCenter/View/44215/Spokane-County-SWMP?bidId=.

Comprehensive Solid and Hazardous Waste Management Plan. (2016, June 14). Whatcom County, Washington: https://www.whatcomcounty.us/DocumentCenter/View/6723/Whatcom-County-Comprehensive-Solid-and-Hazardous-Waste-Management-Plan.

2019 Comprehensive Solid Waste Management Plan. (2019, November). Retrieved from King County Solid Waste Division, Seattle: https://your.kingcounty.gov/dnrp/library/solid-waste/about/planning/2019-comp-plan.pdf.

CORSIA. (2018, August 9). Frequently Asked Questions (FAQs): https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_FAQs_Update_9Aug18.pdf.

CORSIA Eligible Fuels. (n.d.). Retrieved from ICAO Environment: https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx.

CORSIA Methodology for Calculating Actual Life Cycle Emissions Values. (2022). ICAO. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf.

CORSIA Supporting Document . (2019). *CORSIA Eligible Fuels - Life Cycle Assessment Methodology. ICAO.* Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20Supporting%20Document_CORSIA%20Eligible%20Fuels_LCA%20Methodology.pdf.

DeMent. (2017, November 7). Revisiting Roosevelt: the landfill of a truly epic scale. Retrieved from The Goldendale Sentinel: Revisiting Roosevelt: the landfill of a truly epic scale | News | goldendalesentinel.com.

Department of Water and Waste Management. (2016, November 14). *Thurston County Waste Export and Transportation Agreement*. First Amendment.

Disposal. (n.d.). Retrieved from Solid Waste Services: https://my.spokanecity.org/solidwaste/locations/#:~:text=2022%20Trash%20Disposal%20Rates%20%E2%80%93%20a,and%20North%20County%20transfer%20stations.

Disposal Fees – Solid waste, recycling, unsecured loads, and Cleanup LIFT Discount. (2022, January 1). Retrieved from King County: https://kingcounty.gov/depts/dnrp/solid-waste/facilities/disposal-fees.aspx.

Draft Environmental Impact Statement, Cedar Hills Regional Landfill 2020 Site Development Plan and Facility Relocation.

Drop-off Services. (n.d.). Retrieved from Waste Connections of Washington, Inc: https://wcnorthwest.com/dropoff.

Gillmore. Waste Tonnage Volumes. Received in email dated 06 July 2022.

Haydary, J. (2016). Gasification of Refuse-Derived Fuel (RDF). Retrieved from *GeoScience Engineering,* 37-44: https://www.researchgate.net/publication/306085514_Gasification_of_Refuse-Derived_Fuel_RDF.

ICAO. (2021). CORSIA States for Chapter 3 State Pairs. Retrieved from International Civil Aviation Organization: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_States_for_Chapter3_State_Pairs_Sept2020.pdf.

ICAO Environment. (n.d.). Retrieved from Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) : https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx.

King County Solid Waste Division . (2019). *Comprehensive Solid Waste Management Plan* . Seattle : King County. Retrieved from: https://your.kingcounty.gov/dnrp/library/solid-waste/about/planning/2019-comp-plan.pdf.

King County (n.d.). Cedar Hills Regional Landfill Development. Retrieved from: https://kingcounty.gov/en/dept/dnrp/waste-services/garbage-recycling-compost/solid-waste-facilities/cedar-hills-development.

Kitsap County Board of Commissioners. (2000). *Contract Amendment KC-479-00 with Waste Management of Washington, Inc:* https://www.kitsap.gov/das/Documents/OVTS%20Operations%20Plan%20for%20RFP%202020-125%20Addendum%205.pdf.

Kitsap County Solid and Hazardous Waste Management Plan. (2018). Chapter 8, Transfer Systems for Waste and Recyclables. Retrieved from Kitsap County Department of Public Works: https://www.kitsapgov.com/pw/Documents/2018_SHWMP_Web.pdf.

Landfill Disposal Agreement. (2018, December 3). *Metro, an Oregon Metropolitan Service District and Waste Management Disposal Services of Oregon, Inc.*

Landfills and waste transport. (n.d.). Metro: https://www.oregonmetro.gov/landfills-and-waste-transport.

Leigh, April. (2022, April 5). Thurston County News Release. Retrieved from Thurston County: https://www.thurstoncountywa.gov/tchome/pages/newsreleasedetail.aspx?List-ID=2253.

Lopez, L., Pitzler, D., & Wallace, B. (2017, May 9). *Memorandum: Transportation and Disposal Evaluation– Phase 1 Results.* Retrieved from Metro: https://www.oregonmetro.gov/sites/default/files/2017/05/09/Transport_Disposal_Procurement_Technical_Memo_20170509.pdf.

L.P. Clark County. (2006, January 1). *Contract Regarding Solid Waste Recycling, Transfer, Transport and Out-Of-County Disposal Between Clark County, Washington and Columbia Resource Company.*

LRI Landfill. (n.d.). Retrieved from: https://www.lriservices.com/lri-landfill.

Materials Recovery Facility or MRF. (n.d.). Retrieved from Columbia Resource Company: https://www.columbiaresourcecompany.com/materials-recovery-facility.

Municipal Solid Waste Flow. (2016). Retrieved from Department of Ecology State of Washington: https://public.tableau.com/app/profile/solidwastemgmt/viz/MunicipalSolidWasteFlow2016/Dashboard1.

New King County Solid Waste Disposal Rates for 2023. (2022, September 30). Retrieved from King County: https://content.govdelivery.com/accounts/WAKING/bulletins/32dc4fd.

2022 Organics Management Law. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Waste-Toxics/Reducing-recycling-waste/Waste-reduction-programs/Organic-materials/2022-organics-management-law.

1095.9 PBS Regulated Waste Management. (2019, June 14). Retrieved from U.S. General Services Administration: https://www.gsa.gov/directive/regulated-waste-management.

Port of Seattle: Sustainable Aviation Fuels Help the Environment and the Economy. (2019, March 05). Retrieved from Aviation Benefits Beyond Borders: https://aviationbenefits.org/newswire/2019/03/port-of-seattle-sustainable-aviation-fuels-help-the-environment-and-the- economy/#:~:text=The%20use%20of%20sustainable%20aviation%20fuels%20benefits%20the,sulphur%20content%203%20Reducing%20particulate%20matter.

Pierce County. (2008). *PCRCD dba LRI Waste Handling Agreement.*

Public Works. (n.d.). Thurston County Washington: https://www.thurstoncountywa.gov/pw/sw-grhome/Pages/sw-Garbage.aspx.

Renewable Energy System Incentive Program . (n.d.). Retrieved from Energy Program: https://www.energy.wsu.edu/RenewableEnergy/RenewableEnergySystemIncentiveProgram.aspx.

2030 Regional Waste Plan, Equity, health and the environment. (2019, March 7). Metro, Portland: https://www.oregonmetro.gov/sites/default/files/2019/03/22/2030RegionalWastePlan_03222019_1.pdf.

Resource Conservation and Recovery Act of 1976. Public Law 94-580-Oct. 21, 1976: https://www.govinfo.gov/content/pkg/STATUTE-90/pdf/STATUTE-90-Pg2795.pdf.

Resource Conservation and Recovery Act (RCRA) Overview. (2022, June 29). Retrieved from United States EPA : https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview.

Solid Waste & Recycling Data. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Research-Data/Data-resources/Solid-waste-recycling-data.

Seattle Public Utilities. (2018, May 14). *Solid Waste Collection and Transfer Contract between City of Seattle and Waste Management of Washington, Inc*. Seattle Public Utilities.

Seattle Public Utilities Station Monthly Tons 2022 Year End Summary Monthly Tons Report. Seattle Public Utilities, 01 November 2022.https://www.seattle.gov/documents/Departments/SPU/Services/Garbage/Station%20Monthly%20Trips_Landscape%202022-combined.pdf

Skagit County Solid Waste Management Plan. (2017, September). Retrieved from Green Solutions, South Prairie: https://www.skagitcounty.net/PublicWorksSolidWaste/Documents/SCSWMP%202018-2023.pdf.

Snohomish County Public Works. (n.d.). Getting down to Basics: Where does our Garbage go? Retrieved from: https://www.snohomishcountywa.gov/DocumentCenter/View/44630/Where-Does-Our-Garbage-Go--English?bidId=.

Solid Waste & Recycling Data. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Research-Data/Data-resources/Solid-waste-recycling-data.

Solid Waste Services Contract FAQs. (2022, March 22). Retrieved from Thurston County Public Works: https://www.thurstoncountywa.gov/tchome/SiteAssets/Pages/publicmeetings/Contract%20FAQs.pdf.

Southwest Clean Air Agency. (2018, October 10). Cowlitz County Headquarters Landfill. Received from: Title V Basis Statement: SW14-20-R0BAS.PDF (swcleanair.gov).

Spokane County and Waste Connections of Washington, Inc. (2014, September 9). *Service Contract For Transfer Station Operation And Maintenance And Solid Waste Transportation And Disposal Services.*

2016 Supplement to the Tacoma-Pierce County Solid Waste Management Plan. (2016). Retrieved from Pierce County Department of Public Works and Utilities: https://co.pierce.wa.us/DocumentCenter/View/38769/2015_SupplementFULL_2016-08-10?bidId=.

Tacoma-Pierce County Solid and Hazardous Waste Management Plan: 2021-2040. (2022, October 25). Retrieved from Pierce County: https://issuu.com/pierceco/docs/shwmp_final.

Thurston County Solid Waste Advisory Committee. (2022, March 2). Retrieved from *Meeting Minutes:* https://www.co.thurston.wa.us/solidwaste/swac/2022/SWAC%20March%20Minutes.pdf.

Universal Waste . (2022, January 22). Retrieved from United States EPA: https://www.epa.gov/hw/universal-waste.

USEPA. (2022, August). *Washington State-Level Project and Landfill Totals from the LMOP Databse.* Retrieved from United States Environmental Protection Agency: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.epa.gov%2Fsystem%2Ffiles%2Fdocuments%2F2022-08%2Flmopdatawa.xlsx&wdOrigin=BROWSELINK.

Yong-Chil,S., Md Tanvir, A., Won-Seok, Y.(2018). Retrieved from Gasification of Municipal Solid Waste: https://www.intechopen.com/chapters/59269#B4, DOI: 10.5772/intechopen.73685.

Washington Statewide Waste Characterization Study. (2009). Published in June 2010, Department of Ecology and Cascadia Consulting Group.

Washington Statewide Waste Characterization Study. (2015). Published in October 2016, Department of Ecology and Cascadia Consulting Group.

Washington Statewide Waste Characterization Study. (2020-2021). Published in August 2021, Department of Ecology and Cascadia Consulting Group.

Waste Connections. (n.d.). Retrieved from Finley Buttes Landfill: https://www.wasteconnections.com/finley-buttes-landfill.

EXP | 451 Montgomery Street, Suite 300 | San Francisco, CA 94104
t: +1. 954.999.8292

exp.com

TASK
3

MUNICIPAL SOLID WASTE TO LIQUID FUELS STUDY

Port of Seattle + King County Solid Waste Division

Report Name:
Task 3 – Identify and Evaluate Facility Locations

2023-06-30

prepared by

EXP
451 Montgomery Street, Suite 300 | San Francisco, CA 94104
Principal, Marcos Souza: marcos.souza@exp.com
Project Manager, Joseph Gale: joseph.gale@exp.com

TABLE OF CONTENTS

exp.

TABLE OF CONTENTS

CONTINUED

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

- **AMA** – Advanced Methanol Amsterdam
- **ASTM** – American Society for Testing and Materials
- **ATJ** – Alcohol-to-jet
- **ATJ-SPK** – Alcohol to Jet Synthetic Paraffinic Kerosene
- **BHS** – Bulk Handling Systems
- **bpd** – Barrels per day
- **BTL** – Biomass to Liquid
- **CCS** – Carbon Capture and Storage
- **CEPCI** – Chemical Engineering Plant Cost Index
- **CO** – Carbon monoxide
- **CO_2** – Carbon Dioxide
- **FT** – Fischer-Tropsch
- **FT-SPK** – Fischer-Tropsch Synthetic Paraffinic
- **FT-SPK/A** – Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics
- **GHG** – Greenhouse gas
- **GTL** – Gas-to-liquids
- **H_2** - Hydrogen
- **HEFA** – Hydro-processed Esters and Fatty Acids
- **HTW** – High Temperature Winkler
- **HVO** - Hydrotreated Vegetable Oil
- **ICAO** – International Civil Aviation Organization
- **KC** – King County
- **kWh** – Kilowatt Hours
- **LCFS** – Low Carbon Fuel Standard
- **MIT** – Massachusetts Institute of Technology
- **mm** – Millions
- **mmgpa** – Million Gallons per Annum
- **MRF** – Material Recovery Facility
- **MSW** – Municipal Solid Waste
- **mt** – Metric Ton
- **mtpa** – Metric Tons per Annum
- **OLCV** – Oxy Low Carbon Ventures, LLC
- **PEM** – Polymer-electrolyte Membrane
- **PNW** – Pacific Northwest
- **POS** – Port of Seattle
- **PPI** – Proton Power, Inc.
- **RDF** – Refuse Derived Fuel
- **RFS** – Renewable Fuel Standard
- **RINs** – Renewable Identification Numbers
- **RNG** – Renewable Natural Gas
- **RSB** – Roundtable on Sustainable Biomaterials
- **RWGS** – Reverse Water Gas Shift
- **SAF** – Sustainable Aviation Fuel
- **SEA** – Seattle-Tacoma International Airport
- **SFW** – Sumitomo SHI FW
- **SMDS** – Shell Middle Distillate Synthesis
- **Syncrude** – Synthetic crude
- **Syngas** – Synthetic gas
- **TIC** – Total Investment Cost
- **TRL** - Technology Readiness Level
- **USEPA** – United States Environmental Protection
- **WSU** – Washington State University

3

TASK 3 – IDENTIFY AND EVALUATE FACILITY LOCATIONS

3. Task 3 - Identify and Evaluate Facility Locations

3.1. Executive Summary

The State of Washington currently generates over 5 million tons of MSW annually, a significant portion of which is viable for renewable fuel production.

This Task 3 Report presents a comprehensive review for the identification and evaluation of suitable site locations for a renewable fuels production facility utilizing municipal solid waste (MSW) as feedstock. The evaluation criteria, structured approach, and considerations for facility placement are discussed, taking into account factors such as infrastructure, permitting requirements, environmental constraints, logistics of feedstock and fuel transport, and community acceptance. Additionally, this report examines the costs associated with sustainable aviation fuel (SAF) production and provides a review of greenhouse gas (GHG) emissions compared to conventional jet fuel. The analyses determined a minimum of 40 acres is required for small-scale facilities, while larger-scale operations necessitate 100 acres for an annual production capacity of 25 million gallons. The advantages and disadvantages of a centralized plant versus split facility locations are discussed, along with key considerations outlined below.

Site Selection Criteria

To assess potential facility sites, the authors developed scoring criteria encompassing various factors. These include infrastructure availability, utility accessibility, geological conditions for carbon sequestration, social acceptance, and proximity to landfills as the feedstock source. Industrial areas zoned for this purpose were prioritized to minimize costs associated with rezoning and to avoid project delays. Based on these criteria, fourteen (14) properties were selected for further evaluation, with parcels near the Columbia River landfills showing the most promise. Other viable locations include areas in proximity to refineries and the Centralia Generator Station in Central Washington.

Permitting Requirements

Successful project progress hinges on obtaining the necessary permits from federal, state, and municipal entities. This report provides an overview of the relevant permits and permitting bodies encompassing air quality, water quality, effluent discharge, hazardous materials handling, zoning regulations, wildlife impact assessment, and other environmental and building requirements.

Transportation Modes

An MSW-to-SAF production plant requires substantial amounts of solid material for feedstock and yields a significant volume of liquid fuels. Potential modes of transportation considered are rail, barge, and truck. Availability of these modes is contingent upon local access to waterways, rail lines, and roads. This report presents transportation routes and modes, including rail transportation of MSW or refuse-derived fuel (RDF) from various regions to landfills along the Columbia River. Fuel transportation from the Columbia River region to potential blending stations is also examined, with options including rail, barge and truck transport.

Financial Considerations

A high-level financial model developed for the project indicates that the Minimum Sales Price (MSP) for SAF is primarily influenced by the facility's size rather than the production pathway. Capital costs for a 25 million-gallon-per-year facility can exceed one billion dollars, with MSP calculations factoring in capital and operating costs, transportation expenses, staffing requirements, financing costs, and an assumed 15% return on equity. Smaller plants with a production of around 10 million gallons per year may require an MSP of approximately $10 per gallon, while larger-scale operations in the range of 25 million gallons per year exhibit MSPs ranging from $7.70 to $9 per gallon. A sensitivity analysis conducted indicates that variations in financing costs and tipping fees have the greatest impact on the MSP.

Byproducts and Market Demand

The MSW-to-SAF production process yields valuable byproducts, such as renewable diesel, LPG, naphtha, ethanol, and ethylene. These byproducts have a high demand in the market and can be sold at or above market price due to their renewable nature. Ethanol and ethylene, if produced in surplus, are easily marketable and highly sought after in the chemical industry.

Lifecycle GHG Emissions Calculation

The accurate calculation of lifecycle GHG emissions is essential for establishing the renewable status of MSW as a feedstock source and SAF as a renewable product. This report highlights the importance of determining the carbon intensity (CI) factor, which influences financial support, subsidies, tax incentives, and eligibility for RIN credits. Existing models, such as IATA's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), are discussed, but there is a need for standardized models specific to the MSW-to-SAF process. Efforts by the GREET model developers to modify this application are ongoing with an updated version anticipated in the fall of 2023; the implications and accuracy of these models is essential and must be emphasized.

Conclusion and Recommendations

In conclusion, this report presents a structured evaluation of site locations for an MSW-to-SAF production facility. The comprehensive analysis covers various aspects, including site selection criteria, permitting requirements, transportation modes, financial considerations, byproducts, and GHG emissions calculation. Calculation methodologies for lifecycle GHG emissions is most critical for a project at this feasibility stage. It is crucial for stakeholders to engage in discussions with relevant authorities to ensure alignment on the appropriate calculation methodology and input parameters for emission reduction is the key driver for SAF production.

3.2. Siting Selection

This section identifies potential locations for a renewable fuels production facility within the Pacific Northwest region and evaluates the suitability of these locations regarding technical criteria, available plot space and infrastructure (e.g., roads, rail, power, water, and natural gas), potential for carbon emission reduction, permitting requirements, and social criteria (e.g., community acceptance, local labor impacts and availability, or social benefits). Potential locations are evaluated with respect to financial aspects, cost and revenue streams, products and by-products, wastes, effluents and emissions, carbon intensity and future risks.

3.2.1. Approach

Determining site selection for a renewable fuels production facility is one of the most challenging aspects of this study because it involves the consideration of multiple factors, early on in project feasibility. The following siting criteria are reviewed in more detail followed by an assessment of potential sites in Washington and northern Oregon.

Landfill Proximity – Transportation costs have a substantial impact on the overall costs of SAF production. Thus, a location in close proximity to a landfill is advantageous as it minimizes the need for extensive transportation of MSW or RDF. This section examines the pros and cons of several state landfills in remote locations in Washington and Oregon, weighing their suitability as potential sites.

Industrial Area – An industrial area, including existing or demolished industrial facilities (e.g., brownfields) already zoned for industrial use, offers simplified permitting processes and existing infrastructure and transportation connections. However, logistics for MSW delivery and fuel transport can be challenging, as brownfield sites often tend to be situated farther from landfills and end-users of fuel products.

Refinery Proximity – Refineries and their surrounding areas present a unique form of an industrial zone. In addition to the advantages of simplified permitting and existing utility systems, refineries may have gas and water treatment plants that can be utilized, reducing capital costs. The availability of storage and blending facilities at refineries further enhances the appeal of these locations. However, logistics for MSW, environmental considerations, and community acceptance are crucial factors that need careful attention in this context.

Transfer stations serve as initial collection points where RDF can be separated from collected waste. Unfortunately, a single transfer station's MSW flow is generally insufficient to support the establishment of a viable renewable fuels production facility, and space availability poses a limitation. Most transfer stations are situated in urban areas, necessitating rezoning efforts. Therefore, transfer stations are not further discussed as feasible site locations in this report.

3.2.2. Siting Criteria

3.2.2.1. Technical

Plant design allows for varying options of facility configuration. As discussed in **Task 1**, there are two main pathways to produce SAF from MSW: The Fischer-Tropsch (FT) synthesis, which is the most mature process, or through the conversion of MSW into alcohol as an intermediate product, followed by the ATJ route to produce SAF.

A renewable fuels production facility may be built as one straight-through plant with all process units together on a single site, or depending on the chosen process, the plant may be split into units and each unit built at a different location. The conventional gasification based SAF production plant produces CO_2 which can either be emitted into the atmosphere or captured and utilized, exported, or sequestered. Alternatively, the CO_2 can also be converted into alcohol or fuel if additional hydrogen is supplied (preferably with green or blue hydrogen to avoid additional GHG emissions from hydrogen production). The process steps and critical components of which have been presented in **Task 1**.

The site assessment is based on the four scenarios developed in **Task 1, Section 1.10.9**. These design scenarios encompass two pathways: the Fischer-Tropsch (FT) pathway and the Alcohol-to-Jet (ATJ) pathway.

3.2.2.1.1. Single Straight-through Process Plant

A single straight-through process plant has multiple advantages. All process units can be built close together, integrating processes and energy. Utility units such as water make-up, cooling water system, instrument, and plant air, service the whole plant; the same applies for off-sites, office and maintenance buildings, and infrastructure connections.

3.2.2.1.2. Production Split

A split of production may be required if all the site requirements cannot be fulfilled in one location or strategic considerations make a split advantageous. Reasons to opt for split locations include:

Site constraints – Insufficient space for a full facility at one location, zoning restrictions for certain processing steps, or logistical issues.

Transportation advantages – For example, sorting the waste at the source and having shorter transportation distances to the SAF production plant, resulting in reduced GHG emissions.

Ethanol collection – Collecting ethanol from various locations for a common, larger ATJ facility.

3.2.2.1.3. MSW Sorting

MSW sorting and RDF separation is mostly a mechanical process with minimal environmental impact. Material Recovery Facilities (MRFs) are modularized systems which can easily be installed at landfills or transfer stations. This split could possibly reduce transportation costs as only the RDF needs to be shipped to the renewable fuels production facility. MRFs can also be installed at multiple locations and allow for utilization of MSW from smaller landfills or larger transfer stations, resulting in RDF collection from multiple sources for the renewable fuels production facility.

3.2.2.1.4. Fischer-Tropsch Pathway

The Fulcrum Plant located in Nevada operates by producing synthetic crude solely through the FT synthesis process. The produced syncrude is then transported to a refinery for the hydrocracking and isomerization step. It is important to note that the split between the FT synthesis and subsequent refining should only be considered if non-technical factors strongly support it. From a technical standpoint, this is not recommended due to the instability of FT waxes and the special transportation requirements associated with them. The following assessment will not include the consideration of this split.

3.2.2.1.5. Ethanol Production for ATJ Route

Ethanol can be produced from various sources, e.g. fermentation of agricultural or forestry waste, conversion of syngas into ethanol that is derived from industrial offgases such as steel mills, or from gasification of forestry residue or MSW. Ethanol is a stable alcohol and easy to handle and transport. A production split with one facility producing ethanol and a separate facility producing SAF from ethanol could under certain conditions provide significant benefits.

- One potential scenario for this split case is utilization of ethanol from various sources and channeling it into a single large ATJ facility. In this scenario, ethanol, derived from different feedstock such as MSW, agricultural crops, or other renewable sources, would serve as the primary input for the ATJ production process.
- Another possible reason for considering a split is if a large-scale plant faces plot space constraints. Dividing the production process and utilizing separate, smaller sites could allow for more efficient utilization of available space and enable the establishment of multiple production facilities to meet the overall production capacity required.

A production split comes with several disadvantages which must also be taken into account:

- Logistics may be more complex as an additional good has to be shipped from one or multiple sources to an ATJ facility.
- Both facilities need additional storage capacities for ethanol, which reduces the plot plan advantages of split locations.
- The energy efficiency will be reduced and may lead to a higher overall CI. The ATJ plant has a high energy demand. In the case of a combined MSW-to-fuels plant, most of the waste heat generated during gasification of the solid waste can be recovered and used in the ATJ process, thus reducing the need for external heat and minimizing the carbon intensity.
- More operating staff as administrative and maintenance personnel are required for each location.

3.2.2.1.6. Carbon Capture and Utilization or Sequestration

The typical solid waste based renewable fuels production facility, whether through the FT or the ATJ pathway, generates CO_2 which needs to be removed from the process. The standard configuration washes the CO_2 out of the syngas and emits it into the atmosphere which results in a penalty regarding Carbon Intensity (CI). This penalty can be avoided if the captured CO_2 is either sequestered or further utilized. Survey of the determined site needs to include a geological assessment for sequestration potential as well as analysis to the proximity to CO_2 pipelines for possible export and utilization. CO_2 could also be trucked out in liquefied form. All forms of utilization or sequestration have their own carbon footprint which needs to be taken into consideration when evaluating the overall benefits.

3.2.2.1.7. Optimal Capacities and Plot Space

The technologies as well as currently built and planned facilities with their associated capacities have been discussed in **Task 1**. A comparison of the capital costs in **Table 1.20** and **Table 1.21** of **Task 1** shows the impressive advantages of building larger plants. However, there are also arguments against this approach including:

Maturity – The conversion of MSW into fuel has only been applied at a few plants, more so in a pilot plant size rather than a commercial one. Whereas single process steps are mature, others are still in development.

Financing – Even with specific costs declining with increasing plant size, the total costs increase with the plant size. The limited risk that investors are willing to take also limits the investment capital that can be raised. New developments such as the ATJ pathway and improvements in biological processing have realistic chances for cost reductions compared to the conventional Fischer-Tropsch pathway and could be available on a commercial-scale in a few years. Such considerations are just examples which favor risk sharing and limited willingness to invest larger amounts today. See **Task 4** for additional project financing criteria.

Logistics – Feedstock availability and sustainability, and transportation costs may be other limiting factors.

Plot Space – Larger plants require more plot space. The plot space for plants as per our model scenarios is between 40 and 100 acres. If the plot space is limited but other factors are favorable at a certain location, a smaller plant might be a better solution.

As evident from the discussion above, there is not one optimal capacity. The plant size depends on various technical, commercial, environmental, social, and other factors and is often a compromise of all. For the purpose of this report, the locations identified and discussed will be tested with respect to all four scenarios developed in **Task 1**.

3.2.2.2. Permitting

The permitting process for an industrial facility carries significant time requirements and can lead to substantial delays with huge cost implications. A comprehensive site assessment must carefully evaluate permitting considerations at various levels.

Effluents and emissions regulations play a crucial role in determining the allowable levels of gaseous emissions, encompassing ozone-depleting substances and GHG emissions, as well as solid waste management and water sourcing and treatment requirements.

Zoning regulations dictate the permissible industrial plant types and outline other local requirements that must be adhered to during the siting process.

Community acceptance and the level of local population activism can have a notable impact on the duration of the permitting process. It is essential to consider the attitudes and engagement of the community, as it can significantly influence the timeline and outcome of the permitting procedures.

The regulatory acceptance of the produced fuel as a renewable fuel is contingent upon various factors. The manner in which the fuel is processed, the extent to which the renewable fuels production facility or its components can be integrated into existing facilities (e.g., refineries), and the definition of feedstock necessary for the final fuel to be recognized as renewable fuel are among the factors that necessitate careful consideration.

Appendix 3.A – Permitting, Guidelines & Regulations, provides a detailed overview of the permitting process on federal, state and local level.

3.2.2.3. Infrastructure Requirements

A potential renewable fuels production facility requires certain infrastructure for its operations.

3.2.2.3.1. Roads

The heaviest load to be transported on the access road to a site will be heavy equipment during construction. The road access should also be assessed with regards to transportation of heavy modules.

Truck access during normal operations is expected for delivery of nitrogen and other consumables required for regular operations and for removal of ash, sulfur and other by-products. Depending on the location and rail or barge access, transportation of MSW and fuel must also be shipped by truck. A truck trailer has a payload of up to 11,000 gallons, requiring about 8 trucks per day for a 25 mmgpa SAF plant.

3.2.2.3.2. Rail

Direct rail access allows for the delivery of MSW and other feedstocks to a facility and for the supply of renewable fuel and byproducts from the facility to final consumers or blending stations. A rail system should be able to handle unit trains and have space for the unloading of MSW and for liquid fuel loading.

A unit train can transport around 10,000 tons of solid waste. This would be sufficient for plant operations of three days for a 25 million gallons per year SAF production plant. The frequency would potentially change to six days if MSW could be sorted elsewhere and only RDF be shipped to the plant site.

A DOT 117 railcar can load up to around 28,000 gallons of liquid fuel. This would result in approximately three rail cars being filled per day for shipping SAF to a blending station. A logistics study and negotiations with rail operators will determine whether a few rail cars e.g., once per week or a complete unit train once per month are more economical.

3.2.2.3.3. Water

Water access may be attractive when shipping goods over longer distances. Ship loading and unloading facilities are expensive if they need to be built for this specific application. Assuming waste sorting facilities would be close to a landfill or at the renewable fuels production facility, MSW or RDF transportation by truck or rail is most likely. Using vessels or barges for fuel transport is more likely and will be assessed during the following site selection.

3.2.2.3.4. Utilities

The facility is a multi-step processing plant with several mechanical and chemical process steps. This section describes the required utilities and where they may be sourced from. The quantities of utilities needed depend on plant configuration and plant size, selected technologies and other factors and are provided in more detail in **Section 1.10** of **Task 1**.

Process water for the conversion process, cooling water, tap water and fire water are all permanent requirements of a facility. Thus an industrial connection to water supply is required at the site. However, the plant design can be adapted to meet the amount of fresh water that is available.

Electric power drives motors for compressors and pumps, and is used for electric heaters, control and safety systems, HVAC and other smaller applications. The use of renewable power would significantly benefit the overall carbon footprint of a potential facility. A 25 million gallon per year plant is expected to need about 20 to 25 MW of electric power for basic design and up to 160 MW of preferably renewable power in the case of product optimization and yield maximization as described in **Task 1**.

Natural gas is required for initiating the conversion process until the MSW can provide sufficient heat for a self-sustaining operation and for smaller permanent or intermittent use cases. Natural gas may also be replaced by Renewable Natural Gas (RNG) as collected from landfill gas or wastewater treatment plants which would be favorable for the overall carbon footprint.

Nitrogen, oxygen and hydrogen can be produced on-site from electricity, water and natural gas, but can also be delivered by pipeline over-the-fence if pipeline supply is available. While on-site production for all technical gases is considered in this study, an over-the-fence supply could reduce capital cost and benefit the carbon footprint of a potential facility.

Proximity to a CO_2 pipeline would possibly allow for excess CO_2 to be fed into a pipeline for industrial use or sequestration. This opportunity would reduce the overall carbon emissions and improve the CI factor further.

3.2.2.4. Logistics and Related Costs

3.2.2.4.1. Overview

Based on various routing pairs and transportation modes, this section identifies the costs associated with logistics routing, involving different traffic types between various origins and destinations. The transportation mode was assumed to be either rail, truck or barge however barge transportation relies on some trucking in all instances to move materials from origin to destination as further explained in the barge section below.

The routes and transportation modes discussed in this study are as follows:

- MSW or RDF modal by rail
    - MSW from King County to Centralia followed by
    - Refuse from Centralia to Roosevelt or Columbia Ridge Landfill
    - King County to Roosevelt and Columbia Ridge Landfill
- Jet fuel from Columbia River or Roosevelt landfill to following blending stations:
    - Renton Terminal
    - Harbor Island (exemplary for a port location near Seattle-Tacoma International Airport)
    - BP Cherry Point Refinery (exemplary for a refinery in NW Washington)

The case of producing ethanol and shipping the ethanol to another location for the ATJ process will not be further discussed. The volumetric flow of ethanol is almost twice as high as that of jet fuel for the same amount of RDF used and therefore would increase the transportation cost portion for jet fuel significantly. Furthermore, the split location is a very specific case and only feasible if e.g., multiple ethanol sources feed into one larger ATJ plant.

Most solid waste today is shipped to the Roosevelt Landfill or Columbia Ridge Landfill utilizing train transportation. Therefore this mode has been used to determine the transportation costs of solid waste.

For jet fuel, we have assumed either barge transportation from Roosevelt or Columbia Ridge to Harbor Island or Cherry Point Refinery as both start and end points have water access. Rail transportation has been evaluated for Columbia Ridge and Roosevelt to Renton Terminal and to Cherry Point Refinery, and truck transportation from Roosevelt landfill to Renton Terminal. This comparison shows significant cost advantages for rail transportation compared to barges and trucks.

3.2.2.4.2. Rail Transportation

Rail transportation with its private rights-of-way presents a very different competitive environment than does trucking or water carriage which utilize public highways and waterways. In addition, railroad rates are designed to yield whatever the market will bear. The rail carrier pricing calculus considers the costs incurred in providing transportation, the market value of the commodity to be transported and competitive transport options, with the first serving as a floor while most of the evaluation hinges on the last.

As a result, shippers or receivers of high volume, low value bulk commodities such as MSW and the other commodities contemplated by this study are well advised to take a strategic approach to potential contracting with railroads. Any prospective railroad customer must recognize that there exists a window of opportunity which, if seized, can impact future cash flows significantly over the entire economic life of a plant it operates or develops. Once the window of opportunity closes, any railroad customer's leverage to negotiate will decline significantly while that of its serving railroad(s) will increase. In the paragraphs that follow, amounts expressed in the context of rail and barge transportation are best understood as potential prices for facility transport, not costs to the carriers since rail lines in this country are not subject to open access. As a result, intramodal competition is very limited and prices can exceed costs to the extent allowed under regulations, which are rather lenient. That said, truck and barge operations tend to be open access, with lower barriers to entry and thus lower prices, especially for shorter hauls like those reviewed in this study.

Three primary routes were identified to move MSW from the King County Rail yards to either Roosevelt Landfill, Columbia Ridge Landfill directly or Columbia Ridge Landfill via the Centralia Generator Station. Rail transportation economics is best characterized as featuring high fixed costs and low variable costs. As such, the greater the volume, the less the cost per car. In addition, because competition in the rail industry can be limited, greater cost savings are found where more than one railroad operator can be used.

The tonnage and container volumes for the small and large plant capacities as defined for the four scenarios in **Task 1, Section 1.10.9**, were utilized along with waybill data samples from a third-party aggregator who collects them from the railroads to derive a total cost to move MSW across each of the three primary routes. As discussed above, there are significant cost savings associated with increased volumes moved per day. The cost in a competitive (meaning the county can easily change from BNSF to UP or vice versa) environment can easily be 20% lower than in a non-competitive (meaning the county is beholden to one rail carrier) environment.

Table 3.1: MSW Transportation Costs by Rail

Origin:	King County (Seattle, WA)		
Destination:	Roosevelt Landfill (Roosevelt, WA) Columbia Ridge Landfill, OR		
STCC Desc.	Municipal garbage waste, solid		
Equip. Type	Flats 60'-70' 263k		
Units	**Tons/Car**	**Segment**	**Total Cost per ton**
42	24	BNSF UP	$44.30 $43.86
61	24	BNSF UP	$37.50 $36.45
170		BNSF UP	$30.20 $30.56

The shipping of jet fuel from Roosevelt or Columbia Ridge landfill to Renton Terminal or BP Cherry Point refinery can be done by using 3 - 5 cars per day but also by intermediate storing of fuel and sending railcars less frequently, e.g. move 6-10 cars every other day or a unit train even less frequently resulting in lower transportation costs.

Table 3.2: Fuel Transportation Costs by Rail

Origin:	**Columbia Ridge Landfill (Arlington, OR)**		
Destination:	BP Cherry Point Refinery (Blaine, WA) Renton Terminal		
STCC Desc.	Jet fuel		
Equip Desc.	Tank - >22M and <32M gallons		
Units	**Tons/Car**	**Segment**	**Total Cost per barrel**
1	85	Total	$4.73 $3.91
3	85	Total	$3.91 $3.09

3.2.2.4.3. Barge Transportation

The daily volumes on which to derive prices is 530 and 2,100 barrels to cover the range of capacities as per the four scenarios mentioned above. Daily pricing information was provided by several barge companies in the State of Washington and the Port of Morrow. The analyses reflected the assumption that fuel would be transported from the origin (Columbia Ridge Landfill) to the Port of Morrow via truck. This could be done either by tanker truck or ISO container. However, our research did not reveal any ISO containers available moving from Portland, OR to the Seattle area so they would likely need to be procured from Vancouver, WA. Because this would add a significant carbon footprint to the operation, the Team decided to run the analysis only with tanker trucks. The downside to this is that tanker trucks need to be offloaded into a storage facility (compared to ISO containers that can be left at the Port to be transported on demand without the need to construct additional storage at the Port).

The analysis of barge/truck transportation utilized the barrels per day goals listed in **Table 3.3** to derive frequency of transportation. Regarding truck transportation the volumes of SAF require a minimum of 2 trips per day and a maximum of 9 trips per day. The fuel would then be stored at the Port of Morrow until an adequate volume was reached to fill a barge. SAF would require between 6 and 22 barges to reach their volume goals.

The analysis then comprehended a computation of the cost to reach either Harbor Island or BP Cherry Point. The latter is a longer trip from the Port of Morrow and increases the cost and price of transportation. The costs for trucking and intermediate storage make up around half of the total transportation costs for barge transport and impacts the competitiveness of barge transportation significantly. Harbor Island may face an additional disadvantage as the current infrastructure does not allow for utilization of pipelines from Harbor Island to the airport or another blending station; loading the fuel onto trucks would result in additional costs.

Table 3.3: Fuel Transportation Costs by Truck and Barge

	Product	SAF	
	Production Rate (bll/day)	530	2100
Total Costs			
	Trucking Costs per Year	$499,200	$1,934,400
	Storage Costs at Port Morrow	$283,307	$283,307
	Barging Costs (To Harbor Island)	$1,200,960	$4,403,520
Total Costs to Harbor Island (Yearly)		**$1,983,467**	**$6,621,227**
	Cost per BBL	$10.28	$8.66
Additional Barging costs to BP Refinery		$181,865	$666,841
Total Cost to BP Refinery (Yearly)		**$2,165,333**	**$7,288,068**
	Cost per BBL	$11.22	$9.53

3.2.2.4.4. Truck Transportation

A review of transportation between the Roosevelt Landfill and Renton Terminal employing only trucks was studied to estimate weekly and annual costs. In this scenario, the Team assumed tanker trucks would be used exclusively because there is no modal change. Local Washington State trucking companies were surveyed to estimate charges in connection with this trip.

The distance between Roosevelt Landfill and Renton Terminal is approximately 240 miles. This is an important note as federal regulations limit truck drivers' hours of service (HOS) to 11 hours of driving and 13 hours of work (including stops for gas, helping with loading and unloading, etc.). A trip of 240 miles is right at the limit of what a truck driver can manage under federal law in connection with a road trip from origin to destination and back. If drivers incur any delays due to traffic, weather, longer than normal loading or unloading times, etc., they would be required to stop and spend the night at a hotel prior to making the return trip, a "layover." This study reflected the assumption that 25% of truck trips would require a layover, which has been added to the overall cost estimates although perhaps some of those costs could be avoided if loads could be staged to depart the landfill in the early evening so as to avoid both "rush hours."

The overall annual costs and the resulting specific costs per barrel are listed below in **Table 3.4**. The costs per truck are the same, independent of the number of trucks needed per day. In opposite to quantity leverages by rail and barge, larger quantities to be transported by truck do not result in cost savings per barrel.

Table 3.4 Trucking Costs

Ethanol:					
Gals/Truck	11,300				
Truck Trips/week		48	96		
Truck Trips/ Year		2496	4992		
SAF:					
Gals/Truck	10,000				
Truck Trips/week				16	62
Truck Trips/ Year				810	3210
Combined Costs:					
Truck Days/Week		5	5	5	5
Truck Trips per Day		10	19	3	12
Weekly Trucking Costs		$175,224	$350,448	$56,882	$225,382
Loading/Unloading Fees/wk		$6,720	$13,440	$2,181	$8,644
Layover Costs Factor/wk		$2,400	$4,800	$779	$3,087
Total Weekly Trucking Costs		$184,344	$368,688	$59,843	$237,112
Yearly Trucking Cost		**$9,585,888**	**$19,171,776**	**$3,111,819**	**$12,329,848**
Cost per BBL		$14.34	$14.34	$16.13	$16.13

3.2.2.4.5. Conclusion

Logistics is too complex to solve with linear programming or similar tools. Rail is the preferred solution for solid waste transportation for medium and long distances; this mode is already used by several counties who ship their waste to Roosevelt or Columbia Ridge landfills, and unit trains or larger groups of rail cars minimize the track slot requirements and operate at lower costs.

Trucks provide the highest routing and capacity flexibility, but they have no cost advantage for larger capacities and the already high costs per mile increase even more when the trucks cannot return to their base within one day. On the other hand, truck transportation might be beneficial when a site location has other significant cost advantages which more than compensate the higher truck transportation costs.

Barge transportation is not a stand-alone solution. It can only be considered in combination with truck or rail. Intermediate storages, to buffer the different transportation capacities of barges, truck and rail, and intermodal transfer stations increase the capital cost significantly.

3.2.2.5. Staffing

The staffing requirements of a renewable fuels production facility are contingent upon several factors. These factors include the type and complexity of process units, whether the site is a greenfield or brownfield location, and the need for operating personnel in offsite and utility areas. Additionally, administrative and general service personnel are necessary for the smooth functioning of the facility. While certain services can be outsourced to third parties, this report includes them in the overall staffing count.

For a plant with an annual production capacity of 25 million gallons, approximately 135 personnel are required. Among these, around one-fifth of the staff are allocated to daytime positions, while the remaining 80 percent serve as shift operators. A detailed breakdown of staffing requirements for different plant sizes and types can be found in Appendix 3.C – Staffing.

3.2.3. Site Evaluation

This section provides the approach and methodology to identify applicable sites for a potential renewable fuels production facility. Based on the previously mentioned siting criteria in **Section 3.1**, this study evaluated viable sites that were within proximity to large landfills, industrial areas (brownfields), and in proximity to refineries. Specific to these criteria, the following section discusses space availability, surrounding infrastructure, geological conditions for carbon sequestration, proximity to CO2 pipelines, permitting requirements, community acceptance, proximity to landfills, and operational risk.

3.2.3.1. Evaluation Methodology

Space Availability

An understanding of the regional distribution coupled with the availability of existing Land Use data allowed for the preselection of specific counties to determine available areas. Land Use data allowed for the extraction of all industrial areas over 40 acres in Washington State and northern Oregon. Additional parcels were identified through past studies, reports and evaluations obtained in preliminary research conducted by the Port of Seattle.

Surrounding Infrastructure

Once applicable sites were determined, potential sites were analyzed to identify proximities to roadways, railroads, and potential waterways capable of transporting MSW and fuel. The three methods of transportation accounted for were utilized independently or jointly depending on feasibility of cost. The same tools and resources were utilized to identify potential sources of raw water and electricity for each parcel.

Geological Conditions for Carbon Sequestration

Understanding the geology surrounding the selected sites allowed for the identification of areas suitable for in situ carbon remineralization, which requires an abundance of basalts, volcanic, and ultramafic rock properties in the area.[1] This method of sequestering carbon undergoes a few chemical processes when injecting CO_2 charged water into the mafic rock (referring to basalt). The mineralization process of carbon uses a geochemical trapping mechanism to sequester stable, non-toxic carbonates with a low risk of leakage into the atmosphere or underground aquifers.[2] The Columbia River Basalt Group (CRBG) is an ideal opportunity for in situ carbon sequestration due to the consistent conclusions of dissolution behavior from various studies overtime.

The surface geology of potential sites was examined to identify the geological compositions of each site's land and surrounding areas. Correlating the ideal mineral make-up with this sequestering process was part of the evaluation process, seeking areas that are in an abundance of basalt flows and volcanic rock.

Proximity to CO_2 Pipelines

Currently no CO_2 pipelines exist in the Pacific Northwest. While there have been studies, such as the Net Zero America Study conducted by Princeton University[3], proposing the construction of a CO_2 trunk line across all Pacific Northwest states in the coming decade, it is important to note that relying on such a pipeline for CO_2 export would be infeasible for the timeline of this project.

Given the absence of established CO_2 pipelines in the region and the projected timeframe for the development of potential infrastructure, alternative methods for CO_2 management and mitigation should be explored for the purposes of this project.

Permitting Requirements

Potential sites were evaluated for applicable permitting requirements at the federal, state, and local level. **Section 3.7** further outlines applicable permitting and regulatory requirements for development of a renewable fuels production facility in the Pacific Northwest region.

1 Childers, J., Daniels, R., MacLeod, L., Rowe, J., & Walker, C. (2020). Opportunities for Geologic Carbon Sequestration in Washington State. Department of Earth and Space Sciences University of Washington, Seattle. Retrieved from https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/45569/Opportunities%20for%20Carbon%20Sequestration%20in%20Washington.pdf?sequence=1.

2 McGrail, P., Schaef, H., Spane, F. (2016, November 18). ACS Publications, Environmental Science & Technology Letters 4 (1), 6-10. Retrieved from: https://pubs.acs.org/doi/10.1021/acs.estlett.6b00387.

3 Princeton University (2020). Net Zero America. Retrieved from: https://climateinvestigations.org/co2-pipelines-2022-reference-material/.

Community Acceptance

Potential sites were evaluated for their socioeconomic indicators, applying a variety of demographic information. Community acceptance was explored using a supplemental demographic index score composed of various socio-economic factors. The results for each factor were compared to that of the national average to evaluate the vulnerability of each potentially impacted community from construction of a renewable fuels production facility in their communities. Lower supplemental demographic index scores are associated with a lower impact on vulnerability within communities.[4]

Proposed potential sites for construction of a renewable fuels production facility were limited to industrial zones that would not result in land acquisition or increased activity that might induce new off-site development.

Proximity to Landfills

Once all evaluation site locations were confirmed, landfills, waste collections facilities, and disposal services in nearby areas were identified utilizing local City and County websites. Addresses of all waste disposal centers, routes to and from the sites coordinates, and landfills were compiled, measured and evaluated on a per potential site basis.

3.2.3.2. Evaluation Results

In the northwest Washington region, several potential sites have been identified in close proximity to existing refineries. These sites offer ample space and the necessary infrastructure to accommodate a renewable fuels production facility. To optimize logistics and minimize transportation costs, it is recommended that MSW sorting facilities be located at transfer stations or landfills, with only RDF being transported to the facility. Additionally, utilizing the tank farms within the refineries for SAF storage and blending with conventional jet fuel could result in significant cost savings.

Along the I-5 corridor south of the Seattle Metropolitan area, applicable potential sites have been identified and assessed in this study. These sites, including brownfields that meet zoning and infrastructure requirements, show promise for hosting a renewable fuels production facility. Furthermore, some of these sites have the potential for carbon sequestration, adding to their suitability.

Another set of potential site locations evaluated are situated along the Columbia River, spanning southern Washington and northern Oregon. These sites, located near the Roosevelt and Columbia Ridge Landfills, over access to the necessary infrastructure and transportation modes. One notable advantage of these sites is their proximity to renewable energy sources, allowing for sustainable power supply. However, a drawback is the long distance required to ship SAF to potential blending stations or refineries. Due to the one-way operation of petroleum product pipelines from north to south, they cannot be utilized for this purpose. Nonetheless, with access to marine, rail, and road transportation, the most cost-effective and environmentally friendly mode of transportation can be selected for delivering SAF to the desired blending stations.

3.3. End-Products and Their Markets

3.3.1. SAF

Global demand for jet fuel will continue to rise through 2050 and will continue to be met with mostly petroleum-based fuels, according to the U.S. Energy Information Administration's (EIA) International Energy Outlook 2019 (IEO2019).[5] The aviation industry has committed to reducing carbon emissions by 50% from their 2005 level by 2050. Blending lower carbon SAF with fossil jet fuel will be essential to meeting this goal. This is reflected in the IEA's Sustainable Development Scenario (SDS), which anticipates biofuels reaching around 10% of aviation fuel demand by 2030, and close to 20% by 2040.[6]

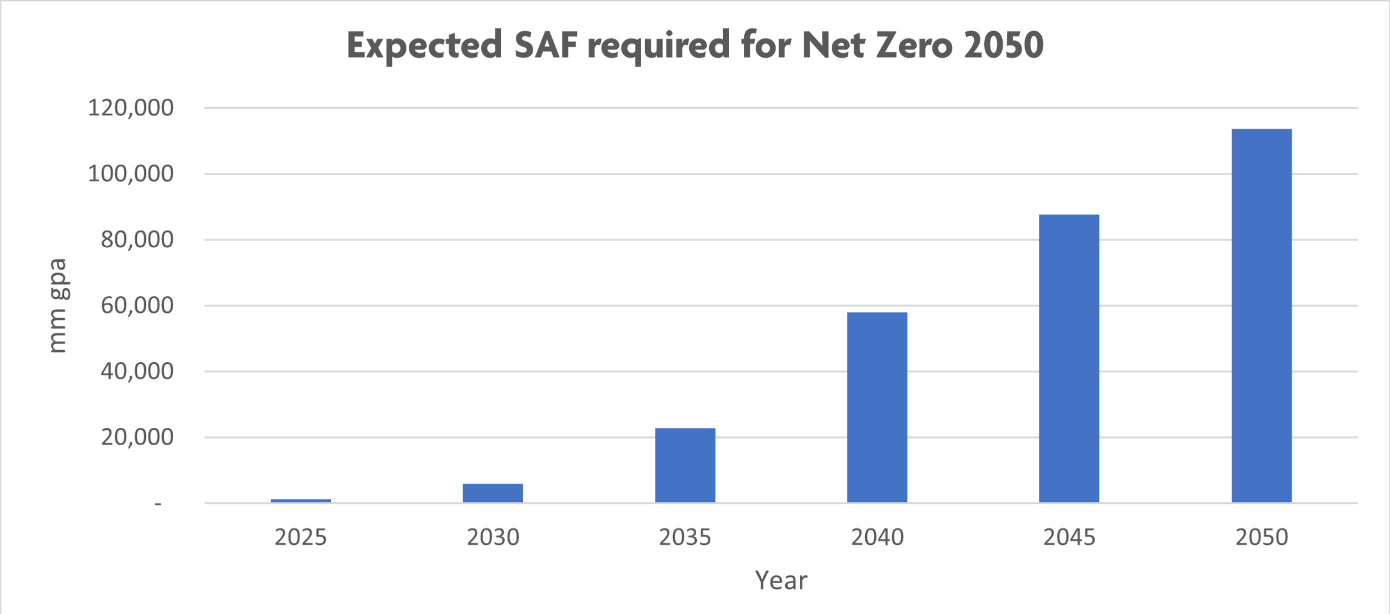
The aviation industry is assessing and testing various options to reach the 2050 goal. Renewable jet fuel (SAF) is the only fuel that can be used immediately to replace fossil fuel based jet fuel, and it will be the largest contributor for the next thirty years. Electric and hydrogen powered planes will only be commercially available in significant numbers from end of the 2030's or later for short range and not before 2050 for long range flights.

According to the International Air Transport Association (IATA), approximately 100 million liters (25 million gallons per year

4 US EPA (2023). EJScreen EPA's Environmental Justice Screening and Mapping Tool (Version 2.11). Retrieved from EPA: https://ejscreen.epa.gov/mapper/.
5 US EIA (2019, November 6). EIA Today in Energy, EIA projects energy consumption in air transportation to increase through 2050. Retrieved from: https://www.eia.gov/todayinenergy/detail.php?id=41913.
6 Pharoah LeFeuvre (2019, March 18). IEA Commentary, Are aviation biofuels ready for takeoff? Retrieved from: https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off.

(mmgpa)) of SAF were produced in 2021, and about 5 billion liters (1,250 mmgpa) of SAF production annually are projected by 2025[7]. IATA estimates that SAF production would need to reach 449 billion liters per year (114,000 mmgpa) by 2050 in order to mitigate the majority of global emissions by the aviation industry, as shown in Figure 3.1.[8]

Figure 3.1 – SAF Development to Reach Net Zero by 2050



Compared to conventional kerosene, SAF makes for a CO2 reduction of up to 80% over the entire lifecycle[9].

The National Renewable Energy Laboratory (NREL) reports in its 2020 Transportation Annual Technology Baseline an alternative jet fuel price at $3.38-$5.63 per gasoline gallon equivalent (gge), and the conventional jet fuel price at $1.95/gge. The EIA reports the annual spot price for kerosene-type jet fuel for the U.S. Gulf Coast region was $1.86/gallon for 2021 (the monthly spot price for Dec 2022 was $2.90/gallon). In February 2022, IATA noted that the price of SAF is "about two and a half times the price of jet kerosene."[10]

Tax incentives of $1.25 - $1.75 per gallon of SAF depending on GHG lifecycle reduction are proposed or announced in BBBA (Build Back Better Act). The Sustainable Aviation Fuel Act and Sustainable Skies Act propose $1.50 up to $2.0 per gallon depending on GHG reduction.

3.3.2. Renewable Diesel

Renewable diesel is a co-product at SAF production, the proportions in the product slate may vary depending on the design and even have a certain flexibility during operations.

The diesel fuel market is growing. For the next ten years, a CAGR of 1% to 4% on global basis is forecasted[11] with the growth being mainly driven by heavy equipment, heavy transportation such as trucks, railroad locomotives, construction equipment, and marine vessels. Electric power and hydrogen are expected to only replace fossil fuels in the long term.

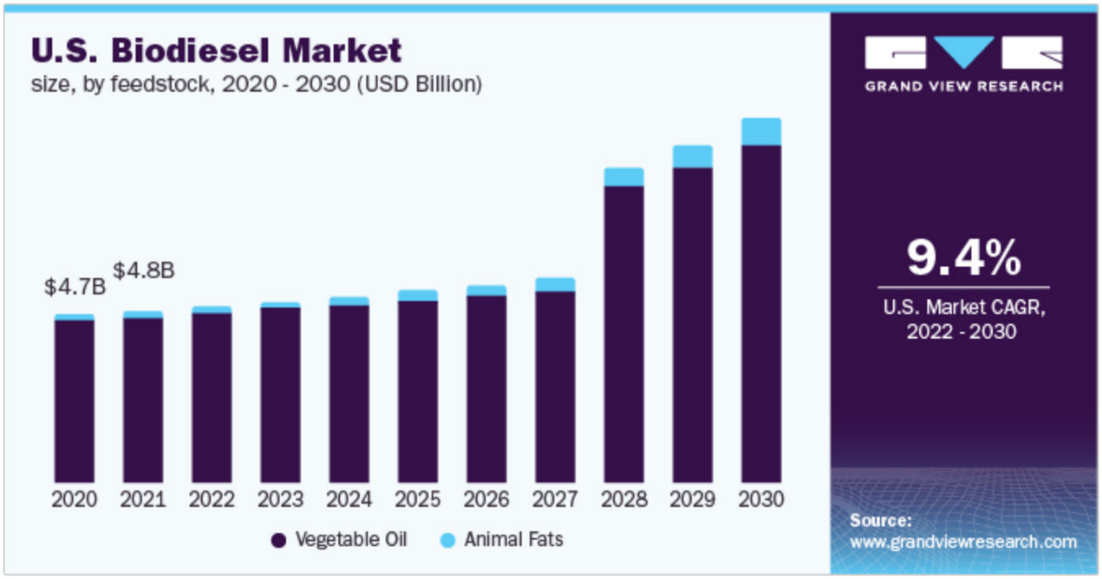
The biodiesel market CAGR is forecasted at 9.4% in 2022 – 2030 timeframe. Biodiesel will mainly be produced from vegetable

7 Chemical Engineering (2022, May). Chemical Engineering, pages 12-20.
8 IATA (2023). IATA Fact Sheet, Net zero 2050: sustainable aviation fuels. Retrieved from: www.iata.org/flynetzero.
9 IATA (2023). IATA Programs and Policy, Developing Sustainable Aviation Fuel. Retrieved from: https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/.
10 Congressional Research Service (2022, July 7). Congressional Research Services, Sustainable Aviation Fuel: In Brief. Retrieved from: https://crsreports.congress.gov/product/pdf/R/R47171/2.
11 Future Market Insights (2023). Future Market Insights, No. 2 Diesel Fuel Market. Retrieved from: https://www.futuremarketinsights.com/reports/no-2-diesel-fuel-market.

oil and animal fats with growing demand for both feedstocks as shown in **Figure 3.2**.[12] The U.S. produced around 1,850 mmgpa biodiesel in 2020.[13] EIA predicts in 2023 biodiesel production in U.S. of 115,000 bpd (1,700 mmgpa)[14].

In the Washington market, renewable diesel as SAF by-product may be blended with conventional diesel at refineries or fuel ground vehicles at airports.

Figure 3.2 – U.S. Biodiesel Market



Global Biodiesel demand stood at 25 million tons in 2020 and is forecast to reach 48.02 million tons by 2030.[15]

The renewable diesel market will be doubling in the next eight to ten years whereas the SAF market is exponentially growing in the next thirty years. Demand for SAF will exceed renewable diesel demand within the next ten to fifteen years resulting in a significant increase in feedstock demand for renewable diesel and SAF production. The food for fuel debate and credit generation in the LCFS program will result in renewable feedstocks such as animal fats, used cooking oil, and distiller's corn oil covering most of the demand increase in renewable diesel and SAF[16]. With increasing demand for renewable feedstocks, sustainable solid waste such as forestry waste and MSW will grow their market share in renewable fuel production.

The average price for diesel in the United States was around 5.3 USD/U.S. gallon in end of 2022.[17].

Commodity merchants and investment firms such as Citadel, Gunvor and Trafigura are bolstering U.S. teams that specialize in trading renewable fuels as demand soars.[18]

3.3.3. Naphtha

Naphtha is a co-product in the Fischer-Tropsch pathway for SAF production with at least 15% in the product slate.

12 Grand View Research (2023). Grand View Research, Biodiesel Market Size, Share & Trends Analysis Report By Feedstock, 2022-2030. Retrieved from: https://www.grandviewresearch.com/industry-analysis/biodiesel-market.
13 US EIA (2023). U.S. Energy Information Administration, Monthly Biodiesel Production Report. Retrieved from: https://www.eia.gov/biofuels/biodiesel/production/.
14 Erin Voegele (2022, January 11). Biodiesel Magazine, EIA predicts US biodiesel production will expand in 2022, 2023. Retrieved from: https://biodieselmagazine.com/articles/2517934/eia-predicts-us-biodiesel-production-will-expand-in-2022-2023.
15 Businesswire (2022, April 21). Businesswire, Global Biodiesel Market Analysis to 2030. Retrieved from: https://www.businesswire.com/news/home/20220421005642/en/Global-Biodiesel-Market-Analysis-to-2030---by-Application-Product-Type-Sales-Channel-and-Region---ResearchAndMarkets.com.
16 Ryan Standard (2022, March 7). Fastmarkets, Renewable diesel margins shrinking on rapidly changing market dynamics. Retrieved from: https://www.fastmarkets.com/insights/renewable-diesel-margins-shrinking-on-rapidly-changing-market-dynamics.
17 MYLPG (2023, January 16). Chart of fuel prices in United States of America, 16 January 2023. Retrieved from: https://www.mylpg.eu/stations/united-states-of-america/prices/.
18 Laura Sanicola and Devika Krishna Kumar (2021, June 21). Reuters, Traders beef up U.S. renewable fuel teams as demand soars. Retrieved from: https://www.reuters.com/business/sustainable-business/traders-beef-up-us-renewable-fuel-teams-demand-soars-2021-06-18/.

Naphtha is a liquid hydrocarbon mixture used as solvent, diluent, and as raw material for conversion to gasoline[19] and chemicals. The growing demand for petrochemicals, like ethylene and propylene for the manufacturing of plastics, is driving the global naphtha market[20].

The naphtha market is expected to grow at a CAGR of between 3.5% and 4.5% over the next ten to fifteen years.

Naphtha is traded at $675 per ton USD as of January 13, 2023. The price closely follows the crude oil price and varied between $400 and $950 in the last ten years. Naphtha can be traded through various trading platforms or directly sold to offtakers or refineries.

3.3.4. LPG

LPG is together with naphtha a co-product in the Fischer-Tropsch pathway for SAF production with at least 5% in the product slate.

LPG is a mixture of propane and butane and used as heating gas in households or for various applications in refineries. In 2022, the average price for LPG in the U.S. varied between 2.5 and 3 US-$ per gallon with short-term peaks exceeding this range[21].

The LPG produced at an SAF facility could also be used as fuel gas replacing natural gas which is used for various operating modes of this facility.

3.3.5. Ethanol

The global ethanol market size was valued at USD 89.1 billion in 2019 and is anticipated to register a compound annual growth rate (CAGR) of 4.8% from 2020 to 2027. The demand for the product is driven by growing usage of the product as a biofuel.[22]

In 2021, U.S. fuel ethanol production (as measured by renewable fuels and oxygenate plant net production of fuel ethanol) equaled about 15 billion gallons (0.4 billion barrels). Fuel ethanol production fell in 2020 mainly because lower overall gasoline demand reduced ethanol blending into motor gasoline. However, continuing a trend since 2010, in 2021, total annual fuel ethanol production exceeded annual fuel ethanol consumption, as measured by the amount that is blended into motor gasoline, by about 1.1 billion gallons. The United States exported about 1.3 billion gallons (29.8 million barrels) of fuel ethanol to at least 87 countries in 2021.[23]

GHG savings are now at the center of interest in the climate change debate whereas they had been a welcome side-effect of the earlier policies. Future technological developments in low-carbon generation of electricity or hydrogen could break the current dominance of renewable fuels in the ground transportation sector.[24] This could make ethanol an attractive feedstock for SAF production. On the production side, the large ethanol production capacity from biomass and the relatively high cost of ethanol produced from MSW is not expected to make MSW derived ethanol competitive without specific incentive programs.

The average U.S. market price for ethanol was fluctuating between 2.00 and 2.88 USD per gallon in 2022 with an average price of around $2.50.[25]

3.3.6. Ethylene

Ethylene is an intermediate product in the ATJ pathway for production of SAF from ethanol.

Ethylene is a base chemical mainly produced by steam cracking of ethane and naphtha. Ethylene is feedstock for polyethylene, ethylene glycol, ethylene oxide, poly vinyl chloride (PVC), polystyrene, and other chemicals. The ethylene market is growing with an expected CAGR of around 4% to 6% during the next decade. The Asia Pacific region is having the largest market share whereas

19 Britannica (2023). Britannica, Science, Naphtha. Retrieved from: https://www.britannica.com/science/naphtha.
20 Data Bridge Market Research (2023). Global Naphtha Market, Industry Trends and Forecasts to 2029. Retrieved from: https://www.databridgemarketresearch.com/reports/global-naphtha-market.
21 MYLPG (2023, January 16). Chart of fuel prices in United States of America, 16 January 2023. Retrieved from: https://www.mylpg.eu/stations/united-states-of-america/prices/.
22 Grand View Research (2023). Ethanol Market Size, Share and Trend Analysis Report. Retrieved from: https://www.grandviewresearch.com/industry-analysis/ethanol-market.
23 U.S. EIA (2023). U.S. Energy Information Administration, Biofuels explained, Ethanol. Retrieved from: https://www.eia.gov/energyexplained/biofuels/ethanol-supply.php.
24 S&P Global Commodity Insights (2023). S&P Global Commodity Insights, Ethanol Market Analysis. Retrieved from: https://www.spglobal.com/commodityinsights/en/ci/products/biofuels-ethanol.html.
25 Trading Economics (2023). Ethanol, Trading Economics. Retrieved from: https://tradingeconomics.com/commodity/ethanol.

the North American market is the fastest growing market for ethylene.

In North America a growing source of ethylene is shale gas production where ethylene is recovered as a by-product which sometimes even led to a surplus of available ethylene in the market. As a result, the market price in the U.S.A is about 30% to 50% lower than elsewhere[26] with a current spot price of around $450 per metric ton of ethylene.

The efforts to produce less carbon intense or even carbon neutral plastics could shift the demand from fossil fuel based ethylene to ethylene derived from renewable sources. According to the U.S. National Renewable Energy Laboratory (NREL), production of ethylene from hydrocarbons is the largest carbon dioxide–emitting process in the chemical industry. Compared to hydrocarbon processes, bioethylene from ethanol reduces carbon dioxide (CO_2) emissions by 70–80%.[27]

3.4. Financial Criteria

3.4.1. Overview

Financial aspects are another pillar for a solid evaluation of conversion technologies to generate renewable fuels besides the technologies and their maturity, feedstock availability, and potential site and logistics considerations. The cost elements used in this high-level cost estimate are derived from the findings of this study.

We estimated a minimum sales price (MSP) for SAF based on capital and operating costs, logistics, waste composition and handling, and financing costs. This is the minimum price, before subsidies and tax incentives, required for SAF to operate a plant profitably. We also conducted a sensitivity analysis to see the impact of changes in the cost factors on the MSP. The results of that analysis are also included in this section.

3.4.2. Design Scenarios

The team developed four scenarios, in which they compared four technical concepts to understand the impact of technology chosen, capacity, and taking additional measures to reduce the carbon intensity on increase in product yield, costs and plot space.

The study evaluates two scenarios which take into consideration the minimum feasible design capacities of the individual process units for the FT and ATJ pathway, and two scenarios for FT and ATJ pathways to produce 25 million gallons per year of SAF. A plant size of 25 million gallons per year SAF capacity is the authors' recommended plant size as it is cost effective, technically feasible and each of the larger landfills can provide sufficient MSW for this capacity. Recently, the State of Washington passed a bill to provide incentives for SAF production plants producing at least 20 million gallons per year of SAF[28] which can be satisfied with a plant having an annual production capacity of 25 million gallons.

- **Scenario 1:** Process plant based on Fischer-Tropsch synthesis and hydro-processing with a capacity similar to the Fulcrum Nevada plant.
- **Scenario 2:** Process plant based on ethanol production followed by the ethanol to jet fuel conversion through the ATJ process. The waste gasification and ethanol synthesis are based on a capacity as built by Enerkem, and the ethanol-to-fuels conversion (ATJ process) for similar capacity will go onstream in the near future.
- **Scenario 3:** Conventional process plant similar to Scenario 1 but scaled-up to a production capacity of 25 million gallons per year of SAF.
- **Scenario 4:** Process plant for 25 million gallons per year capacity with optimized yield and reduced CO_2 emissions. The additional measures include a CO_2 into CO conversion (reverse water gas shift reaction) and additional hydrogen production with the hydrogen produced from renewable energy through water electrolysis. We have based Scenario 4 on the ATJ process as there was some more data available, but the results apply for both process pathways.

Table 3.5 lists the key data for the four scenarios.

26 Business Analytiq (2023, January). Ethylene price index, Business Analytiq. Retrieved from: https://businessanalytiq.com/procurementanalytics/index/ethylene-price-index/.
27 Access Science (2014, January). Ethylene from bioethanol, McGrawHill. Retrieved from: https://www.accessscience.com/content/briefing/aBR0120141.
28 Washington State Legislature. (April 2023) Senate Bill 5447. Retrieved from: https://app.leg.wa.gov/billsummary?BillNumber=5447&Year=2023&Initiative=false.

Table 3.5: Key Data for Four Technical Concepts Assessed in this Study

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Key data	FT pathway RDF: 500 mtpd SAF: 8.6 mmgpa Naphtha + LPG: 2.15 mmgpa	ATJ pathway RDF: 720 mtpd SAF: 12.7 mmgpa Renewable diesel: 1.6 mmgpa	FT pathway RDF: 1,450 mtpd SAF: 25 mmgpa Naphtha + LPG: 6 mmgpa	ATJ pathway RDF: 720 mtpd Hydrogen: 80 mtpd SAF: 25 mmgpa Renewable diesel: 3 mmgpa

Note:

- mtpd - metric tons per day
- mmgpa - million gallons per year
- RDF - Refuse Derived Fuel, the suitable portion of MSW
- SAF - Sustainable Aviation Fuel
- LPG - Liquid Petroleum Fuel, mainly propane and butane

3.4.3. Capital Costs

The capital cost estimates have been developed for the four design scenarios as defined above. They are based on cost information retrieved from publications and websites of SAF producers and vendors, and industry experience. The data were based on various capacities and also published in different years. We have refined the data, scaled them to match the capacities of our scenarios using industry-standard factors of between 0.6 to 0.8 depending on the type of process unit[29], and escalated the cost data to a first quarter 2023 cost level applying the Chemical Engineering Plant Cost Index[30].

The gasifier is the most expensive single item in the plant and the least reliable part. All vendors we talked to recommended selecting a standard mature type and size and for larger capacities using multiple gasifiers in parallel. This would also increase the overall plant availability and finally be more cost efficient even with slightly higher capital costs.

Some cost data for offsites and utilities had to be added based on our own internal database.

The Total Investment Costs (TIC) include project management, license and technology fees, infrastructure, engineering, procurement services, supplies of equipment and materials, civil works, construction, first fill of catalysts and chemicals, commissioning, and start-up.

Owner's cost, legal fees, insurances, cost for land purchase and development, and other non-plant related costs are assumed with 25% of the TIC.

TIC and Owner's cost are summed up to Total Plant Cost (TPC).

The published cost information was either for a complete plant or for a portion of it. Therefore, the authors have chosen to break down the plant into process units and use a top-down approach for each unit. The low degree of project definition at this stage also favors a top-down approach as no details are available about the process, the location, the availability and limitation of utilities, yield maximization, CO_2 capture and sequestration, possibility of modularization, site accessibility, construction strategies,

29 Larry R. Dysert, CCC, Chair, AACE International Technical Board, Sharpen Your Cost Estimating Skills, Cost Engineering Vol.45/No.6, June 2003, retrieved from: https://www.costengineering.eu/images/papers/Sharpen_Your_Cost_Estimating_Skills.pdf.
30 Chemical Engineering (June 2023). Retrieved from: www.chemengonline.com.

and other factors impacting the capital costs.

The Association for the Advancement of Cost Engineering (AACE) International's 18R-97 defines the expected cost accuracy as a function of project delivery level and typical estimating method used, see Table 5.2. A cost estimate with the given project definition is a AACE Class 5 estimate, which defines the accuracy of being in a range of -20 to -50% for the low range and +30 to +100% for the high range.31

Table 3.6: Cost Estimate Classification Matrix

	Primary Characteristic	*Secondary Characteristics*		
Estimate Class	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges[a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgement, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology, availability of applicable reference cost data, and many other risks affect the range markedly. The +/- value represents typical precentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

3.4.4. Operating Costs

The plant consumes various utilities for the process and for buildings such as water, electricity, and natural gas. Water is used as potable water, for cooling, steam production, and possibly hydrogen production via water electrolysis. Electricity and natural gas are also required in higher amounts.

Utility costs are based on cost data retrieved from the Washington State Department of Commerce[32] for electricity and U.S. Energy Information Administration for the Washington natural gas industrial price[33] The model uses the average electricity price of $41.30 per MWh and an average gas price of $10 per 1000 standard cubic feet (scf) of natural gas. The water price is highly dependent on the plant location and potential water source such as public network, river water, other surface water or well water. We have used a water price of 0.2 US-Cents per gallon based on inhouse experience.

Other utilities, chemicals and consumables play a minor role cost-wise and are factored into the total utility costs. Industry experience recommends adding 20% of the utility costs above for these items.

31 AACE International Recommended Practice No. 18R-97, Cost Estimate Classification System – As Applied in Engineering, Procurement and Construction for the Process Industries, 2020.
32 Choose Washington (2023). Washington State Department of Commerce. Retrieved from: http://choosewashingtonstate.com/why-washington/our-strengths/low-cost-energy/
33 US EIA (2023). U.S. Energy Information Administration, Natural Gas. Retrieved from: https://www.eia.gov/dnav/ng/hist/n3035wa3m.htm.

Washington recently introduced a new CO_2 tax based on certificates to be purchased in an auction. We have assumed a medium price of $50 per ton of CO_2 emitted[34].

Annual maintenance costs are typically between 2% and 3% of the Total Investment Costs (TIC) for petrochemical plants. They can go up to 5% for equipment working in highly abrasive or corrosive environments. We have assumed 3% due to the lower maturity and a higher maintenance demand for solid material handling equipment such as MRF's and gasifiers.

3.4.5. Personnel Costs

Appendix 3.C provides details about the assumed staffing requirements for the plant. We have based the staffing requirements and personnel costs on industry experience and information from operators of similar plants.

3.4.6. Feedstock and Products

The feedstock for the renewable fuels production facility is RDF, which refers to the portion of MSW that is suitable for conversion into renewable fuels. In our cost model and cost considerations, waste sorting has been included as part of the fuel production facility. This means that the MSW will be delivered to the facility, sorted on-site, and only the rejected waste will be sent to landfills.

The tipping fees in Washington consist of waste hauling, transfer stations, rail or other waste transportation to landfills and the landfill operations itself.

The model is based on the assumption that the MSW will be delivered free of charge and that the facility receives a tipping fee of $40 per ton of RDF. The rejected waste will be sent to the landfill and the landfill receives their tipping fees per usual.

The plant configurations maximize production of SAF. The MSP as shown in this section is before subsidies and tax incentives. By-products of the SAF production process are renewable diesel, or naphtha and LPG depending on the chosen process. All these by-products can be sold in the market and generate additional revenue. The market development and current sales prices were discussed in the previous **Section 3.4 – End Products and their Markets.** This cost development is based on an average sales price of $4.00 per gallon of naphtha, LPG or renewable diesel.

3.4.7. Transportation and Third-Party Costs and Savings

MSW is shipped to the facility with final products shipped out.

Tipping fees already account for the transportation costs of shipping waste to landfills. In the financial model, the potential renewable fuels production facility is ideally situated near a landfill in the Columbia River region, eliminating the need for additional waste transportation costs. No expenses related to waste transportation are considered unless the plant's capacity increases or a landfill reaches its maximum capacity, requiring the diversion of additional waste. In such cases, rail transportation costs may arise, as outlined in **Section 3.2.2.4 – Logistics and Related Costs.**

Regarding fuel transportation, truck, rail, and barge options are available depending on the facility and blending station locations. Transportation costs can vary significantly and are influenced by market factors and competition rather than actual costs. Per the cost model, rail transportation is selected as the most cost-effective option for fuel transportation.

3.4.8. Financial Parameters and Assumptions

Financing and capital costs constitute the largest portion of the total costs, ranging from 60% to 85%. These costs are crucial in determining a realistic MSP for SAF. It is essential to carefully select and analyze the relevant parameters associated with financing and capital expenses to ensure an accurate assessment of the MSP.

In a typical project financing scheme, the selected approach involves 20% equity and 80% debt. Investors in this scenario expect a return on equity ranging from 12% to above 20%, while for the model being utilized, a return on equity of 15% has been chosen. Debt financing is typically about 1% to 2% above prime rate. Although the current prime rate exceeds 8%, resulting in an interest rate of over 10%, it is anticipated that the interest rate will be lower at the time of financing. The model being employed assumes a debt interest rate of 7% with a 15-year term.

34 Todd Myers, Washington Policy Center, The cost of Washington's new CO2 tax: the bad news and the less bad news, https://www.washingtonpolicy.org/publications/detail/the-cost-of-washingtons-new-co2-tax-the-bad-news-and-the-less-bad-news

3.4.9. Financial Model

A financial model has been developed for the four scenarios. A sensitivity analysis shows the impact of key parameters on price of fuel. **Table 3.7** lists the chosen input parameters and **Table 3.8** shows the capital and operating costs and the resulting minimum sales price for SAF.

Table 3.7 – Input Parameters for Financial Model

Operating time	8000	hours per year
Feedstock	RDF	
Natural gas	10	USD / 1000 scf
Electricity	0.0413	USD / kWh
Water	0.002	USD / gal
CO2 emission tax	50	USD / ton CO2
Revenue for naphtha, LPG and renewable diesel	4	USD/gal
Tipping fees for the facility	40	USD/ton RDF
Debt to Equity ratio	80:20	
Return on equity	15%	per year
Debt interest rate	7%	per year
Debt term	15	years

Table 3.8 – Financial Model Results

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
RDF feed	tons per day	500	720	1,450	720
SAF capacity	mill. gal / year	8.6	12.7	25.0	25.0
Total fuel capacity	mill. gal / year	10.7	14.1	31.3	27.8
Capital costs:					
Total Investment Costs (TIC)	million USD	455	595	1,100	880
Owner's costs	million USD	114	149	275	220
Total Plant Costs (TPC)	million USD	569	744	1375	1100
TPC per gallon per year capacity	**USD/gal a fuel**	**52.9**	**52.7**	**44.0**	**39.6**
Operating costs:					
Natural Gas	USD/gal SAF	0.00	0.03	0.00	0.04
Electricity	USD/gal SAF	0.29	0.28	0.29	2.38
Water	USD/gal SAF	0.02	0.02	0.02	0.02
Other operating costs	USD/gal SAF	0.15	0.15	0.14	0.17
CO_2 emission tax	USD/gal SAF	0.41	0.42	0.41	0.12
Maintenance	USD/gal SAF	1.59	1.41	1.32	1.06

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total operating costs	**USD/gal SAF**	**2.46**	**2.31**	**2.19**	**3.78**
Personnel costs	**USD/gal SAF**	**1.53**	**1.04**	**0.71**	**0.65**
Transportation costs (fuel transportation)	**USD/gal SAF**	**0.10**	**0.10**	**0.11**	**0.11**
Feedstock credit (tipping fees)	**USD/gal SAF**	**-0.78**	**-0.76**	**-0.77**	**-0.38**
Revenue from by-products	**USD/gas SAF**	**-1.00**	**-0.44**	**-1.00**	**-0.44**
Financial costs					
Return on equity	USD/gal SAF	1.98	1.76	1.65	1.32
Debt payments	USD/gal SAF	5.82	5.15	4.84	3.87
Total financial costs	**USD/gal SAF**	**7.80**	**6.91**	**6.49**	**5.19**
Minimum Sales Price (MSP)	**USD/gal**	**10.11**	**9.15**	**7.72**	**8.90**

The EIA reports the current May 2023 spot price for kerosene-type jet fuel for the U.S. Gulf Coast region at 2.25 $/gal after an average price of 3.37 $/gal in 2022[35].

3.4.10. Sensitivity Analysis

A sensitivity analysis was conducted to assess the highest risks and potential cost reductions. A comprehensive comparison can be found in Appendix 3.E. The key findings are summarized below:

Financial Costs, including interest rates and capital payback time, constitute 60% to 85% of the total annual costs, depending on the scenario.

- Changes in financing terms can lead to variations of up to $1 per gallon of SAF compared to the modeled rate.
- Alterations in the return on equity can result in an impact of approximately 50 centers per gallon.

Electricity prices have a significant impact on Scenario 4, primarily due to the high electricity demand for the electrolyzer. The MSP range for this scenario is $4 per gallon, considering electricity costs between 3 cents per kWh and 10 cents per kWh. The price difference for the other scenarios is less than 60 cents per gallon within this range.

Tipping fees received for accepting RDF have a notable influence on the MSP for SAF. The risk on the lower side is up to 80 cents per gallon if no tipping fees are received, while the benefit could be in the same range if the tipping fees increase to $80 per ton instead of the modeled $40 per ton.

The CO_2 tax or the purchase price for CO_2 certificates is projected to increase in the coming years. If no additional measures such as carbon capture and utilization or sequestration (CCUS) are implemented or the yield is not improved with increased CO_2 conversion into fuel, a higher CO_2 tax should be considered. An increase from the current $50 to $100 per ton of CO_2 emitted would result in a 50 cents per gallon increase in fuel costs.

35 US EIA (2023). U.S. Energy Information Administration, Petroleum & Other Liquids. Retrieved from: https://www.eia.gov/dnav/pet/hist/EER_EPJK_PF4_RGC_DPGD.htm.

Transportation cost for fuel account for approximately 1% of the total costs. Truck transportation costs are more than three times higher than rail transportation costs. The sensitivity analysis indicates an impact of around 30 cents per gallon on the MSP if truck transportation or a similarly expensive mode is chosen. Even in a worst-case scenario, transportation costs would not increase the fuel price by more than 50 cents per gallon.

Natural gas prices have minimal impact on the MSP for all four scenarios.

These findings highlight the highest impact factors on potential fuel costs, providing valuable insights into cost management and decision-making for this potential renewable fuels production facility.

3.5. Environmental Constraints

3.5.1. Lifecycle Carbon Emissions

3.5.1.1. LCA Models

MSW as a fuel feedstock has primarily been utilized in rare cases, with a focus on converting waste into alcohols such as methanol or ethanol. There is no well-established model for the determination of the lifecycle GHG emissions for the conversion of MSW into renewable diesel or jet fuel.

In reviewing the models and results for waste-to-fuel systems in literature and other modelling tools, the system boundary of the assessment often includes consideration of the emissions associated with current waste management practices to determine if there is a net increase or decrease in GHG emissions when redirecting wastes to fuel production. This balance depends heavily on what the current waste management practice is (e.g. landfilling, composting, etc.), projections of market changes if the waste is used for bioenergy, and on the fuel conversion process that is used to convert the waste feedstock into energy. As such, the CI of fuels produced from MSW reported in the literature can vary from jurisdiction to jurisdiction, and from pathway to pathway[36] This section explains the two leading models.

The basic formula for both models calculates the CI of SAF by determining the GHG emissions for the production of SAF from waste and the combustion in an aircraft plus secondary processes such as utility supply, transportation and storage. Credit will be given for avoided emissions. Whereas the calculation of production and combustion are very similar in all models, there are significant differences in the credits that shall apply for avoided emissions.

CORSIA[37] assumes the MSW as landfilled waste and follows the methodology described in EPA's Waste Reduction Model (WARM)[38] for landfilled waste. The GHG emission formula does not only include the avoided landfill methane emissions as credit but subtracts from these avoided emission credits those the landfill management would receive for utilization of captured landfill gas for electricity production and for avoided biogenic carbon sequestration as some of the biogenic carbon will not decompose when being buried. Uisung Lee and others of Argonne National Laboratories have applied the CORSIA formula for MSW-to-fuels production and show that the avoided credits for utilization of landfill gas and for avoided carbon sequestration could be higher than those for avoided methane emissions and hence turn the credit negative. This makes the avoided emissions a penalty rather than a credit which could result in even higher carbon intensity factors for jet fuel made from MSW of up to 105 g CO_2e/MJ instead of conventional fossil fuel with 91 g CO_2e/MJ despite utilizing waste with high biogenic carbon content[39].

Canada follows a different approach for the lifecycle emission calculations for waste-to-energy and waste-to-fuels processes. They see the conversion of MSW into fuels as waste recycling and give credit for the avoided landfill methane emissions. They argue that a consequential approach which takes into consideration changes in GHG emissions from second life use such as landfill gas

36 Environment and Climate Change Canada (2023). Fuel LCA Model - Methodology, Environment and Climate Change Canada, Cat. No.: En4-418/2020E-PDF, ISBN: 978-0-660-36531-2. Retrieved from: https://publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2020/eccc/En4-418-2020-eng.pdf.

37 CORSIA. (2022, June). Retrieved from CORSIA Eligible Fuels – Life Cycle Assessment Methodology: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V5.pdf.

38 US EPA (2020 November). US Environmental Protection Agency, Documentation Chapters for Greenhouse Gas Emission, Energy and Economic Factors Used in the Waste Reduction model (WARM). Retrieved from: https://www.epa.gov/warm/documentation-chapters-greenhouse-gas-emission-energy-and-economic-factors-used-waste.

39 Lee, Uisung, Cai Hao, Ou, Longwen, Thatiana, PAhola, Wang, Yixuan, Wang, Michael (2023, January 1). Journal of Cleaner Production, Life cycle analysis of gasification and Fischer-Tropsch conversion of municipal solid waste for transportation fuel production, Journal of Cleaner Production, Volume 382, 135114. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0959652622046881.

capture and utilization or biogenic carbon sequestration would require to use this approach for the whole product life, also for the first life of the waste.[40] However, both CORSIA and Canada's GHGenius[41] do not take into account any carbon footprint prior to waste collection.

WARM also discussed waste recycling as a waste management method. WARM defines recycling as a "process that takes materials or products that are at end of life and transforms them into either (1) the same product (closed-loop) or (2) a secondary product (open-loop)"[42] and provides guidelines for this case. Unfortunately, CORSIA does not follow the recycling pathway but rather the landfill pathway. GREET has not yet published a calculation model for MSW-to jet fuel but an article published recently by Uisung Lee and others of Argonne National Laboratories[43] lets us assume that they tend to follow the CORSIA model.

The above discussion shows the need to develop common rules and to consider the use of MSW as a way of recycling and not landfilling. The consequential approach taken by CORSIA is inconsistent and does not meet the definition in WARM for open-loop recycling. No other feedstock for energy or fuel production will be penalized for missed opportunities for alternative use such as landfill gas capture and utilization or burying biogenic carbon in the ground.

We have not followed CORSIA but the Canadian GHGenius model for our GHG emission calculations, and we encourage all stakeholders to enter into discussions with the authorities to follow the Canadian model and use their approach for the GREET model.

To meet grant and tax incentive requirements in the State of Washington, achieving a GHG emissions reduction of 50% or more typically necessitates the implementation of additional measures such as CCUS. It also involves a more rigorous selection of waste components, preferably focusing on paper and compostables, and other carbon reducing measures in accordance with the CORSIA[44] model.

Fuel production and combustion from MSW, using the current waste composition without additional treatment, exhibits a slightly lower CI compared to that of fossil fuels, ranging from 75 - 80 gCO_2eq/MJ. However, the CI can be significantly reduced by accounting for the credit earned from avoiding landfill gas emissions. CCUS implementation can further reduce the CI achieving a 90% reduction in carbon emissions with potential for a negative CI.

Another study[45] compared the carbon intensity of Fischer-Tropsch and ATJ pathways. The study estimated CI scores of 32.89 g CO_2eq/MJ for FT and 52.88 g CO_2eq/MJ for ATJ crediting a CI for avoided landfill gas emissions, which is more in conformance to this report and the GHGenius model. Their model assumed a lower yield for the ATJ process than what vendors provided for **Task 1** of this study which resulted in the higher CI factor compared to our model.

3.5.1.2. GHG Modeling

This study uses an inhouse developed model for the calculation of the GHG emissions which, as explained above, follows the Canadian LCA model rather than CORSIA. A GREET Model for MSW will not be available until the fall of 2023. The parameters are based on data developed for other tasks of this study; a detailed overview is listed in **Appendix 3.F**. The CI factors in our model may only be used for a first orientation due to the high-level nature of this study.

Tables 3.9, **3.10**, and **3.11** show the CI in g CO_2eq per MJ fuel based on the lower heating value of jet fuel for the three MSW compositions today, future, and zero plastics as defined in Task 2. The lifecycle GHG emissions when using MSW for fuel production would be less than half of those from fossil jet fuel. CCUS would bring additional benefits and credits as it reduces not

40 Environment and Climate Change Canada (2023). Fuel LCA Model - Methodology, Environment and Climate Change Canada, Cat. No.: En4-418/2020E-PDF, ISBN: 978-0-660-36531-2. Retrieved from: https://publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2020/eccc/En4-418-2020-eng.pdf.

41 GHGenius (2023). GHGenius, Squared Consultants. Retrieved from: https://www.ghgenius.ca.

42 US EPA (2020 November). US Environmental Protection Agency, Documentation Chapters for Greenhouse Gas Emission, Energy and Economic Factors Used in in the Waste Reduction model (WARM). Retrieved from: https://www.epa.gov/warm/documentation-chapters-greenhouse-gas-emission-energy-and-economic-factors-used-waste.

43 Lee, Uisung, Cai Hao, Ou, Longwen, Thatiana, PAhola, Wang, Yixuan, Wang, Michael (2023, January 1). Journal of Cleaner Production, Life cycle analysis of gasification and Fischer-Tropsch conversion of municipal solid waste for transportation fuel production, Journal of Cleaner Production, Volume 382, 135114. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0959652622046881.

44 CORSIA Methodology for Calculating Actual Life Cycle Emission Values, ICAO document, June 2022, https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO document 07 - Methodology for Actual Life Cycle Emissions - June 2022.pdf

45 Pooja Suresh, Robert Malina, Mark D. Staples, et al., Life Cycle Greenhouse Gas Emissions and Cost of Production of Diesel and Jet Fuel from Municipal Solid Waste, Environmental Science & Technology 2018, 52, 12055 – 12065.

only the GHG emissions of the non-biogenic carbon but also for sequestering biogenic carbon within the fuel production process. We estimated a potential carbon credit for CCUS of 60 to 80 g CO_2eq/MJ including the energy demand for the CCUS process in case no other CO_2 conversion steps as described in the following **Section 3.6.2** are taken.

Table 3.9 – Carbon Intensity for MSW Composition for 2021

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CI Production	49.73	55.56	49.80	15.87
CI Combustion	25.57	25.57	25.57	25.57
CI Avoided	-35.91	-38.96	-35.94	-19.76
CI Transportation*)	0.9	0.9	0.9	0.9
CI Total	**40.29**	**43.34**	**40.33**	**22.58**

Notes:
*) CI Transportation as per CORSIA[46] recommendation
CI in g CO_2eq/MJ

Table 3.10 – Carbon Intensity for MSW Composition "Future"

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CI Production	37.06	41.41	37.14	11.82
CI Combustion	19.05	19.05	19.05	19.05
CI Avoided	-36.83	-39.69	-36.88	-20.26
CI Transportation*)	0.9	0.9	0.9	0.9
CI Total	**20.18**	**21.68**	**20.21**	**11.51**

Notes:
*) CI Transportation as per CORSIA[47] recommendation
CI in g CO_2eq/MJ

Table 3.11 – Carbon Intensity for MSW Composition "Zero Plastics"

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CI production	11.57	12.94	11.59	3.70
CI combustion	5.95	5.95	5.95	5.95
CI avoided	-49.76	-53.66	-49.82	-27.4
CI transportation*)	0.9	0.9	0.9	0.9
CI total	**-31.34**	**-33.87**	**-31.38**	**-16.85**

Notes:
*) CI Transportation as per CORSIA[48] recommendation
CI in g CO_2eq/MJ

A comparison of the different MSW compositions shows a significant advantage for the carbon intensity of using biogenic carbon-based materials to maximize the avoidance of fossil carbon-based products.

46 CORSIA. (2022, June). Retrieved from CORSIA Eligible Fuels – Life Cycle Assessment Methodology: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V5.pdf.
47 Ibid.
48 CORSIA. (2022, June). Retrieved from CORSIA Eligible Fuels – Life Cycle Assessment Methodology: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V5.pdf.

A future waste strategy has to take into consideration the utilization of waste as feedstock to reduce landfill growth but also the impact of various waste components on carbon intensity.

The model "Zero Plastics" is possibly a very hypothetical case but shows impressively the impact of non-biogenic carbon on the carbon intensity of the fuel.

It should be noted that our model and its results and consequences for future waste compositions are based on using the approach as taken by GHGenius. The results for a CORSIA based model would be totally different, a reduction of GHG emissions of 50% compared to conventional fuel are almost not achievable with MSW due to the high sequestered biogenic carbon content of all wood products (forestry waste, demolition wood, etc.) which would turn the avoided landfill credit negative. Paper and compostables as sole feedstocks would reduce the modelled GHG emissions below the 50% threshold. On the other hand, compostables have a high moisture content and require a lot of energy for an upstream drying process which negatively impacts the carbon balance. In addition, gasification vendors strongly recommended not to use a higher content of compostables or better avoid them at all.

3.5.2. Emission Reduction Strategies

The operation of the renewable fuels production facility will produce emissions that can be influenced by the facility design and sourcing of feedstocks and utilities.

In conventional plant design the CO_2 generated during the solid waste to syngas conversion will be captured from the syngas and emitted into the atmosphere. This CO_2 is not fully carbon neutral because some of the RDF originates from fossil carbon, e.g. plastics or rubber. The CO_2 emissions can be reduced or avoided by utilizing or sequestering the captured CO_2, if there are opportunities for such applications, or by adding low-carbon hydrogen into the process to convert some or all of the CO_2 into carbon monoxide, which can be further converted into fuel.

Avoiding feedstocks with higher CI such as plastics or rubber decreases the carbon intensity of the emissions. On the other hand it increases the amount of solid waste that otherwise would be converted into fuels if the plastics and rubber could not be recycled in another way.

The utilization of electric power from renewable sources could reduce the carbon footprint of a renewable fuels production facility. A water electrolyzer operating with renewable power to produce green hydrogen or electric heaters as substitute for fired heaters are possible applications.

SAF by-products such as renewable LPG or renewable diesel could replace fossil fuels for internal processes and help reducing the overall carbon emissions of the facility.

Heat integration, heat recovery, or high efficiency motors and heaters are some more examples of energy efficiency and lowering carbon emissions.

The carbon intensity of transportation and logistics also has potential for reductions. The site location can be selected to minimize the distances that MSW, RDF and fuels need to be shipped, the mode of transportation and the possibility to use renewable fuels (electric or hydrogen driven trucks or locomotives) or using low carbon fuels such as renewable diesel are some examples.

Renewable power could be used for heating and cooling purposes, and depending on the distance between the facility and urban areas low- or zero emission buses could bring operations personnel to the site.

3.5.3. Contaminants and Their Impacts

MSW contains many materials not suitable for fuel processing. As mentioned in **Task 1**, the first conversion step is the conversion of RDF to syngas. The main components for further fuel production are hydrogen and carbon monoxide. Regular waste contains glass, metals, non-organic and hazardous waste, electronics and other materials that need to be sorted out first and will go into recycling or to a landfill. Wood, paper, plastics and other components which form the RDF contain materials that cannot be separated mechanically and must be removed from the syngas before it enters a catalytic conversion step. Sulfur can be separated and recovered, chlorides and metals will be bound to special adsorbent materials and sent to specialized companies for recovery once the adsorbent material is saturated and replaced. Other materials will be bound and enclosed in the ash coming out of the gasifier and may be used in construction or as filling material as the contaminants are not bleachable in the ash. Syngas purification is a multi-stage process and requires a careful design to avoid contaminants damaging the catalysts and also to get the contaminants out in a form that will not result in additional hazardous waste.

3.6. Permitting, Guidelines & Regulations

Without obtaining the required federal, state, and local permits, and adhering to relevant regulations, development of a renewable fuels production facility will come to a standstill. **Table 3.12** provides a high-level overview of the permits, guidelines, and regulations applicable to this facility.

Table 3.12 - Summary of Relevant Facility Permits

Category	Permit
FEDERAL	
Air	• National Ambient Air Quality Standards (NAAQS) • National Emission Standards for Hazardous Air Pollutants (NESHAPs) • New Source Review (NSR)
Effluent	• National Pollutant Discharge Elimination System (NPDES) permit program
Waterbodies/Marine **Waters/Shoreline + Wetlands**	• Nationwide Permit (NWP) • State Programmatic General Permit (SPGP) • Regional General Permit (RGP)
STATE	
Air	• Air Operating Permit • Notice of Construction Permit • Prevention of Significant Deterioration (PSD) Air Quality Permit
Effluent/Wastewater	• NPDES Permit • State Waste Discharge (SWD) Permits • Reclaimed State Waste Discharge Permit
Industrial Facilities	• Active Water Permits • Active Air Permits • Active Solid Waste Permits • Active Hazardous Waste Permits • Notice of Construction
Runoff/Stormwater	• Industrial Stormwater Permit • Construction of Stormwater General Permit
Wastes/Hazardous Materials	• Storage of Dangerous Waste Permit • Solid Waste Permit
Water	• Water Treatment Plant General Permit • Water Rights Permit

Water Quality	• Water Quality Permit
	  • A. State Waste Discharge Permits
	  • B. National Pollutant Discharge Elimination Systems Permits

Category	Permit
Waterbodies/Marine Waters/Shoreline	• Substantial Development Permits • Hydraulic Project Approval
Wetlands	• Wetlands Permit • Joint Aquatic Resources Permit (JARPA)
Wildlife	• State Species-Specific Action Plans
LOCAL	
Land	• Floordplain Development Permit • Land Use Development Permits • Building Permits
Stormwater/Runoff	• Municipal Stormwater Permit (Depends on individual counties)

3.7. Community Acceptance

This section provides an overview of community acceptance concerns and considerations, with respect to regional and local stakeholders, towards the development of a potential future renewable fuels production facility.

Despite being a component to the permitting process, community acceptance of proposed infrastructure development demands further emphasis with regional focus. Development of a proposed renewable fuels production facility can be rejected for multiple reasons, such as pollution, noise, diminished views (i.e., NIMBY), ecological impacts, safety concerns, and decreased property values. Rejection from a community can delay or even bring a project to a complete standstill. As a result, obtaining community buy-in is essential, and may be referred to as obtaining a 'social license'.

Social license is obtained when a proposed project is sustainable and generates social, environmental, and economic benefits for the community throughout its life. This section outlines a high-level strategy to generate community acceptance and obtain a social license for infrastructure projects, regardless of the location of the proposed site.

3.7.1. Develop a High-Level Site Plan

High-level site plan development for the proposed project defines geographical areas to ensure that future infrastructure development aligns with policy, legal, and institutional frameworks. Once project boundaries and areas of impact are determined, the next step is to obtain baseline data to create a preliminary impact assessment. Examples of baseline data include:

- Natural, critical, or sensitive habitats that could be modified within the project's area of influence, as well as endangered, protected, or threatened species.
- Classifications of land use within the area of influence, land use rights, and land conflict information.
- Land use planning (e.g., proposed developments/infrastructure).
- Current climate impacts and projections, and issues related to climate change that should influence the design/planning.
- Climate resilience (e.g., adaptation measures for vulnerable groups).
- Areas used by stakeholders to generate a livelihood.
- Labor and working conditions.[49]

3.7.1.1. Public Outreach and Stakeholder Coordination

The developer must next identify stakeholder groups (e.g., vulnerable groups such as indigenous communities) and their leaders, develop a relationship with them, and partner to detect and prioritize community concerns and needs. Identifying a community

49 Step-by-Step Guide to Integrating Community Input into Green Infrastructure Projects. © 2018 Environmental Law Institute®, Washington, D.C., and Amigos Bravos, Taos, N.M.

champion could prove beneficial. It is best to engage the community as early as possible to avoid members feeling like the community was only engaged as an afterthought and to create and implement a plan to engage the stakeholders throughout the project. The broader community may also be impacted by the project and should be included in the process (e.g., transport to/from the site may use the roads of surrounding communities). It may prove beneficial to appoint a separate local consultant for stakeholder engagement.

Public involvement and agency involvement processes are initiated to:

- Provide information about the proposed infrastructure development's purpose, need, and potential alternatives.
- Obtain feedback about this information from the public interested in and affected by the proposed infrastructure development.
- Inform those interested in the proposed infrastructure development of project related environmental effects.
- Provide timely public notices to the interested parties so that they may submit comments and participate in public open meetings concerning the proposed infrastructure development.
- Record comments received from interested parties.

3.7.1.2. Public Coordination Early and Often

Local communities should be consulted and engaged with at numerous stages throughout project planning and development to obtain a social license. Conduct a meeting early in the process to obtain stakeholder input before major project decisions are made. Through public notices in local newspapers and flyer hand-outs, project teams may create awareness to upcoming public meetings and garner important, stakeholder turnout. Example locations might include town halls, libraries, community centers, etc. Community champions could also prove invaluable for projects targeting a larger geographic area. The following should be prioritized at public meetings:

- The industrial community should be engaged to determine the stress the project will have on existing infrastructure (e.g., more trucks delivering resources could generate more traffic in an area already heavily burdened). The project should also integrate with existing infrastructure.
- The positive impacts of the project on the community must be communicated. Typical examples include employment opportunities and educational benefits for the local and broader community, such as partnering with a university to conduct research and development (R&D) or testing new technologies).
- The negative impacts of the project on the community must be identified (e.g., unwanted smells, runoff, NIMBY) and strategies to mitigate these impacts.[50]

3.7.1.3. Obtain and Incorporate Community Feedback

Project information should be distributed to the community (e.g., available at libraries and project website) and translated into multiple languages, as appropriate. Incorporating community input into the project includes weighing ideas that compete or analyzing alternatives to reduce or avoid all predicted social and environmental risks, identifying community goals, and determining the path to achieving the goals. Comments made during community input sessions should be clearly addressed. Project descriptions should be succinct and in plain language. They should also clearly indicate how the project will 'give back' to the local community holistically. For example, in exchange for permission to construct the project, the developer might create a playground or contribute funds into an underprivileged school program. Once complete, this facility will require staff, which could lead to employment opportunities for the local community. Regardless of the selected design scenario, the minimum number of permanent staff anticipated is 80. Experience with other industrial facilities shows that such a facility also creates business for adjacent communities, e.g. maintenance workshops, transportation, catering, and accommodation.

Involve the Community in Implementation and Monitoring

The project team may involve the community in project implementation and monitoring, as appropriate and wherever practical. Community members generally require training to do this.

50 Fredl, C., & Reichl, J. (2016). Realizing Energy Infrastructure Projects - A Qualitative Empirical Analysis of Local Practices to Address Social Acceptance . Energy Policy, Volume 89, 184-193.

Community Updates on Project Progress

The project team may update the local community on project developments using different online and virtual platforms. Community updates and engagement are essential to foster the relationships established throughout project planning and development.

3.8. Conclusion

The study has identified three areas in Washington and northern Oregon as potential sites, with a detailed assessment resulting in a shortlist of four parcels in the Columbia River region, including adjacent to the Roosevelt and Columbia Ridge Landfills. Two other promising property locations are near refineries, and one is situated at the Centralia Generator Station in central Washington.

Considering community acceptance, it is crucial to engage all stakeholders and local communities in early project planning processes.

In terms of transportation, rail is the most cost-effective mode for both MSW and fuel. Truck transportation offers greater flexibility but comes with higher costs for longer distances. Utilizing a combination of barge and truck transportation requires additional transloading and intermediate storage facilities, leading to significant cost increases.

Renewable byproducts of SAF production, such as naphtha, LPG, and diesel, already have a strong and growing market demand and are expected to be sold at or above market prices due to their renewable nature.

To be competitive, SAF relies on subsidies and tax incentives. The minimum sales price for SAF, raning from $7.70 to $10 per gallon of jet fuel, is approximately three to four times higher than the current market price of conventional jet fuel.

The accuracy and agreement of the calculation model for lifecycle GHG emissions are crucial for establishing MSW as a renewable source and SAF as a renewable product. This model's results differ significantly among various models and can greatly impact the project's feasibility and level of financial support through subsidies and tax incentives. Therefore, it is important for all relevant stakeholders to agree on the model to be utilized before or at the outset of planning efforts as this may determine the feasibility of the project.

3.9. References

AACE International Recommended Practice No. 18R-97, Cost Estimate Classification System – As Applied in Engineering, Procurement and Construction for the Process Industries, 2020.

Access Science (2014, January). Ethylene from bioethanol, McGrawHill. Retrieved from: https://www.accessscience.com/content/briefing/aBR0120141.

Business Analytiq (2023, January). Ethylene price index, Business Analytiq. Retrieved from: https://businessanalytiq.com/procurementanalytics/index/ethylene-price-index/.

Britannica (2023). Britannica, Science, Naphtha. Retrieved from: https://www.britannica.com/science/naphtha.

Businesswire (2022, April 21). Businesswire, Global Biodiesel Market Analysis to 2030. Retrieved from: https://www.businesswire.com/news/home/20220421005642/en/Global-Biodiesel-Market-Analysis-to-2030---by-Application-Product-Type-Sales-Channel-and-Region---ResearchAndMarkets.com.

Chemical Engineering (2022, May). Chemical Engineering, pages 12-20.

Childers, J., Daniels, R., MacLeod, L., Rowe, J., & Walker, C. (2020). Opportunities for Geologic Carbon Sequestration in Washington State. Department of Earth and Space Sciences University of Washington, Seattle. Retrieved from: https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/45569/Opportunities%20for%20Carbon%20Sequestration%20in%20Washington.pdf?sequence=1.

Chemical Engineering (2023, June). Retrieved from: www.chemengonline.com.

Choose Washington (2023). Washington State Department of Commerce. Retrieved from: http://choosewashingtonstate.com/why-washington/our-strengths/low-cost-energy/.

Congressional Research Service (2022, July 7). Congressional Research Services, Sustainable Aviation Fuel: In Brief. Retrieved from: https://crsreports.congress.gov/product/pdf/R/R47171/2.

CORSIA. (2022, June). Retrieved from CORSIA Eligible Fuels – Life Cycle Assessment Methodology: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V5.pdf.

Data Bridge Market Research (2023). Global Naphtha Market, Industry Trends and Forecasts to 2029. Retrieved from: https://www.databridgemarketresearch.com/reports/global-naphtha-market.

Environment and Climate Change Canada (2023). Fuel LCA Model - Methodology, Environment and Climate Change Canada, Cat. No.: En4-418/2020E-PDF, ISBN: 978-0-660-36531-2. Retrieved from: https://publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2020/eccc/En4-418-2020-eng.pdf.

Fredl, C., & Reichl, J. (2016). Energy Policy, Realizing Energy Infrastructure Projects - A Qualitative Empirical Analysis of Local Practices to Address Social Acceptance. Energy Policy, Volume 89, 184-193.

Future Market Insights (2023). Future Market Insights, No. 2 Diesel Fuel Market. Retrieved from: https://www.futuremarketinsights.com/reports/no-2-diesel-fuel-market.

GHGenius (2023). GHGenius, Squared Consultants. Retrieved from: https://www.ghgenius.ca.

Grand View Research (2023). Grand View Research, Biodiesel Market Size, Share & Trends Analysis Report By Feedstock, 2022-2030. Retrieved from: https://www.grandviewresearch.com/industry-analysis/biodiesel-market.

Grand View Research (2023). Grand View Research, Ethanol Market Size, Share and Trend Analysis Report. Retrieved from: https://www.grandviewresearch.com/industry-analysis/ethanol-market.

Lee, Uisung, Cai Hao, Ou, Longwen, Thatiana, PAhola, Wang, Yixuan, Wang, Michael (2023, January 1). Journal of Cleaner Production, Life cycle analysis of gasification and Fischer-Tropsch conversion of municipal solid waste for transportation fuel production, Journal of Cleaner Production, Volume 382, 135114. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0959652622046881.

IATA (2023). IATA Fact Sheet, Net zero 2050: sustainable aviation fuels. Retrieved from: www.iata.org/flynetzero.

IATA (2023). IATA Programs and Policy, Developing Sustainable Aviation Fuel. Retrieved from: https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/.

McGrail, P., Schaef, H., Spane, F. (2016, November 18). ACS Publications, Environmental Science & Technology Letters 4 (1), 6-10. Retrieved from: https://pubs.acs.org/doi/10.1021/acs.estlett.6b00387.

MYLPG (2023, January 16). Chart of fuel prices in United States of America, 16 January 2023. Retrieved from: https://www.mylpg.eu/stations/united-states-of-america/prices/.

Pooja Suresh, Robert Malina, Mark D. Staples, et al., Life Cycle Greenhouse Gas Emissions and Cost of Production of Diesel and Jet Fuel from Municipal Solid Waste, Environmental Science & Technology 2018, 52, 12055 – 12065.

Princeton University (2020). Net Zero America. Retrieved from: https://climateinvestigations.org/co2-pipelines-2022-reference-material/.

Pharoah LeFeuvre (2019, March 18). IEA Commentary, Are aviation biofuels ready for takeoff? Retrieved from: https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off.

Ryan Standard (2022, March 7). Fastmarkets, Renewable diesel margins shrinking on rapidly changing market dynamics. Retrieved from: https://www.fastmarkets.com/insights/renewable-diesel-margins-shrinking-on-rapidly-changing-market-dynamics.

S&P Global Commodity Insights (2023). S&P Global Commodity Insights, Ethanol Market Analysis. Retrieved from: https://www.spglobal.com/commodityinsights/en/ci/products/biofuels-ethanol.html.

Sanicola, Laura and Krishna Kumar, Devika (2021, June 21). Reuters, Traders beef up U.S. renewable fuel teams as demand soars. Retrieved from: https://www.reuters.com/business/sustainable-business/traders-beef-up-us-renewable-fuel-teams-demand-soars-2021-06-18/.

Sphera (2022). The Consumer Goods Forum. Life Cycle Assessment of Chemical Recycling for Food Grade Film. Retrieved from: www.theconsumergoodsforum.com/wp-content/uploads/2022/04/life-cycle-assessment-of-chemical-recycling-for-food-grade-film.pdf.

Step-by-Step Guide to Integrating Community Input into Green Infrastructure Projects. © 2018 Environmental Law Institute®, Washington, D.C., and Amigos Bravos, Taos, N.M.

Suresh, Pooja, Malina, Robert, Staples Mark D., et al. (2018) Environmental Science & Technology, Life Cycle Greenhouse Gas Emissions and Cost of Production of Diesel and Jet Fuel from Municipal Solid Waste, Volume 52, 12055 – 12065.

Trading Economics (2023). Ethanol, Trading Economics. Retrieved from: https://tradingeconomics.com/commodity/ethanol.

US EIA (2023). U.S. Energy Information Administration, Biofuels explained, Ethanol. Retrieved from: https://www.eia.gov/energyexplained/biofuels/ethanol-supply.php.

US EIA (2023). U.S. Energy Information Administration, Monthly Biodiesel Production Report. Retrieved from: https://www.eia.gov/biofuels/biodiesel/production/.

US EIA (2023). U.S. Energy Information Administration, Natural Gas. Retrieved from: https://www.eia.gov/dnav/ng/hist/n3035wa3m.htm.

US EIA (2023). U.S. Energy Information Administration, Petroleum & Other Liquids. Retrieved from: https://www.eia.gov/dnav/pet/hist/EER_EPJK_PF4_RGC_DPGD.htm.

US EIA (2019, November 6). U.S. Energy Information Administration, EIA Today in Energy, EIA projects energy consumption in air transportation to increase through 2050. Retrieved from: https://www.eia.gov/todayinenergy/detail.php?id=41913.

US EPA (2023). EJScreen EPA's Environmental Justice Screening and Mapping Tool (Version 2.11). Retrieved from EPA: https://ejscreen.epa.gov/mapper/.

US EPA (2020, November). US Environmental Protection Agency, Documentation Chapters for Greenhouse Gas Emission, Energy and Economic Factors Used in the Waste Reduction model (WARM). Retrieved from: https://www.epa.gov/warm/documentation-chapters-greenhouse-gas-emission-energy-and-economic-factors-used-waste.

Voegele, Erin (2022, January 11). Biodiesel Magazine, EIA predicts US biodiesel production will expand in 2022, 2023. Retrieved from: https://biodieselmagazine.com/articles/2517934/eia-predicts-us-biodiesel-production-will-expand-in-2022-2023.

Washington State Legislature. (April 2023) Senate Bill 5447. Retrieved from: https://app.leg.wa.gov/billsummary?BillNumber=5447&Year=2023&Initiative=false.

Zhou, P., Simons, J., Wallach, T., Youngman, J. (2022, May 16). McKinsey, Advanced recycling: Opportunities for growth. Retrieved from: www.mckinsey.com/industries/chemicals/our-insights/advanced-recycling-opportunities-for-growth.

EXP | 451 Montgomery Street, Suite 300 | San Francisco, CA 94104
t: +1. 954.999.8292

exp.com

A

TASK 3 – APPENDIX A | PERMITTING, GUIDELINES, AND REGULATIONS

Task 3 - Appendix A | Permitting, Guidelines, and Regulations

This Appendix supports section **3.7 – Permitting, Guidelines & Regulations** and provides relevant permitting, guidelines and regulations to review/adhere to for development of a renewable fuel production facility in the identified regions evaluated in the Task 3 Report.

3.A.1. Federal Level

3.A.1.1. Air

The United States Environmental Protection Agency (US EPA) is the agency with the authority to implement the Clean Air Act (CAA), which identifies hazardous pollutants and limits pollutants from facilities. Under the CAA:

- The National Ambient Air Quality Standards (NAAQS) regulates lead, carbon monoxide, ozone, particulate matter, nitrogen dioxide, and sulfur dioxide.
- The National Emission Standards for Hazardous Air Pollutants (NESHAPs) outlines emission standards for hazardous air pollutants.
- The New Source Review (NSR) forms a pre-construction review process for new and modified stationary emissions sources.

3.A.1.2. Effluent

Effluent guidelines are national wastewater discharge standards that are developed by EPA on an industry-by-industry basis. Direct dischargers to a water body are subject to the National Pollutant Discharge Elimination System (NPDES) permit program under the Clean Water Act (CWA). Indirect dischargers to a municipal treatment plant (publicly owned treatment works) fall under the Pretreatment Program. NPDES permits are issued by States and EPA regional offices. The EPA issues NPDES permits on tribal lands and in federal waters off the coast but has delegated authority to issue other NPDES permits to the Washington Department of Ecology and the Oregon Department of Environmental Quality (ODEQ).[1]

3.A.1.3. Energy

The Energy Policy Act regulates country wide energy production across various sources, such as renewable energy, energy efficiency, coal, oil, gas, tribal energy, climate change technology, etc. The Energy Independence and Security Act strives to achieve objectives such as greater energy independence in the US, increased production of clean renewable fuel, promote research on and the deployment of GHG capture, etc.

3.A.1.4. GHG

The US EPA created an Application Tool to determine whether it is mandatory for a facility to report GHGs through the Greenhouse Gas Reporting Programs (GHGRP). The agency also determines regulations for Greenhouse Gas Emissions from Aircraft, Regulations for Emissions from Aircraft Engines, and Regulations for Lead Emissions from Aircraft +C12, and the Renewable Fuel Standard Regulation.

3.A.1.5. Historic Resources

Under the National Historic Preservation Act 36 CFR 60, 61 and the Archaeological Resource Protection Act, developers should do a due diligence review of potential facility locations to confirm if heritage sites will be impacted.

3.A.1.6. Stormwater

The US EPA developed the Industrial Stormwater Pollution Prevention Plan Guide which should be considered during the facility design to provide guidance for managing stormwater within industrial facilities.

3.A.1.7. Waste

This facility may be influenced by the Universal Waste Program, Resource Conservation and Recovery Act (RCRA), and Solid Waste Act.

1 NPDES Permit Basics. (2022, December 23). Retrieved from EPA United States Environmental Protection Agency : https://www.epa.gov/npdes/npdes-permit-basics

3.A.1.8. Waterbodies/Marine Waters/Shoreline + Wetlands

US Army Corps of Engineers (USACE) regulates discharges of dredged or fill material into waters of the United States under section 404 of the CWA and the construction of any structures in or over navigable waters of the United States, and section 10 of the Rivers and Harbors Act of 1899. Section 10 permits are required for structures (such as wharfs, breakwaters, piers, weirs, jetties, bulkheads, and transmission lines) and work that includes dredging or disposing of dredged material. It also includes other modifications to navigable waters of the US, including excavating and filling.[2] Also under section 404 of the CWA, the Nationwide Permit (NWP) NWPs authorize work in streams, wetlands and other waters of the country. Finally, the State Programmatic General Permit (SPGP) Regional General Permit (RGP) may require the project to apply for permit in Lewis County if project activities are within the boundary of Regional General Permit (RGP) No. 9 Port of Chehalis Industrial Developments in Lewis County, Washington.

3.A.1.9. Wildlife/Fisheries

The National Oceanic and Atmospheric Administration (NOAA) Fisheries is the agency enforcing the Endangered Species Act (ESA) Section 7, which requires the NOAA to be consulted when the habitat of an ESA listed marine or anadromous species is affected by a project.

3.A.2. State Level

3.A.2.1. Air

A. **Air Operating Permit:** Issued in Washington by Ecology and other clean air agencies, air operating permits apply to industrial and commercial buildings that emit copious amounts of air pollution. The permit lists all air pollution requirements applicable to industry or businesses in a mater document.[3]

B. **Notice of Construction Permit:** These are issued to ensure that Washington adheres to state and federal air quality requirements.[4]

C. **Prevention of Significant Deterioration (PSD) Air Quality Permit**: This “applies to new, large facilities or changes at existing large facilities that could increase air pollution. It is a “pre-construction” permit because the owner must get the permit before starting construction of the proposed project. Any major change to an existing facility also requires a PSD permit.”[5]

3.A.2.2. Biophysical

The State Environmental Policy Act (SEPA) Environmental Review required for any proposal which involves a government ‘action’ as defined in the SEPA Rules (WAC 197-11-704) and is not categorically exempt (WAC 197-11-800 through 890). SEPA Checklist completed to determine whether a proposals impacts are likely to be significant. This helps to determine if an applicant can put measures in place to avoid, minimize, or counter adverse effects, whether compensatory mitigation measures can offset significant impacts, if an Environmental Impact Statement (EIS) needs to be prepared for further analysis.

3.A.2.3. Clean Fuel

The Clean Fuel Standard may influence the product from this facility. The Renewable Portfolio Standard and Renewable Energy Certificates may be applicable if electricity is produced on site using the landfill gas.

---

2 Rivers and Harbors Act. (2022, August 09). Retrieved from In Port: https://www.fisheries.noaa.gov/inport/item/59646

3 Air operating permit for large sources of air pollution. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Air-Quality-permits/Air-operating-permits

4 Notice of construction permit. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Air-Quality-permits/Notice-of-Construction-permit

5 Prevention of Significant Deterioration (PSD) permit. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Air-Quality-permits/Prevention-of-Significant-Deterioration-PSD

3.A.2.4. Effluent/Wastewater

A. **NPDES Permit:** As discussed at the Federal level, this permit is issued by States. It falls under the State Water Pollution Control Law Chapter 90.48 RCW and Federal Water Pollution Control Act Title 33 USC, Section 1342 et seq.

B. **State Waste Discharge (SWD) Permits:** Aimed at regulating discharges from municipalities/industries to groundwater.[6]

C. **Reclaimed State Waste Discharge Permit**: Parts of the Reclaimed Water Use Act, the permit is issued at the state level.

3.A.2.5. GHG

The Climate Commitment Act could require the facility to report GHGs based on final facility emissions, if the facility meets the following conditions:

- Facilities that emit at least 10,000 metric tons of carbon dioxide equivalent (MT CO_2e) per year of total GHG emissions in Washington.
- Fuel suppliers that produce, import, or deliver products equivalent to 10,000 MT CO_2e of total GHG emissions per year in Washington.
- Electric power entities (EPEs) that import or deliver electricity equivalent to 10,000 MT CO_2e or more per year of total GHG emissions in Washington.

The facility must also adhere to the Energy efficiency standards determined by the Oregon Department of Energy (ODOE).

3.A.2.6. Industrial Facility

Industrial Facility Permits and Regulations consist of multiple permits, some of which have already been discussed:

- Active Water Permits
- Active Air Permits
- Active Solid Waste Permits
- Active Hazardous Waste Permits
- Notice of construction – Discussed above[7]

The ODOE and Energy Siting Council have developed a public guide. The facility may have to adhere to General Standard for Siting Facilities (OAR 345-022), Local Land Use Planning and Siting Facilities (ORS Chapter 215) and Site Certificates.

3.A.2.7. Historic Resources

The Washington State Department of Archaeology and Historic Preservation (DAHP) is the agency overseeing the National Historic Preservation Act.

3.A.2.8. Noise

Under the WDOE, the Noise Control Act Chapter 70.107 RCW, Sound Level Measurement Procedures Chapter 173-58 WAC, and Maximum Environmental Noise Levels Chapter 173-60-WAC will ensure that the project does not exceed maximum environmental noise levels.

3.A.2.9. Previous Contamination

Model Toxics Control Act (MTCA) - Reporting Requirements for Contaminated Sites and Releases. This requirement is determined based on the site selection.

6 Water quality permits. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-quality-permits

7 WA Ecology Industrial Section Permits. (n.d.). Retrieved from Department of Ecology: https://fortress.wa.gov/ecy/industrial/Default.aspx

3.A.2.10. Runoff/Stormwater

- **Industrial Stormwater Permit** – Associated with the NPDES and State Waste Discharge General Permit[8]
- **Construction Stormwater General Permit**

3.A.2.11. Water Quality

Water Quality Permit: "If a municipality or commercial industry releases wastewater into state or federal waters (groundwater or surface water), they must obtain a permit. The permit you need depends on what is in the water you are producing (discharge characteristics) and what water source is receiving it (receiving waters)."[9]

Types of permits:

- **State Waste Discharge Permits**
- **National Pollutant Discharge Elimination System permits**

3.A.2.12. Waterbodies/Marine Waters/Shoreline

The Shoreline Management Act, Shoreline Master Programs, Shorelines of Statewide Significance result in the Substantial Development Permits and Hydraulic Project Approval, depending on the final project location in proximity to a body of water.

Substantial development permits

Key definitions:

- "**Development** means a use consisting of the construction or exterior alteration of structures; dredging; drilling; dumping; filling; removal of any sand, gravel, or minerals; bulkheading; driving of piling; placing of obstructions; or any project of a permanent or temporary nature which interferes with the normal public use of the surface of the waters overlying lands subject to this chapter at any state of water level. (RCW 90.58.030)
- **Substantial development**" means any development of which the total cost or fair market value exceeds the dollar threshold (currently $8,504), or any development which materially interferes with the normal public use of the water or shorelines of the state. (RCW 90.58.030)"[10]

3.A.2.13. Wetlands

- **Wetlands Permit**
- **Joint Aquatic Resources Permit** (JARPA)

3.A.2.14. Wildlife

Through the Oregon Natural Resources and Renewable Energy, Department of Land Conservation and Development, the facility may be subject to Endangered Species Act (Federal) State Species-Specific Action Plans.

3.A.2.15. Hazardous Materials/Wastes

- **Storage of Dangerous Waste Permit**

Only facilities with that have received this permit are allowed to: treat the dangerous waste of other businesses; store it on a long-term basis; or dispose of the waste by burning or burying it. The businesses that receive the permit are often called 'Treatment, Storage, Disposal, or Recycling Facilities' (TSDs or TSDRs). The Department of Ecology State of Washington is authorized by the EPA to administer this permitting process for the state.[11] This permit is under the Hazardous Waste Management Act.

8 Fact Sheet. (2019). Washington State Department of Ecology.
9 Water quality permits. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-quality-permits
10 Shoreline permits & enforcement. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Shoreline-permits-enforcement
11 Dangerous waste permits. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Dangerous-waste-permits

- **Solid Waste Permit**

This adheres to the Solid Waste Handling Standards.

3.A.2.16. Water

- **Water Treatment Plant General Permit**
- **Water Rights Permit:** Required if a facility plans to use any amount of surface water obtained for any purpose obtained from a lake, stream, spring, or river, or groundwater obtained from a well for any purpose.[12]

3.A.3. Local Level - County/Municipal/City

3.A.3.1. Biophysical

State or local agencies will ensure compliance with SEPA.

3.A.3.2. Land

- **Floodplain Development Permit**
- **Land Use Development Permits**
- **Building Permits**

3.A.3.3. Landfills

King County has the following that must be considered: Waste Acceptance Rule, Waste Clearance Policy, Solid Waste Code, Solid Waste Disposal Facility Siting, Title 10 Board of Health Solid Waste Regulations.

3.A.3.4. Waterbodies/Marine Waters/Shoreline

Individual counties have their own Shoreline Master Programs that must be followed.

3.A.3.5. Stormwater/Runoff

Municipal Stormwater Permit depends on individual counties.

3.A.3.6. Waste

- Skagit County (Washington): Chapter 35.21 RCW, Cities and Towns
- 36.58 RCW, Solid Waste Disposal
- 6.58A RCW, Solid Waste Collection Districts

12 Water rights. (n.d.). Retrieved from Department of Ecology State of Washington: https://ecology.wa.gov/Water-Shorelines/Water-supply/Water-rights

B

TASK 3 – APPENDIX B | METHOD(S) OF DELIVERY TO THE FACILITY AND OTHER ROUTE OPPORTUNITIES TO MAXIMIZE DESIRED OPPORTUNITIES

Task 3 - Appendix B | Method(s) of Delivery of MSW to the Facility and Other Route Opportunities to Maximize Desired Opportunities

This Appendix supports **Section 3.3.2.4 – Logistics and Related Costs.** The team conducted a study based on the routing pairs and transportation modes in **Table 3B.1** below to identify the costs associated with routing as many as four different types of traffic between various origins and destinations. The transportation mode was assumed to be either rail or barge however barge transportation relies on some trucking in all instances to move materials from origin to destination as further explained in the barge section below.

Table 3B.1: Traffic Type, Routing Pairs and Transport Modes Analyzed

Type	Condition	From	To	By	Metric Tons Per Day	40-Foot Containers Per Day
MSW	Solid	King County	Roosevelt Landfill	Rail	1,000 / 1,440 / 4,000	42 / 61 / 170
MSW	Solid	King County	Columbia Ridge Landfill	Rail	1,000 / 1,440 / 4,000	42 / 61 / 170
MSW	Solid	King County	Centralia Generator Station	Rail	1,000 / 1,440 / 4,000	42 / 61 / 170
RDF	Solid	Centralia Generator Station	Columbia Ridge Landfill	Rail	500 / 720 / 2,000	21 / 31 / 42
Type	**Condition**	**From**	**To**	**By**	**Barrels Per Day**	**Pounds Per Hour**
Ethanol	Liquid, Flammable	Columbia Ridge Landfill	BP Cherry Point Refinery	Rail	1,836 / 3,673	21,150 / 42,300
Ethanol	Liquid, Flammable	Columbia Ridge Landfill	BP Cherry Point Refinery	Barge	1,836 / 3,673	21,150 / 42,300
Ethanol	Liquid, Flammable	Columbia Ridge Landfill	Harbor Island	Barge	1,836 / 3,673	21,150 / 42,300
Ethanol	Liquid, Flammable	Columbia Ridge Landfill	Renton Terminal	Rail	1,836 / 3,673	21,150 / 42,300
SAF	Liquid, Flammable	Columbia Ridge Landfill	BP Cherry Point Refinery	Rail	530 / 1,000 / 1,900 / 2,100	6,270 / 11,830 / 22,476 / 24,842
SAF	Liquid, Flammable	Columbia Ridge Landfill	BP Cherry Point Refinery	Barge	530 / 1,000 / 1,900 / 2,100	6,270 / 11,830 / 22,476 / 24,842
SAF	Liquid, Flammable	Columbia Ridge Landfill	Harbor Island	Barge	530 / 1,000 / 1,900 / 2,100	6,270 / 11,830 / 22,476 / 24,842
SAF	Liquid, Flammable	Columbia Ridge Landfill	Renton Terminal	Rail	530 / 1,000 / 1,900 / 2,100	6,270 / 11,830 / 22,476 / 24,842

Rail transportation with its private rights-of-way presents a very different competitive environment than does trucking or water carriage which utilize public highways and waterways. In addition, railroad rates are designed to yield whatever the market will bear. The rail carrier pricing calculus considers the costs incurred in providing transportation, the market value of the commodity to be transported and competitive transport options, with the first serving as a floor while most of the evaluation hinges on the last.

As a result, shippers or receivers of high volume, low value bulk commodities such as MSW and the other two commodities contemplated by the Port of Seattle are well advised to take a strategic approach to potential contracting with railroads. The Port, or for that matter, any prospective railroad customer, must recognize that there exists a window of opportunity which, if seized, can impact future cash flows significantly over the entire economic life of a plant it operates or develops. Once the window of opportunity closes, any railroad customer's leverage to negotiate will decline significantly while that of its serving railroad(s) will increase. In the paragraphs that follow, amounts expressed in the context of rail and barge transportation are best understood as potential prices to the Port, not costs to the carriers since rail lines in this country are not subject to open access. As a result, intramodal competition is very limited and prices can exceed costs to the extent allowed under regulations, which are rather lenient. That said, truck and barge operations tend to be open access, with lower barriers to entry and thus lower prices, especially for shorter hauls like those reviewed in this study.

3.B.1. MSW Rail Transportation

The City of Seattle does or has moved MSW from railyards owned by Union Pacific and BNSF to points south. This study reflects the assumption that those flows would continue and be utilized with the purpose of converting MSW to ethanol or SAF. Three, primary routes were identified to move MSW from the King County Rail yards to either Roosevelt Landfill, Columbia Ridge Landfill directly or Columbia Ridge Landfill via the Centralia Generator Station. Rail transportation economics is best characterized as featuring high fixed costs and low variable costs. As such, the greater the volume, the less the cost per car. In addition, because competition in the rail industry can be limited, greater cost savings are found where more than one railroad can be used.

The tonnage and container volumes listed in **Table 3B.1** above were utilized along with waybill data samples from a third-party aggregator who collects them from the railroads to derive a total cost to move MSW across each of the three, primary routes. Utilizing the metric tons and containers per day results in 24 tons of MSW per container/car. Prices for 42/61/170 containers/cars per day are illustrated below. As discussed above, there is significant cost savings associated with increased volumes moved per day. A competitive (meaning the county can easily change from BNSF to UP or vice versa) and non-competitive (meaning the county is beholden to one rail carrier) are also listed to provide a range of possible outcomes. The results of each analysis are listed below.

Table 3B.2: Estimated Charges of Moving MSW in Containers Between King County and Roosevelt Landfill via Rail Transportation at Various Volumes

Units	Tons/Car	Segment	Comp. Total Rev./car ($)	Non-Comp. Total Rev./car ($)	TOTAL Comp. Cost ($)	TOTAL Non-Comp. Cost ($)
42	24	BNSF	831.06	1054.87	34,904.52	44,304.54
61	24	BNSF	688.74	885.17	42,013.14	53,995.37
170	24	BNSF	552.88	710.57	93,989.60	120,796.90

Total charge per day ranges from $35,000 to $121,000. A seven days per week operation would result in annual costs of between $13,000,000 and $44,000,000.

Table 3B.3: Estimated Charges of Moving MSW in Containers between King County and Columbia Ridge Landfill via Rail Transportation at Various Volumes

Units	Tons/Car	Segment	Comp. Total Rev./car ($)	Non-Comp. Total Rev./car ($)	TOTAL Comp. Cost ($)	TOTAL Non-Comp. Cost ($)
42	24	UP	822.86	1044.17	34,560.12	43,855.14
61	24	UP	669.46	860.4	40,837.06	52,484.40
170	24	UP	559.57	719.16	95,126.90	122,257.20

Total charges per day range from $35,000 to $122,000. A seven days per week operation would result in annual costs of between $13,000 and $44,000.

Table 3B.4: Estimated Charges of Moving MSW in Containers between King County and Centralia Generating Station via Rail Transportation at Various Volumes

Units	Tons/Car	Segment	Comp. Total Rev./car ($)	Non-Comp. Total Rev./car ($)	TOTAL Comp. Total Rev. ($)	Non-Comp. TOTAL Rev. ($)	TOTAL Joint Cost ($)
42	24	UP	411.38	524.85	17,277.96	22,043.70	
42	24	BNSF	375.96	479.22	15,790.32	20,127.24	42,170.94
61	24	UP	297.89	382.85	18,171.29	23,353.85	
61	24	BNSF	272.75	350.53	16,637.75	21,382.33	44,736.18
170	24	UP	266.1	341.99	45,237.00	58,138.30	
170	24	BNSF	231.91	298.06	39,424.70	50,670.20	108,808.50

Transportation from King County to Centralia Generator Station requires movement across both BNSF and UP. The total estimated charges associated with each pairing is located in the far right column under the heading "TOTAL Joint Cost." The accompanying move from Centralia to Columbia Ridge Landfill did not have any history of waybill data, likely meaning this is not a route the railroads serve. If they did, charges would likely be significant and would be in addition to the Total Joint Costs listed above which are on par with direct moves between King County and the Roosevelt or Columbia Ridge Landfills.

3.B.2. Ethanol Rail Transportation

Once MSW reaches either the Roosevelt or Columbia Ridge Landfills, it will be converted into either ethanol or SAF. These intermediate products will then be transported from the landfills to BP Cherry Point or Renton Terminal (if transported by rail). This section shows the potential charges associated with transporting ethanol from Columbia Ridge Landfill to either BP Cherry Point or Renton Terminal. **Table 3B.1** lists volume goals of between 1,836 and 3,673 barrels per day. This translates into between 3 and 5 railcars per day. The prices listed below are estimates of the prices that need to be paid to transport 3 - 5 cars per day but: 1) pricing may decrease if volumes are able to move less frequently (i.e. – move 6-10 cars every other day) and 2) depending on the railroads' operations, they may only serve the facility only 1 - 3 times per week.

Table 3B.5: Estimated Charges of Moving MSW in Containers between the Columbia Ridge Landfill and BP Cherry Point via Rail Transportation at Various Volumes

Units	Tons/Car	Segment	Comp. Total Rev./car ($)	Non-Comp. Total Rev./car ($)	TOTAL Comp. Total Rev. ($)	TOTAL Non-Comp. Total Rev. ($)
3	85	Total	2,140.00	3,096.35	5,778.00	8,360.15
5	85	Total	2,138.30	3,093.85	11,549.96	16,711.34

The estimated total cost per day ranges from about $6,000 to $17,000. A seven days per week operation would result in annual costs of between $2,100,000 and $6,100,000.

Table 3B.6: Estimated Charges of Moving Ethanol in Containers between the Columbia Ridge Landfill and Renton Terminal via Rail Transportation at Various Volumes

Units	Tons/Car	Segment	Comp. Total Rev./car ($)	Non-Comp. Total Rev./car ($)	TOTAL Comp. Total Rev. ($)	TOTAL Non-Comp. Total Rev. ($)
3	85	Total	1,691.75	2,449.32	4,567.73	6,613.16
5	85	Total	1,690.05	2,446.82	9,128.76	13,216.43

The estimated total charge per day ranges from about $5,000 to $13,000. A seven days per week operation, would result in annual costs of between $1,700,000 and $4,800,000.

3.B.3. SAF Rail Transportation

The same caveats described in the first paragraph in connection with Ethanol Rail Transportation apply to SAF as well. One to three railcars per day would hold the desired barrels of SAF required by the operation. While the prices below reflect daily service, costs may decrease if volumes are able to move less frequently (i.e. – move 6-10 cars every other day) and, depending on the railroad's operations, they may only serve the facility 1-3 times per week.

Table 3B.7: Estimated Charges of Moving SAF in Containers between the Columbia Ridge Landfill and BP Cherry Point via Rail Transportation at Various Volumes

Units	Tons/Car	Segment	Comp. Total Rev./car ($)	Non-Comp. Total Rev./car ($)	TOTAL Comp. Total Rev. ($)	TOTAL Non-Comp. Total Rev. ($)
1	85	Total	2,352.30	3,163.18	2,352.30	3,163.18
3	85	Total	1,876.31	2,618.10	5,628.93	7,854.30

The estimated total charge per day ranges from about $2,500 to $8,000. A seven days per week operation would result in annual costs of between $800,000 and $2,900,000.

Table 3B.8: Estimated Charges of Moving SAF in Containers between the Columbia Ridge Landfill and Renton Terminal via Rail Transportation at Various Volumes

Units	Tons/Car	Segment	Comp. Total Rev./car ($)	Non-Comp. Total Rev./car ($)	TOTAL Comp. Total Rev. ($)	TOTAL Non-Comp. Total Rev. ($)
1	85	Total	1,958.87	2,615.57	1,958.87	2,615.57
3	85	Total	1,482.88	2,070.49	4,448.64	6,211.47

The estimated total charge per day ranges from about $2,000 to $6,200. A seven days per week operation would result in annual costs of between $700,000 and $2,300,000.

3.B.4. Barge Transportation Summary

Barge transportation options listed in **Table 3B.1** were analyzed in connection with both ethanol and SAF movements. The route pairings analyzed included:

- Ethanol from Columbia Ridge Landfill to BP Cherry Point;
- Ethanol from Columbia Ridge Landfill to Harbor Island;
- SAF from Columbia Ridge Landfill to BP Cherry Point and
- SAF from Columbia Ridge Landfill to Harbor Island.

Similar to rail transportation, a range of potential daily volumes were provided as a base on which to derive pricing. Daily pricing information was provided by several barge companies in the State of Washington and the Port of Morrow. The analyses reflected the assumption that ethanol/SAF would be transported from origin (Columbia Ridge Landfill) to the Port of Morrow via truck. This could be done either by tanker truck or ISO container. However, our research did not reveal any ISO containers available moving from Portland, OR to the Seattle area so they would likely need to be procured from Vancouver, WA. Because this would add a significant carbon footprint to the operation, the Team decided to run the analysis only with tanker trucks. The downside to this is that tanker trucks need to be offloaded into a storage facility (compared to ISO containers that can be left at the Port to be transported on demand without the need to construct additional storage at the Port).

The analysis of barge/truck transportation utilized the barrels per day goals listed in **Table 3B.1** to derive frequency of transportation. Regarding truck transportation of ethanol between the landfill and the Port of Morrow, a minimum of 7.7 trips would need to occur per day and a maximum of 15.5 trips daily. The lower volume goals of SAF require a minimum of 2 trips per day and a maximum of 9 trips per day.

The ethanol/SAF would then be stored at the Port of Morrow until an adequate volume was reached to fill a barge. Ethanol would require a minimum of 19 and a maximum of 38 barges to reach annual volume goals. SAF would require between 6 and 22 barges to reach their volume goals.

The analysis then comprehended a computation of the cost to reach either Harbor Island or BP Cherry Point. The latter is a longer trip from the Port of Morrow and increases the cost and price of transportation.

The combined charges of truck and barge transportation per day to move ethanol between Columbia Ridge and Harbor Island is approximately $15,800 when transporting the lower volume goal and $30,850 when transporting the higher volume goal. This results in between $5,700,000 and $11,300,000 in annual charges.

The combined charges of truck and barge transportation cost per day to transport SAF between Columbia Ridge and Harbor Island is approximately $5,400 when transporting the lower volume goal and $18,000 when transporting the higher volume goal. This results in between $2,000,000 and $6,600,000 in annual charges.

Between Columbia Ridge and BP Cherry Point, the combined charges of truck and barge transportation of ethanol are between $17,300 and $34,000 per day or $6,300,000 and $12,400,000 annually. Combined truck and barge transportation of SAF are between $6,000 and $20,000 per day or between $2,100,000 and $7,300,000 annually.

Table 3B.9 below further breaks down the range of potential prices to transport ethanol and SAF via truck between Columbia Ridge Landfill and the Port of Morrow and by barge between the Port of Morrow and either Harbor Island or BP Cherry Point. Estimated storage costs at the Port of Morrow include the cost of leasing land and constructing a new storage facility to hold the ethanol/SAF between transportation modes.

Table 3B.9: Summary Barging Cost Model

Product	Ethanol		SAF	
Production Rate (bll/day	1,836	3,673	530	2,100
Production Options	Ethanol Low	Ethanol High	SAF Low	SAF High
Ethanol	1836	3673	/	/
SAF	/	/	530	2,100
Production Days/Week	7	7	7	7
Production/WK (BBL) Gal/BBL 42	12,852	25,711	3,710	14,700
Production/wk (GAL)	539,784	1,079,862	155,820	617,400
Production per Year				
BBL	668,304	1,336,972	192,920	764,400
Gallons	28,068,768	56,152,824	8,102,640	32,104,800
Total Costs				
Trucking Costs per Year	$1,684,800	$3,369,600	$499,200	$1,934,400
Storage Costs at Port Morrow	$283,308	$283,308	$283,308	$283,308
Barging Costs (To Harbor Island)	$3,803,040	$7,606,080	$1,200,960	$4,403,520
Total Costs to Harbor Island (Yearly)	$5,771,148	$11,258,988	$1,983,468	$6,621,228
Cost per BBL	$8.64	$8.42	$10.28	$8.66
Additional Barging Costs to BP Refinery	$575,908	$1,151,816	$181,866	$666,841
Total Cost to BP Refinery (Yearly)	$6,347,056	$12,410,804	$2,165,333	$7,288,069
Cost per BBL	$9.50	$9.28	$11.22	$9.53

C

TASK 3 – APPENDIX C | STAFFING

Task 3 - Appendix C | Staffing

This Appendix supports **Section 3.3.2.5 – Staffing** by detailing the staff count for the four scenarios introduced in **Section 1.10.9**. The four scenarios are summarized below.

Scenario 1: Process plant with MSW preparation (sorting, drying, pelletizing), gasifier, gas cleaning, FT synthesis, hydrocracking / isomerization and fractionation for processing 500 mtpd of RDF and producing 6.3 mmgpa of SAF. OSBL units including water treatment, wastewater handling, air separation unit, maintenance and office building, final product storage.

Scenario 2: Process plant with MSW preparation (sorting, drying, pelletizing), two gasifiers, common gas cleaning, ethanol synthesis, and hydro-processing units for processing 720 mtpd of RDF into 24 mmgpa of ethanol as intermediate product and 13 mmgpa of SAF as final product. OSBL units including air separation unit, water treatment, wastewater handling, other utility units, maintenance and office building, intermediate ethanol and final product storage.

Scenario 3: Process plant with MSW preparation (sorting, drying, pelletizing), three gasifiers, gas cleaning, FT synthesis, hydrocracking / isomerization and fractionation for processing 2000 mtpd of RDF and producing 25 mmgpa of SAF. OSBL units including water treatment, wastewater handling, air separation unit, maintenance and office building, final product storage.

Scenario 4: Process plant with MSW preparation (sorting, drying, pelletizing), two gasifiers, gas cleaning, CO_2 into CO conversion (reverse water gas shift reaction), ethanol synthesis, and hydro-processing units for processing 720 mtpd of RDF and 80 mtpd of additional hydrogen into 25 mmgpa of SAF.

The results of this staffing analysis are summarized in **Table 3C.1** and differentiates between shift and daytime personnel. The daytime maintenance personnel have also been assigned to the various process units but may most likely be pooled. The demand for operating and maintenance personnel assumes a low maturity of the processes and therefore higher degree of operations supervisory and activities in the plant. The headcount is based on EXP's own experience.

Table 3C.1: A Table to Summarize the Anticipated Number of Staff Required During Day and Night Shifts for Four Scenarios

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Shift	Daytime	Shift	Daytime	Shift	Daytime	Shift	Daytime
MSW sorting	4	2	4	2	6	3	4	2
Gasification, gas cleaning, FT	6	4			10	6		
Hydrocracking	4	2			4	2		
Gasification, gas cleaning, Ethanol production			6	4			8	4
ATJ			4	2			4	2
Offsites and utilities incl. electrolyzer and ASU	2	2	2	2	4	2	6	2
Management, admin	2	10	2	10	2	10	2	10
Other services	2		2		2		2	
Total	**80**	**20**	**80**	**20**	**112**	**23**	**104**	**20**

D

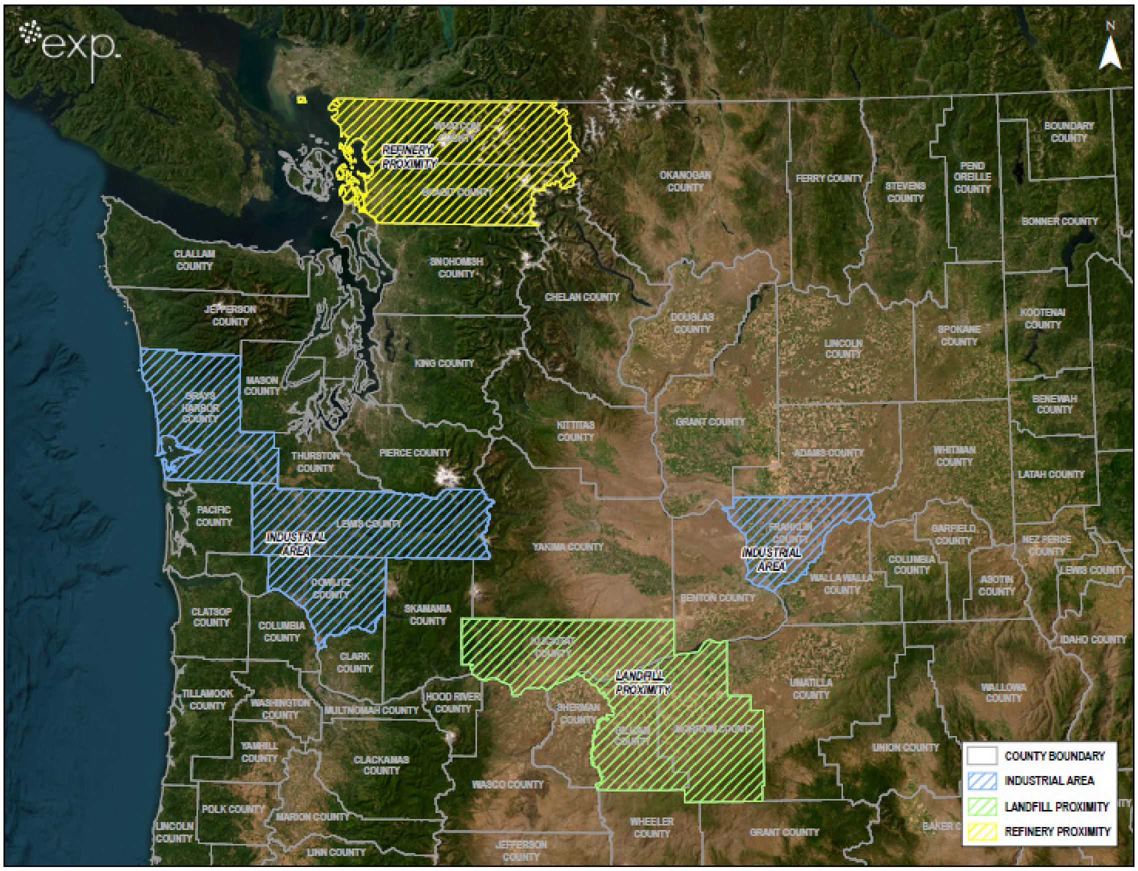
TASK 3 – APPENDIX D | SITE ASSESSMENT

Task 3 – Appendix D | Site Assessment

This Appendix details the individual site assessments for 14 parcels of land with the potential to host a renewable fuels production facility. The parcels are located across the three broad categories indicated in **Figure 3.D.1:** the yellow area indicates parcels located in close proximity to a refinery; blue areas are parcels in industrial areas, and the green area indicates sites in close proximity to landfills.

This review of potential sites for the location of a renewable fuels production facility is solely for preliminary evaluation purposes and does not constitute any commitment or engagement in actual development activities. No contact or communication has been initiated with property owners in connection with this desktop review.

Figure 3.D.1: Viable Facility Site Locations in WA and OR



3D.1 Site Evaluation Methodology

1.1 Space Availability

An understanding of the regional distribution coupled with the availability of existing Land Use data allowed for the preselection of specific counties to determine available areas. Land Use data allowed for the extraction of all industrial areas over 40 acres (with the exception of one parcel, 13-B); a total of ten (10) parcel locations were extracted. An additional four (4) parcels were identified through past studies, reports, and evaluations obtained in preliminary research tasks regarding site conditions.

1.2 Surrounding Infrastructure

The sites were analyzed using GIS tools, EPA's NEPAssist[1], and Google Maps[2] to identify proximities to roadways, railroads, and potential waterways capable of transporting MSW and fuel. The three methods of transportation accounted for may be utilized independently or jointly depending on feasibility of cost. The same tools and resources were utilized to identify potential sources of raw water and electricity for each parcel.

Figure 3.D.2: Geographic Distribution of Selected Parcels

Of the fourteen (14) sites selected, nine (9) counties are represented either in Washington or Oregon, evident in **Figure 3.D.2**. The Washington Utilities and Transportation Commission (UTC) published a resource that enabled the identification of natural gas pipeline operators servicing each county in Washington[3]. The natural gas operators for the counties in Oregon were identified through the American Geoscience Institutes Interactive map of pipelines in the United States.[4]

---

[1] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[2] *Google Maps*. (n.d.). Retrieved from https://www.google.com/maps.

[3] *Pipeline Operators by County* . (n.d.). Retrieved from Washington Utilities and Transportation Commission : https://www.utc.wa.gov/pipeline-operators-county.

[4] *Interactive map of pipelines in the United States*. (n.d.). Retrieved from American Geosciences Institue: https://www.americangeosciences.org/critical-issues/maps/interactive-map-pipelines-united-states.

1.3 Geological Conditions for Carbon Sequestration

The University of Washington Department of Earth and Space Science published a report titled "Opportunities for Geologic Carbon Sequestration in Washington State." This report explores four different methods for sequestering carbon.[5] Understanding the geology surrounding the selected sites allowed for the identification of areas suitable for one of the methods in particular: *In situ carbon remineralization,* which requires an abundance of basalts, volcanic, and ultramafic rock properties in the area.

This method of sequestering carbon undergoes a few chemical processes when injecting the carbon dioxide charged water into the mafic rock (referring to basalt). The mineralization process of carbon uses a geochemical trapping mechanism to sequester stable, non-toxic carbonates with a low risk of leakage into the atmosphere or underground aquifers.[6,7] The Columbia River Basalt Group (CRBG) is an ideal opportunity for in situ carbon sequestration due to the consistent conclusions of dissolution behavior from various studies overtime.

The surface geology of each parcel was examined using a GIS tool, the Washington Geologic Information Portal from the Washington State Department of Natural Resources (WA DNR).[8] For the parcels located south of the Columbia River in Oregon, a similar tool was utilized from the State of Oregon Department of Geology and Mineral Industries (DOGAMI)[9]. These resources produced in-depth material on the geological compositions of the site's land and surrounding areas. Correlating the ideal mineral make-up with this sequestering process was part of the evaluation process, seeking areas that are in an abundance of basalt flows and volcanic rocks.

1.4 Community Acceptance

Each parcel was evaluated for their socioeconomic indicators using the EPA's Environmental Justice Screening and Mapping Tool (EJScreen Tool).[10] This resource is a GIS based function that supplies a variety of demographic information, detailed in **Section 3.3.1**, for all areas in the United States.

1.5 Distance Between Site and Landfill(s)

Once all evaluation site locations were confirmed, nearby areas for landfills, waste collections facilities, and disposal services were identified through City and County websites as well as Google Maps. Compiling the addresses of all the waste disposal centers, the routes to and from the sites coordinates, and landfills addresses were measured and recorded.

---

[5] Childers, J., Daniels, R., MacLeod, L., Rowe, J., & Walker, C. (2020). Opportunities for Geologic Carbon Sequestration in Washington State. *Department of Earth and Space Sciences University of Washington, Seattle*. Retrieved from https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/45569/Opportunities%20for%20Carbon%20Sequestration%20in%20Washington.pdf?sequence=1.

[6] Goldberg, D., Kent, D., & Olsen, P. (2010). Potential on-shore and off-shore reservoirs for CO2 sequestration in Central Atlantic magmatic province basalts. *PNAS Vol. 107, No. 4* , 1327-1332. Retrieved from: https://www.pnas.org/doi/full/10.1073/pnas.0913721107.

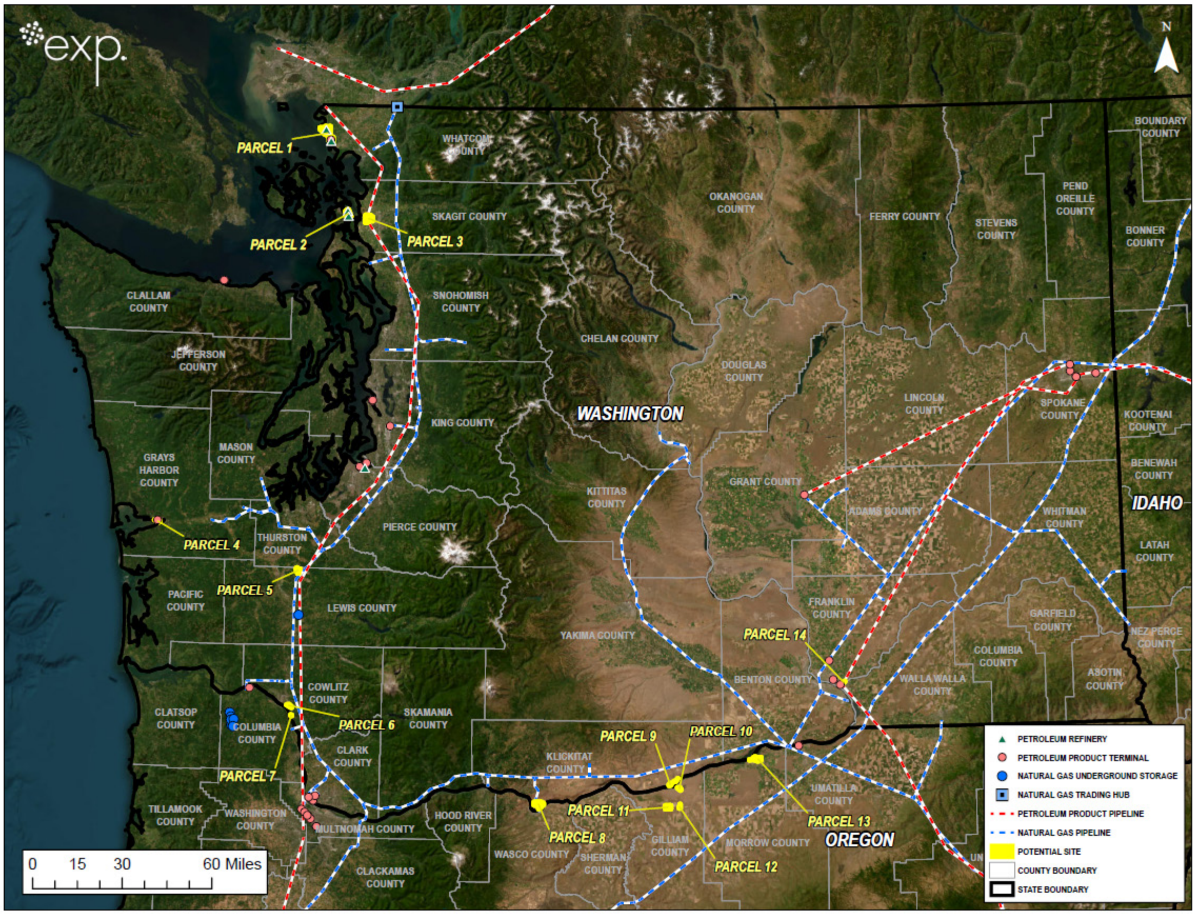
[7] Peter McGrail, Herbert Schaef, Frank Spane. (2017). *Environmental Science & Technology Letters 4* (1), 6-10 DOI: 10.1021/acs.estlett.6b00387.

[8] *Washington Geologic Information Portal*. (n.d.). Retrieved from https://geologyportal.dnr.wa.gov/2d-view#subsurface?-14541230,-12662713,5497126,6380126?Surface_Geology,500k_Surface_Geology,Map_Units.

[9] *Interactive Maps & Geospatial Data*. (n.d.). Retrieved from State of Oregon Separtment of Geology and Mineral Industries: https://www.oregongeology.org/gis/.

[10] *EJScreen: Environmental Justice Screening and Mapping Tool*. (n.d.). Retrieved from EPA: https://www.epa.gov/ejscreen.

Figure 3.D.3: Proximity of Pipelines to Selected Parcels



3D.2 Site Evaluation Matrix

This section summarizes the individual evaluation of each parcel of land according to the methodology described in **Section 3D.1** and the description of each parcel listed in **Section 3D.3**. The ranking for this evaluation was based on a scale of 1-5, with one being least desirable and five as the most beneficial to the project in each category. However, the ranking was category specific and is explained below. The scores were totaled to rank the parcels from most to least desirable.

Space Availability

Parcels of land with more space available are more desirable for this project. This is because a larger site offers multiple advantages, such as space for a laydown area during construction, increased safety distances from hazardous areas, storage space, and more flexibility with the design of the plant layout. However, the facility size is also dependent on technology selection and partnership opportunities. As a result, this factor is not included in this evaluation matrix.

Surrounding Infrastructure

Sites surrounded by infrastructure that a facility could tap into are preferred because it cuts costs and development times. Parcels were ranked according to the following:

1 – Sites missing more than two categories of infrastructure.

2 – Sites missing two categories of infrastructure.

3 - Sites with access to all types of infrastructure included in the study but without the certainty of a guaranteed supply of electricity, or sites missing one category of infrastructure (e.g., marine access because the site is landlocked).

4 - Parcels with access to all types of infrastructure studied (i.e., vehicular access, rail access, marine access, raw water, and electricity).

5 - Parcels that meet the above criteria and with access to infrastructure on site (e.g., a rail stop that is already used to transport goods to and from site or an existing refinery dock as part of marine access).

Geological Conditions

Sites with geological conditions favorable for onsite carbon sequestration are preferred over those without carbon sequestration potential. This is because transporting CO2 across long distances to far away sites for sequestering experiences a mileage penalty. Parcels were evaluated according to the following ranking:

1 – The parcel is not suitable for carbon sequestration, and there is no potential (or unknown potential) of sequestering carbon in the parcel's surroundings.

3 – The parcel is not suitable for carbon sequestration but, there is potential for carbon sequestration in the parcel's surroundings.

5 – The parcel is suitable for carbon sequestration onsite.

Natural Gas Pipeline

Natural gas is required during operation of the facility. As a result, a site with access to the pipeline was allocated five points, and sites without access were allocated one point.

1 – No access a natural gas pipeline operator

5 – Access to a natural gas pipeline operator

Community Acceptance

A lower SDI score is associated with a less significant impact on vulnerability within communities. The lowest SDI score in this analysis is the 7th percentile (Parcel 1-A) and the highest score is 87th percentile (Parcel 6). According to the EPA's EJSCREEN, sites above the 80th percentile are at risk of EJ considerations.[11] As a result, sites below the 80th percentile are awarded maximum points and sites above the marker receive no points.

1 – Parcels above the 80th percentile

5 – Parcels below the 80th percentile

Distance to Landfill

Parcels near the five landfills with sufficient feedstock for a standalone plant (i.e., Roosevelt Regional Landfill, Columbia Ridge Landfill, Finley Buttes, Cedar Hills, and LRI Landfill) are more advantageous than parcels located a further distance away. This is due to the additional mileage penalty. For multiple parcel sites (i.e., 1-A and 1-B), the midpoint (coordinates) of the parcel(s) was taken to determine the distance between site and landfill(s).

1 – Parcels with a minimum distance to one of the five landfills of ≥ 100 miles

2 – Parcels with a minimum distance to one of the five landfills between 50 ≤ 100 miles.

4 – Parcels with a minimum distance to one of the five landfills between 10 < 49 miles.

5 - Parcels with a minimum distance to one of the five landfills of < 10 miles.

Table 3.D.1: Evaluation Matrix

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Space availability	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Surrounding Infrastructure	3	5	3	4	3	2	5	4	3	4	3	4	4	5
Geological Conditions	1	3	5	3	5	3	3	5	5	5	5	5	3	1
Natural Gas Pipeline	5	5	5	5	5	5	1	5	5	5	5	5	5	5
Community Acceptance	5	5	5	1	5	1	5	1	5	5	5	5	5	5
Distance to Landfills	1	2	2	2	2	1	1	2	5	4	5	5	4	2
TOTAL	**15**	**20**	**20**	**15**	**20**	**12**	**15**	**17**	**23**	**23**	**23**	**24**	**21**	**18**

[11] *Using EPA's EJSCREEN.* (2019, May 17). Retrieved from A Step by Step Guide to Finding Demographic Information:https://www.ezview.wa.gov/Portals/_1988/Documents/Documents/EJ_HowToUseEPA_EJ_Screen_2019.pdf.

Based on the author's evaluation criteria of potential site locations, parcel 12 achieved the highest score with 24 points. Parcels 9, 10, and 11 tied in second place with a total of 23 points. These four parcels obtained the highest rankings due to their favorable conditions: surrounded by existing infrastructure (e.g., vehicular, rail, and marine access, electricity etc.) instead of requiring the construction of new infrastructure, geological conditions that allow for onsite carbon sequestration, access to the natural gas pipeline, location within an area that will pose less significant impacts on vulnerable communities (i.e., below the 80th percentile according to the EPA's EJSCREEN), and within a maximum distance of 49 miles from one of the five landfills with sufficient feedstock for a standalone plant (i.e., Roosevelt Regional Landfill, Columbia Ridge Landfill, Finley Buttes, Cedar Hills, and LRI Landfill). Parcel 6 obtained the lowest score in the evaluation, with a total of 12 points. While it did have access to the natural gas pipeline, the site lacked access to the same number of existing infrastructures as many other sites. It also did not have carbon sequestration opportunities on site (although there is potential in the surroundings), posed a threat to vulnerable communities (i.e., below the 80th percentile according to the EPA's EJSCREEN), and is located more than 100 miles from the nearest of the five landfills deemed suitable for this project.

3D.3 Individual Site Evaluations

The following tables summarize pertinent information used to evaluate each site according to the methodology described in **Section 3D.1**. Additional information and map of each site is available after each table. This information was key to creating the site evaluation matrix in **3D.2**.

CRITERIA	PARCEL 1: Light & Heavy Impact Industrial	
Space Availability	**Parcel 1-A** (48° 53' 42.777" N, 122° 43' 24.903" W) 20,702,859 ft^2, intended for light impact industrial purposes. Zone class LII in Whatcom County, WA. **Parcel 1-B** (48° 51' 49.691" N, 122° 43' 26.741" W) 288,549,630 ft^2, intended for heavy impact industrial purposes. Zone class HII in Whatcom County, WA.	
Surrounding Infrastructure	**Parcel 1-A** • Existing Vehicular Access: Located less than 6 miles from the main highway, I-5. Equipped with parking Infrastructure. • Existing Rail Access: o Pacific Western Rail Systems station is sited 6.2 miles directly east of 1-A o Located roughly 28 miles north of the Fairhaven Railway Station • Raw Water: Terrell Creek along the northern boundary and small ponds (e.g., Unruh Reservoir and Heide Pond). **Parcel 1-B** • Existing Vehicular Access: Boasts existing lots for parking, loading, and unloading materials. • Existing Rail Access: Existing rail infrastructure within the boundaries of 1-B. Southern part of site is roughly 17 miles from Fairhaven Railway Station. • Existing Marine Access: Three marine port access points, all three border the southern site 1-B jurisdictions. • Raw Water: Contains marshy wetlands and ponds throughout the area. • Electricity: Due to the identified infrastructure on both sides, it is presumed that electricity is provided to either property.	
Geological Conditions	**Both Parcels** Parcels 1-A and 1-B lie on a geologic Pleistocene continental glacial drift. The WA DNR Geologic Information Portal describes the site to include "Pleistocene till and outwash clay, silt, sand, gravel, cobbles, and boulders deposited by or originating from continental glaciers; locally includes peat, nonglacial sediments, modified land, and artificial fill."[12] No basaltic flows or volcanic rock properties suitable for *in situ carbon remineralization* to sequester carbon onsite.	
Natural Gas Pipeline	**8 operators in Whatcom County:** • BP Pipelines North America • Cascade natural Gas Corporation • Ferndale Pipeline System • Northwest Pipeline	• Olympic Pipeline Company • Petrogas West • Puget Sound Energy • Trans Mountain Pipeline (Puget Sound)
Community Acceptance	**Parcel 1-A** Low supplemental demographic index score in the 7th percentile. **Parcel 1-B** Low supplemental demographic index score in the 46th percentile.	
Distance to Landfills	**From the Approx. Midpoint Coordinate between Parcel 1-A and 1-B:** 48°52'13.8"N 122°43'24.8"W Roosevelt Regional Landfill: 335 miles Columbia Ridge Landfill: 361 miles Finley Buttes: 366 miles Cedar Hills: 126 miles LRI Landfill: 147 miles	

Parcel 1: Additional Information

Surrounding Infrastructure

Existing Rail Access: Two loading and unloading stations within the Cherry Point Refinery, which is located on Brown Road, in between Jackson Road and Blaine Road. Additional rail loading and unloading stations towards the southern border of parcel 1-B, identified on Alcoa Intalco Works and Tosco Refining Company properties.

- The Pacific Western Rail Systems station for rail transportation is sited 6.2 miles directly east of 1-A. The station is in the vicinity of the vehicular access point to the I-5 highway.
- The northern site (1-A) is located roughly 28 miles north of the Fairhaven Railway Station and the southern part of site 1-B is roughly 17 miles from the station.
- Existing Marine Access: Satellite imaging suggests there are three marine port access points for the sites; All three border the southern site 1-B jurisdictions.
- The furthest southern point of access is located on Creamer Rd., which is roughly 5 miles away from the north site.
- The second is located off Intalco Rd., which is approximately 4 miles south of the north site.
- The final is located on Pipeline Rd., just over 2 miles from the north site.
- All marine access is located on the west coast, along the Strait of Georgia.

Raw Water: Both sites show general land cover to be comprised of medium intensity development, woody wetlands, pasture, and emergent herbaceous wetlands.[13]

[12] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources : https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases
[13] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

Figure 3.D.4: Site Boundary of Parcels 1-A and 1-B

CRITERIA	PARCEL 2: Tesoro Anacortes Refinery
Space Availability	**Parcel 2-A** (48° 29' 15.810" N, 122° 33' 44.975" W) 46,634,808 ft^2 (intended for industrial activity) **Parcel 2-B** (48° 28' 18.420" N, 122° 33' 24.487" W) 33,505,393 ft^2 (intended for industrial activity)

Surrounding Infrastructure	Both Parcels
	• Existing Vehicular Access: Access for truck transportation across the entire site. Contains existing lots for parking and additional areas are equipped for truck loading and unloading.
	• Existing Rail Access: Sites have railroad transportation access and unloading capabilities.
	  ○ An established direct link to the BNSF mainlines.
	  ○ The site currently receives crude and biofuels via train.
	• Existing Marine Access: Barge and vessel access for marine loading and unloading is available with two existing refinery docks.
	• Raw Water: The site is a peninsula so there is an abundant supply of raw water.
	• Electricity: Multiple electric companies supply Fidalgo Island with power, this site is no exception.

Geological Conditions	Both Parcels No basaltic flows or volcanic rock properties suitable for *in situ carbon remineralization* to sequester carbon onsite. However, there is an opportunity to sequester carbon in the surrounding areas.
Natural Gas Pipeline	4 operators in Skagit County: • Cascade natural Gas Corporation • Northwest Pipeline • Olympic Pipeline Company • Trans Mountain Pipeline (Puget Sound)
Community Acceptance	Both Parcels Low supplemental demographic index score in the 35th percentile.
Distance to Landfills	**From the Approx. Midpoint Coordinate between Parcel 2-A and 2-B:** 48°28'43.5"N, 122°33'37.7"W Roosevelt Regional Landfill: 306 miles Columbia Ridge Landfill: 329 miles Finley Buttes: 335 miles Cedar Hills: 95.2 miles LRI Landfill: 115 miles

Parcel 2: Additional Information

Surrounding Infrastructure

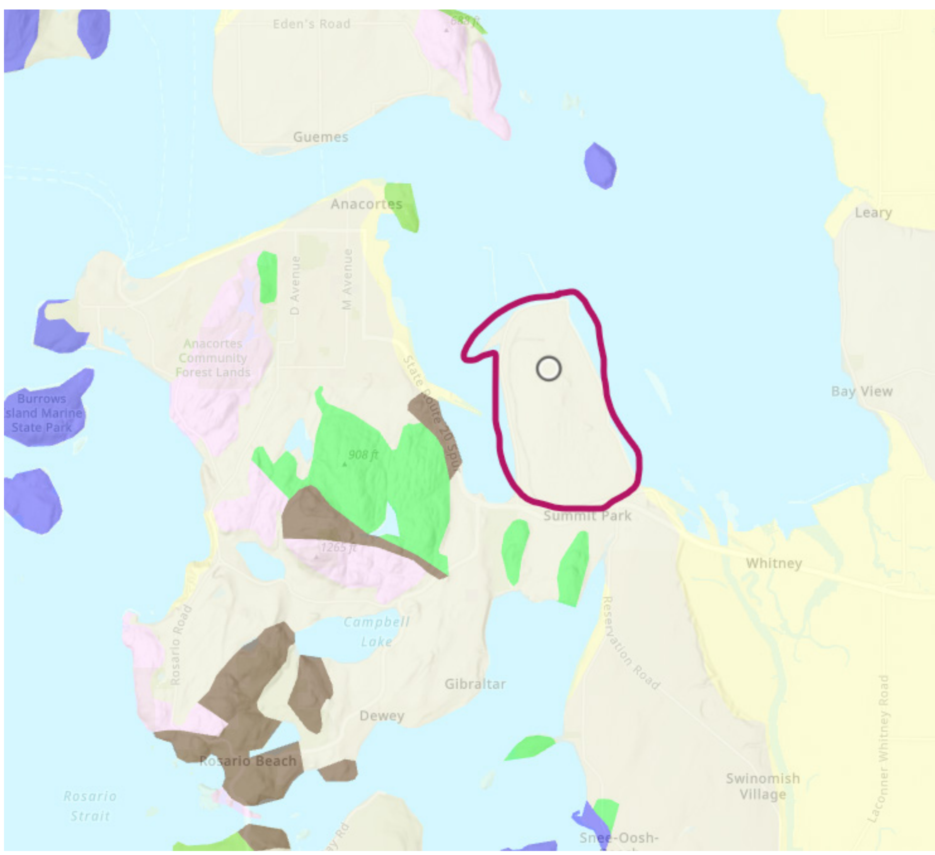
Existing Marine Access: Two existing refinery docks into Fidalgo Bay and the aquatic reserve with connecting bays such as Padilla Bay, Samish Bay, and Bellingham Bay all connected to the Rosario Strait. The southern travel route is through the Swinomish Channel which ultimately feeds into Skagit Bay.[14,15]

Raw Water: The general land cover is majority high intensity development, pasture, emergent herbaceous wetland, and woody wetland.[16]

Geological Conditions

Parcels 2-A and 2-B lie on a geologic Pleistocene continental glacial drift. The WA DNR Geologic Information Portal describes the site to include "Pleistocene till and outwash clay, silt, sand, gravel, cobbles, and boulders deposited by or originating from continental glaciers; locally includes peat, nonglacial sediments, modified land, and artificial fill."[17]

Figure 3.D.5: Brown Areas Surrounding the Parcels have Carbon Sequestration Potential



---

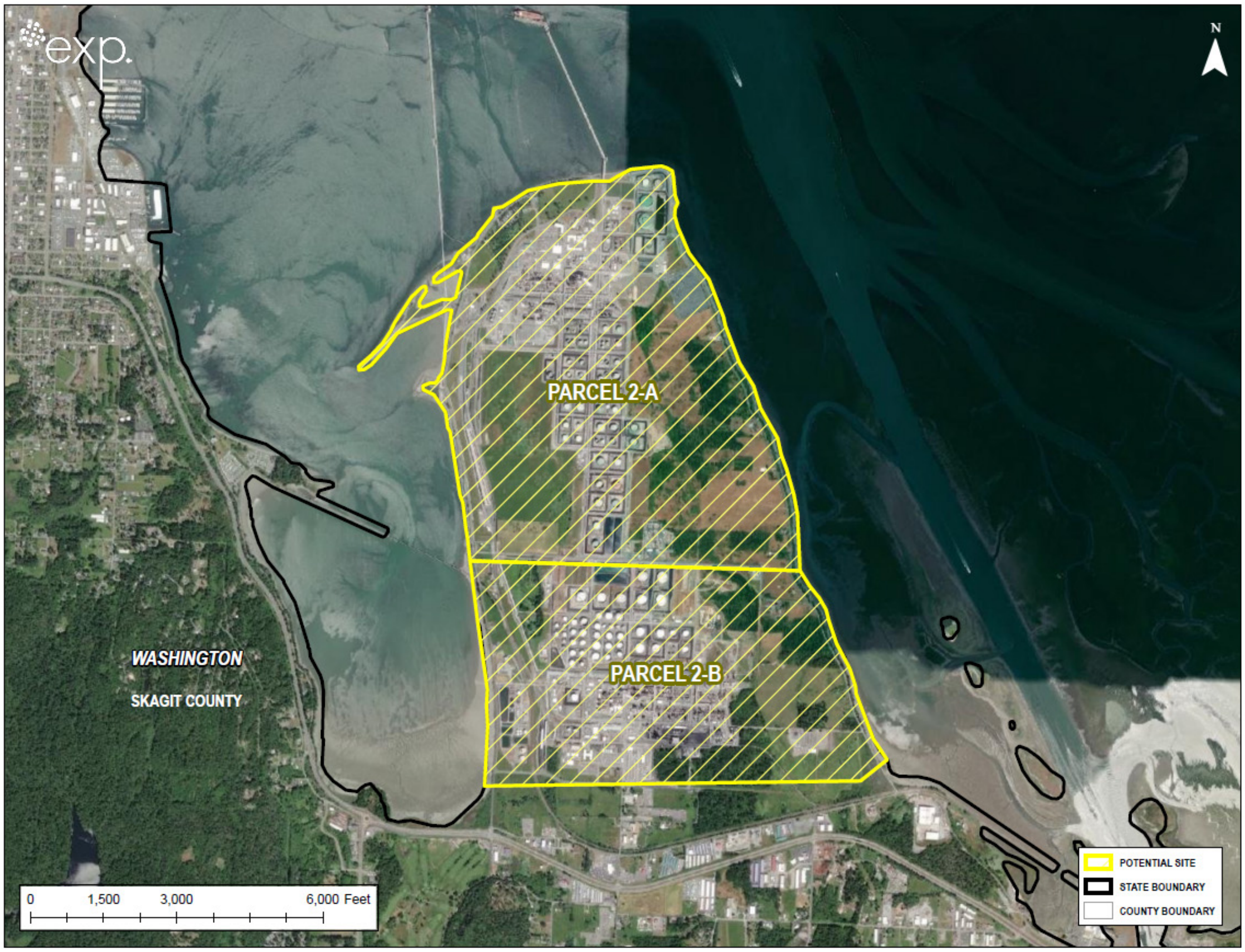
[14] WSP, 2016. Aviation Biofuels Infrastructure Feasibility Study, Final Report. P-00318568.

[15] WSP, November 2016. Aviation Biofuels Infrastructure Feasibility Study, Site Evaluation Technical Memorandum. P-00318568.

[16] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[17] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources: https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Figure 3.D.6: Site Boundary of Parcels 2-A and 2-B



CRITERIA	PARCEL 3: Olympic Pipeline Bayview/Allen Terminal
Space Availability	147,303,534 ft^2, located in Skagit County, WA, and intended for industrial activity. (48° 27' 30.617" N, 122° 24' 39.284" W)
Surrounding Infrastructure	• Existing Vehicular Access: The site is accessible via vehicle, including trucks. • Existing Rail Access: The site offers access to rail transportation. There is a railroad endpoint just east of Fredonia Rd. which runs through the site itself. Another rail endpoint is located on the very west-side of the boundary of parcel 3. ○ A previous study recommended the installation of a rail spur off the BNSF mail line to the site. • Existing Marine Access: As a landlocked site, there is no immediate marine access onsite. The Skagit River lies to the east of the site and the Padilla and Fidalgo bays to the west. • Raw Water: The western portion of the site is underdeveloped wetlands – a likely source of raw water. • Electricity: Since the site retains a portion of the Skagit Regional Airport, it is likely to include access to electricity.
Geological Conditions	Shows to have local volcaniclastic rock deposits, but no basaltic flows. Existing properties are suitable for *in situ carbon remineralization* to sequester carbon.
Natural Gas Pipeline	4 operators in Skagit County: • Cascade natural Gas Corporation • Northwest Pipeline • Olympic Pipeline Company • Trans Mountain Pipeline (Puget Sound)
Community Acceptance	Low supplemental demographic index score in the 17^{th} percentile.
Distance to Landfills	**From Coordinate (48° 27' 30.617" N, 122° 24' 39.284" W)** Roosevelt Regional Landfill: 299 miles Columbia Ridge Landfill: 322 miles Finley Buttes: 327 miles Cedar Hills: 87.7 miles LRI Landfill: 108 miles

Parcel 3: Additional Information

Surrounding Infrastructure

Raw Water: The general land cover is mainly pasture, developed land of either low, medium, or high intensity, mixed forest, woody wetlands, and cultivated crops.[18]

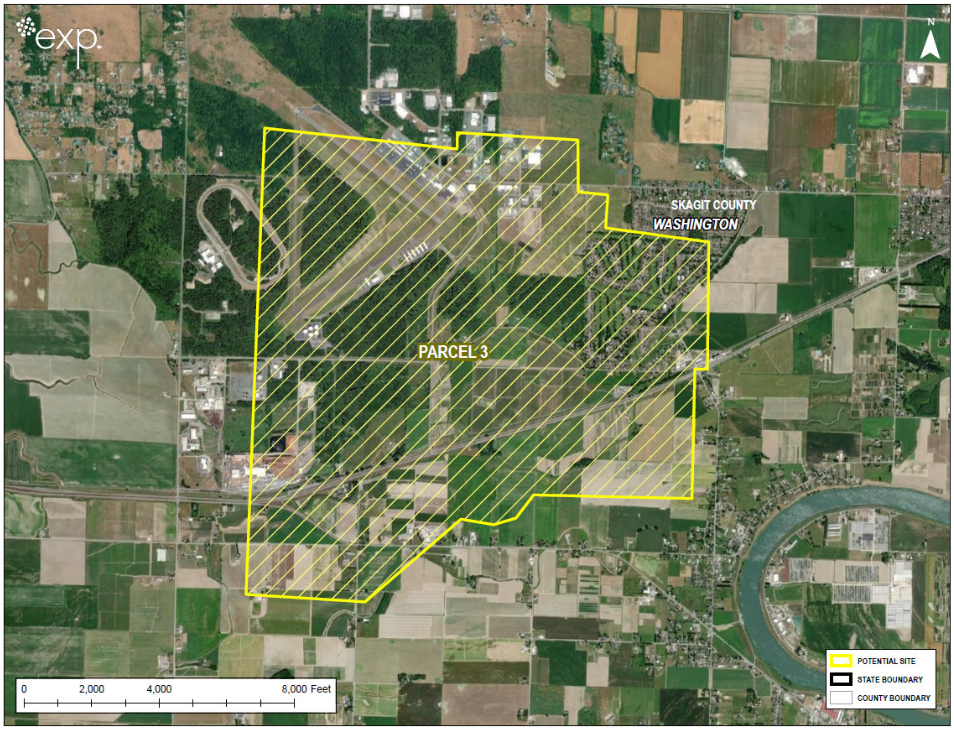
Geological Conditions

Parcel 3 lies on a few different geological identifications, including the 1) Pleistocene continental glacial drift, 2) Quaternary alluvium, and 3) Quaternary fragmental volcanic rocks and deposits. The WA DNR Geologic Information Portal describes the site to include:

- "Pleistocene till and outwash clay, silt, sand, gravel, cobbles, and boulders deposited by or originating from continental glaciers; locally includes peat, nonglacial sediments, modified land, and artificial fill." [19]
- "Quaternary unconsolidated or semi consolidated alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes peat, muck, and diatomite; locally includes beach, dune, lacustrine, estuarine, marsh, landslide, lahar, glacial, or colluvial deposits; locally includes volcaniclastic or tephra deposits; locally includes modified land and artificial fill."
- "Holocene dacitic to andesitic pyroclastic flow deposits of 1980 Mount St. Helens eruptions, mostly poorly sorted, ash-sized, crudely graded deposits of glass shards, pumice, broken phenocrysts, and lithic fragments and lesser lapilli- to block-sized pumice and lithic fragments. Quaternary pyroclastic deposits, debris flows, laharic deposits, tephra, ash, pumice, near-vent fragmental deposits, and fluvial gravel, sand, and silt; local rockfall breccia, caldera-collapse megablocks, cross-cutting andesite dikes, welded tuff, and irregular intrusions; minor lacustrine deposits; rare dacite flows."

[18] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.
[19] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources : https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Figure 3.D.7: Site Boundary of Parcel 3



CRITERIA	PARCEL 4: REG Grays Harbor Refinery
Space Availability	20,559,749 ft^2, located in Grays Harbor County, WA, and intended for industrial activity. (46° 58' 2.145" N, 123° 51' 6.310" W)

Surrounding Infrastructure	• Existing Vehicular Access: The refinery is a heavily developed plot of land with multiple avenues for vehicular transport to enter and exit the premise, mainly through Port industrial Road.
	• Existing Rail Access: The site offers access to rail transportation.
	  ○ Directly accessible via railroad with its own interconnected system of lines coming in and exiting the site.
	  ○ A rail spur leads directly to the marine access dock for seamless loading/offloading.
	• Existing Marine Access: Borders the Chehalis River for mainland marine accessibility.
	• Raw Water: The entire site borders the Chehalis River, and a few onsite ponds exist.
	• Electricity: Due to the surrounding infrastructure, existing organizations, and proximity to civilization, it is presumed that the sight is provided with electricity.

Geological Conditions	Shows to have local volcaniclastic rock deposits, but no basaltic flows. However, there is an opportunity to sequester carbon in the surrounding areas.
Natural Gas Pipeline	2 operators in Grays Harbor County: • Cascade natural Gas Corporation • Northwest Pipeline
Community Acceptance	High supplemental demographic index score in the 86th percentile.
Distance to Landfills	From Coordinate (46° 58' 2.145" N, 123° 51' 6.310" W) Roosevelt Regional Landfill: 279 miles Columbia Ridge Landfill: 275 miles Finley Buttes: 315 miles Cedar Hills: 110 miles LRI Landfill: 86.2 miles

Parcel 4: Additional Information

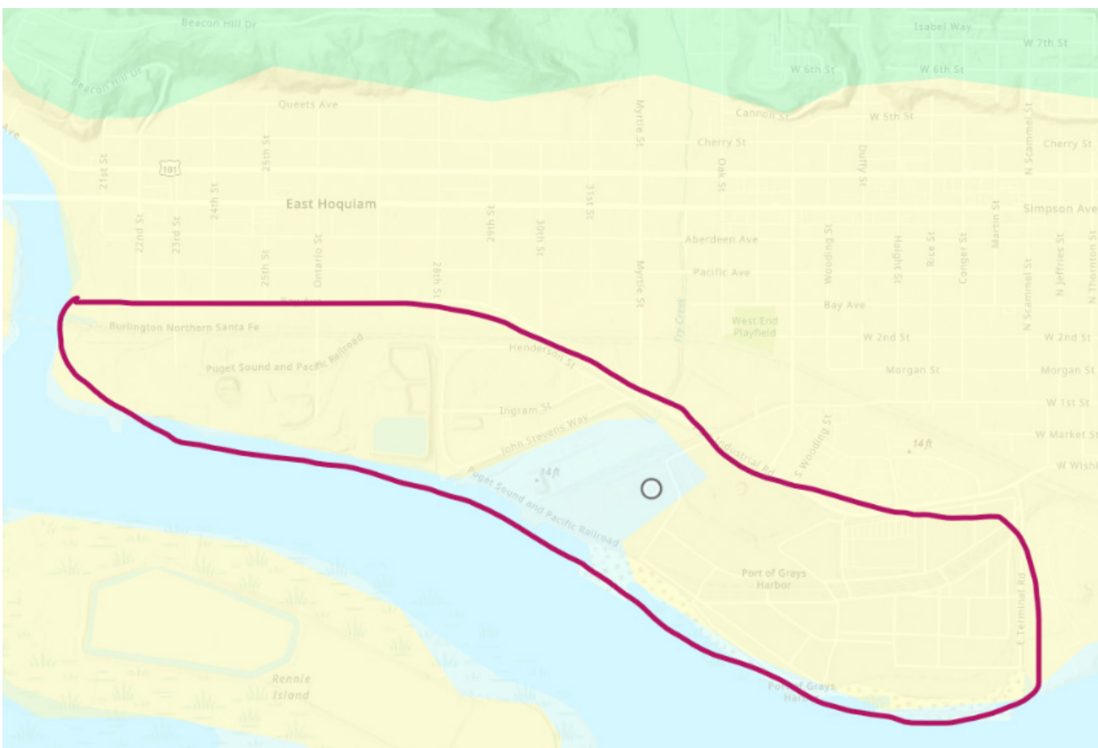
Surrounding Infrastructure

<u>Raw Water</u>: The entire site borders the Chehalis River. Furthermore, the site offers a few onsite ponds placed towards the eastern end of the land plots.[20]

Geological Conditions

Parcel 4 lies on a couple of different geological identifications. The site is partly occupied by bodies of fresh or salt water, and the rest Quaternary alluvium. The WA DNR Geologic Information Portal describes the site to include, "Quaternary unconsolidated or semi consolidated alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes peat, muck, and diatomite; locally includes beach, dune, lacustrine, estuarine, marsh, landslide, lahar, glacial, or colluvial deposits; locally includes volcaniclastic or tephra deposits; locally includes modified land and artificial fill." [21]

Figure 3.D.8: The Green Areas Surrounding Parcel 4 Show Potential for Carbon Sequestration



[20] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.
[21] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources: https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Figure 3.D.9: Site Boundary of Parcel 4

CRITERIA	PARCEL 5: Centralia Generation Station
Space Availability	34,943,796 ft^2, intended for rural area industrial purposes with a zone classification of RAI in Lewis County, WA. (46° 45' 0.937" N, 122° 51' 10.835" W)
Surrounding Infrastructure	• Existing Vehicular Access: The site is located roughly 20 minutes' drive east of I-5 and is readily accessible by road with multiple functional routes surrounding the site. Contains existing lots for parking, loading, and offloading transported materials. • Existing Rail Access: The site includes its own railroad loop, the Burlington Northern Santa Fe (BNSF) with an extension loop for storage, loading, and offloading purposes. The loop wraps around the northern part of the site just north of Big Hanaford Road, with an extension loop for storage, loading, and offloading. • Existing Marine Access: As a landlocked site, there is no convenient means of marine access for this location. • Raw Water: The site is bountiful of raw water supply since it is surrounded by ponds and bordering creeks. • Electricity: Assumed access to electricity since the northern border of the site is home to the generation station and most of the built infrastructure.
Geological Conditions	Shows to have an abundance of basaltic flows and local volcaniclastic rock deposits. This site is presumed suitable for *in situ carbon remineralization* to sequester carbon.
Natural Gas Pipeline	4 operators in Lewis County: • Cardinal FG • Northwest Pipeline • Olympic Pipeline Company • Puget Sound Energy
Community Acceptance	Low supplemental demographic index score in the 26th percentile.
Distance to Landfills[22]	From Coordinate (46° 45' 0.937" N, 122° 51' 10.835" W) Roosevelt Regional Landfill: 233 miles Columbia Ridge Landfill: 230 miles Finley Buttes: 269 miles Cedar Hills: 82.1 miles LRI Landfill: 48.3 miles

[22] *Lewis County Solid Waste Utility.* (2023). Retrieved from Lewis County Washington : https://lewiscountywa.gov/departments/solid-waste/.

Parcel 5: Additional Information

Surrounding Infrastructure

Raw Water: The general land cover includes evergreen forest, medium and high intensity development, open water, emergent herbaceous wetland, barren land, and shrubs.[23]

Geological Conditions

Parcel 5 lies on a couple of different geological identifications. The site is occupied by tertiary nearshore sedimentary rocks, as well as Quaternary alluvium. The WA DNR Geologic Information Portal describes the site to include:

- "Pliocene-Miocene siltstone, sandstone, and conglomerate; fossiliferous, concretionary, and carbonaceous. Miocene micaceous feldspathic sandstone and conglomerate with minor siltstone; locally pebbly, bioturbated, and (or) cross-bedded; commonly carbonaceous. Oligocene-Eocene nearshore marine to nonmarine basaltic conglomerate, sandstone, tuffaceous siltstone, pumice-lithic lapilli tuff, claystone, and lignite; basaltic sandstone, siltstone, and sandy pebble conglomerate; locally interbedded with basaltic andesite flows; commonly with coal; locally contains mica and quartz pebbles. Eocene marine to nonmarine micaceous feldspathic sandstone, siltstone, shale, carbonaceous siltstone, claystone, and thick coal seams; locally interbedded with basalt flows and volcaniclastic rocks." [24]

- "Quaternary unconsolidated or semi consolidated alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes peat, muck, and diatomite; locally includes beach, dune, lacustrine, estuarine, marsh, landslide, lahar, glacial, or colluvial deposits; locally includes volcaniclastic or tephra deposits; locally includes modified land and artificial fill."[25]

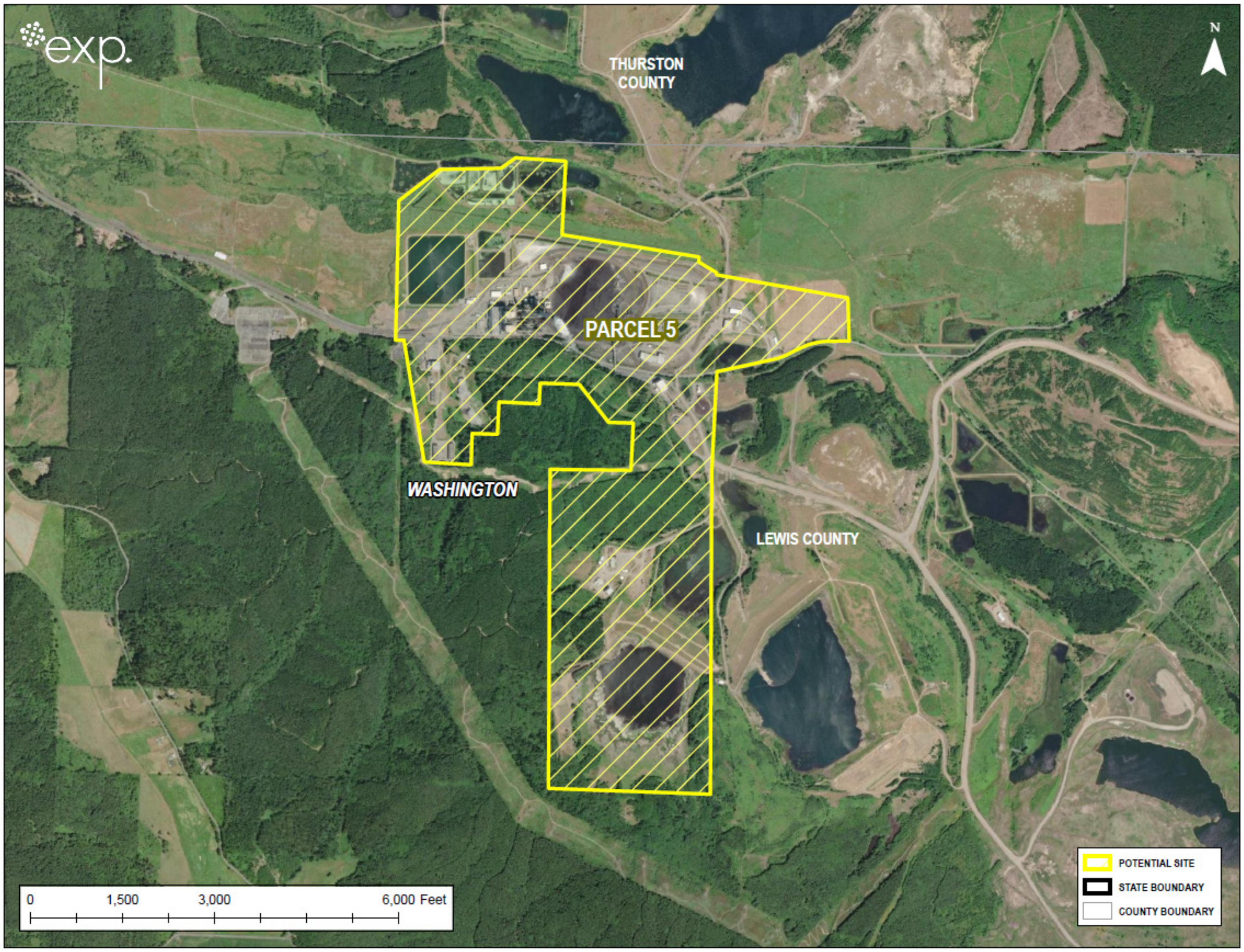
---

[23] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[24] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources: https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

[25] *Washington Geologic Information Portal* . (n.d.). Retrieved from Washington Department of Natural Resources: https://geologyportal.dnr.wa.gov/2d-view#wigm?-14009732,-13070473,5541602,5978210?Surface_Geology,500k_Surface_Geology,Map_Units,Subsurface_Geology,Borehole_information.

Figure 3.D.10: Site Boundary of Parcel 5



CRITERIA	PARCEL 6: Anchor Point Industrial Site
Space Availability	**Parcel 6-A** (46° 5' 36.278" N, 122° 53' 10.125" W) 24,986,255 ft^2, intended for industrial activity, located in Cowlitz County, WA. **Parcel 6-B** (46° 5' 14.068" N, 122° 52' 11.829" W) 404,365 ft^2, intended for industrial activity, located in Cowlitz County, WA.
Surrounding Infrastructure	Both Parcels • <u>Existing Vehicular Access:</u> Existing vehicular access is located near the southern end of the site and is referred to as "Owl Creek" driveway. • <u>Existing Rail Access</u>: The Burlington Northern Santa Fe (BNSF) lines run directly through the parcels, but it is unknown if the line stops and serves the site directly. • <u>Existing Marine Access</u>: The site borders the Cowlitz River to the north and Carrolls Channel of the Columbia River on the west. Currently, there are no marine terminals serving the site from these two water bodies. • <u>Raw Water</u>: The primary development area of the site is surrounded by woody and emergent herbaceous wetlands and leaves approximately 335 acres for wetland mitigation.
Geological Conditions	Both Parcels Potentially has local volcaniclastic rock deposits, but no basaltic flows. However, there is an opportunity to sequester carbon in the surrounding areas.
Natural Gas Pipeline	7 operators in Cowlitz County: • Cascade natural Gas Corporation • Northwest Pipeline • Airgas Merchant Gas Kalama • KB Pipeline • Olympic Pipeline Company • Nippon Dynawave Packaging Company • Solvay Chemicals
Community Acceptance	Both Parcels High supplemental demographic index score in the 87th percentile.
Distance to Landfills	From the Approx. Midpoint Coordinate between Parcel 6-A and 6-B: (46°05'24.2"N 122°52'20.3"W) <u>Roosevelt Regional Landfill</u>: 180 miles <u>Columbia Ridge Landfill</u>: 177 miles <u>Finley Buttes</u>: 216 miles <u>Cedar Hills</u>: 130 miles <u>LRI Landfill</u>: 106 miles

Parcel 6: Additional Information

Surrounding Infrastructure

Existing Vehicular Access: The Site is located west of Interstate-5 (I-5) and the nearest interchange is State Route 432 (SR-432), located approximately one-half mile northeast of the Site. Existing vehicular access is located near the southern end of the site and is referred to as "Owl Creek" driveway - named due to its proximity to Owl Creek on the southern edge of the driveway. This gravel drive is approximately 20-ft. wide and enters the site from Old Pacific Highway, crosses under two bridges carrying the northbound and southbound lanes of I-5 (see Figure 6), and then crosses under a railroad bridge carrying the BNSF Rail Mainline. The gravel drive continues into the site in a northwesterly direction and passes through low lying areas, surrounded by wetlands. The existing horizontal clearance between the columns for the BNSF structure of approximately 16.5 feet is the driveway's horizontal constriction point, reducing the driveway to essentially one lane at this location. This driveway currently serves the truck and trailers that export the stockpiled dredged materials from the site.

Existing Rail Access: The Burlington Northern Santa Fe (BNSF) lines run directly through the parcels, but it is unknown if the line stops and serves the site directly. The BNSF Railway owns and operates a two-track main line adjacent to the site that runs between Tacoma and Vancouver, Washington. The rail line is primarily used by BNSF and Union Pacific Railroad (UPRR) freight trains, but it also hosts a significant number of Amtrak passenger trains. The main line has an operational capacity of about 60 trains per day and is generally at a use of 50 trains per day. However, there are plans to increase the number of passenger trains each day from 10 to 18 in the next few years so BNSF is currently building a third main track through the area to accommodate the increase in passenger trains. There is a location on the main line, just southeast of the Anchor Point site, called Longview Junction South that is a signal control point with crossovers that allow trains to move between the two mainline tracks. It is also the south entrance to the Longview Yard, which is operated jointly by BNSF and Union Pacific.

Existing Marine Access: The Anchor Point site is bordered by the Cowlitz River to the north, and Carrolls Channel of the Columbia River on the west. Currently, there are no marine terminals serving the site from these two water bodies. The Columbia River is located west of the site on the far side of Cottonwood Island, as shown in Figure 4. Future connectivity of the Anchor Point Industrial Site to any of these water bodies is not included in this study and will be evaluated by the property owners. The Cowlitz River is too shallow to provide marine access to the site, except for perhaps temporary construction access via barge. Carrolls Channel is also quite shallow (with depths of approximately 20 feet). The Owner 's separate Marine Study identifies marine access opportunities for the site.

Raw Water: The primary development area of the site is surrounded by woody and emergent herbaceous wetlands and leaves approximately 335 acres for wetland mitigation.[26]

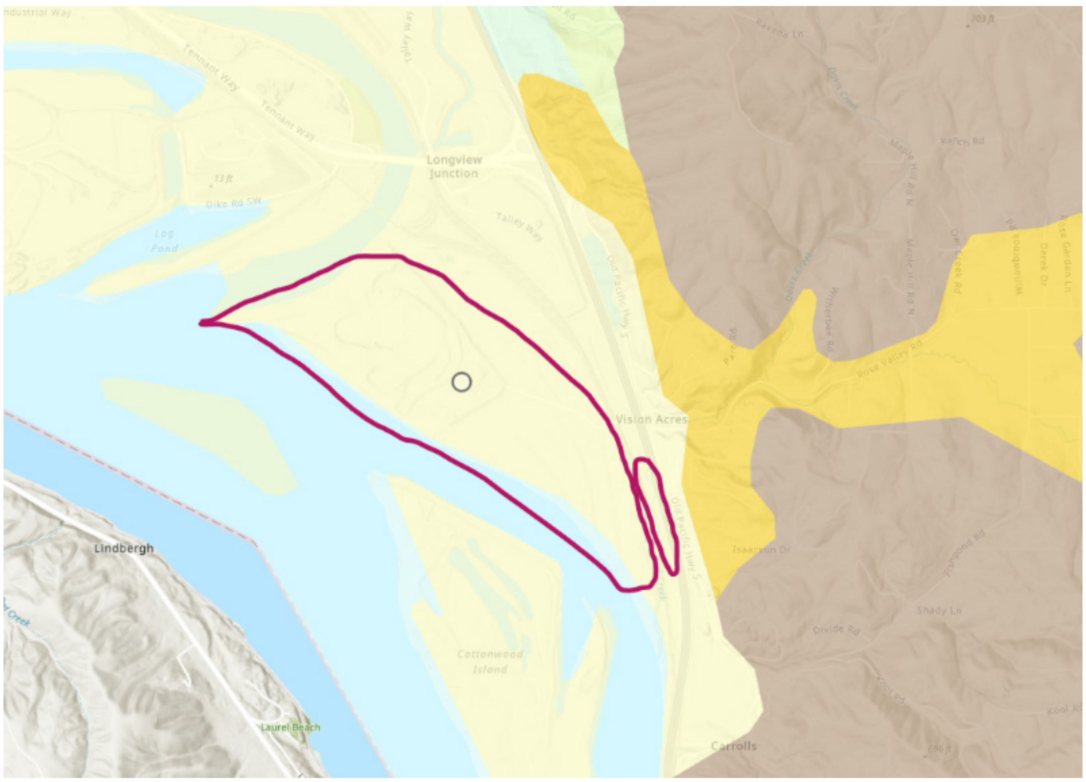
Electricity: A low and high-power requirement of 20 megawatt (MW) and 300 MW were explored for this site, both of which would entail construction of an onsite substation. For 20 MW, the substation would be fed via overhead lines from the BPA transmission line and then back to the BPA line. The point of connection could be anywhere along the eastern property line as needed for site planning/critical areas. Estimated footprint for substation is 200 ft. wide by 200 ft. Long and the construction timeline is approximately 1-year. Permitting timeline is approximately 6-months to 1-year and could be a joint submittal with the site design. A 300 MW substation would require construction of a 230kV overhead line extending to the BPA Longview substation, which is approximately 6-miles northwest of the site and located along SR 432 and the Columbia River. The costs for constructing this length of overhead line were not part of this study and are to be determined based on the future facility that will occupy the site.

[26] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

Geological Conditions

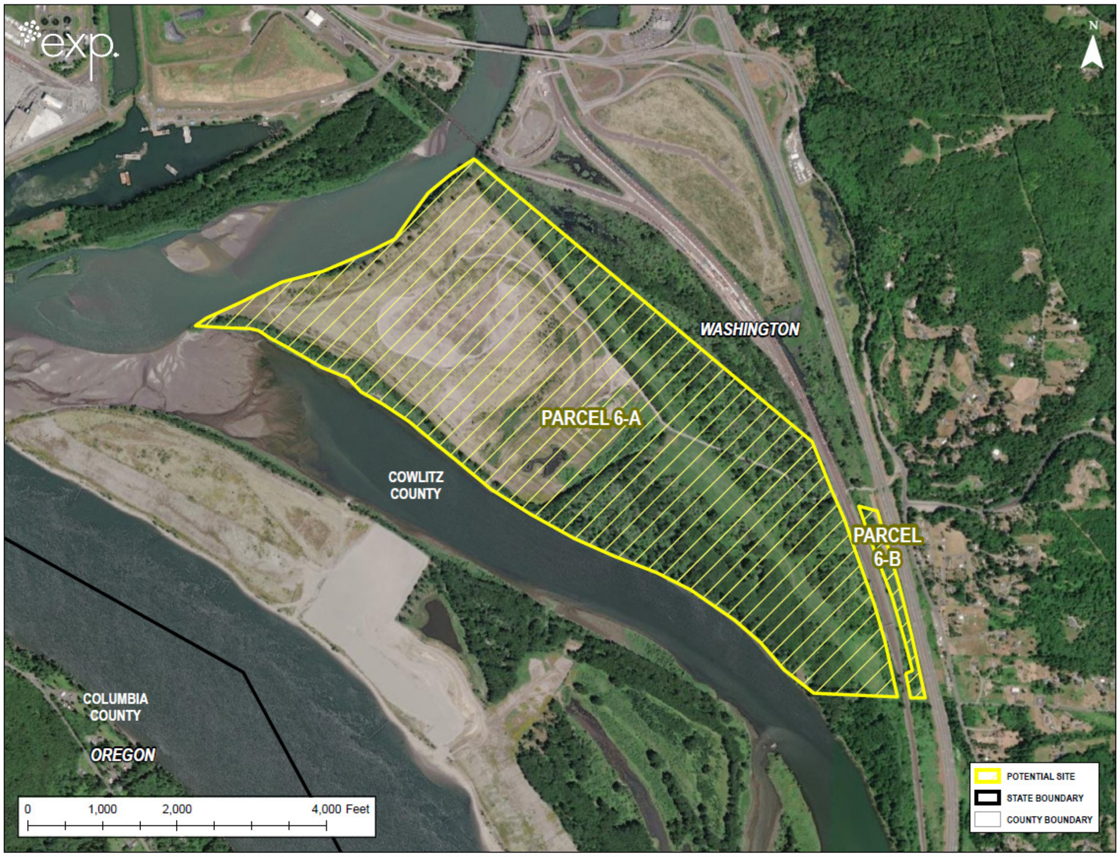
Parcel 6-A and 6-B lie on geological Quaternary alluvium. The WA DNR Geologic Information Portal describes the site to include, "Quaternary unconsolidated or semi consolidated alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes peat, muck, and diatomite; locally includes beach, dune, lacustrine, estuarine, marsh, landslide, lahar, glacial, or colluvial deposits; locally includes volcaniclastic or tephra deposits; locally includes modified land and artificial fill."[27]

Figure 3.D.11: Gold and Brown Areas Surrounding Parcel 6 Determined Suitable for Carbon Sequestration



[27] *Geology GIS Data and Databases.* (n.d.). Retrieved from Washington State Department of Natural Resources : https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Figure 3.D.12: Site Boundary of Parcels 6-A and 6-B



CRITERIA	PARCEL 7: Port of Kalama
Space Availability	3,826,669 ft^2 (46° 2' 49.484" N, 122° 52' 15.405" W)
Surrounding Infrastructure	• Existing Vehicular Access: The parcel sits on the Columbia River in Southwest Washington, immediately off Interstate 5. It is situated in the heart of the Pacific Northwest (PNW), only 30 miles northwest of Portland, Oregon, and approximately 120 miles south of Seattle, Washington. • Existing Rail Access: The site is served by the Burlington Northern/Santa Fe and Union Pacific railroads. • Existing Marine Access: The site includes six miles of riverfront property adjacent to the 43 ft federally maintained deep draft navigation channel of the Columbia River. ○ A large dock is accessible within the same development, just south of the parcel border. • Raw Water: Raw water is plentiful. The site borders the Columbia River and small inlets exist from this river encroaching on the site. • Natural Gas and Electricity: All necessary utilities are adjacent to the site and ready to serve, including electricity, potable water, sewer, natural gas, storm water, telephone, and fiber optics.[28]
Geological Conditions	Potentially has local volcaniclastic rock deposits, but no basaltic flows. However, there is an opportunity to sequester carbon in the surrounding areas.
Natural Gas Pipeline	/
Community Acceptance	Low supplemental demographic index score in the 26th percentile.
Distance to Landfills	From Coordinate (46° 2' 49.484" N, 122° 52' 15.405" W) Roosevelt Regional Landfill: 175 miles Columbia Ridge Landfill: 172 miles Finley Buttes: 211 miles Cedar Hills: 133 miles LRI Landfill: 110 miles

[28] 1 Eastwind Rd, Kalama, WA 98625 - for Lease | portofkalama.com.

Parcel 7: Additional Information

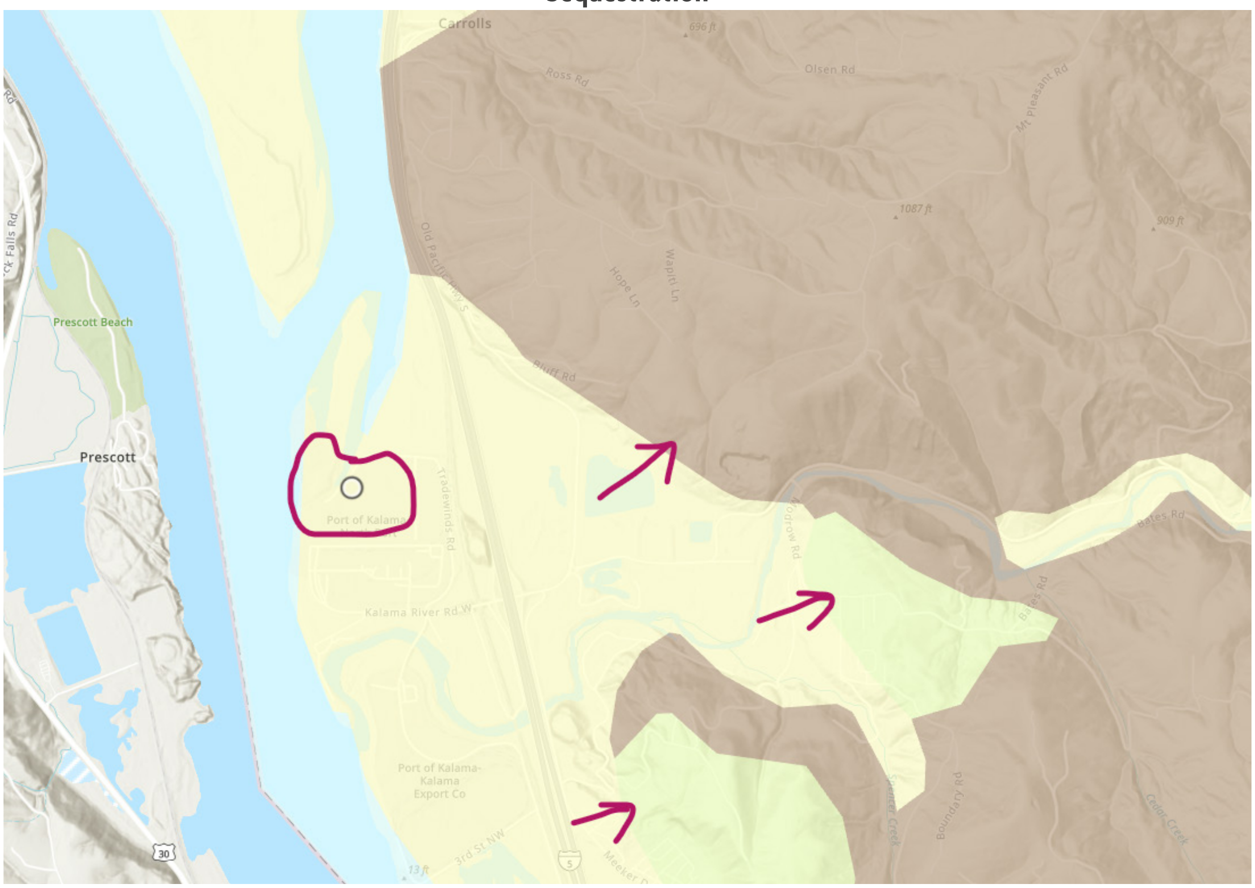
Surrounding Infrastructure

Raw Water: The general land cover comprises of woody and emergent herbaceous wetlands with various level of development, in addition to herbaceous grasslands.[29]

Geological Conditions

Parcel 7 lies on geological Quaternary alluvium. The WA DNR Geologic Information Portal describes the site to include, "Quaternary unconsolidated or semi consolidated alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes peat, muck, and diatomite; locally includes beach, dune, lacustrine, estuarine, marsh, landslide, lahar, glacial, or colluvial deposits; locally includes volcaniclastic or tephra deposits; locally includes modified land and artificial fill." [30]

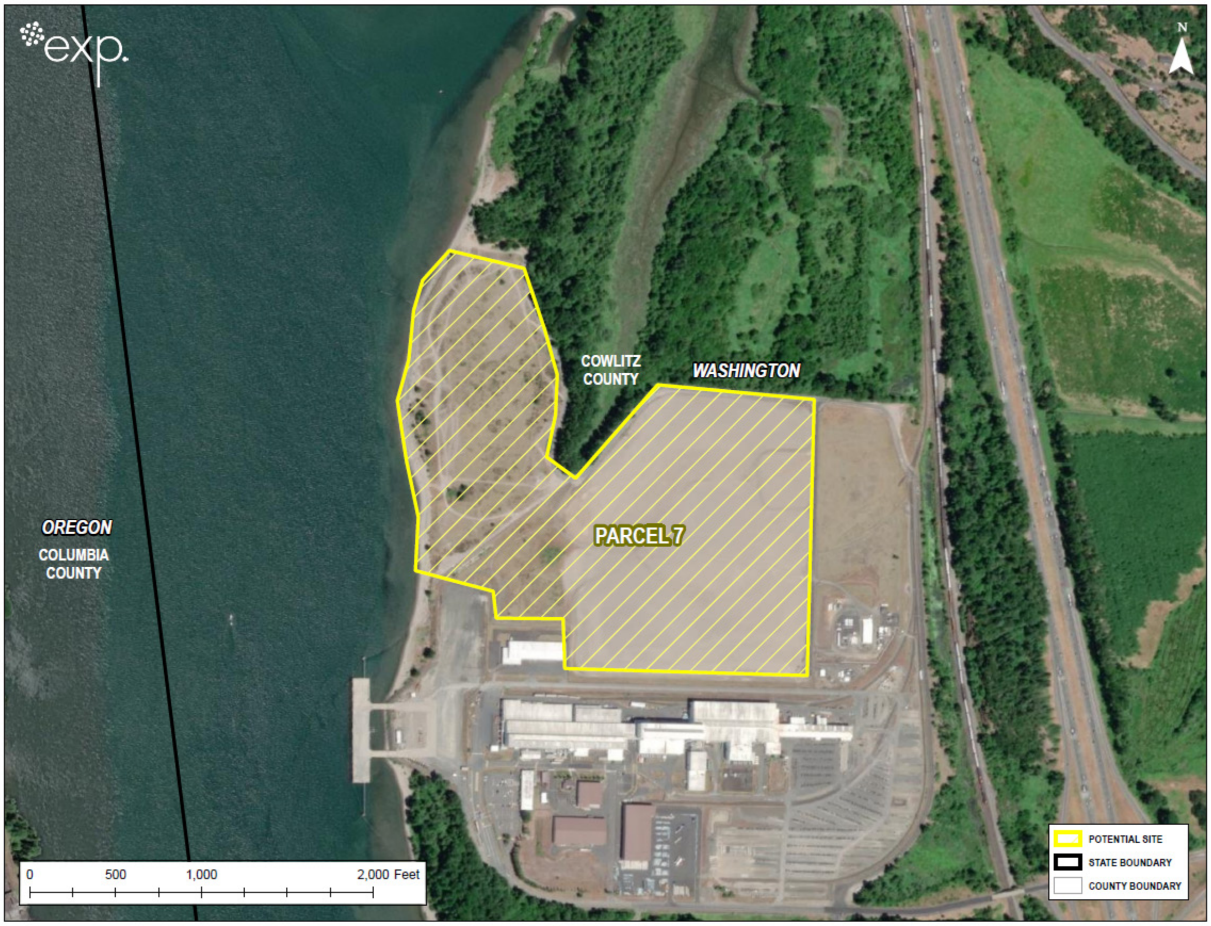
Figure 3.D.13: Light Green and Brown Areas Surrounding Parcel 7 Determined Suitable for Carbon Sequestration



[29] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[30] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources: https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Figure 3.D.14: Site Boundary of Parcel 7



CRITERIA	PARCEL 8
Space Availability *All parcels are in Klickitat County, WA	**Parcel 8-A** (45° 37' 55.622" N, 121° 8' 33.963" W) 20,702,859 ft², zone class GI, intended for general industrial practices. **Parcel 8-C** (45° 37' 3.480"N, 121° 8' 28.074" W) 3,884,069 ft², zone class IP, intended for industrial park uses. **Parcel 8-B** (45° 38' 26.874" N, 121° 9' 55.203" W) 288,549,630 ft², zone class IP, intended for industrial park uses. **Parcel 8-D** (45° 38' 23.698" N, 121° 7' 43.699" W) 57,977,229 ft², zone class IP, intended for industrial park uses.
Surrounding Infrastructure	• <u>Existing Vehicular Access:</u> The site is conveniently located near Highway 197 (which crosses the Columbia River) for travel North and South of the Washington and Oregon borders. It is also accessible to I-84 and Highway 14 for travel East and West along the Columbia River. • <u>Existing Rail Access</u>: Rail access is available inside parcel 8-A for the BNSF line. The Union Pacific rail line is located south across the Columbia River, just off highway 197. • <u>Existing Marine Access</u>: The site is located directly north of the Columbia River and is also central to the Dalles Dam on Columbia River. There are a couple of docks and storage lots (specifically, E Dock Rd) along the river's edge for ease of marine loading/offloading. • <u>Raw Water</u>: Is readily available since the site is located on the northern shoreline of the Columbia River. There are also small lakes and ponds on along the "shoreline." • <u>Electricity</u>: Due to the surrounding infrastructure, existing organizations, and proximity to civilization, it is presumed that the sight is provided with electricity.
Geological Conditions	**All Parcels** There is an abundance of basaltic flows and local volcaniclastic rock deposits. This site is presumed suitable for *in situ carbon remineralization* to sequester carbon.
Natural Gas Pipeline	**4 operators in Klickitat County:** • Avista Corporation • Klickitat PUD • Northwest Natural • Northwest Pipeline
Community Acceptance	**Parcels 8-A, 8-C, and 8-D** High supplemental demographic index score in the 75th percentile. **Parcel 8-B** High supplemental demographic index score in the 81st percentile.
Distance to Landfills	**From the Approx. Midpoint Coordinate between Parcel 8-A, 8-B, 8-C, & 8-D:** (45°37'49.5"N 121°08'50.1"W) <u>Roosevelt Regional Landfill</u>: 56.2 miles <u>Columbia Ridge Landfill</u>: 55.9 miles <u>Finley Buttes</u>: 95.0 miles <u>Cedar Hills</u>: 229 miles <u>LRI Landfill</u>: 183 miles

Parcel 8: Additional Information

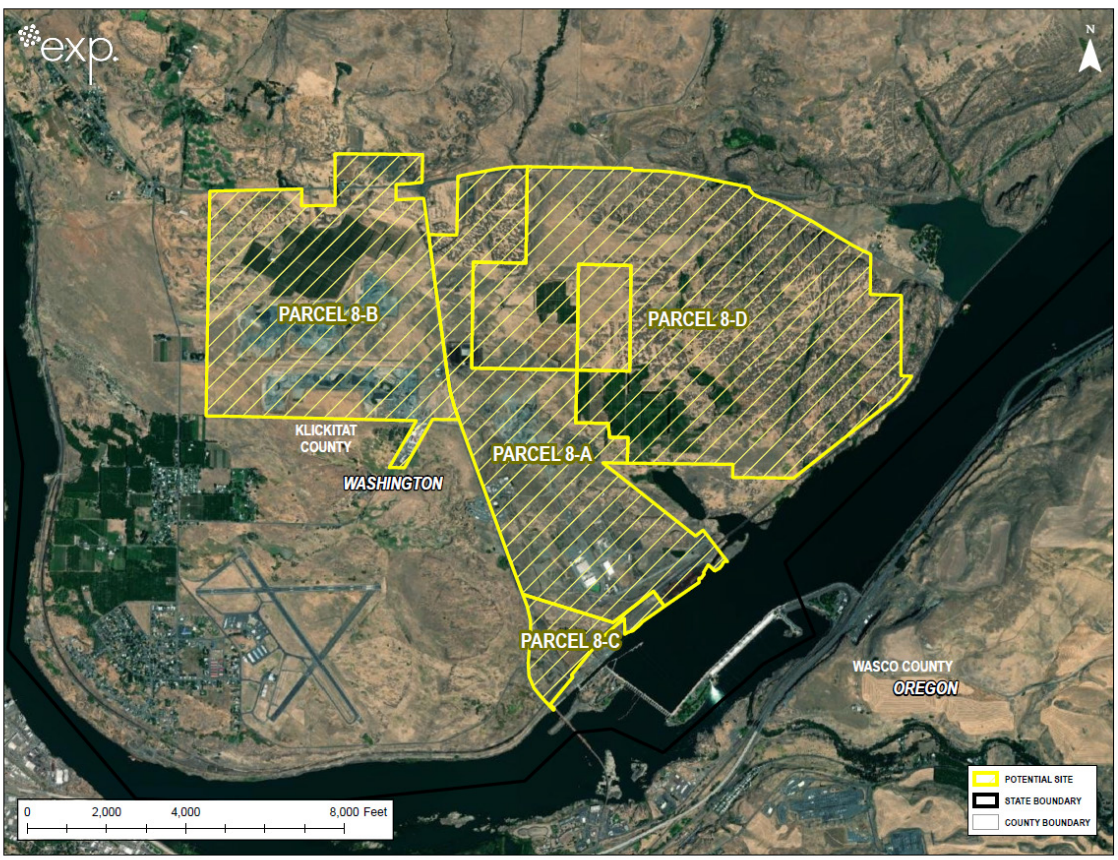
Surrounding Infrastructure

Raw Water: The site's location on the northern shoreline of the Columbia River ensures it will have access river water as well as raw water from small lakes and ponds on along the "shoreline," such as Hess Park, Joe's Lake, Spearfish Lake, Threemile Creek, and Little Spearfish Lake. The vast majority of the land cover is grasslands, shrubs, and various levels of development. [31]

Geological Conditions

Parcel 8-A, 8-B, 8-C, and 8-D lie on geological tertiary volcanic rocks and are part of the Columbia River Basalt Group. The WA DNR Geologic Information Portal describes the site to include, "Miocene generally fine-grained flood basalt flows; local invasive flood basalt sills and dikes, hyaloclastite, pillowed lava flows, and peperites; local intracanyon flows, saprolites, and pillow-palagonite complexes; local coarsely plagioclase-phyric flood basalt flows; feeder dikes in the Clarkston 1:100,000-scale quadrangle and neighboring areas; commonly interbedded with tuff-aceous sandstone, siltstone, and conglomerate, most of which are parts of the Ellensburg and Latah Formations." [32]

Figure 3.D.15: Site Boundary of Parcels 8-A, 8-B, 8-C and 8-D



[31] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[32] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources : https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

CRITERIA	PARCEL 9: Industrial Park
Space Availability	**Parcel 9-A** 15,877,151 ft² (45° 44' 5.726" N, 120° 14' 4.885" W) **Parcel 9-B** 4,455,570 ft² (45° 44' 53.515" N, 120° 12' 32.438" W) **Parcel 9-C** 2,132,605 ft² (45° 45' 16.569" N, 120° 11' 26.471" W) *All parcels are intended for industrial park purposes with a zone class of IP in Klickitat County, WA.

Surrounding Infrastructure	All Parcels
	• Existing Vehicular Access: Well located because highway WA-14 runs through all three sites for mainland transport.
	• Existing Rail Access: All three sites are in very close proximity to the BNSF railway line. It runs:
	  ○ Along the southern border of **9-A** (in between the site and the Columbia River)
	  ○ To the south of **9-B**
	  ○ Along the northern border of **9-C**
	• Existing Marine Access:
	  ○ **9-A and 9-C** are directly accessible since they border the Columbia River.
	  ○ **9-B** is slightly inland but, still in very close proximity to the river and likely has access.
	• Raw Water:
	  ○ An abundant supply of raw water from the Columbia River.
	  ○ A few spots of water and wetlands identified for parcels **9-A and 9-C**.
	  ○ Site 9-A appears to be agricultural land and would likely use a system with raw water for production
	  ○ **9-B** has indications of a stream or creek path, but it is unconfirmed whether the stream is dried.
	• Electricity: With surrounding infrastructure, civilization, and power lines, all three sites are likely to be provided with electricity.

Geological Conditions	**9-A:** Potentially has local volcaniclastic rock deposits, but no basaltic flows. **9-B and 9-C:** An abundance of basaltic flows and local volcaniclastic rock deposits. These portions of the site are presumed suitable for *in situ carbon remineralization* to sequester carbon.
Natural Gas Pipeline	4 operators in Klickitat County: • Avista Corporation • Klickitat PUD • Northwest Natural • Northwest Pipeline
Community Acceptance	All Parcels High supplemental demographic index score in the 68th percentile.
Distance to Landfills	**From the Approx. Midpoint Coordinate between Parcel 9-A, 9-B, & 9-B:** (45°44'38.4"N 120°13'15.2"W) Roosevelt Regional Landfill: 5.3 miles Columbia Ridge Landfill: 70.4 miles Finley Buttes: 82.1 miles Cedar Hills: 221 miles LRI Landfill: 242 miles

Parcel 9: Additional Information

Surrounding Infrastructure

Raw Water: Majority of the landcover for all parcels is consumed by cultivated crops, shrubs, grasslands, pasture, and all levels of development.[33]

Geological Conditions

Parcel 9-A lies on a couple of different geological identifications. The site is occupied by Quaternary loess, as well as Quaternary alluvium. The WA DNR Geologic Information Portal describes the site to include:

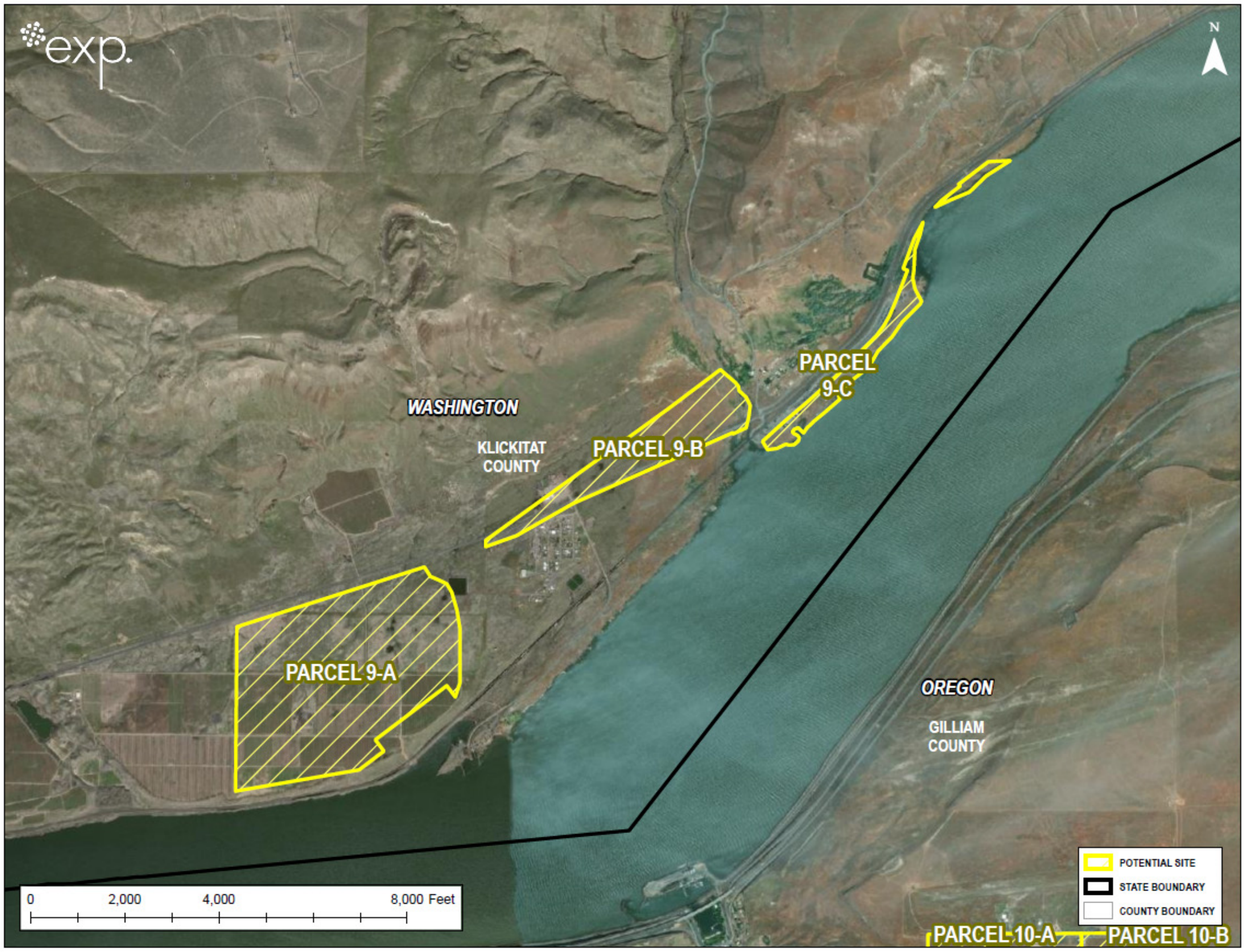
- "Quaternary eolian silt and fine sand; includes clay, caliche, tephra, and paleosols; locally includes outburst flood deposits."
- "Quaternary unconsolidated or semi consolidated alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes peat, muck, and diatomite; locally includes beach, dune, lacustrine, estuarine, marsh, landslide, lahar, glacial, or colluvial deposits; locally includes volcaniclastic or tephra deposits; locally includes modified land and artificial fill."
- Parcels 9-B and 9-C also lie on a couple of different geological identifications. These parcels are occupied by Quaternary alluvium and tertiary volcanic rocks and are part of the Columbia River Basalt Group. The WA DNR Geologic Information Portal describes this part of the site to include:
- "Miocene generally fine-grained flood basalt flows; local invasive flood basalt sills and dikes, hyaloclastite, pillowed lava flows, and peperites; local intracanyon flows, saprolites, and pillow-palagonite complexes; local coarsely plagioclase-phyric flood basalt flows; feeder dikes in the Clarkston 1:100,000-scale quadrangle and neighboring areas; commonly interbedded with tuff- aceous sandstone, siltstone, and conglomerate, most of which are parts of the Ellensburg and Latah Formations." [34]
- "Quaternary unconsolidated or semi consolidated alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes peat, muck, and diatomite; locally includes beach, dune, lacustrine, estuarine, marsh, landslide, lahar, glacial, or colluvial deposits; locally includes volcaniclastic or tephra deposits; locally includes modified land and artificial fill." [35]

[33] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[34] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources: https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

[35] *Geology GIS Data and Databases*. (n.d.). Retrieved from Washington State Department of Natural Resources: https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Figure 3.D.16: Site Boundary of Parcels 9-A, 9-B and 9-C



CRITERIA	PARCEL 10: Arlington
Space Availability	**Parcel 10-A** (45° 43' 1.596" N, 120° 10' 41.903" W) 5,778,606 ft^2, intended for land intensive industrial uses, with a zone class of M2 in Gilliam County, OR. **Parcel 10-B** (45° 42' 46.348" N, 120° 9' 59.663" W) 13,342,127 ft^2, intended for industrial uses, with a zone class of M1 in Gilliam County, OR.

Surrounding Infrastructure	Both Parcels
	• Existing Vehicular Access: Interstate 84 access points are only 3.3 miles from the property.
	• Existing Rail Access:
	  ○ The site offers close proximity (within 8 miles) to an active Union Pacific Railroad spur that services Shutler Station
	  ○ Arlington Spur, a shorter sub spur only three cars in length, is available 3.2 miles from site.
	  ○ The final railroad in relatively the same proximity is the Palouse River & Coulee City line, which runs south to Condon.[36]
	• Existing Marine Access: The site is located approximately 4.2 miles to the Columbia River barge system with a 10-minute approximate travel time.[37]
	• Raw Water: Sites are relatively close to the Columbia River. There is no raw water at the surface level of either site.
	• Electricity: Power is provided by Pacific Power.

Geological Conditions	Both Parcels An abundance of basaltic flows and local volcaniclastic rock deposits. This site is presumed suitable for *in situ carbon remineralization* to sequester carbon. Parcels 10-A and 10-B lie on the geological Columbia River Basalt Group. The DOGAMI Interactive Map of Geospatial Data describes this particular site to include, "Basalt and basaltic andesite lava flows; the most widely distributed geologic unit in the Pacific Northwest. Many individual flows were immense, covering large parts of eastern Oregon and Washington and western Idaho, and several flows traveled over 400."[38]
Natural Gas Pipeline	1 operator in Gilliam County: • Gas Transmission Northwest LLC Pipeline
Community Acceptance	Both Parcels Supplemental demographic index score in the 51st percentile.
Distance to Landfills	**From the Approx. Midpoint Coordinate between Parcel 10-A, and 10-B:** (45°43'07.4"N 120°10'13.1"W) Roosevelt Regional Landfill: 76.5 miles Columbia Ridge Landfill: 11.9 miles Finley Buttes: 42.6 miles Cedar Hills: 250 miles LRI Landfill: 271 miles

[36] Mitchel, 2013. Arlington Mesa Industrial Park, Intermodal, pp.5.

Parcel 10: Additional Information

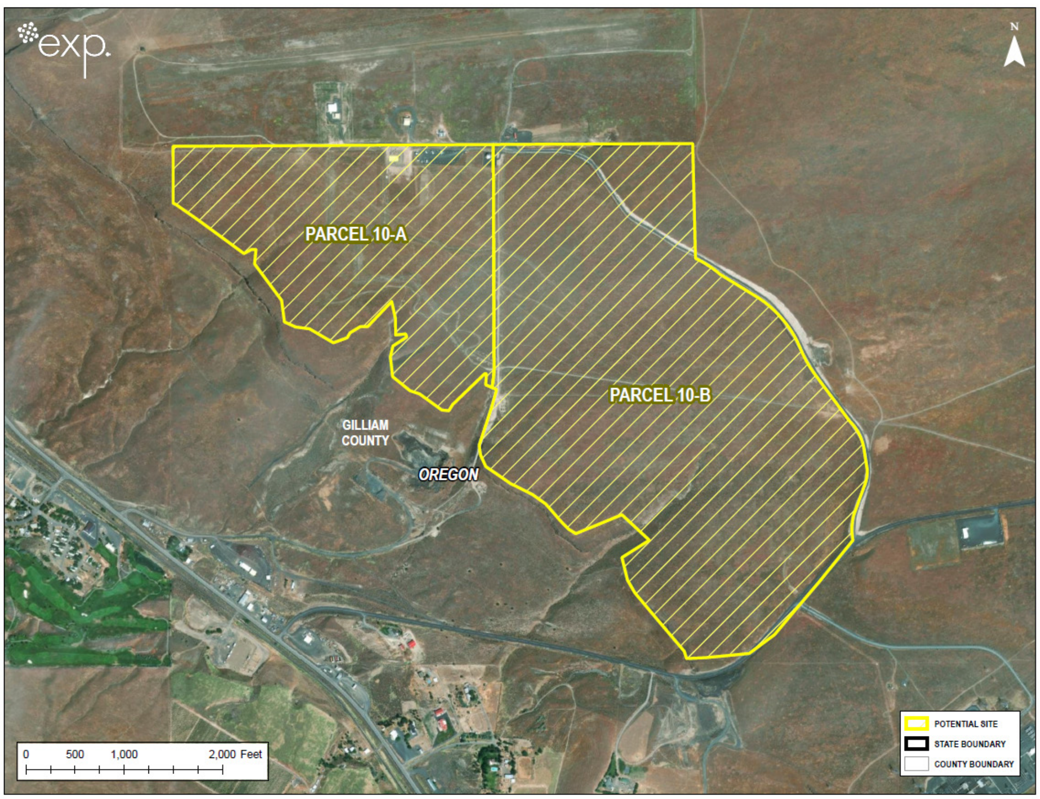
Surrounding Infrastructure

Existing Vehicular Access: Interstate 84 access points are only 3.3 miles from the property and offer quick travel to Tri-Cities (1.1 hours), Portland (2.0 hours), Seattle (3.5 hours), and Boise (4.5 hours). It is noteworthy that Interior truck routes keep major California markets within a day's drive. Uncongested travel makes trips throughout the vicinity very efficient.[39]

Raw Water: The general land cover indicates a vast space of grasslands and shrubs.[40]

Electricity: A Power Study has been completed for 250MW redundant service from Slatt Substation, which receives power from 5 separate top tier power generation facilities including John Day and McNary Dams, Coyote Springs gas plant, Boardman coal plant. In addition, several wind farms, including Sheppard's Flat wind farm (the world's largest), provide power direct capacity to the site. Wind energy generation came to Gilliam County in 2001 with the Condon Wind Farm and has since expanded to more than 1,257 MW generation capacity from 683 turbines. Shepard's Flat adds substantial power generation to the grid. More than 3,000 MW of wind energy generation is currently planned or proposed for construction. Other innovative renewable, industrial sized, energy firms have located in the county including S4 and Waste Management. Fiber Optic conduit is already installed throughout Arlington Mesa Industrial Park.[41]

Figure 3.D.17: Site Boundary of Parcels 10-A and 10-B



[37] Mitchel, 2013. Arlington Mesa Industrial Park, Intermodal, pp.5.

[38] *Geologic Map of Oregon* . (n.d.). Retrieved from https://gis.dogami.oregon.gov/maps/geologicmap/.

[39] Mitchel, 2013. Arlington Mesa Industrial Park. Access, pp.4.

[40] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[41] Mitchel, 2013. Arlington Mesa Industrial Park, Utilities, Power, pp.9.

CRITERIA	PARCEL 11: Waste Management
Space Availability	**Parcel 11-A** (45° 37' 20.979" N, 120° 15' 17.549" W) 13,863,216 ft^2 **Parcel 11-B** (45° 37' 20.603" N, 120° 15' 54.120" W) 13,547,234 ft^2 **Parcel 11-C** (45° 37' 34.404" N, 120° 14' 35.466" W) 38,721,650 ft^2 **Parcel 11-D** (45° 37' 2.909" N, 120° 14' 43.880" W) 2,015,990 ft^2 *All parcels are intended for general industrial practices, with a zone class of M-G in Gilliam County, OR.

Surrounding Infrastructure	All Parcels
	• Existing Vehicular Access: The site has existing infrastructure for smooth vehicular transport, accompanied by paved lots for parking, trucking, etc.
	• Existing Rail Access:
	  ○ The site is near site 12 so one might be able to utilize the same railroad spurs.
	  ○ The Palouse River & Coulee City line runs just south of this site and connects to the Union Pacific line near Arlington.
	• Existing Marine Access: All sites are landlocked so there is no direct marine access. The closest marine access points are the Port of Arlington and Port of Morrow.
	• Raw Water: Not readily available.
	  ○ No surface level bodies of water such as creeks, streams, etc. exist on site.
	  ○ There are two potential pond plots in site 11-A boundaries.
	  ○ This site is a low rainfall area, averaging only 8 inches annually.
	• Electricity: Due to existing infrastructure and current occupant, it assumed that electricity is served to the site.

Geological Conditions	All Parcels There is an abundance of basaltic flows and local volcaniclastic rock deposits. This site is presumed suitable for *in situ carbon remineralization* to sequester carbon.
Natural Gas Pipeline	1 operator in Gilliam County: • Gas Transmission Northwest LLC Pipeline
Community Acceptance	All Parcels Supplemental demographic index score in the 51st percentile.
Distance to Landfills[42]	From the Approx. Midpoint Coordinate between Parcel 11-A, 11-B, 11-C, & 11-D: 45°37'18.9"N 120°15'08.7"W Roosevelt Regional Landfill: 76.7 miles Columbia Ridge Landfill: 1.6 miles Finley Buttes: 47.9 miles Cedar Hills: 251 miles LRI Landfill: 271 miles

Parcel 11: Additional Information

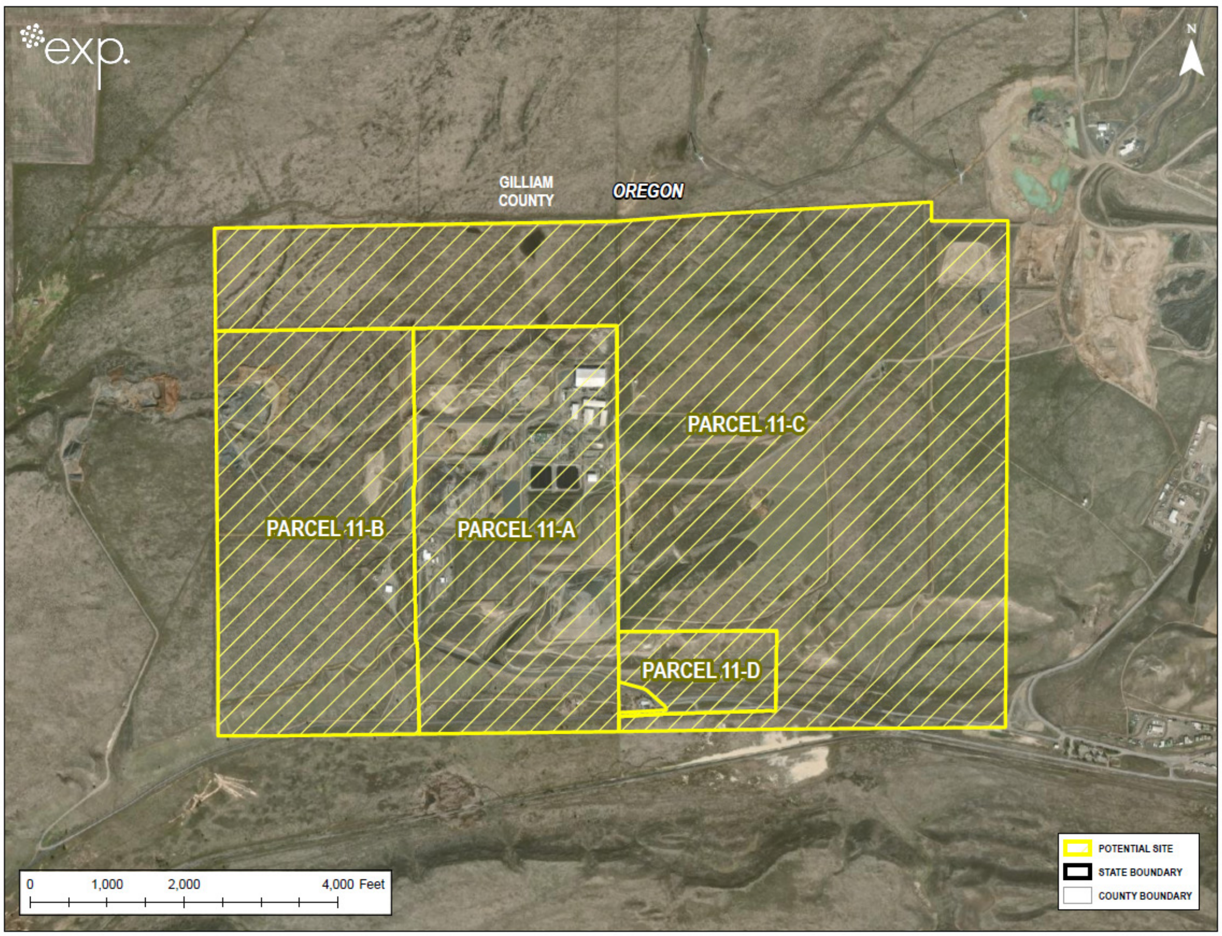
Surrounding Infrastructure

Raw Water: The general land cover is mainly consumed by grasslands, shrubs, and various levels of development.[43]

Geological Conditions

Parcels 11-A, 11-B, 11-C, and 11-D all lie on both, geological Alkali Canyon Formation as well as the Columbia River Basalt Group terrains. The DOGAMI Interactive Map of Geospatial Data describes this particular site to include: "Sedimentary rocks interbedded with Saddle Mountains Basalt flows near Pendleton... Basalt and basaltic andesite lava flows; the most widely distributed geologic unit in the Pacific Northwest. Many individual flows were immense, covering large parts of eastern Oregon and Washington and western Idaho, and several flows traveled over 400." [44]

Figure 3.D.18: Site Boundary of Parcels 11-A, 11-B, 11-C and 11-D



[42] *Columbia Ridge Landfill and Green Energy Plant*. (n.d.). Retrieved from WM: https://www.wmnorthwest.com/landfill/columbiaridge.htm.

[43] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[44] *Geologic Map of Oregon* . (n.d.). Retrieved from https://gis.dogami.oregon.gov/maps/geologicmap/.

CRITERIA	PARCEL 12: Shutler Station
Space Availability	14,110,071 ft², intended for intermodal industrial purposes with a zone class of II in Gilliam County, OR. (45° 37' 37.651" N, 120° 10' 6.881" W)

Surrounding Infrastructure	• Existing Vehicular Access: The site is accessible by vehicles from the John Day Highway leading to I-84.
	• Existing Rail Access: The site allows unit trains to maneuver onsite to offload, store, & stage products.
	  ○ The site borders the Palouse River & Coulee City railway line to the north.
	  ○ The Shutler Station is available onsite.
	  ○ The Arlington Spur on Highway 19 is approximately 7 miles from site.
	• Existing Marine Access: There is no direct marine access onsite is available.
	  ○ The northern end of the site is roughly 7.4 miles south of the Columbia River.
	  ○ The Port of Arlington is located 7 miles away and the Port of Morrow is 27.4 miles away.
	• Raw Water: No identified raw water at the surface level and the area experiences low rainfall with an average of 8 inches annually.
	  ○ Shutler Station is served by two wells, each rated at over 90 gallons per minute with 390,000 gallons of water storage at the park.
	• Electricity: Onsite windmills for renewable power generation.
	  ○ Site is located in close proximity to major electrical power transmission lines.
	  ○ Fiber optic cable is available on site. Service can be provided to the site by Wind Wave Communication
	  ○ Waste Management's methane generation unit supplies 16 MW of power 24/7 to grid intertie adjacent to the site for reliable renewable generation in addition to "grid power."

Geological Conditions	Shows to have an abundance of basaltic flows and local volcaniclastic rock deposits. This site is presumed suitable for *in situ carbon remineralization* to sequester carbon.
Natural Gas Pipeline	1 operator in Gilliam County: • Gas Transmission Northwest LLC Pipeline
Community Acceptance	Supplemental demographic index score in the 51st percentile.
Distance to Landfills	From Coordinate (45° 37' 37.651" N, 120° 10' 6.881" W) Roosevelt Regional Landfill: 80.1 miles Columbia Ridge Landfill: 3.7 miles Finley Buttes: 42.6 miles Cedar Hills: 254 miles LRI Landfill: 275 miles

Parcel 12: Additional Information

Surrounding Infrastructure

Existing Vehicular Access: Shutler Station Industrial Park's central location offers convenient travel to Portland, Seattle, Boise, Salt Lake City, Kennewick, Pasco, and Richland. It is noteworthy that interior truck routes keep major California markets within a day's drive. Uncongested travel makes trips throughout the vicinity very efficient.[45]

- Portland - 136 miles
- Seattle - 257 miles
- Salt Lake City - 630 miles
- Boise - 294 miles
- Tri-Cities - 77 miles
- San Francisco - 661 miles
- Bend - 170 miles
- Spokane - 217 miles

Existing Rail Access: The site borders the Palouse River & Coulee City railway line to the north. The railway line has two (2) rail spurs off short line each approximately 4,400 ft long. Additional track or storage space is feasible. There is the Shutler Station serviced by the Union pacific Railroad spur through Watco companies, with no travel necessary. Then the Arlington Spur on Highway 19, relatively 7 miles from the site with an approximate 8 minutes of travel time. The site itself allows unit trains to maneuver onsite to offload, store, and stage products including wind turbine components. [46]

Raw Water: The general land cover includes cultivated crop, grasslands, and a few spots with development. [47]

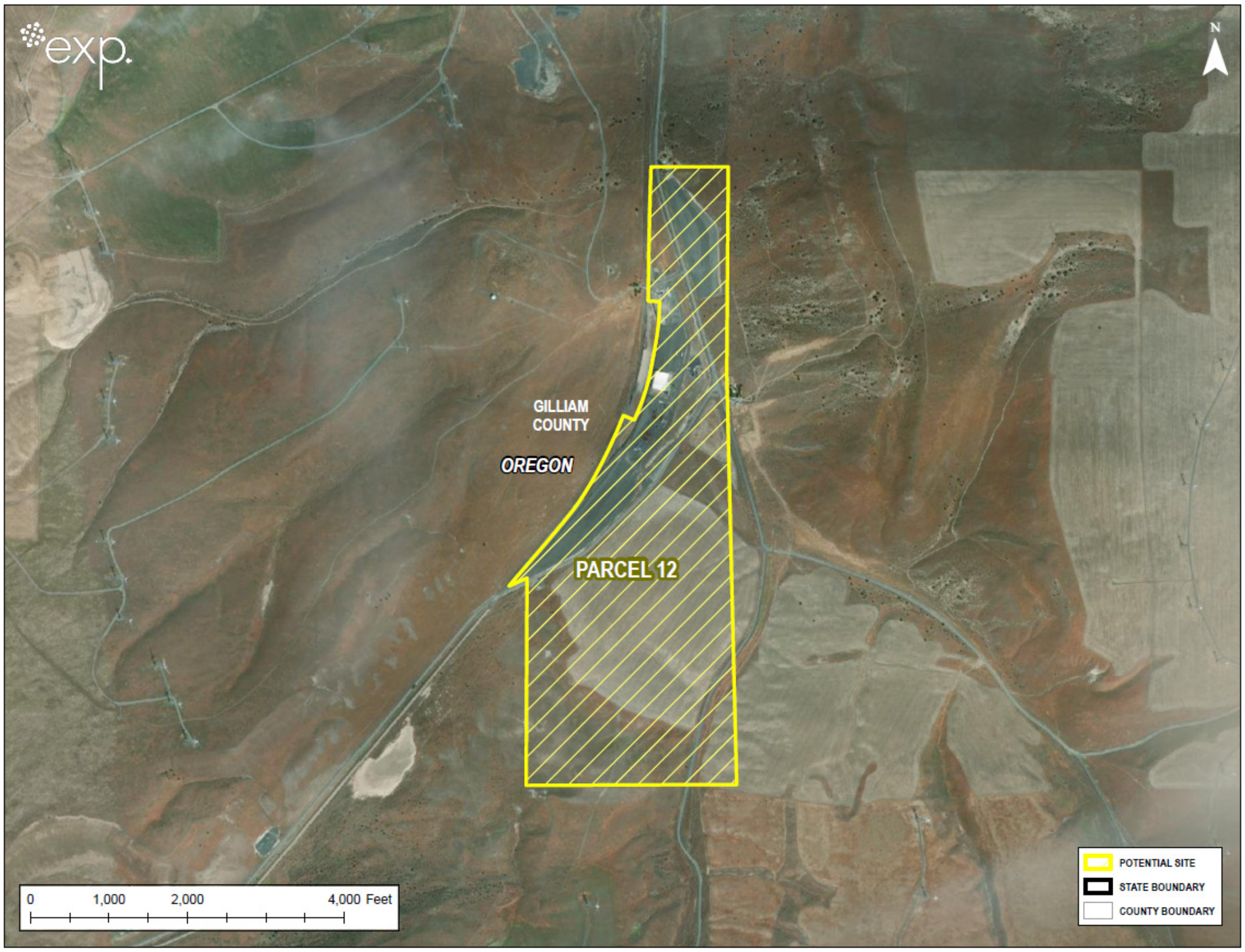
Electricity: Columbia Basin Electric Cooperative supplies power to the park; current power availability is 5 megawatts with room for additional expansion with demand.[48]

Geological Conditions

Parcel 12 lies on the geological Columbia River Basalt Group. The DOGAMI Interactive Map of Geospatial Data describes this site to include, "Basalt and basaltic andesite lava flows; the most widely distributed geologic unit in the Pacific Northwest. Many individual flows were immense, covering large parts of eastern Oregon and Washington and western Idaho, and several flows traveled over 400." [49]

[45] Mitchel, 2012. Shutler Station Industrial Park, Access, pp.4.
[46] Mitchel, 2012. Shutler Station Industrial Park, Intermodal, pp.5.
[47] Mitchel, 2012. Shutler Station Industrial Park, Intermodal, pp.5.
[48] Mitchel, 2012. Shutler Station Industrial Park, Utilities, Power, pp.9.
[49] *Geologic Map of Oregon* . (n.d.). Retrieved from https://gis.dogami.oregon.gov/maps/geologicmap/.

Figure 3.D.19: Site Boundary of Parcel 12



CRITERIA	PARCEL 13: Port of Morrow
Space Availability	**Parcel 13-A** (45° 51' 19.730" N, 119° 37' 30.385" W) 65,515,708 ft^2 **Parcel 13-B** (45° 51' 27.895" N, 119° 39' 22.956" W) 27,290,817 ft^2 *Both sites are intended for industrial port activities, with a zone class of PU in Morrow County, OR.

Surrounding Infrastructure	Both Parcels
	• Existing Vehicular Access: An excellent location for vehicular transport.
	  ○ Site 13-A is adjacent to US-730 and in close proximity to Interstate 84.
	  ○ Both sites are equipped with existing lots for parking, loading, and offloading of materials.
	• Existing Rail Access: The site includes a rail spur from the Union Pacific railway line. The spur consists of a rail loop (Rail Loop Drive) for convenient loading, offloading, and storage
	• Existing Marine Access:
	  ○ **Site 13-A**: No, since it is located adjacent to, but inland of, site 13-B.
	  ○ **Site 13-B:** Yes, since it borders the Columbia River.
	• Raw Water: There are water plots on both sites.
	  ○ **Site 13-B** also has access to a bay-like feature with water from the Columbia River.
	
	Electricity: Site 13-B is directly adjacent to the Portland General Electric utility company facility. Due to existing infrastructure on both sites, and this proximity, it is the assumption that electricity accompanies this property.

Geological Conditions	Both Parcels No basaltic flows or volcanic rock properties suitable for *in situ carbon remineralization* to sequester carbon. However, there is an opportunity to sequester carbon in the surrounding areas.
Natural Gas Pipeline	3 operators in Morrow County: • Cascade natural Gas Corp. Pipeline • Gas Transmission Northwest LLC Pipeline • Lamb Weston, INC. Pipeline
Community Acceptance	Both Parcels Supplemental demographic index score in the 74th percentile.
Distance to Landfills	From the Approx. Midpoint Coordinate between Parcel 13-A and 13-B: 45°51'29.9"N 119°38'28.6"W Roosevelt Regional Landfill: 72.2 miles Columbia Ridge Landfill: 40.8 miles Finley Buttes: 16.1 miles Cedar Hills: 241 miles LRI Landfill: 266 miles

Parcel 13: Additional Information

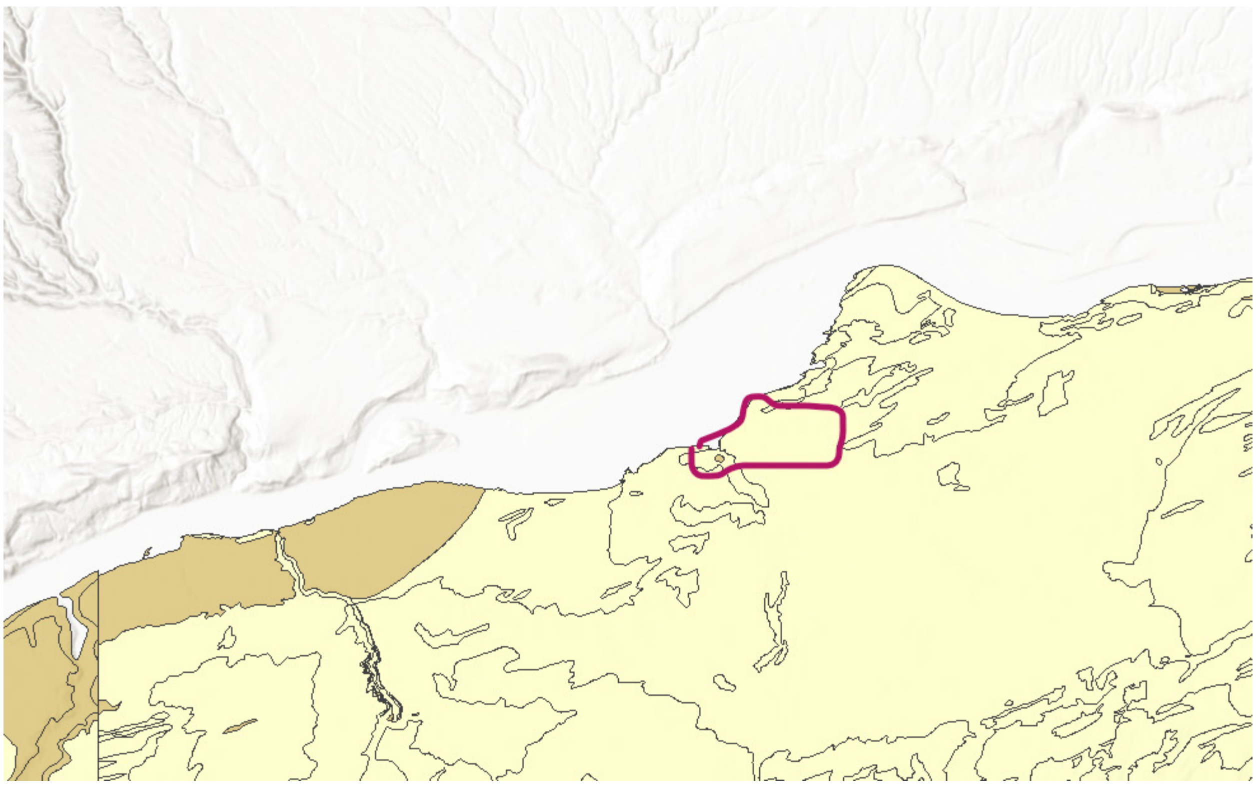
Surrounding Infrastructure

Raw Water: The site itself has majority of its land cover consumed with cultivated crops, development, open water and a few emergent and herbaceous wetland areas.[50]

Geological Conditions

Parcels 13-A and 13-B lie on a geologic Quaternary. The DOGAMI Interactive Map of Geospatial Data describes this site to include, "Deposits of unconsolidated sediments. Includes alluvium, colluvium, river and coastal terrace, landslide, glacial, eolian, beach, lacustrine, playa and pluvial lake deposits, and outburst flood deposits left by the Missoula and Bonneville floods."[51]

Figure 3.D.20: The Light Brown Areas in the Surroundings of Parcel 13 are Suitable for Carbon Sequestration



[50] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

[51] *Geologic Map of Oregon* . (n.d.). Retrieved from https://gis.dogami.oregon.gov/maps/geologicmap/.

Figure 3.D.21: Site Boundary of Parcels 13-A and 13-B

CRITERIA	PARCEL 14: Pasco Tidewater Terminal
Space Availability	6,570,334 ft^2, located in Franklin County, WA, and is intended for industrial activity. (46° 13' 22.545" N, 119° 1' 10.927" W)

Surrounding Infrastructure	• Existing Vehicular Access: Ease of access for vehicular transport since the site is directly adjacent to US-12 which is interconnected with multiple major highways in many various directions.
	• Existing Rail Access:
	  ○ Site lies on the BNSF rail line & includes a few rail spurs for stops to load, unload, and store cargo.
	  ○ Nearby railroad stations also include Amtrak Pasco Station (Washington Intermodal), Burlington Northern Santa Fe, and Watco Company.
	• Existing Marine Access: Readily available since the site resides on Snake River just 2 miles away from the Columbia River. Both waterways are connected.
	• Raw Water: None apart from the marine access to Snake River.
	• Electricity: Current occupants serve a water treatment plant. Water treatment requires electricity so the site must have access to a utility provider.

Geological Conditions	No basaltic flows or volcanic rock properties suitable for *in situ carbon remineralization* to sequester carbon. Parcels 14 lies on a geologic Pleistocene outburst flood deposit area. The WA DNR Geologic Information Portal describes the site to include "Pleistocene gravel and sandy gravel deposits with interbedded silt lenses; deposited as benches along the main stem of the Snake River as a result of rapid draining of glacial Lake Bonneville; also, widespread silt, sand, gravel, and boulder deposits deposited during multiple catastrophic drainings of glacial Lake Missoula; includes glaciolacustrine deposits."[52]
Natural Gas Pipeline	5 operators in Franklin County: • Avista Corporation • Cascade natural Gas Corp. Pipeline • Marathon Pipeline West • Northwest Pipeline • Tidewater Terminal Company
Community Acceptance	Supplemental demographic index score in the 53rd percentile.
Distance to Landfills	From Coordinate (46° 13' 22.545" N, 119° 1' 10.927" W) Roosevelt Regional Landfill: 85.5 miles Columbia Ridge Landfill: 96.9 miles Finley Buttes: 67.3 miles Cedar Hills: 209 miles LRI Landfill: 241 miles

[52] *Geology GIS Data and Databases.* (n.d.). Retrieved from Washington State Department of Natural Resources : https://www.dnr.wa.gov/programs-and services/geology/publications-and-data/gis-data-and-databases.

Parcel 14: Additional Information

Surrounding Infrastructure

Raw Water: The majority of the land cover is medium to high development with surrounding grassland.[53]

Figure 3.D.22: Site Boundary of Parcel

[53] *NEPAssist*. (n.d.). Retrieved from EPA: https://nepassisttool.epa.gov/nepassist/nepamap.aspx.

E

TASK 3 – APPENDIX E | SENSITIVITY ANALYSIS

Task 3 - Appendix E | Sensitivity Analysis

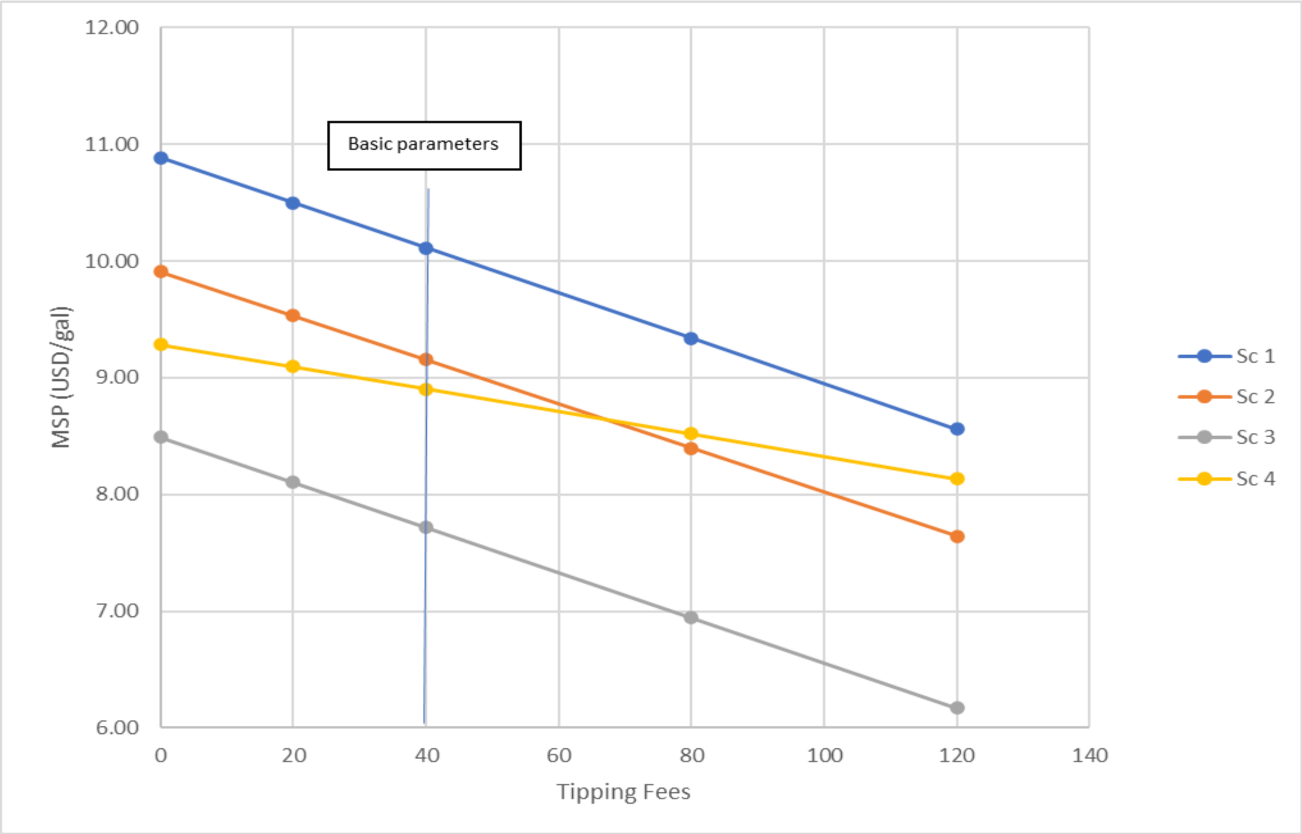
A sensitivity analysis allows for better understanding of the impact of possible deviations and fluctuations of major parameters on the resulting MSP of SAF. The following graphics enable a quantification of the risks and benefits associated with changes in the specific cost item.

3.E.1. Tipping Fees

Changes in tipping fees have a significant impact on the MSP and an increase would help make renewable fuel more competitive provided all other cost factors remain unchanged. The product yields for Scenarios 1, 2 and 3 result in a similar impact of changes in tipping fees. Scenario 4 has a higher yield, i.e., needs less MSW per gallon of fuel and is therefore less sensitive to changes in tipping fees.

Fuel costs could be reduced by up to 75 cents per gallon when increasing the tipping fees for RDF from $40 to $80 per ton, or the costs and consequently the MSP could increase by up to 78 cents if no tipping fee could be charged.

Figure 3.E.1: Tipping Fees

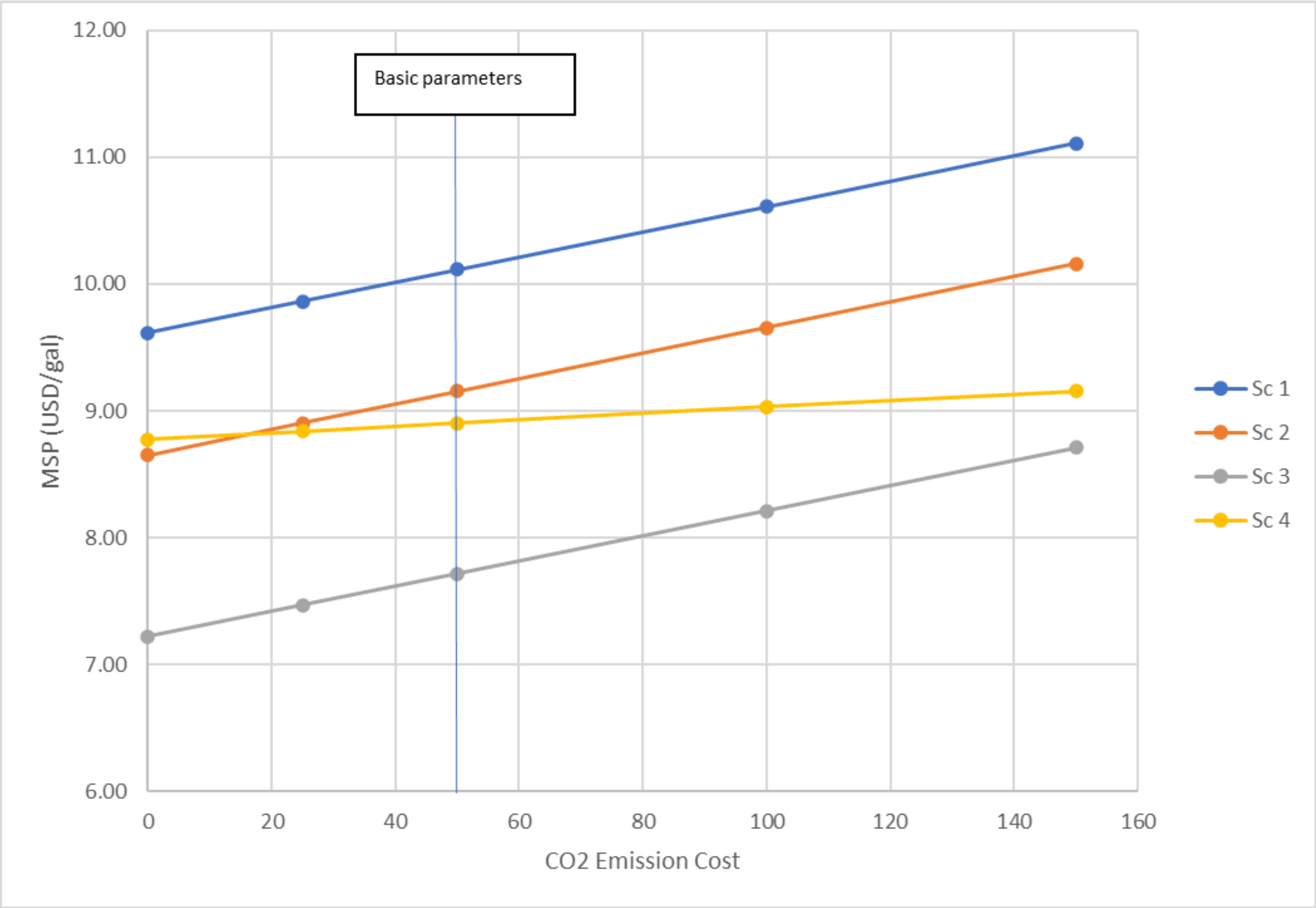


3.E.2. CO_2 Emission Costs

The specific CO_2 emissions are similar for Scenarios 1, 2 and 3 resulting in a similar impact of changes in CO_2 emission costs. Scenario 4 has lower specific CO_2 emissions and is therefore less sensitive to changes in CO_2 emission costs.

It is expected that the cost for CO_2 emissions will increase over the next years and $100 to $150 per ton of emitted CO_2 could be reached during the lifetime of the plant. This would result in about one dollar of additional cost per gallon of fuel if no other measures like CCUS or yield increase by adding renewable hydrogen were taken.

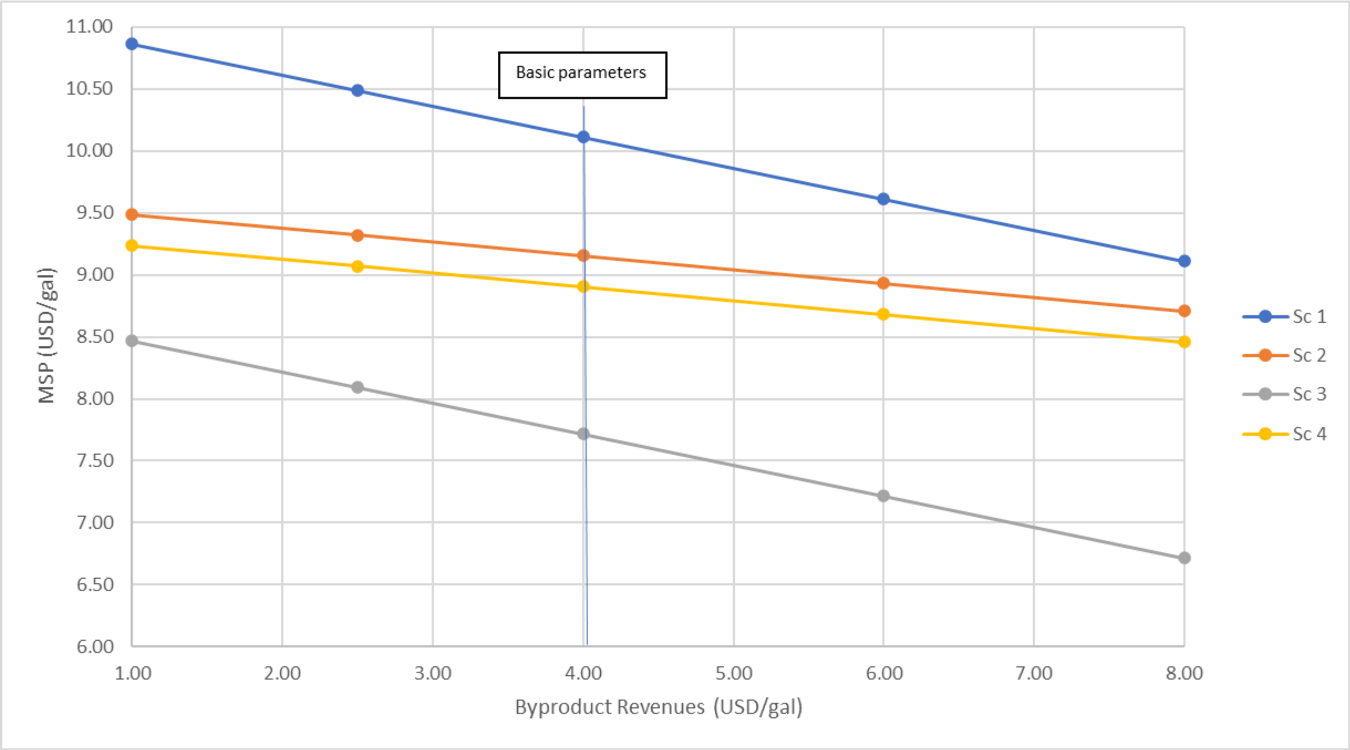
Figure 3.E.2: CO_2 Emission Costs



3.E.3. By-product Revenues

The revenues from by-products are a significant portion of the cost and revenue streams, and the risks of change in the prices of these by-products should not be ignored. The FT process (Scenarios 1 and 3) generates about 20% by-products and is more sensitive to changes in by-product revenues than the ATJ process (Scenarios 2 and 4) with only 10% by-products.

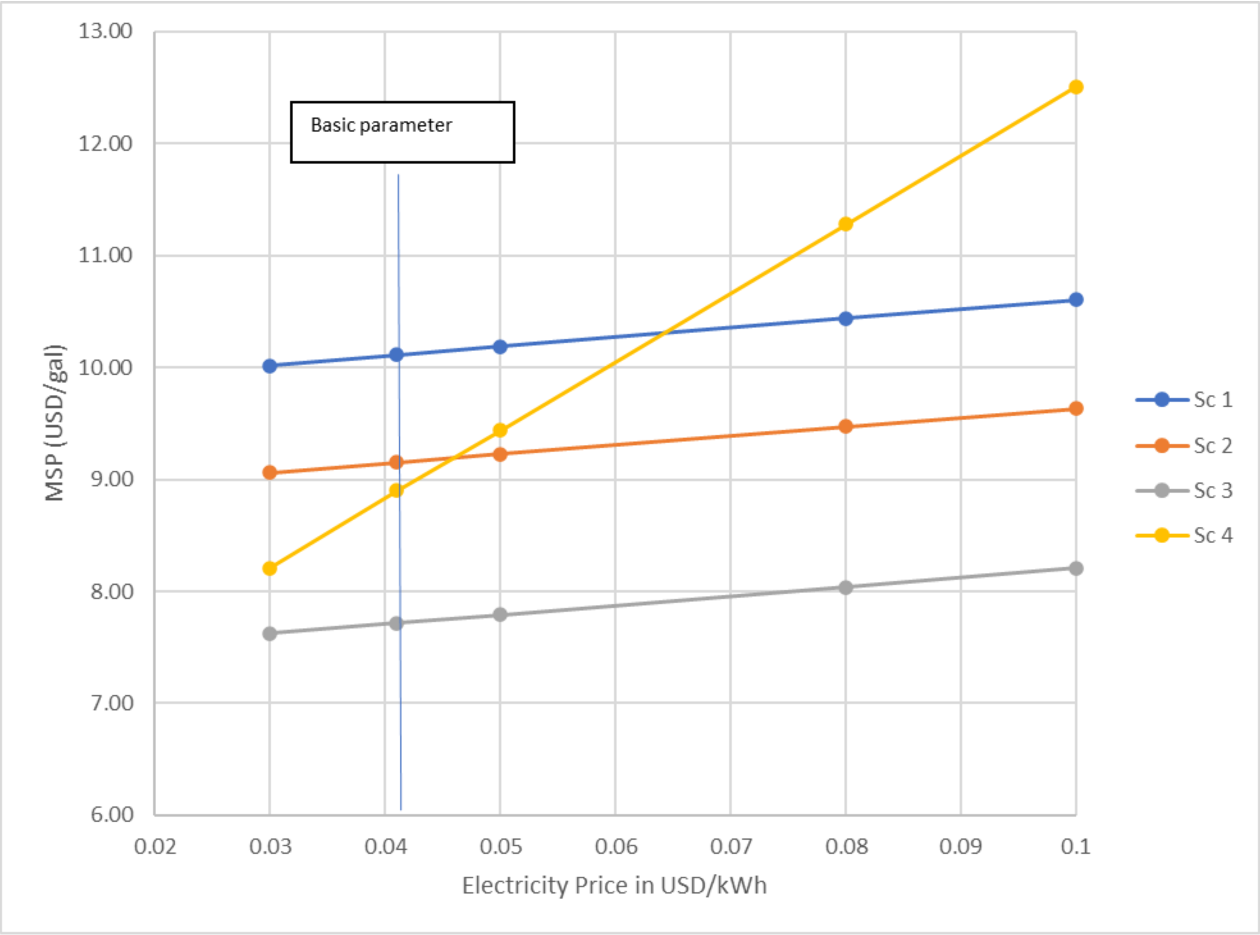
Figure 3.E.3: By-product Revenues



3.E.4. Electricity

A low electricity price is beneficial for making the fuel competitive. This is applicable for Scenario 4 which models a plant that increases the yield by adding renewable hydrogen from water electrolysis. This plant concept is very sensitive to changes in the price of electricity. Two requirements are mandatory to make Scenario 4 viable: The electricity for the water electrolysis has to be produced from renewable sources, and the price of electricity must be low. If these two requirements cannot be fulfilled on a long-term basis, a process with CCUS should be favored.

Figure 3.E.4: Electricity

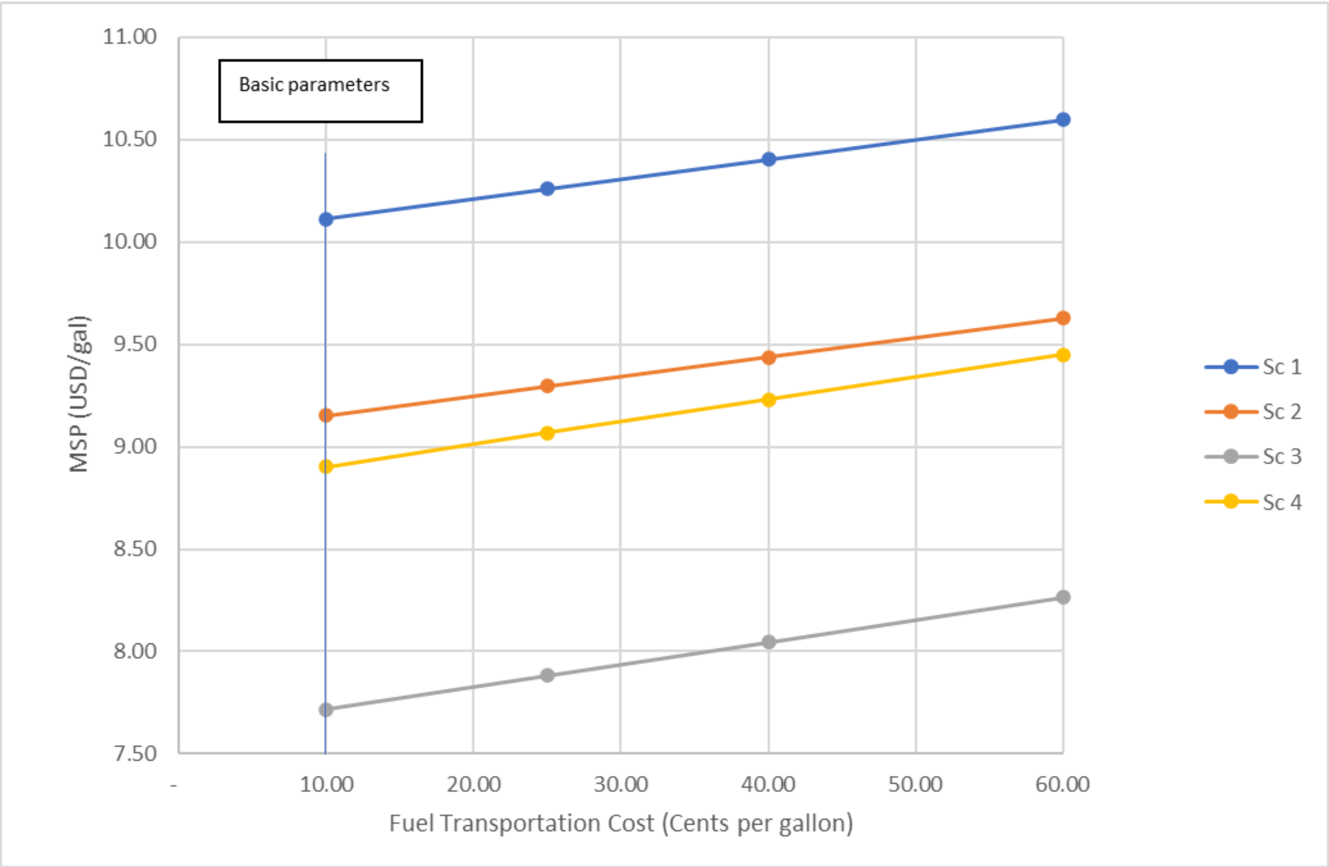


3.E.5. Transportation Costs

Our logistics study showed that the lowest cost option uses rail transportation with around 10 cents per gallon fuel transportation costs. Around 25 cents per gallon could be expected for a mixed barge and truck transportation and the costs further increase to around 40 cents per gallon for truck only transportation from a production site at the Columbia River to a blending station close to Seattle airport. This can increase the MSP by up to 50 cents per gallon.

This sensitivity analysis looks at these different costs as well as assumes a further cost increase.

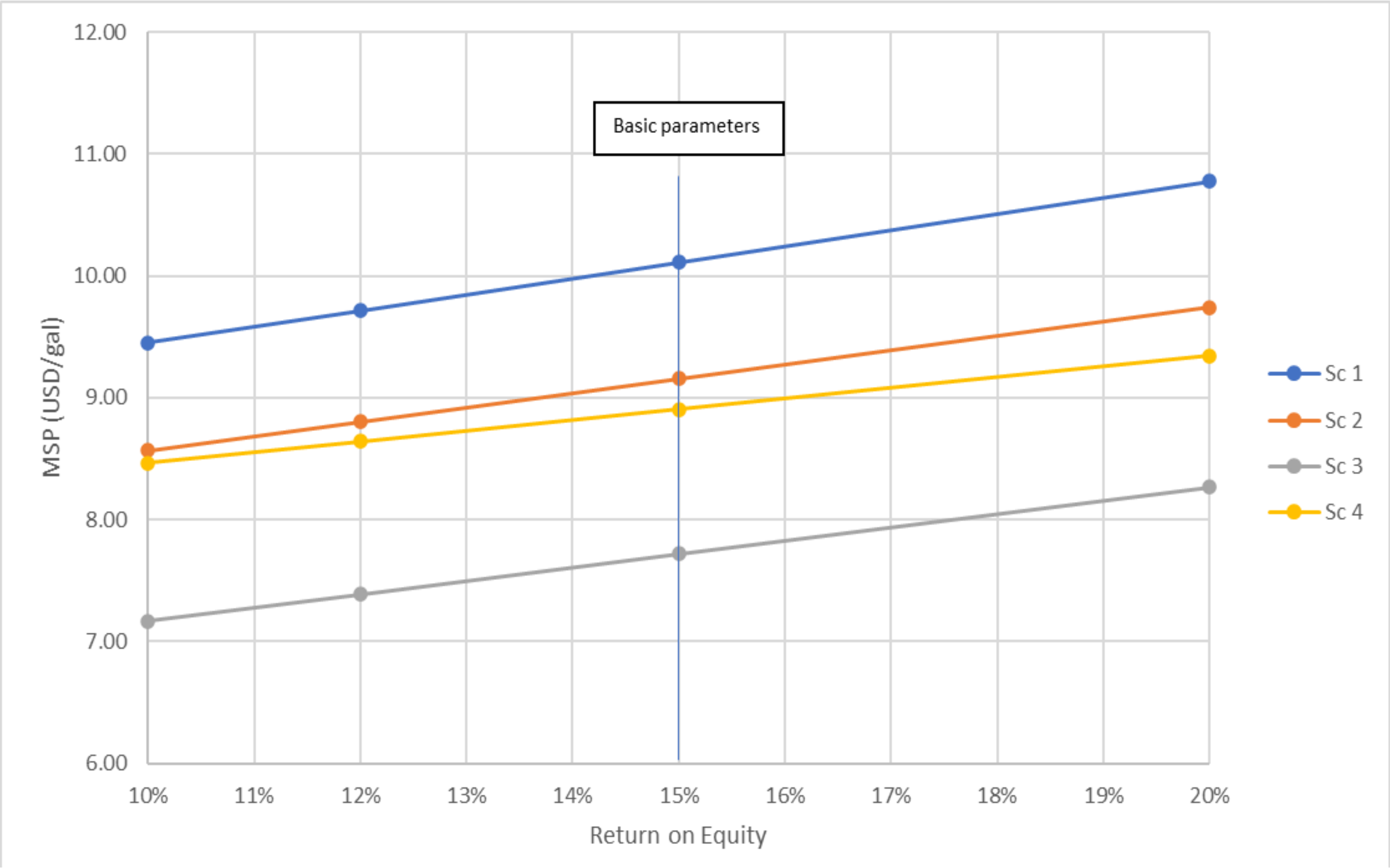
Figure 3.E.5: Transportation Costs



3.E.6. Return on Equity

The return on equity that investors are willing to accept may reduce or increase the MSP by around 50 cents per gallon compared to the typical rate chosen in the model.

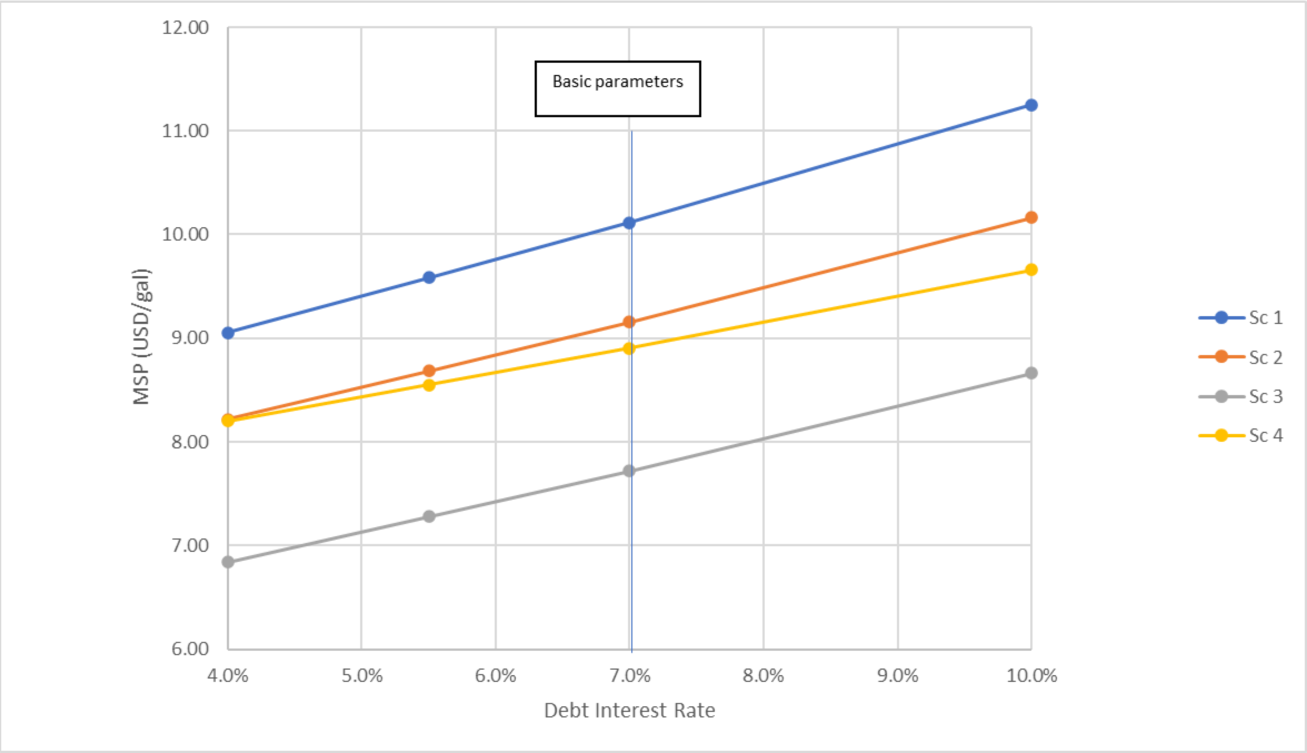
Figure 3.E.6: Return on Equity



3.E.7. Debt Interest Rate

The graphic shows impressively the importance of financing on the competitiveness of the project. The understanding of how interest rates will be calculated, the inclusion of potential risks and the creditworthiness of the lenders in the project partnership is imperative to make such a project competitive.

Figure 3.E.7: Debt Interest Rate

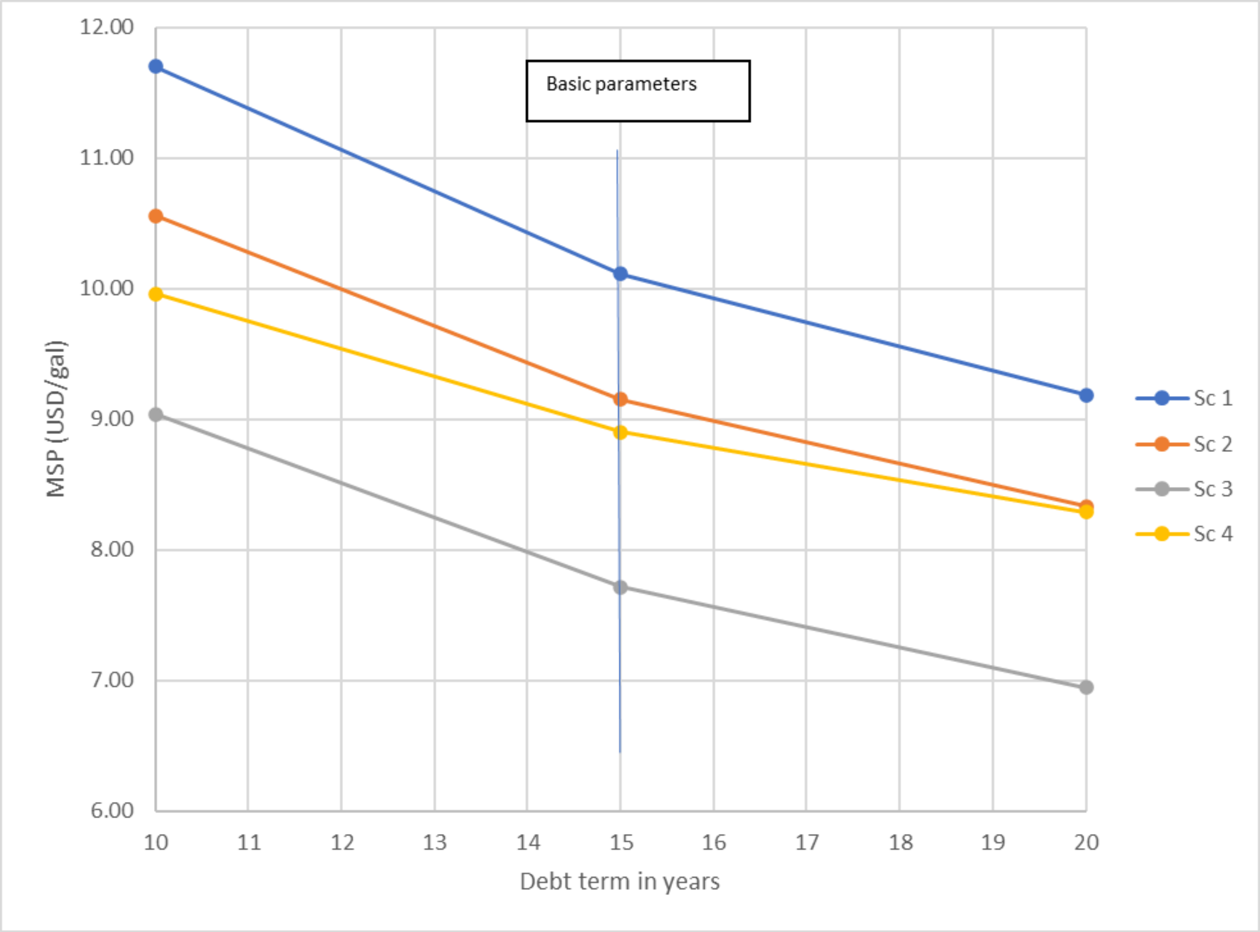


3.E.8. Debt Term

Longer debt terms reduce the annual costs but extend the time period for paying interest. A dynamic cash flow model may be used to find the sweet spot provided there is negotiation room regarding flexibility in the terms.

The debt term has significant impact on the MSP. We have chosen 15 years as the basis for our model, as financial institutions typically request this term. The graphs show the impact of shorter and longer debt periods on the MSP.

Figure 3.E.8: Debt Term



F

TASK 3 – APPENDIX F | GHG EMISSION CALCULATION MODEL, SUPPLEMENTAL DATA

exp.

Task 3 - Appendix F | GHG Emission Calculation Model, Supplemental Data

This Appendix supports **Section 3.6.1 – Lifecycle Carbon Emissions** with GHG emission and CI factor calculations based on the following parameters. Basic assumptions for this model include:

- The elemental analysis does not list impurities such as N_2, S, P, and others.
- The elemental analysis is on dry basis, not including moisture.
- Food and yard waste have a very high moisture content and are better composted than used for SAF production. We have calculated with 10% of the total food and yard waste being part of the RDF.
- Plastics, rubber, and leather do not decompose under anaerobic conditions, i.e., they do not produce landfill gas.
- For the carbon intensity, we use an energy allocation method, which leads to the same CIs among the fuel products.
- GHG emissions for fuel production and combustion are high-level estimates based on carbon balances around these systems.
- CO_2 emissions from biogenic carbon are considered carbon neutral.
- Avoided landfill emissions are the real uncontrolled CH_4 emissions that would have occurred in case RDF has been landfilled. Consequences of alternative use of waste are not considered.
- Landfill waste emissions are 50vol-% CO_2 and 50vol-% CH_4 [1]
- The model is based on a 75% capture rate of landfill gas and 19.5% oxidation rate of CH_4 [1]
- Conversion factor of CH_4 into CO_2: 27.25[1]

The following tables are based on the MSW composition for 2021 and shall explain the path to calculating the CI factor.

Table 3.F-1: Basic composition data of RDF components and carbon specifics

Basic Data RDF components									
	C	H	O	Moisture	LHV (MJ/wet kg)	Degradable organic carbon	Decomposition rate	C biogenic %	C biogenic emissions
Paper	43.5%	6.0%	44.0%	6%	18.60	0.405	0.41	100%	16.6%
Plastics	60.0%	7.2%	22.8%	2%	32.60	-	-	0%	0.0%
Rubber	78.0%	10.0%	0.0%	2%	31.30	0.390	-	80%	0.0%
Leather	60.0%	8.0%	11.6%	10%	16.70	0.390	-	50%	0.0%
Textiles	55.0%	6.6%	31.2%	10%	16.00	0.300	0.50	50%	15.0%
Wood	49.5%	6.0%	42.7%	8%	14.00	0.425	0.12	100%	5.1%
Food	48.0%	6.4%	37.6%	72%	6.00	0.140	0.84	100%	11.8%
Yard waste	47.8%	6.0%	38.0%	60%	7.00	0.200	0.28	100%	5.6%

1 The landfill waste emission data are based on Lee, Uisung, Cai Hao, Ou, Longwen, Thatiana, PAhola, Wang, Yixuan, Wang, Michael (2023, January 1). Journal of Cleaner Production, Life cycle analysis of gasification and Fischer-Tropsch conversion of municipal solid waste for transportation fuel production, Journal of Cleaner Production, Volume 382, 135114. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0959652622046881

Table 3.F-2: RDF composition based on 2021 MSW data

Specific RDF composition								Avoided emissions	
		C	H	O	C biog	C fossil	C emiss	CH4 emiss	CO2 equiv
		kg/h	kg/h	kg/h	kg/h	kg/h	kg/h	kg/h	kg/h
Total mass flow (dry) [kg/h]	20833.3								
Paper	33.60%	3045.0	420.0	3080.0	3045.0	0.0	1162.4	774.9	21116.0
Plastics	26.50%	3312.5	397.5	1258.8	0.0	3312.5	0.0	0.0	0.0
Rubber	0.90%	146.3	18.8	0.0	117.0	29.3	0.0	0.0	0.0
Leather	0.00%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Textiles	7.20%	825.0	99.0	468.0	412.5	412.5	225.0	150.0	4087.5
Wood	27.20%	2805.0	340.0	2419.7	2805.0	0.0	289.0	192.7	5250.2
Food	2.30%	230.0	30.7	180.2	230.0	0.0	56.4	37.6	1023.7
Yard waste	2.30%	229.0	28.8	182.1	229.0	0.0	26.8	17.9	487.5
TOTAL	100.00%	10592.8	1334.7	7588.7	6838.5	3754.3	1759.5	1173.0	31964.9
		50.8%	6.4%	36.4%					
LHV (dry) [MJ/kg]	19.5								

CH_4 emissions avoided: 236.1 kg/h.

CH_4 emissions avoided are based on 1173 kg/h CH_4 emissions, 25% non-captured landfill gas and 80.5% non-oxidized carbon.

Table 3.F-3: Results for Scenario 1

RDF	500.00	mtpd
	20,833.33	kg/h
C in RDF	10,592.79	kg/h
Fuel	4,147.29	kg/h
Fuel	43.2	MJ/kg
Fuel	179,162.79	MJ/h
C biog	6838.5	kg/h
C fossil	3754.3	kg/h
C in fuel	3,525.19	kg/h
C in ash	211.86	kg/h
C in CO_2	6,855.74	kg/h
CO_2	25,137.72	kg/h
	603.31	mtpd
Energy conversion efficiency:	44%	

GHG emissions		
C fossil in RDF	3,754.25	kg/h
C fossil in fuel	1,249.38	kg/h
C fossil in ash	75.09	kg/h
C fossil in CO_2	2,429.78	kg/h
CO_2 fossil	8,909.20	kg/h
	213.82	mtpd
CI prod	9.73	g CO_2eq/ MJ
CI avoided	35.91	g CO_2eq/ MJ
CI combustion	25.57	g CO_2e/MJ
CI transportation	0.9	g CO_2e/MJ
Total GHG	40.29	g CO_2e/MJ

Table 3.F-4: Results for Scenario 2

RDF	720.00	mtpd
	30,000.00	kg/h
C in RDF	15,253.62	kg/h
Fuel	5,542.64	kg/h
	43.2	MJ/kg
	239,441.86	MJ/h
C in fuel	4,711.24	kg/h
C in ash	305.07	kg/h
C in CO_2	10,237.31	kg/h
CO_2	37,536.79	kg/h
	900.88	mtpd
Energy conversion efficiency:	**41%**	

GHG emissions		
C fossil in RDF	5,406.12	kg/h
	1,669.74	kg/h
C fossil in ash	108.12	kg/h
C fossil in CO_2	3,628.26	kg/h
CO_2 fossil	13,303.62	kg/h
	319.29	mtpd
CI prod	55.56	g CO_2e/MJ
CI avoided	38.69	g CO_2e/MJ
CI combustion	25.57	g CO_2e/MJ
CI transportation	0.9	
Total GHG	**43.34**	**g CO_2e/MJ**

Table 3.F-5: Results for Scenario 3

RDF	1,450.00	mtpd
	60,416.67	kg/h
C in RDF	30,719.10	kg/h
Fuel	12015.50	kg/h
	43.2	MJ/kg
	519,069.77	MJ/h
C in fuel	10,213.18	kg/h
C in ash	614.38	kg/h
C in CO_2	19,891.54	kg/h
CO_2	72,935.63	kg/h
	1,750.46	mtpd
Energy conversion efficiency:	**44%**	

GHG emissions		
C fossil in RDF	10,887.33	kg/h
	3,619.71	kg/h
C fossil in ash	217.75	kg/h
C fossil in CO_2	7,049.87	kg/h
CO_2 fossil	25,849.52	kg/h
	620.39	mtpd
CI prod	49.80	g CO_2e/MJ
CI avoided	35.94	g CO_2e/MJ
CI combustion	25.57	g CO_2e/MJ
CI transportation	0.9	
Total GHG	**40.33**	**g CO_2e/MJ**

Table 3.F-6: Results for Scenario 4

RDF	720.00	mtpd
	30,000.00	kg/h
C in RDF	15,253.62	kg/h
Fuel	10,852.71	kg/h
	43.2	MJ/kg
	468,837.21	MJ/h
C in fuel	9,224.81	kg/h
C in ash	305.07	kg/h
C in CO_2	5,723.74	kg/h
CO_2	20,987.05	kg/h
	503.69	mtpd
Energy conversion efficiency:	**80%**	

GHG emissions		
C fossil in RDF	5,406.12	kg/h
	3,269.41	kg/h
C fossil in ash	108.12	kg/h
C fossil in CO_2	2,028.58	kg/h
CO_2 fossil	7,438.14	kg/h
	178.52	mtpd
CI prod	15.87	g CO_2e/MJ
CI avoided	19.76	g CO_2e/MJ
CI combustion	25.57	g CO_2e/MJ
CI transportation	0.9	
Total GHG	**22.58**	**g CO_2e/MJ**

TASK
4

MUNICIPAL SOLID WASTE TO LIQUID FUELS STUDY

Port of Seattle + King County Solid Waste Division

Report Name:
Task 4 – Project Financing

2023-06-30

prepared by

EXP
451 Montgomery Street, Suite 300 | San Francisco, CA 94104
Principal, Marcos Souza: marcos.souza@exp.com
Project Manager, Joseph Gale: joseph.gale@exp.com

TABLE OF CONTENTS

LIST OF TABLES

ABBREVIATIONS

- **AMA** – Advanced Methanol Amsterdam
- **ASTM** – American Society for Testing and Materials
- **ATJ** – Alcohol-to-jet
- **ATJ-SPK** – Alcohol to Jet Synthetic Paraffinic Kerosene
- **BHS** – Bulk Handling Systems
- **bpd** – Barrels per day
- **BTL** – Biomass to Liquid
- **CCS** – Carbon Capture and Storage
- **CEPCI** – Chemical Engineering Plant Cost Index
- **CO** – Carbon monoxide
- **CO_2** – Carbon Dioxide
- **FT** – Fischer-Tropsch
- **FT-SPK** – Fischer-Tropsch Synthetic Paraffinic
- **FT-SPK/A** – Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics
- **GHG** – Greenhouse gas
- **GTL** – Gas-to-liquids
- **H_2** - Hydrogen
- **HEFA** – Hydro-processed Esters and Fatty Acids
- **HTW** – High Temperature Winkler
- **HVO** - Hydrotreated Vegetable Oil
- **ICAO** – International Civil Aviation Organization
- **KC** – King County
- **kWh** – Kilowatt Hours
- **LCFS** – Low Carbon Fuel Standard
- **MIT** – Massachusetts Institute of Technology
- **mm** – Millions
- **mmgpa** – Million Gallons per Annum
- **MRF** – Material Recovery Facility
- **MSW** – Municipal Solid Waste
- **mt** – Metric Ton
- **mtpa** – Metric Tons per Annum
- **OLCV** – Oxy Low Carbon Ventures, LLC
- **PEM** – Polymer-electrolyte Membrane
- **PNW** – Pacific Northwest
- **POS** – Port of Seattle
- **PPI** – Proton Power, Inc.
- **RDF** – Refuse Derived Fuel
- **RFS** – Renewable Fuel Standard
- **RINs** – Renewable Identification Numbers
- **RNG** – Renewable Natural Gas
- **RSB** – Roundtable on Sustainable Biomaterials
- **RWGS** – Reverse Water Gas Shift
- **SAF** – Sustainable Aviation Fuel
- **SEA** – Seattle-Tacoma International Airport
- **SFW** – Sumitomo SHI FW
- **SMDS** – Shell Middle Distillate Synthesis
- **Syncrude** – Synthetic crude
- **Syngas** – Synthetic gas
- **TIC** – Total Investment Cost
- **TRL** - Technology Readiness Level
- **USEPA** – United States Environmental Protection
- **WSU** – Washington State University

4

TASK 4-PROJECT FINANCING

4. Task 4 - Project Financing

4.1 Executive Summary

This Task Report addresses the suggested pathways to finance a renewable fuels production facility emphasizing seven variables. These variables can impact project financing structure and include technology selection, performance guarantees, facility siting, commercial agreements, federal and state financial support, strategic partnerships, and financing sources. While there is a plethora of established pathways to finance traditional infrastructure projects, opportunities for emerging pre-commercial industrial and energy technologies are limited. Financing SAF production facilities are less viable due to expected negative cash flow. Government financial support can lower investor risk and offset costs associated with SAF facilities. The result would be economically feasible renewable fuel projects.

The considerations to finance a renewable fuel production facility include:

Technology Selection – The maturity expressed through the Technology Readiness Level (TRL) combined with the commercial success of the FT and ATJ processes reduces investor risk. Increasing the financial feasibility of a project is the main objective. Additionally, developers often overlook the criterion of operations and maintenance (O&M) when drafting a project budget due to their lack of operations history. Investors will reject projects without an effective financeable plan.

Performance Guarantees – This development is based on relatively new technologies with minimal/no commercially operating facilities and with a high potential for integration issues. Persuading a financeable entity to guarantee the performance of an individual technology poses a significant challenge. Engineering, procurement, and construction firms (EPCs) do not serve as performance guarantees. Performance insurance is expensive (up to 7% of a project's capital costs) and sometimes is a necessary option.

Facility Siting – Site selection impacts facility design and engineering and must be secured or have an exclusive purchase option before financing discussions commence. The cost and access to a site impact financing. For example, selecting a site without access to utilities or a workforce to construct the facility requires additional capital.

Commercial Agreements – The longevity of the contract increases finance opportunities. Some Financiers prefer 15-year contract terms, but the more commoditized the product, the less critical the term. Other factors impacting agreements include the counterparty, pricing, liquidated damages, and force majeure clause.

Federal and State Financial Support for Renewable Fuel Projects – Government financial support relevant to this project includes:

- *Federal Support:* Inflation Reduction Act (IRA) Grants and Policy - Sustainable Aviation Fuel (SAF) and Section 1703 Loan Guarantee, as well as the Loan Programs Office Title 17 Energy Infrastructure Reinvestment (New Section 1706).
- *State Support:* IRA – Fueling Aviation's Sustainable Transition (FAST)

Strategic Partnerships – There are opportunities to work with partners to finance a renewable fuel project. Examples of strategic partnerships and their importance are explored as a preview to **Task 5**.

Financing Sources – Renewable fuel projects may be financed through traditional and non-traditional means. Traditional project financing options include equity and debt. Non-traditional examples are purely debt sources which make them more attractive yet harder to obtain.

4.2 Introduction

This section reviews financing concepts and the primary components that affect the financial feasibility of a renewable fuels production facility. The outcome of this section presents a comprehensive guide to securing financial support for a facility using newer technologies. This guide also addresses typical finance and investment requirements, risk, project-specific concepts, gaps, and mitigation methods for a project using relatively new technologies.

For this study, a traditional project refers to an industrial production facility incorporating technologies with a TRL maturity of 9, actual systems proven in an operational environment.

Table 4.1: Typical Financing Opportunities for Traditional Projects

Financing Opportunity	Definition
Developer Capital	Developer capital is funding offered to aid the growth of established businesses.
Investor Equity	Investor equity is an investor's stake in the business. A business can raise capital by selling equity through public stock offerings or private placements.
Primary debt	Primary debt raises capital by selling debt instruments (e.g., bonds, debentures, promissory notes, etc.). Individuals and institutions that lend money become creditors and must be repaid the principal amount plus interest.
Mezzanine debt	Mezzanine debt represents a hybrid of debt and equity financing that gives the lender the right to convert the debt to an equity interest in the company in case of default. This is an attractive option to investors because it offers greater returns in comparison to typical debts, often in the range of 12%-20% annually.[1]
Partnerships (preview to Task 5)	Project financing may be obtained from industry partnerships benefiting both parties involved. For example, SAF offtake agreements represent an agreement between a producer and a buyer to purchase all or a substantial part of the output or product produced by a project. In 2022, 42 total offtake agreements were announced between airlines and fuel producers (e.g., Gevo, Fulcrum, and Neste).[2] This can also be equity-in-kind; rather than providing a direct dollar infusion a discount or "donation" of equipment or services might be provided.

Project financing is nuanced and bespoke, with financing structures impacted by multiple variables including:

- Technology Selection
- Performance Guarantees
- Facility Siting
- Commercial Agreements
- Federal and State Financial Support
- Strategic Partnerships
- Financing Source(s)

1 Investopedia. (2023). Financial Term Dictionary. Retrieved from: https://www.investopedia.com/financial-term-dictionary-4769738.
2 ICAO Environment. (2023, March 14). SAF Offtake Agreements, Tracker of SAF Offtake Agreements. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx.

The following **Sections 4.3-4.9** discuss the multiple variables defined here, specific to securing project finance for a project using relatively new technology.

Preferences for project financing can vary. Financing for a new facility considers many aspects, including advantageous opportunities for project developers. Project developers tend to prefer primary debt financing to equity financing because they retain a majority of project ownership. Most financing structures of traditional projects result in approximately 70% primary debt and 30% equity. Typically, a project developer will retain 10-30% equity in a project. However, there is no clear cut pathway to secure financing for technology systems not yet proven in a commercially operational environment.

In addition, providing satisfying performance or technology wraps can be challenging for engineering, procurement, and construction (EPC) firms. To mitigate these challenges, New Risk and other specialized insurance companies offer coverage plans which benefit technologies without sufficient proof of performance or when the technology provider's financial standing is inadequate for project financing. Still, the reliance on a single insurance product may not be sufficient. Two insurance policies are typically required and must be purchased prior to project execution.

- **Policy 1**
    - Begins at mechanical completion and covers commissioning, start-up, and performance testing (contractually defined in the EPC agreement and financing documents).
    - This policy covers corrections/repairs needed to meet the performance guarantee.
    - There is a sizeable deductible.
- **Policy 2**
    - Begins when Policy 1 ends.
    - Term is typically 7-10 years. This term varies depending on financing requirements.
    - Serves as a warranty to cover equipment failures. Note – Coverage may differ from the "Performance guarantees" covered under Policy 1.
    - There is a sizeable deductible.

EPC firms cannot provide a financeable performance wrap for a project of this size. Generally, if technology has not been widely deployed, EPCs will not provide the guarantees needed. EPCs do not act as insurance companies. To reduce risks, EPC firms can work with insurance providers to scale their operations. For this section and to serve as an example, the authors assess an insurer of breakthrough technologies, New Energy Risk.

New Energy Risk has developed a guide for emerging industrial and energy technologists and developers to successfully scale pre-commercial applications in the context of project finance. **Table 4.2** summarizes New Energy Risk's identified challenges, opportunities, and solutions for project financing to effectively scale pre-commercial industrial and energy technology businesses. However, the current technologies, capital and operating costs associated with a renewable fuels production facility would typically not qualify for the funding described in this New Energy Risk study as development would ultimately lose money (i.e., operate in the red or experience a negative cash flow).

Table 4.2: New Energy Risk – Project Finance Guide Summary

New Energy Risk, Industrial & Energy Technology Project Finance – A Startup and Developer's Guide to Scaling and Commercial Success[3]
This guide defines project finance as the financing of the construction of an industrial or energy infrastructure facility. It is defined as primarily funded by debt and relies on cash flows generated by the infrastructure asset to repay the debt. Project finance comprises a corporate development structure and fundraising with a goal: to source large quantities of low-cost non-dilutive capital (i.e., funding not in exchange for business equity or ownership) and reduce frictions in the process. Multinational banks and the municipal bond market have traditionally been sources of project finance for large infrastructure projects. More recently, non-bank counterparties and private market pathways have joined the project financing markets, particularly for smaller technology projects and those with higher technology risk. However, technology risks are usually not financed by lenders. It is instead typically financed by Government loan programs (e.g., US Department of Energy Loan Programs Office (DOE LPO)). It is imperative to distinguish *technology* project finance from *infrastructure* project finance due to the greater technical performance of a technology project. The framework presented balances commercial and technical developments and empowers owners of greater risk technology with tools and best practices to increase the probability of securing project finance. It can save owners months of development time (pre-and post-commercial), equity dilution, and expenses. Three key takeaways include: 1. Projects are deemed more reliable if they receive a stand-alone credit profile (SACP) after entering partnerships with creditworthy parties. This is attributed to separating the project sponsor from the project entity, which elevates the bank's confidence in repayment. 2. The front-end loading (FEL) process is notable for de-risking technology, which builds confidence for an EPC firm. 3. The commercial and technical development process results in project risk mitigation. This elevates projects from an SACP to a highly-creditworthy stand-alone credit profile (HC-SACP) – signifying superior commercial and technical quality that is of investment grade.

Government financial support can offset costs and combat losses associated with renewable fuel production facilities with newer technologies. This support lowers investor risk and promotes the economic viability of these projects. For example, the Department for Transport in the United Kingdom shortlisted eight (8) SAF projects which will receive a share of £15 million ($20 million) in grant funding targeted for the development of large scale SAF production plants across the UK.[4]

Back in 2014, the United States Department of Agriculture (USDA) awarded Fulcrum Sierra Biofuels, LLC a $105 million loan for a biorefinery to produce SAF from MSW. In 2009, the USDA's Biorefinery Assistance Program supplied a $54.5 million loan guarantee

3 New Energy Risk. (2021). *Industrial & Energy Technology Project Finance, A Startup and Developer's Guide to Scaling and Commercial Success*. Retrieved from: https://newenergyrisk.com/wp-content/uploads/2021/11/NER-Project-Finance-Guide.pdf.

4 Surgenor, C. (2021, August 02). Green Air . Retrieved from Eight UK sustainable aviation fuel projects shortlisted to share £15 million in government grant funding: https://www.greenairnews.com/?p=1455.

to Sapphire Energy in New Mexico for an algae-to-crude oil facility. In 2011, Fremont Community Digester in Michigan received a $12.8 million loan for a facility that generates electricity from biogas derived from agricultural and food waste. In the same year, INEOS New Plan Bioenergy in Florida acquired a $75 million loan utilized towards their development of cellulosic ethanol produced from MSW and woody biomass.[5] The continuance of administering these funds and programs indicates an attractive return on investment for not only the governmental entities but for the emerging of developers within this market, searching for financial support to offset risk and initial startup.

All the finance options considered in this study have Total Installed Costs (TIC) exceeding $500 million, with several technology options having TICs over $1 billion.

4.3 Technology Selection Impact on Project Financing

The selection of technology and its corresponding Technology Readiness Level (TRL) impact project financing. In Task 1, the project assumes the utilization of MSW as feedstock, converted into fuel using the FT or ATJ process. These technologies have limited commercial and operational experience, making financing more costly and difficult to obtain. FT and ATJ process TRLs and investment risks are defined with relevant impacts to financial feasibility below. A key takeaway is the higher the TRL (more examples of proven commercial success), the lower the level of investor risk; this increases the financial feasibility of a project. However, it is also worth noting that the higher the level of risk (lower TRL), the higher the expected return on investment. Additional technological considerations surrounding a facility that is not process specific (i.e., operations and maintenance) are subsequently introduced to demonstrate their impact on project financing.

4.3.1. Process Technologies

4.3.1.1. Fischer Tropsch

The primary example of a current operation using the FT process is Fulcrum BioEnergy's Sierra BioFuels Plant in Reno, Nevada – the world's first "commercial-scale plant" to convert MSW into transportation fuels.[6] This facility became operational in December 2022.[7] The path Fulcrum took to secure project financing is not atypical for developers using breakthrough technology. The process from concept to commercialization spanned approximately 15 years. The Fulcrum plant established a framework for future technologies. The developer intends to take the lessons learned and build multiple similar units across the country, and the demonstrated commercial success of its first facility will drastically reduce the level of risk presented to investors interested in additional facilities and increases the financial feasibility of the next project.[8]

Another key consideration is the relationship between the TRL and investment risk. **Table 4.3** summarizes the TRL of key technologies in Fulcrum's Biofuels Reno Facility. As the TRL of more technologies used in this process mature, the level of investment risk will decrease, improving the financial feasibility of the next project. However, a significant (and often overlooked) problem is the cohesive integration of all operational technology systems, working together efficiently and without delay. Even when using commercially proven technologies, issues will almost always arise if the technologies have never been coupled in quite the same configuration. For example, MRFs are a well proven technology as evidenced by the list of multiple commercially proven MRFs in Task 1 and the TRL in **Table 4.3**.

Despite the technology's proven success in isolation, several groups reported challenges integrating MRFs into commercial developments, including the MRFs difficulty in sorting out solids (typically metals and glass) to meet the inlet requirements for gasification. This type of issue is frequently discovered during commissioning and/or initial operation. Most issues that arise are correctable after investing time and additional finances. Financing organizations are aware of these risks and price their financing accordingly.

5 Fletcher, Jay. "USDA Announces Loan Guarantee to Help Innovative Company Turn Waste into Renewable Jet Fuel." *USDA*, www.usda.gov/media/press-releases/2014/09/04/usda-announces-loan-guarantee-help-innovative-company-turn-waste. Accessed 19 May 2023.

6 Bioenergy International. (2021, July 07). Retrieved from Fulcrum BioEnergy completes construction of Sierra BioFuels W2F plant: https://bioenergyinternational.com/fulcrum-bioenergy-completes-construction-of-sierra-biofuels-w2f-plant/.

7 Fulcrum Bioenergy. (n.d.). Retrieved from Sierra BioFuels Plant & Feedstock Processing Facility: https://www.fulcrum-bioenergy.com/sierra-biofuels.

8 Ibid.

Table 4.3: A Summary of the Fulcrum Biofuels Reno Facility

Fulcrum Bioenergy - Reno Project		
Process	Technology Provider	Current TRL
MSW Sorting	Lubo Systems Material Recovery Facility (MRF)	9
Gasifier	ThermoChem Recovery Int. (TRI)	7-8
POx	Arvos/Linde	8
Gas Purification	Arvos	7
Fischer Tropsch	Johnson Matthey	7
Hydrotreating* *For future Fulcrum projects	Topsoe	9

Fulcrum is a private company with limited publicly available information regarding problems discovered on their path to commercial operation or solutions to those problems. This information is not anticipated to become available, but perhaps Fulcrum will share their "lessons learned" at a future date. The technologies used at Fulcrum's facility may be available to other project developers interested in utilizing them. This Fulcrum facility minimizes the technological risk associated with a future facility of similar use-case, ensuring the opportunity to available project finance for similar facilities.

4.3.1.2. Alcohol-to-Jet

ATJ represents an alternative pathway to SAF production via ethanol with LanzaTech, Enerkem, and LanzaJet technologies as precedents, evaluated below.

LanzaTech's fermentation process for the production of ethanol from MSW is simpler and more stable than other chemical processes. However, in comparison to Fulcrum Bioenergy (FT process), LanzaTech does not have a commercial operation utilizing MSW/RDF feedstock. This poses a greater challenge to financial feasibility. Once LanzaTech has a successful commercial demonstration plant using applicable feedstock sources, financial feasibility for LanzaTech's ethanol facility becomes more financeable.

Enerkem's catalytic conversion (a chemical rather than biological process) of waste-to-alcohol technology is already commercialized, with additional units either under construction or anticipated to break ground soon. This technology requires gasification prior to ethanol production.

Regardless of how the ethanol is produced, LanzaJet owns the only commercialized process for the conversion of ethanol to jet fuel. The organization currently operates a demonstration facility that converts ethanol to SAF with a new commercial facility anticipated in 2023. As this facility establishes operational experience, the TRL associated with LanzaJet's process will increase, lowering the investment risk and simplifying subsequent project financing. **Table 4.4** evaluates the current TRL values for ATJ processes and technology providers.

Table 4.4: A Summary of Alcohol-to-Jet Processes, Technology Providers, and Current TRL

Alcohol-to-Jet		
Process	Technology Provider	Current TRL
MSW Sorting	Lubo Systems MRF	9
Gasifier	Enerkem	8-9
Gas Purification	Enerkem	8-9
Ethanol Synthesis	Enerkem	8-9
ATJ	LanzaJet	7

4.3.2. Additional Considerations – Operations and Maintenance

Technologies for a commercial fuel production facility require a sophisticated operational, maintenance, and management team. Once technology selection between the FT and ATJ processes is complete, the relative operational and maintenance difficulty is considered for project financing.

Financial organizations critically evaluate how O&M services are provided. For many project developers without operational history, it is critical to develop a feasible financeable plan to ensure the O&M requirement satisfies financial requirements. Failing to do so will result in investors rejecting the development – a temporary or permanent fate suffered by many developers since O&M is often overlooked, in terms of time and financial resources required to create a detailed execution plan to satisfy financiers.

To offset the limited operational history, a project developer may obtain a strategic partner or subcontractor early in project development. For example, a strategic partner can provide previous experience, insight, and additional safety measures to support the success of the plant (e.g., maintain O&M expectations), as well as navigate the selection of technology and integration of those technology systems early in project development.

4.4 Performance Guarantees

Performance guarantees are enforceable commitments by a corporate entity to supply the necessary resources to a prospective contractor and to assume all contractual obligations of the prospective contractor.[9] Performance guarantees may also be referred to as performance bonds or contract bonds. A bank or an insurance company provides a performance bond to ensure a contractor completes a designated project.[10] Given the fact that a renewable fuel production facility utilizes newer technologies, with minimal history of commercially operating facilities, it can be challenging to get a financeable entity to guarantee the performance of an individual technology. Convincing the entity to guarantee that each technology will perform in harmony with the others is an even harder feat.

Another consideration is that an EPC contractor can only guarantee their work and not associated technologies. Additionally, they minimize their exposure via Liquidated Damages (LDs) limits in the EPC contract. Liquidated Damages appear in some legal contracts as an estimate of otherwise intangible or hard-to-define losses to one of the parties. It is a provision that allows for the payment of a specified sum should one of the parties be in breach of contract.[11] An example is if Business A is contracted to provide a service to Business B but, fails to do so. Business A could be entitled to a specified sum of money, or a percentage of the total costs, due to liquidated damages. Therefore, if the system does not perform as contracted, the EPC's financial exposure is limited to the maximum LDs as specified in the contract. That amount is typically not adequate coverage to satisfy the financing requirements. As a result, it is evident that the EPCs are inefficient sources of insurance.

Instead of relying on performance bonds, developers can turn to performance insurance. Financing sources determine if performance insurance is required; that determination hinges in large part on how commercially proven the technologies are for similar applications. If required, performance insurance is expensive, reaching as much as 7% of the project's capital cost and consists of two components:

- Coverage through commissioning and initial commercial operation (achieving performance targets).
- Performance coverage through "X" years of operation.

Although expensive, performance insurance might be the only way a project using technology with limited commercialization can secure financing. This type of insurance is relatively new; thus, pricing might be a bit volatile as the risk/reward profile is refined by the insurance industry. The availability of this insurance is a recent development and as such the market remains dynamic. As more underwriters join the market, their capacity will increase, and partnerships will be entered into, as required, to provide coverage for ever larger projects.

9 U.S. Department of Energy. (2016, July). Acquisition Guide, Chapter 9.2 Performance Guarantees. FAR 9.104 and 9.105; DEAR 909.104-3 and 970.9070. Retrieved from: https://www.energy.gov/sites/prod/files/2016/07/f33/07_06_16-AG_Chap_9-2-Performance_Guarantees.pdf.

10 Ancheta, A. (2020, December 08). *What Is a Performance Bond and How Does It Work?* Retrieved from Investopedia : https://www.investopedia.com/terms/p/performancebond.asp

11 Potter, C. (2022, August 02). *What Are Liquidated Damages (LDs)? How They Work, With Example*. Retrieved from Investopedia: https://www.investopedia.com/terms/l/liquidateddamages.asp

Current underwriters include:

- **Lloyd's of London:** A British insurance and reinsurance marketplace (not an insurance company).
- **Allianz:** A leading and global integrated financial services provider with German roots, founded in 1890.
- **AXA XL:** A global commercial insurance company and division of AXA – a French company.
- **New Energy Risk**: An American performance insurance solutions company targeting breakthrough technologies.
- **Munich Re:** One of the top providers of reinsurance, primary insurance, and insurance-related risk solutions in the world, based in Germany.

Current brokers include:

- **AON**: AON is an American multinational financial services firm selling a range of risk-mitigation products, including Commercial Risk, Investment, Wealth, Health, and Reinsurance solutions.
- **CAC Specialty**: CAC Specialty is the fastest-growing (organic) broker in the U.S. providing American Risk & Insurance Solutions, Structured Solutions & Financings, and Focused Industry & Other Specializations.

Coverage through commissioning can range up to $50 million and coverage post commissioning can reach $200 million-plus. Higher coverage is achieved through partnerships. Note that coverage limits are dynamic. The available limits increased dramatically over the last few years and may continue to grow.

4.5 Facility Siting Impacts on Financing

Site selection of a renewable fuel production facility impacts facility design and engineering significantly and consequently, project financing requirements. A project site must be secured, or at least have an exclusive purchase option before serious financing discussions may commence. Securing the site is critical and must be determined early in the development process, ideally before developing the EPC proposal. For example, a confidential developer shared a situation they encountered in which their primary site was not contractually secured and subsequently, sold to another developer. Shifting to a new project site required significant reworking of designs and engineering and resulted in a net increase of $40-50 million in overall project costs – a considerable amount for a $250 million project.

Table 4.5 provides examples of critically important siting considerations as they relate to project financing. For example, selecting a site without access to utilities or a workforce to construct the facility requires more capital.

Table 4.5: Examples of Siting Factors to Consider for Financing Considerations

COST *As a portion of overall costs	
Purchase Price	
Permitting Difficulty *Impacts financing via overall costs and schedule	• State and local authorities support (or lack thereof) • Local residents NIMBY (not in my backyard) historical activism
Impact on Construction	• Laydown Yard • Facility Layout • Site Preparation (earthwork) • Geotechnical Foundations
Carbon Intensity	• Transport of feedstock and product impact carbon intensity (CI) calculations – directly affecting revenue • *Some renewable fuel products sales price is determined using a formula which includes a CI component.
ACCESS TO…	
Site during construction, commissioning, and operation	
Infrastructure	Rail, highways, roads, pipelines, utilities (water, electricity, and sewer)
Workforce	Construction Labor
Operational and Maintenance Support	

4.6 Commercial Agreements

Commercial agreements are typically a contract written between business entities or agreements regulating the business relationship. With respect to project financing, the longer the tenor the better. Most financing prefers 15-year contract terms, but the more commoditized the product, the less critical the time period. Within reason, the term may be less or more than what the financing organization is targeting. Note that the higher the risk taken on by the financing partners, the greater the equity stake or higher interest rate.

Additional components impacting financial organizations' acceptance of existing commercial agreements include, but are not limited to, term, counterparty, pricing, liquidated damages, and force majeure clause, as shown in **Table 4.6**.

Table 4.6: Examples of Components Impacting a Financial Organizations' Acceptance of Existing Commercial Agreements

Component	Example
Term	• 15-year target (typically a 7–20-year range) • Is the product a commodity, easily sold on the market?
Counterparty	• Creditworthiness • Capacity to perform (e.g., what percentage of their business does the project represent) • Reputation/History
Pricing	• Inflation adjustments • Ties to commodity indexes
Liquidated Damages (LDs)	• If they fail to perform, what happens?
Force Majeure Clause	• Project exposure to natural disaster and resilience of operations

Financial organizations' acceptance of existing commercial agreements is dependent upon the above components, all of which determine the quality of a commercial agreement. The higher the quality, the lower the risks, the more attractive the financing terms and easier it will be to finance a renewable fuels production facility.

4.7 Federal and State Financial Support for Renewable Fuel Projects

Federal and State financial support for renewable fuels projects is a significant contributing factor for financial feasibility as well as the renewable fuel cost to potential buyers. Policy development to support the advancement of global SAF supplies may be categorized into four (4) broad categories:

1. Government funding for SAF research and development, demonstration, and deployment (RDD&D).
2. Targeted incentives and tax relief to expand SAF supply infrastructure (e.g., Capital grants, loan guarantee, making SAF projects eligible for tax advantaged business status, allowing for the accelerated depreciation/'bonus' depreciation, Business Investment Tax Credit (ITC) for SAF investments, performance-based tax credit, and bonds/green bonds).
3. Targeted incentives and tax relief to assist SAF facility operation (e.g., Blending incentives such as the Blenders Tax Credit (BTC), production incentives such as the Producer's Tax Credit (PTC), excise tax credits for SAF, support for feedstock supply establishment and production).
4. Recognition and valorization of SAF environmental benefits (e.g., Recognizing SAF benefits under carbon taxation or cap-and-trade systems).[12]

The United States provides federal and state financial support for renewable fuel projects through several of the above-mentioned policy options. Under the 2023 *National Aeronautics Science & Technology Priorities*, which replaces the 2006 *National Aeronautics and Research Development Policy*, achieving sustainable aviation is a top priority. SAF production and supply is key to achieving this priority and increasing this production domestically directly aligns with the United States' *SAF Grand Challenge Roadmap*. This roadmap aims to increase the production of SAF to at least 3 billion gallons per year by 2030, and 35 billion gallons per year by 2050.[13] Despite government support for biofuels projects, this renewable fuel production facility is not eligible to apply for this specific category of funding. Applicable and available government funding opportunities are summarized below.

12 ICAO Committee on Aviation Environmental Protection. (2022). *Guidance on Potential Policies and Coordinated Approaches for the Deployment of Sustainable Aviation Fuels.* https://www.icao.int/environmental-protection/Documents/SAF/Guidance%20on%20SAF%20policies%20-%20Version%201.pdf: ICAO.

13 Council, A. I. (2023). *National Aeronautics Science & Technology Priorities.* Executive Office of the President of the United States . Retrieved from https://www.whitehouse.gov/wp-content/uploads/2023/03/032023-National-Aeronautics-ST-Priorities.pdf.

4.7.1. Federal Support

4.7.1.1. Direct Support

Inflation Reduction Act (IRA) Grants - Sustainable Aviation Fuel (SAF)

Section 40007 of the IRA:

Under this section, the Secretary of Transport must implement a "competitive grant program for eligible entities to carry out projects located in the United States that produce, transport, blend, or store sustainable aviation fuel, or develop, demonstrate, or apply low-emission aviation technologies."[14] The new grant program called Fueling Aviation's Sustainable Transition (FAST) is relevant to this project, particularly concerning the sub section SAF (FAST-SAF). The second less relevant sub section is called FAST-Tech since it concerns low-emission aviation technologies. *To be eligible for funding, the SAF produced must meet the IRA definition of SAF.* Airport sponsors are eligible participants.

Funding is available until 2026 and is allocated as follows:

- SAF production, blending, transportation, or storage projects: $244.53 Million.
- Low-emission aviation technologies – development, demonstration, or applications: $46.53 Million.
- Program oversight: $5.94 Million.

Section 1703 Loan Guarantee:

As a continuation of the DOE Section 1703 Loan Program, the IRA authorizes an additional $40 billion in loan guarantees thereby approximately tripling the amount of available funds. The funds are a loan from the Federal Financing Bank to finance projects using innovative technologies.[15]

Loan Programs Office Title 17 Energy Infrastructure Reinvestment (New Section 1706):

The IRA authorized a new loan authority for the Loan Programs Office under Title 17 that will finance projects that retool, repower, repurpose, or replace energy infrastructure that has ceased operations, or enables operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or anthropogenic emissions of greenhouse gasses. Under Section 1716, the DOE may issue up to $250 billion in loan guarantees. With broad funding applicability, interested applicants are encouraged to reach out with questions to familiarize themselves with the new program and existing Title 17 application process. The DOE will issue further guidance regarding how to apply and possibly issue a rulemaking on this new program. Appropriations for this program are authorized through September 30, 2026. Individual awards will be ongoing while funding remains available.[16]

4.7.1.2. Indirect Support

The IRA supports rapid scale-up of domestic SAF production to minimize the price gap between Jet-A Fuel and SAF. For a nascent SAF industry, the IRA aims to build upon the foundations set under the 2021 Sustainable *Aviation Fuel Grand Challenge*. This Challenge set a goal to achieve annual domestic production of 3 billion gallons of SAF by 2030, with associated carbon emission reductions of 20% during the same period. To date, this Challenge has pledged to invest up to $4.3 billion in SAF projects and producers/developers.

Relevant provisions include the SAF Blenders Credit (BTC) and the Clean Fuel Production Credit (CFPC). This is only applicable if the period in which the credits apply is extended since this renewable fuel production facility is not yet constructed.

14 Hileman, J., & Orton, A. 2022. IRA Section 4007 FAST-SAF and FAST-Tech Grant Program. FAA PowerPoint: https://www.transportation.gov/sites/dot.gov/files/2022-12/IRA-Section-40007-FAST-Program-Briefing.pdf.

15 Hansen, K. (2022, August 17). *Norton Rose Fulbright*. Retrieved from The Inflation Reduction Act and DOE loan programs: https://www.projectfinance.law/publications/2022/august/the-inflation-reduction-act-and-doe-loan-programs/#:~:text=The%20Act%20authorizes%20another%20%2440,the%20volume%20of%20available%20funding.

16 *Clean Energy and Climate Solutions Federal Funding Database*. (2023, January 30). Retrieved from Wilson Sonsini : https://www.wsgr.com/en/clean-energy-and-climate-solutions-federal-funding-database.html#biofuels.

4.7.2. State Support

4.7.2.1. IRA - Fueling Aviation's Sustainable Transition (FAST):

Important to note – the DOE expects the grantee to match up to 100% of the awarded grant through the FAST program. In Washington state, matching funds may be provided through Clean Energy Funds if a Washington-based company is awarded the grant.[17]

4.7.2.2. Washington Biofuels Working Group

Washington State University's Office of National Laboratory Partnerships assembled the Sustainable Aviation Biofuels Work Group to share information, identify opportunities, and develop comprehensive recommendations pertaining to the advancement of the SAF industry in Washington state. In the November 2020 Final Report on SAF Opportunities for Washington, the working group outlined exempt facilities bonds as offering one of the best financing tools for advanced biorefining based on waste feedstocks. Under the state's Bond Cap Allocation Program, exempt facilities are initially limited to 20% of the total allocation in any given year, and any one project can only receive up to 30% of that allocation.[18] Modifications to exempt facility allocations could allow bond financing to become a more viable mechanism for financing new SAF facilities and would make Washington an attractive location for investment in new or repurposed facilities.[19]

In the December 2022 Final Report of SAF Updates and Recommendations (Opportunities for Washington), the working group highlighted multiple funding opportunities within the State for entities to capitalize on.[20] One of the opportunities included the IRA 40007 grant, as outlined above. The working group additionally mentioned the Department of Commerce's Sustainable Aviation Technologies and Energies (SATE) Cluster Innovation Accelerator Program grant that aims to promote decarbonization through research, development, and deployment of SAF. These opportunities are created to support the plan for decarbonizing aviation in the long-term, in hopes that similar initiatives and programs will go into effect beyond Washington's borders.

Gifting of public funds at the state-level may also provide opportunity to partially finance a renewable fuels production facility in Washington State. The "Gift of Public Funds Doctrine" refers to a fairly broad set of prohibitions contained in two sections of the Washington State Constitution: Article 8 Section 5 and Article 8 Section 7. While the prohibitions created are broad, there remain a number of actions that government entities may engage in with additional exceptions to Section 7 created by subsequent amendments to the Washington State Constitution. These exceptions include:

- *Public funds may be used by port districts "for industrial development or trade promotion and promotional hosting. (Article 8, Sec. 8).*
- *Political subdivisions can use proceeds from the sale or distribution of water, energy, or stormwater or sewer services to finance the acquisition and installation of materials and equipment for more efficient use of water or energy. However, such financing can only be used in regards to existing structures and cannot be used for conversion from one energy source to another. (Article 8, Sec. 10).*
- *Government entities may, where authorized by the State legislature, issue revenue bonds to fund industrial development projects. (Article 32, Sec. 1).*[21]

17 Group, S. A. (2022). *Sustainable Aviation Fuel Updates and Recommendations (Opportunities for Washington).* Retrieved from: https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=2022-12-01%20SABWG%20REPORT_9cd2afd3-8606-46d2-aa90-42b98fe62972.pdf.

18 Washington Department of Commerce, Bond Cap Allocation Program (n.d.). Retrieved from: www.commerce.wa.gov/about-us/research-services/bond-cap-allocation-program.

19 Sustainable Aviation Biofuels Work Group (2020 November). *Sustainable Aviation Fuel Opportunities for Washington, November 2020 Final Report, Prepared for: The Washington State Governor and the Washington State Legislature*. Retrieved from: https://s3.wp.wsu.edu/upload/sites.2180/2020/SABWG-Final-Report-November-2020-compressed.pdf.

20 Group, S. A. (2022). *Sustainable Aviation Fuel Updates and Recommendations (Opportunities for Washington)* . Retrieved from: https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=2022-12-01%20SABWG%20REPORT_9cd2afd3-8606-46d2-aa90-42b98fe62972.pdf.

21 MRSC (2023). Municipal Research and Services Center of Washington, Gift of Public Funds. Retrieved from: https://mrsc.org/explore-topics/legal/ethics/gift-of-public-funds#What%20is%20Prohibited.

4.8 Strategic Partnerships

Strategic partnerships are of critical importance to securing project financing for a renewable fuels production facility. Opportunities exist to collaborate with partners in financing a renewable fuels project. This section explores examples of strategic partnerships and their significance. Industry examples are provided as precedents and, in certain cases, as sources that should be investigated further because it could serve as a source of capital for this facility.

Strategic partnerships mitigate risk through:

- Commercial agreements (e.g., securing feedstock supply, product off-take).
- Leveraging expertise (e.g., operations/maintenance partners).
- Reducing capital requirements and generally increasing performance expectations (e.g., technology & EPC partners).

Entering into partnerships with well-known entities provides significant project validation. This may also open doors to additional financial institutions and possibly streamline the Due Diligence (DD) timeframe – in part due to the preparation required to on-board partners.

SAF projects have many potential partners, including airlines, energy companies, and waste handlers – all of which have demonstrated their willingness to partner in these types of projects. It is also common for a project to benefit from multiple strategic partners, as evidenced through the examples of partnerships described below.

4.8.1. Examples of Partnership Funding Facilities in the US

4.8.1.1. The United Airlines Ventures (UAV) Sustainable Flight Fund

United Airlines, Air Canada, Boeing, GE, Honeywell, and Aerospace JPMorgan Chase partnered to create a venture capital fund to source more environmentally-friendly air travel options (e.g., electric and hydrogen-powered aircraft) and to increase the availability of SAF – an effort that is vital in building a new SAF industry from scratch. The partners invested $100 million into the fund, which will in turn be invested into developing technologies and startup firms. Investments have already benefited three startups over the past two years.

- Cemvita Factory Inc. is a Texas-based company that received an initial investment of $5 million to continue its efforts to convert carbon dioxide into useful hydrocarbons.[22]
- Dimensional Energy is a New York state-based firm that uses water and carbon dioxide as inputs in the FT process to produce SAF. Carbon dioxide can be obtained from multiple sources, such as from industrial sites, direct air capture, and biological processes (e.g., fermentation). UAV has already committed to purchase a minimum of 300 million gallons of SAF from Dimensional Energy over the next two decades.[23]
- NEXT Renewable Fuels is a Texas-based startup biorefinery with the potential to produce up to 50,000 barrels of SAF per day. UAV will invest up to $37.5 million in NEXT, subject to the firm meeting specified milestones. The start-up's flagship refinery will be located in Port Westward, Oregon, and will commence production in 2026. It is currently in the permitting phase. To lower the risk, NEXT entered into agreement with BP to source 100% of its feedstock – guaranteeing a supply, which has historically been a challenge for smaller facilities.[24]

UAV might offer a potential funding source for this renewable fuel production facility.

22 Bachman, J. (2022, March 29). *United Airlines Invests $5 Million in Startup to Study Greener Jet Fuel*. Retrieved from Bloomberg: https://www.bloomberg.com/news/articles/2022-03-29/united-invests-in-houston-startup-to-study-greener-jet-fuel?leadSource=uverify%20wall.

23 United Airlines . (2022, June 15). *Transforming Yesterday's Emissions into Tomorrow's Sustainable Aviation Fuel: United Announces Agreement with CO2 Utilization Company Dimensional Energy.* Retrieved from PR News Wire : https://www.prnewswire.com/news-releases/transforming-yesterdays-emissions-into-tomorrows-sustainable-aviation-fuel-united-announces-agreement-with-co2-utilization-company-dimensional-energy-301568237.html.

24 *International Airport Review*. (2022, November 18). Retrieved from United becomes first U.S. airline to invest in biofuel refinery: https://www.internationalairportreview.com/news/180937/united-becomes-first-u-s-airline-to-invest-in-biofuel-refinery/.

4.8.1.2. Microsoft Climate Innovation Fund

Microsoft has invested $1 billion into climate innovations through debt and equity capital. In 2022, the Microsoft Climate Innovation Fund invested $50 million into LanzaJet's ATJ, SAF production facility in the state of Georgia called Freedom Pines Fuels. The facility will produce 10 million gallons of fuel annually when it commences operations in late 2023. While Microsoft is a noteworthy investor, LanzaJet has also received financial support from Suncor Energy Inc., Mitsui & Co., Ltd., All Nippon Airways, and British Airways. This facility also received funding from the U.S DOE Bioenergy Technologies Office – highlighting the importance of obtaining funding from multiple sources.[25]

Funding through the Microsoft Climate Innovation Fund is based on four criteria:

- *Climate impact*: Meaningful, measurable climate solutions in the areas of carbon, water, waste, and ecosystems.
- *Underfunded markets*: Investing where the capital need for climate solutions is not being met.
- *Shared alignment*: Technologies that are relevant to Microsoft's core business and that of our customers.
- *Climate Equity*: Ensuring developing economies and underserved communities benefit from climate solutions.[26]

4.8.2. Examples of Partnership Funding International Facilities

4.8.2.1. Fly Green Fund

Fly Green Fund is a non-profit organization, founded in 2015, offering businesses and individuals the opportunity to contribute towards sustainable air travel by reducing their carbon footprint after using the organization's carbon calculator. 75% of funds raised go towards the purchase of SAF for Swedish airports while the remaining 25% is invested into market development and SAF demand and production initiatives support in Scandinavia.[27] The Fly Green Fund was founded by Karlstad Airport, SkyNRG, and the Nordic Initiative for Sustainable Aviation (NISA) with partners in Swedavia and the Sveriges Regionala flygplaster (SRF).[28]

4.8.2.2. Avinor & Quantafuel Pre-Purchase Agreement

In 2016, Oslo Gardermoen Airport became the first airport in the world to offer biofuel to all airlines through the airport's existing fuel farm and hydrant dispenser system. Utilization of existing infrastructure significantly reduced issues related to logistics costs and fuel transport. Air BP currently supplies the biofuel, but the partnership includes the Lufthansa Group, KLM, SkyNRG, Neste and SAS. Avinor also provides financial assistance by covering logistics costs (i.e., a fixed amount contributed annually) and by contributing towards covering a SAF premium.

In a more recent partnership, Avinor is providing financial assistance to Quantafuel, a Norwegian biofuel producer using MSW as a feedstock, through a pre-purchasing agreement. Avinor has agreed to purchase fuel for NOK 8 million, approximately $770,000 USD.[29]

---

25 *Lanzajet*. (2022, January 13). Retrieved from LanzaJet Secures $50M in Funding from Microsoft Climate Innovation Fund : https://www.lanzajet.com/lanzajet-secures-industry-leading-innovative-financing-with-microsoft-climate-innovation-fund-to-construct-the-worlds-first-commercial-alcohol-to-jet-sustainable-fuel-plant/#:~:text=The%20Microsoft%20Climate%20Innovation%20Fund%20.

26 *Microsoft*. (n.d.). Retrieved from Climate Innovation Fund: https://www.microsoft.com/en-us/corporate-responsibility/sustainability/climate-innovation-fund?activetab=pivot1:primaryr6.

27 *Fly Green Fund*. (n.d.). Retrieved from 75% becomes sustainable aviation fuel and 25% will support market development : https://flygreenfund.se/en/how-it-works/.

28 *Fly Green Fund (b)*. (n.d.). Retrieved from Reduce the carbon emission from your flights: https://flygreenfund.se/en/about-us/.

29 *Airport Suppliers*. (2019, June 25). Retrieved from Avinor Secures Partnership for Production of Sustainable Aviation Fuel: https://www.airport-suppliers.com/avinor-partnership-for-production-of-sustainable-aviation-fuel/.

4.9 Financing Sources

The final variable impacting financing structures is the source of finance. While a plethora of financing organizations provide equity and/or debt for traditional project financing, there are limited sources of non-traditional options. Two non-traditional sources of finance currently exist and are quite attractive, yet difficult to obtain as they are debt-based rather than equity-based.

Equity investors in similar projects expect 15-20% returns on their investment. Interest on debt fluctuates with Prime Interest Rates which are in flux. The current (Q1 2023) Prime Interest Rate is 7.75% and primary debt is generally 1-2% above Prime for these types of projects. If a project cannot secure adequate primary debt and either cannot, or will not bring in additional equity, a project may bring in mezzanine debt. The interest rate, or the ability to even secure the mezzanine debt, is unique to a project. Frequently, this interest rate is 7-10% above Prime Interest Rates, which places it securely between the effective rates for primary debt and equity investors. To achieve acceptable returns, renewable fuel projects currently require support; this support is available from various government entities as outlined in **Section 4.7**. The following examples provide traditional and non-traditional project financing sources.

4.9.1. Traditional Project Financing Sources

Traditional project financing sources of equity and debt are as follows:

4.9.1.1. Equity

BlackRock:

BlackRock represents one of the world's leading providers of investment, advisory and risk management solutions. BlackRock is committed to sustainability, as demonstrated by their commitment to achieve net zero by 2050 or sooner.[30] To achieve this goal, BlackRock has partnered with Temasek, created 'Decarbonization Partners,' and committed $600 million in funds that will be invested in companies and proven technologies capable of reducing/eliminating carbon emissions.[31]

In addition, BlackRock created the BlackRock Foundation funded by the company's charitable contributions.[32] For SAF developments, the BlackRock Foundation has invested $100 million in Breakthrough Energy's Catalyst Program – a platform investing in first-of-a-kind projects and large proven projects using key emerging technologies.[33] The program invested $50 million into LanzaJet's Freedom Pines Fuels to commence construction.[34]

CIG Capital:

CIG Capital is a project funding firm that focuses on Environmental, Socially, Governance (ESG) impactful projects to get the funding they need. Over 98% of large projects do not receive the funding they seek. Often this is not because the projects are too risky or that they are bad projects, rather they lack the needed structure, the de-risking of the business model, support services of the business model, or the right capital stack. CIG solves this dilemma by issuing notes or bonds for the projects it partners with, which provide up to 100% of the required funding for the project, as well as various components of the capital stack or structure, and provide support services for the project. This 100% project funding model is geared to provide the necessary financing and support for projects ranging from $100 million through those in excess of $5 billion.[35]

Marathon Capital:

Marathon Capital is an independent investment bank delivering financial advice to the global energy and infrastructure markets. The firm offers a wealth of experience in the renewable fuels sector, including federal and state regulatory policies, and in advising clients on raising equity and debt capital.[36]

---

30 *About BlackRock*. (n.d.). Retrieved from BlackRock: https://www.blackrock.com/corporate/about-us.

31 *From ambition to action - the path to net zero*. (n.d.). Retrieved from BlackRock: https://www.blackrock.com/corporate/sustainability/committed-to-sustainability.

32 *Expanding firm efforts to address pressing social problems*. (n.d.). Retrieved from BlackRock: https://www.blackrock.com/corporate/about-us/social-impact/our-commitment-to-social-impact.

33 *Breakthrough Energy Catalyst*. (n.d.). Retrieved from Breakthrough Energy: https://breakthroughenergy.org/our-work/catalyst/.

34 *LanzaJet CEO Jimmy Samartzis on the future of sustainable aviation*. (n.d.). Retrieved from Breathrough Energy: https://breakthroughenergy.org/news/sustainableaviationfuel/.

35 *CIG Capital* . (n.d.). Retrieved from https://www.cigcap.com/.

36 *Marathon Capital*. (n.d.). Retrieved from Renewable Fuels & Chemicals: https://www.marathoncapital.com/industries/renewable-fuels-chemicals

4.9.1.2. Debt

World Bank:

The World Bank describes itself as the single largest financier of environmental projects globally. The International Finance Corporation (IFC) is one of five institutions in the World Bank Group and supports private sector investment through loans and grants. The remaining four are the International Bank for Reconstruction and Development (IBRD), the International Development Association (IDA), the Multilateral Investment Guarantee Agency (MIGA), and the International Centre for Settlement of Investment Disputes (ICSID).[37]

SocGen:

Société Générale S.A. is one of Europe's leading financial services groups. It is one of six global lenders in the Aviation Climate-Aligned Finance (CAF) Working Group dedicated to creating an aviation sector climate aligned finance agreement.[38]

Morgan Stanley:

Morgan Stanley is an American multinational investment management and financial services company helping individuals, organizations, and governments raise, manage, and distribute capital.

Morgan Stanley played a vital role in Fulcrum's BioEnergy Facility in Nevada. Instead of supporting Fulcrum's initial plan of obtaining a loan from a traditional commercial bank to finance the project, Morgan Stanley's bond underwriting practice raised over $200 million in tax-exempt municipal bonds (i.e., $175 million in project debt and $44 million in mezzanine debt) through the State of Nevada Department of Business and Industry. Since the project offered environmental benefits, the bonds were categorized as 'green bonds.' By using tax-exempt sources instead of a standard bank loan, Fulcrum benefited from a lower-cost financing deal.[39]

4.9.2. Non-Traditional Project Financing Sources

4.9.2.1. Department of Energy

This report identified one confidential, multi-billion dollar project in which the DOE is considering providing all the capital for as debt. While this may be a challenging path to obtain funds (i.e., ensuring all criteria and requirements are met), the DOE has a history of funding projects, and if the project qualifies, it is a very attractive alternative.

4.9.2.2. Aubrey Capital Management

Aubrey Capital Management is a relatively new financial group, founded in 2006, with offices in the UK. Aubrey Capital Management offers 100% debt on projects that meet their stringent requirements. Besides the commercial agreements mentioned above, the developer must have a site with permits in hand, or at least a clear path to get there before Aubrey Capital Management considers project financing. Once a project meets the requirements of Aubrey Capital Management, it may close in weeks rather than months and provide the developer an immediate exit path if they so choose.

37 The World Bank. (2012). *Air Transport and Energy Efficiency* . Washington, DC: Transport Papers.

38 *Scoiete Generale*. (2022, April 07). Retrieved from Scoiete Generale, one of the founding members of a climate-aligned finance framework to support aviation industry decarbonization : https://www.societegenerale.com/en/news/press-release/aviation-industry-decarbonization-working-group

39 *Using Green Bonds to Turn Garbage into Jet Fuel*. (2019, April 24). Retrieved from Morgan Stanley: https://www.morganstanley.com/ideas/fixed-income-finances-fulcrum-bioenergy

4.10 Conclusion

This Task Report addresses the suggested pathways to finance a renewable fuels production facility emphasizing seven variables. These variables can impact project financing structure and include technology selection, performance guarantees, facility siting, commercial agreements, federal and state financial support, strategic partnerships, and financing sources. While there is a plethora of established pathways to finance traditional infrastructure projects, opportunities for emerging pre-commercial industrial and energy technologies are limited. Financing SAF production facilities are less viable due to expected negative cash flow. Government financial support can lower investor risk and offset costs associated with SAF facilities. The result would be economically feasible renewable fuel projects.

To obtain project financing, developers must focus on their financing plan at the outset of development. A large consideration should be placed on the project's lifecycle. Market feedback can help to refine the financing structure, the business plan, and the technologies deployed before committing to a particular course of action.

The best results are achieved if the developer starts with funds at least equal to 10% of the total expected capital expenditure. Frequently this is not possible, making the path to success slower and more difficult but not necessarily impossible.

4.11 References

About BlackRock. (n.d.). Retrieved from BlackRock: https://www.blackrock.com/corporate/about-us

Airport Suppliers. (2019, June 25). Retrieved from Avinor Secures Partnership for Production of Sustainable Aviation Fuel: https://www.airport-suppliers.com/avinor-partnership-for-production-of-sustainable-aviation-fuel/

Ancheta, A. (2020, December 08). *What Is a Performance Bond and How Does It Work?* Retrieved from Investopedia : https://www.investopedia.com/terms/p/performancebond.asp

Bachman, J. (2022, March 29). *United Airlines Invests $5 Million in Startup to Study Greener Jet Fuel.* Retrieved from Bloomberg: https://www.bloomberg.com/news/articles/2022-03-29/united-invests-in-houston-startup-to-study-greener-jet-fuel?leadSource=uverify%20wall

Banton, C. (2022, December 16). *Equity Financing: What It Is, How It Works, Pros and Cons*. Retrieved from Investopedia : https://www.investopedia.com/terms/e/equityfinancing.asp

BGF. (2022, February 17). Retrieved from BGF explains: What is development capital?: https://www.bgf.co.uk/insights/bgf-explains-what-is-development-capital/

Bioenergy International. (2021, July 07). Retrieved from Fulcrum BioEnergy completes construction of Sierra BioFuels W2F plant: https://bioenergyinternational.com/fulcrum-bioenergy-completes-construction-of-sierra-biofuels-w2f-plant/

Breakthrough Energy Catalyst. (n.d.). Retrieved from Breakthrough Energy: https://breakthroughenergy.org/our-work/catalyst/

CIG Capital. (n.d.). Retrieved from https://www.cigcap.com/

Clean Energy and Climate Solutions Federal Funding Database. (2023, January 30). Retrieved from Wilson Sonsini : https://www.wsgr.com/en/clean-energy-and-climate-solutions-federal-funding-database.html#biofuels

Council, A. I. (2023). *National Aeronautics Science & Technology Priorities.* Executive Office of the President of the United States . Retrieved from https://www.whitehouse.gov/wp-content/uploads/2023/03/032023-National-Aeronautics-ST-Priorities.pdf

Expanding firm efforts to address pressing social problems. (n.d.). Retrieved from BlackRock: https://www.blackrock.com/corporate/about-us/social-impact/our-commitment-to-social-impact

Fly Green Fund. (n.d.). Retrieved from 75% becomes sustainable aviation fuel and 25% will support market development : https://flygreenfund.se/en/how-it-works/

Fly Green Fund (b). (n.d.). Retrieved from Reduce the carbon emission from your flights: https://flygreenfund.se/en/about-us/

From ambition to action - the path to net zero. (n.d.). Retrieved from BlackRock: https://www.blackrock.com/corporate/sustainability/committed-to-sustainability

Fulcrum Bioenergy. (n.d.). Retrieved from Sierra BioFuels Plant & Feedstock Processing Facility: https://www.fulcrum-bioenergy.com/sierra-biofuels

Group, S. A. (2022). *Sustainable Aviation Fuel Updates and Recommendations (Opportunities for Washington).* https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=2022-12-01%20SABWG%20REPORT_9cd2afd3-8606-46d2-aa90-42b98fe62972.pdf: Washington State University.

Hansen, K. (2022, August 17). *Norton Rose Fulbright.* Retrieved from The Inflation Reduction Act and DOE loan programs: https://www.projectfinance.law/publications/2022/august/the-inflation-reduction-act-and-doe-loan-programs/#:~:text=The%20Act%20authorizes%20another%20%2440,the%20volume%20of%20available%20funding

Hileman, J., & Orton, A. 2022. IRA Section 4007 FAST-SAF and FAST-Tech Grant Program. FAA PowerPoint: https://www.transportation.gov/sites/dot.gov/files/2022-12/IRA-Section-40007-FAST-Program-Briefing.pdf

ICAO Committee on Aviation Environmental Protection . (2022). *Guidance on Potential Policies and Coordinated Approaches for the Deployment of Sustainable Aviation Fuels.* https://www.icao.int/environmental-protection/Documents/SAF/Guidance%20on%20SAF%20policies%20-%20Version%201.pdf: ICAO.

ICAO Environment. (2023, March 14). SAF Offtake Agreements, Tracker of SAF Offtake Agreements. Retrieved from: https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx.

International Airport Review. (2022, November 18). Retrieved from United becomes first U.S. airline to invest in biofuel refinery: https://www.internationalairportreview.com/news/180937/united-becomes-first-u-s-airline-to-invest-in-biofuel-refinery/

Investopedia. (2023). Financial Term Dictionary. Retrieved from: https://www.investopedia.com/financial-term-dictionary-4769738.

Lanzajet. (2022, January 13). Retrieved from LanzaJet Secures $50M in Funding from Microsoft Climate Innovation Fund : https://www.lanzajet.com/lanzajet-secures-industry-leading-innovative-financing-with-microsoft-climate-innovation-fund-to-construct-the-worlds-first-commercial-alcohol-to-jet-sustainable-fuel-plant/#:~:text=The%20Microsoft%20Climate%20Innovation%20Fund%20

LanzaJet CEO Jimmy Samartzis on the future of sustainable aviation. (n.d.). Retrieved from Breathrough Energy: https://breakthroughenergy.org/news/sustainableaviationfuel/

Marathon Capital. (n.d.). Retrieved from Renewable Fuels & Chemicals: https://www.marathoncapital.com/industries/renewable-fuels-chemicals

Microsoft. (n.d.). Retrieved from Climate Innovation Fund: https://www.microsoft.com/en-us/corporate-responsibility/sustainability/climate-innovation-fund?activetab=pivot1:primaryr6

Morgan Stanley. (2019, April 24). *Using Green Bonds to Turn Garbage into Jet Fuel.* Retrieved from Morgan Stanley: https://www.morganstanley.com/ideas/fixed-income-finances-fulcrum-bioenergy.

MRSC (2023). Municipal Research and Services Center of Washington, Gift of Public Funds. Retrieved from: https://mrsc.org/explore-topics/legal/ethics/gift-of-public-funds#What%20is%20Prohibited.

New Energy Risk. (2021). *Industrial & Energy Technology Project Finance, A Startup and Developer's Guide to Scaling and Commercial Success.* Retrieved from: https://newenergyrisk.com/wp-content/uploads/2021/11/NER-Project-Finance-Guide.pdf.

Potter, C. (2022, August 02). *What Are Liquidated Damages (LDs)? How They Work, With Example*. Retrieved from Investopedia: https://www.investopedia.com/terms/l/liquidateddamages.asp.

Scoiete Generale. (2022, April 07). Retrieved from Scoiete Generale, one of the founding members of a climate-aligned finance framework to support aviation industry decarbonization : https://www.societegenerale.com/en/news/press-release/aviation-industry-decarbonization-working-group

Stanley, M. (n.d.). Retrieved from https://www.morganstanley.com/

Surgenor, C. (2021, August 02). *Green Air.* Retrieved from Eight UK sustainable aviation fuel projects shortlisted to share £15 million in government grant funding: https://www.greenairnews.com/?p=1455

Sustainable Aviation Biofuels Work Group (2020 November). *Sustainable Aviation Fuel Opportunities for Washington, November 2020 Final Report, Prepared for: The Washington State Governor and the Washington State Legislature*. Retrieved from: https://s3.wp.wsu.edu/upload/sites.2180/2020/SABWG-Final-Report-November-2020-compressed.pdf.

The World Bank. (2012). *Air Transport and Energy Efficiency.* Washington, DC: Transport Papers.

U.S. Department of Energy. (2016, July). Acquisition Guide, Chapter 9.2 Performance Guarantees. FAR 9.104 and 9.105; DEAR 909.104-3 and 970.9070. Retrieved from: https://www.energy.gov/sites/prod/files/2016/07/f33/07_06_16-AG_Chap_9-2-Performance_Guarantees.pdf.

United Airlines . (2022, June 15). *Transforming Yesterday's Emissions into Tomorrow's Sustainable Aviation Fuel: United Announces Agreement with CO2 Utilization Company Dimensional Energy.* Retrieved from PR News Wire : https://www.prnewswire.com/news-releases/transforming-yesterdays-emissions-into-tomorrows-sustainable-aviation-fuel-united-announces-agreement-with-co2-utilization-company-dimensional-energy-301568237.html.

Washington Department of Commerce, Bond Cap Allocation Program (n.d.). Retrieved from: www.commerce.wa.gov/about-us/research-services/bond-cap-allocation-program.

EXP | 451 Montgomery Street, Suite 300 | San Francisco, CA 94104
t: +1. 954.999.8292

exp.com

TASK
5

MUNICIPAL SOLID WASTE TO LIQUID FUELS STUDY

Port of Seattle + King County Solid Waste Division

Report Name:
Task 5 – Project Partnerships

2023-06-30

prepared by

EXP
451 Montgomery Street, Suite 300 | San Francisco, CA 94104
Principal, Marcos Souza: marcos.souza@exp.com
Project Manager, Joseph Gale: joseph.gale@exp.com

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

5

TASK 5 – PROJECT PARTNERSHIPS

5. Task 5 – Project Partnerships

5.1. Executive Summary

Partnerships are formed between entities that have an area of mutual interest even though other aspects of their business may not be related. Each entity contributes in the form of money, time, resources, long-term contracts, facilities, etc. to advance the area of common interest. Task 5 evaluates the financial and logistical benefits of partnerships with entities including private industry and public agencies across the entire supply chain for the fuel production process in ten areas spanning from feedstock sourcing to transporting fuel to an aircraft's wing.

1. **Feedstock source and pre-processing**: The following parties benefit from partnerships: Renewable fuel facilities (feedstock security), landfills (extending its lifespan, supporting zero waste objectives, and revenue diversification), transportation partners (logistical benefits and a new stream of business), waste haulers (diversifying waste drop-off destinations, survival as 'green' initiatives are promoted), and renewable natural gas (RNG) producers (sale of RNG at a higher price than under commercial conditions yet cheaper than grid RNG).
2. **Facility land acquisition or purchase, funding, ownership, development, co-location, and/or operation:** Brownfield sites are "location-efficient" due to their existing connections to infrastructure (e.g., roadways and utilities), allowing project savings on infrastructure expenses associated with greenfield projects. SAF facilities can be co-located to petroleum refineries to enhance profit margins by sharing costs with the refinery, such as service facilities, buildings, and plant management team/engineers. Certain sites with sufficient space to accommodate a SAF facility (e.g., landfill adjacent) eliminate logistical and transportation matters.
3. **Product development, marketing, and sales:** Achieved through offtake agreements between SAF producers and airlines (e.g., Shell Aviation and JetBlue at LAX), partnerships with air cargo carriers (allowing clients to purchase SAF for shipments), and partnerships with pipeline operators (widespread distribution of SAF) offer partnership opportunities in product development, marketing, and sales.
4. **Utilities and required infrastructure:** Utility companies and other public entities are crucial to obtain services (e.g., power, water, rail, road access, etc.). Partnerships with these companies ensure that additional investments will result in added long-term revenue.
5. **Contractor access for both MSW drop-off and fuel transport**: Partnerships for MSW drop-off and fuel transport through an airline fuel consortium can deliver larger quantities of SAF to airports.
6. **Permitting requirements, regulatory standards, and policy framework**: Failing to obtain the required permits may bring the entire project to a halt. Developing strong relationships with government agencies and the public is imperative and can assist navigating through the oftentimes complex permitting process. It will also prove instrumental in meeting the needs of this facility since the process of converting MSW to jet fuel is a relatively new process and must be incorporated into future laws, regulations, policies, tax incentives, and investments.
7. **Siting options and planning level layouts and costs**: This study does not recommend partnerships but, rather the engagement of an experienced consultant to work cooperatively in this early phase of a project. Typical pros and cons of siting options that consultants would consider concern selecting a site close to an existing refiner that becomes a partner, and a site located close to the feedstock and/or airport.
8. **Potential for carbon sequestration, greenhouse gas emission reduction, or similar climate strategies/benefits based on different options**: This facility can partner with eFuel producers, organizations proactively focused on offsetting CO2 (e.g., NativeEnergy), organizations and nonprofits (e.g., Airlines4America), local influences (e.g., the boards and commissions from each region), local universities, and landowners.
9. **Effective policies or regulations from other jurisdictions that could be adopted in King County (KC) to support the recommended outcomes**: The city of San Francisco's 'Mandatory Recycling and Composting Ordinance' and Japan's Act on Promotion of Resource Circulation for Plastics are examples that could be applied in KC.
10. **Potential funding sources such as grants, incentives, and/or credits**: The Grid Resilience and Innovation Partnership (GRIP) Program and the expansion of Section 45Q of the United States Internal Revenue Code.

5.2. Introduction

Partnerships are structured management approaches in which two or more businesses dedicate resources to achieve mutual objectives. Entering into partnership agreements can be beneficial but may also include risks e.g., colliding interests between the partners, one partner running into operational or financial issues, less flexibility to switch to alternatives (e.g., to a different waste supplier or utility supplier), or changes in organizational structures. As a result, partnerships must address risks and responsibilities; pros and cons must be evaluated to determine whether a partnership provides a win/win situation, and for what time horizon the partnership is considered, whether to get a project built and transferred or for the full lifetime of a project.

The more partners involved, the more diluted the focus on the goals of the project and profitability of the plant. Whether it be an equal partnership (same split of shares) or a one-sided partnership in which one partner is much stronger and is responsible for the plant operations, having a proactive approach from the partnership outset is essential to protect one's business interests as well as the well-being of all parties involved. In general, a partnership must be a win/win situation (i.e. both or all partners need to benefit from this partnership). A partnership does also mean it is a long-term commitment and can significantly enhance the chances to get a project financed, whether it is through additional equity brought in, or by improving the financial standing when applying for project financing. **Task 4** explored the role of partnerships in project financing in detail.

Partnering with an entity which is part of the supply chain has the benefit of having better control of that portion to the advantage of the production plant. For example, partnerships with key stakeholders, such as municipal waste companies and recycling companies will be beneficial for a long-term supply of high-quality feedstock at reasonable cost.

The Task 5 Report evaluates the financial and logistical benefits of partnerships with other entities including private industry (e.g., haulers, materials recovery facility (MRF) operators, refineries) and/or other public agencies including federal granting organizations, and/or waste authorities across the entire supply chain for the fuel production process. This includes a total of ten areas spanning from the initial step of feedstock sourcing to the final stage of transporting fuel to an aircraft's wing. The ten areas explored for partnership opportunities in this study are:

1. Feedstock source and pre-processing
2. Facility land acquisition or purchase, funding, ownership, development, co-location, and/or operation
3. Product development, marketing, and sales
4. Utilities and required infrastructure
5. Contractor access for both MSW drop-off and fuel transport
6. Permitting requirements, regulatory standards, and policy framework
7. Siting options and planning level layouts and costs
8. Potential for carbon sequestration, greenhouse gas emission reduction, or similar climate strategies/benefits based on different options
9. Effective policies or regulations from other jurisdictions that could be adopted in King County (KC) to support the recommended outcome; and
10. Potential funding sources such as grants, incentives, and/or credits

5.3. Feedstock Source and Pre-Processing

This section highlights the importance of partnerships for feedstock sourcing and pre-processing.

The SAF Grand Challenge is a U.S. initiative aimed at accelerating the development and deployment of SAF to help decarbonize the aviation industry. Launched in 2019 as a collaboration between multiple government agencies, including the Department of Energy, the Department of Agriculture, the Federal Aviation Administration (FAA), and the National Aeronautics and Space Administration, the SAF Grand Challenge sets ambitious goals for the SAF industry to produce 3 billion gallons of domestic SAF annually. This would amount to a 50% reduction in lifecycle GHG emissions by 2030 and a 100% reduction in life cycle GHG emissions by 2050 (compared to traditional jet fuel). The SAF Grand Challenge also includes six action areas, which cover different aspects of the SAF supply chain, from feedstock sourcing to end use. These six action areas are (1) feedstock innovation, (2) conversion technology innovation, (3) building supply chains, (4) policy and valuation analysis, (5) enabling end use, and (6) communicating progress and building support.

Feedstock innovation promotes increasing the collection of MSW for SAF production.[1] Partnerships with key stakeholders, such as municipal waste companies and recycling companies are beneficial for the long-term supply of high-quality feedstock at a reasonable cost. The goal of such partnerships is to produce benefits such as securing sufficient feedstock in quantity and quality by involving feedstock suppliers as shareholders to ensure their ongoing interest in running a project profitably. The following examples illustrate parties benefiting from such partnerships.

5.3.1. Renewable Fuel Facility

A renewable fuel facility requires a steady supply of feedstock to meet SAF demands and generate profits. It is regarded as a critical component of bringing a facility online. Partnering with a feedstock supplier ensures an uninterrupted supply of feedstock, which can be challenging to obtain. For example, to eliminate the risk of an interrupted supply, NEXT Renewable Fuels (NEXT) partnered with BP Products North America Inc. (BP) to secure a long-term supply of renewable feedstock (animal fats and tallows, cooking oils, virgin seed oils, and greases) for NEXT's proposed renewable diesel facility located in Port Westward, Oregon. BP will source roughly 2 million metric tons or 13.2 million barrels per year of feedstock from its global feedstock aggregation and sourcing network.[2] This facility has benefited from successful partnerships to secure a steady supply of MSW going forward.

5.3.2. Landfills

Landfills are well positioned to attract partnerships with potential renewable fuel production facilities, particularly as waste reduction is prioritized across the country to achieve zero waste objectives. In 2015, the United States Conference of Mayors produced a resolution to support Municipal Zero Waste Principles and a Hierarchy of Materials. At the time of this resolution, 251 million tons of MSW was produced annually in the country. Only 34% of that waste was recovered through recycling and composting. The majority of MSW ended up in landfills and it was recognized that the trend needed to change. This resolution encouraged all cities to adopt a similar set of principles in their local communities.[3] By securing partnerships that divert waste, such as to a renewable fuel production facility, landfills could play a role in achieving these zero waste objectives. While commercial landfills could potentially see decreased profits in pursuing these types of partnerships, as a result of reduced tipping fees of landfilled waste, through extensive communication and identification of a risk/reward profile, a path forward may be actualized. Landfills may still generate revenue despite waste reduction and zero waste policies.

Landfills nearing capacity can be excellent partners for securing a supply of MSW feedstock for SAF production. An example of such a landfill is King County's Cedar Hills Landfill, which is expected to close by 2040 unless the actions detailed in King County Solid Waste Division's (SWD) Re+ initiative are executed by 2030. The existing SWD policy prohibits opening a new facility in the county due to community, environmental, and land use concerns, and would therefore not be feasible. Alternative disposal options that would replace the Cedar Hills Landfill are predicted to be more expensive and worse for the environment. Therefore,

1 SAF Grand Challenge Roadmap. (2022, September). Retrieved from Department of Energy: https://www.energy.gov/sites/default/files/2022-09/beto-saf-gc-roadmap-report-sept-2022.pdf.

2 NEXT Renewable Fuels and BP enter into renewable feedstock supply agreement. (2019, June 11). Retrieved from F+L Daily: https://www.fuelsandlubes.com/renewable-fuels-bp-products-north-america-enter-renewable-feedstock-supply-agreement/#:~:text=(NEXT)%20and%20BP%20Products%20North,facility%20in%20the%20United%20States.

3 In Support of Municipal Zero Waste Principles and a Hierarchy of Materials Management. (n.d.). Retrieved from The United States Conference of Mayors: https://www.usmayors.org/the-conference/resolutions/?category=b83aReso050&meeting=83rd%20Annual%20Meeting.

it is essential to extend the life of this landfill. The Re+ Initiative shifts the region's current solid waste system from a disposal-based approach to one focused on reduction, recovery, recycling, and regeneration. Through development of a circular economy, waste prevention and reduction methods would be encouraged and could potentially make a partnership with the Cedar Hills Landfill to support a renewable fuels production facility. Waste diverted from this landfill would be advantageous as it extends the life of the facility, and also results in environmental and social benefits to the community. [4]

5.3.3. Transportation Partners

Transportation companies that form partnerships with renewable fuel production facilities may benefit financially and in other ways associated with tapping into a new revenue stream, e.g., MSW/RDF and SAF shipping. Long-term partnerships are most desirable as they allow transportation companies to develop efficient, long-term plans based on client demand and profit maximization. From a developer's perspective, outsourcing logistics to a skilled transportation partner can relieve the facility owner of developing plans and managing operation of relevant supply chain considerations.

As an example, Fulcrum BioEnergy has established long-term contracts with Waste Management (WM) and Waste Connections to transport MSW to its Sierra Biorefinery. The contractors deliver MSW via 25-ton tractor trailers to Fulcrum's processing facility, located 15 miles from the SAF production facility, where usable MSW is extracted, and the remainder trucked to a landfill and/or recycling center. The remainder (usable MSW) is transported to the biorefinery. [5] Here, Fulcrum BioEnergy benefit from having a third-party contractor transport and logistically coordinate feedstock supplies for SAF production, while WM and Waste Connections also benefit from their contractor agreement.

5.3.4. Waste Haulers

Waste haulers may enjoy financial benefits by diversifying their waste drop-off destinations when entering partnerships, such as with a renewable fuel facility. This is an imperative strategy to guarantee the prolonged survival of waste hauling companies as policies change to support 'green' initiatives. For example, Zero Waste Washington has a mission to drive "policy change for a healthy and waste-free world."[6] In order for waste hauling companies to remain competitive, it would be wise of these companies to be proactive by engaging with green trends and broadening their client base to offset the repercussions of future policies that avoid the generation and landfilling of wastes. Failing to do so could result in future profit losses as the client base decreases.

The Washington State Department of Ecology is responsible for overseeing solid waste management in the state. This includes regulating and permitting solid waste handling facilities, developing solid waste reduction and recycling programs, and providing technical assistance to local governments and stakeholders. This agency could also act as a potential partner to help coordinate waste flows/hauling through its oversight and relationships with appropriate parties.[7]

5.3.5. RNG Producers

Locating a facility adjacent to a landfill that produces RNG could create a situation in which the renewable fuel facility serves as an offtaker for the RNG. This partnership would be financially beneficial for both parties. For example, the renewable fuel facility could negotiate a long-term stable supply of RNG at an attractive price that is cheaper than grid RNG (which would be the price for a facility located at a distance from the source of RNG) yet more expensive than the price paid by utility companies under commercial conditions. Sourcing RNG offers additional environmental benefits since it is CO2 free and certain markets, such as

California, are already enjoying the sale of RNG due to the state's low-carbon fuel standard.[8]

4 Re+ Strategic Plan: Reimagining a waste-free King County. (2022). King County.
5 Beurteaux, D. (2022, March 23). Is jet fuel from waste finally ready for takeoff? Retrieved from Waste Dive: https://www.wastedive.com/news/waste-jet-sustainable-aviation-fuel-fulcrum-bioenergy-saf/620365/.
6 Zero Waste Washington. (n.d.). Retrieved from Mission and vision: https://zerowastewashington.org/about/mission-and-vision/.
7 Solid waste. (n.d.). Retrieved from State of Washington Department of Ecology: https://ecology.wa.gov/Waste-Toxics/Solid-waste-litter/Solid-waste.
8 Promoting Renewable Natural Gas in Washington State, A Report to the Washington State Legislature. (2018, December). Retrieved from Department of Commerce and Energy Program Washington State University: https://www.commerce.wa.gov/wp-content/uploads/2019/01/Energy-Promoting-RNG-in-Washington-State.pdf.

5.4. Facility Land Acquisition or Purchase, Funding, Ownership, Development, Co-Location, and/or Operation

This section reviews the impact of various forms of partnerships for facility land acquisition/purchase, funding, ownership, development, co-location, and/or operation. Creating partnerships with landowners solidifies the incoming support from the neighborhood. The support of landowners is essential for securing access to the facility, right of way for utilities, long term use of the land where the facility is located, positive impacts on the social acceptance, and many more. The type of partnership and their financial benefits must be negotiated on a case-by-case basis.

In general, partnering with owners of a brownfield site offers numerous environmental and economic benefits. Brownfield sites tend to be 'location-efficient' due to their existing connections to infrastructure (e.g., roadways and utilities). This allows project savings on infrastructure expenses when compared to greenfield projects. It also prevents environmental degradation on new (greenfield) sites. A study by the USEPA revealed that each acre of brownfield redevelopment spares roughly 1.3 – 4.6 acres of new impervious surface construction – avoiding additional repercussions such as stormwater runoff associated with impervious sites.[9] Developing brownfield sites can also breathe life back into abandoned, visually unappealing, and potentially dangerous sites – creating employment opportunities in the process. In certain jurisdictions, local authorities support brownfield site development, making it easier to obtain planning permission/permits on previously built land. [10] Partnerships support the opportunity to obtain a share of ownership and to participate in the project. **Task 4** discusses multiple financing/ownership structure opportunities in detail.

SAF facilities can be co-located to petroleum refineries. Co-locating the facility offers opportunities to enhance profit margins by sharing certain costs with the refinery, such as service facilities (e.g., water distribution, product storage capacity, power distribution, other utilities, etc.), buildings, plant management team/engineers (i.e., experienced personnel to manage and operate the facility that could be in the form of an offtaker), and yard improvements.[11]

Certain sites with sufficient space to accommodate a SAF facility, such as the one landfill adjacent, would eliminate logistical and transportation matters (e.g., additional rail or ship transportation of MSW used to produce SAF) by securing partnerships.

5.5. Product Development, Marketing, and Sales

This section builds on the introduction to **Task 4, Section 8 - Strategic Partnerships,** which highlights several examples of strategic partnerships. Partnerships with offtakers, shippers, and pipeline operators are key to ensuring the sale of the products and expanding into additional markets.

5.5.1. Offtake Agreements

An offtake agreement is an arrangement between two parties (i.e., a producer and a buyer/offtaker) to exchange the producer's future goods for money. Offtake agreements are often negotiated before a factory/facility is developed to secure a market and revenue stream for its products.[12] Offtakers can often provide first-hand information about new or changed demand and enable the plant operator to react early to changing market conditions. They are so instrumental that 97 offtake agreements have been recorded by the International Civil Aviation Organization (ICAO) across the globe from 2013 to 2023. The duration of these agreements range between one and 20 years, and the total offtake volume has historically reached 1.5 billion gallons in a single agreement (for United Airlines, in 2021).[13] **Table 5.1** provides a summary of the total volume of SAF supplied through a specified number of offtake agreements for the top ten fuel producers.

9 Brownfields Program Environmental and Economic Benefits. (2023, February 22). Retrieved from United States Environmental Protection Agency: https://www.epa.gov/brownfields/brownfields-program-environmental-and-economic-benefits.
10 Barrett, J. (2022, May 15). Evolution 5. Retrieved from the benefits of brownfield sites: https://evolution5.co.uk/the-benefits-of-brownfield-sites/.
11 Brandt, K., Garcia-Perez, M., Stockle, C., Tanzil, A., Wolcott, M., & Zhang, X. (2021). Production of Sustainable Aviation Fuels in Petroleum Refineries: Evaluation of New Bio-Refinery Concepts. Frontiers in Energy Research, Volume 9. Retrieved from: https://doi.org/10.3389/fenrg.2021.735661.
12 Segal, T. (2023, January 29). What Is an Offtake Agreement in Project Financing? Retrieved from Investopedia: https://www.investopedia.com/terms/o/offtake-agreement.asp.
13 SAF Offtake Agreements. (n.d.). Retrieved from ICAO Offtake Agreements: https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx.

Table 5.1. A Summary of the Total Volume of SAF Supplied through Offtake Agreements for the Top Ten Fuel Producers[14]

Fuel Producer	Total Offtake Volume (Million Liters)	Number of Offtake Agreements
Gevo	9,360.76	13
Fulcrum	6,719.1	3
Alder Fuels	5,678.12	1
Shell	2,755.07	4
Neste	2,285.72	13
Raven SR	1,561.64	1
DG Fuels	1,457.38	1
OMV	1,433.45	5
Aemetis	1,272.43	9
Dimensional Energy	1,135.62	1
Velocys	1,105.34	2

The two airlines purchasing the most SAF globally through historic offtake agreements are both in the US: United Airlines (boasting six agreements for a total of 2.8 billion gallons) and Delta Airlines (seven agreements totaling 1 billion gallons). While many offtake agreements have been celebrated across the country, two recent examples of agreements entered into during 2023 include:

- Alaska, Delta, JetBlue and Shell Aviation – In March 2023, JetBlue entered into an offtake agreement with Shell Aviation to increase the supply of SAF to Los Angeles International Airport (LAX). Over the next two years, JetBlue will welcome the delivery of up to 10 million gallons of SAF at LAX. The airline will be in a position to choose whether to purchase up to 5 million gallons more of the blend in 2026 – at LAX or another airport.[15] Shell Aviation will also supply up to 10 million gallons of neat SAF to Alaska Airlines and Delta Airlines in Los Angeles.[16, 17]
- Hawaiian Airlines and Gevo Inc. – During the same month, Hawaiian Airlines agreed to purchase 50 million gallons of SAF from Gevo Inc. over a five-year period (starting in 2029). The SAF will be produced at a soon-to-be constructed facility in the Midwest that will deliver SAF to cities in California.[18] This is an excellent precedent because it highlights the ability to secure offtake agreements with airlines prior to the construction phase of the SAF facility.

As mentioned above, ICAO tracks SAF Offtake agreements by date, fuel producer, fuel supplier, fuel user / purchaser, total offtake volume, length of offtake agreement and the source of information.[19] Airlines operating out of SEA may be interested in potential offtake agreements with a facility that regionally sources its feedstock. This type of partnership (offtake agreement) benefits all entities involved and with utilization of local feedstock aims to minimize the carbon intensity of the SAF.

14 Ibid.
15 Sapp, M. (2023, March 15). The Digest. Retrieved from JetBlue and Shell Aviation agree to SAF offtake agreement for LAX: https://www.biofuelsdigest.com/bdigest/2023/03/15/jetblue-and-shell-aviation-agree-to-saf-offtake-agreement-for-lax/#:~:text=Within%20the%20terms%20of%20the,other%20airports%20in%20JetBlue's%20network.&text=Thank%20you%20for%20visting%20the%20Digest.
16 Alaska Airlines (2023, March 23). Alaska Airlines announces agreement with Shell Aviation to help expand sustainable aviation fuel market in Pacific Northwest. Retrieved from: https://news.alaskaair.com/newsroom/alaska-airlines-announces-agreement-with-shell-aviation-to-help-expand-sustainable-aviation-fuel-market-in-pacific-northwest/.
17 Delta Airlines (2023, April 20). Delta, Shell Aviation SAF agreement to fuel LAX hub and accelerate aviation decarbonization. Retrieved from: https://news.delta.com/delta-shell-aviation-saf-agreement-fuel-lax-hub-and-accelerate-aviation-decarbonization.
18 Hawaiian Airlines to buy sustainable aviation fuel. (2023, March 27). Retrieved from Yahoo! News: https://news.yahoo.com/hawaiian-airlines-buy-sustainable-aviation-160300337.html?guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAHa3L4JQf1ylvrSXGsMODpxLtErAz3NGdV3gCXlXcDpVTMrJeBeFgIxws6_hl_-PvvqywiWXNJtFyGEDm9me-FebnF7db7B3rK9CE6pHH4.
19 SAF Offtake Agreements. (n.d.). Retrieved from ICAO Offtake Agreements: https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx.

5.5.2. Partnerships with Air Cargo Carriers

Partnering with shipping companies is an excellent strategy to attract widespread interest and increase demand for SAF produced at the facility. Shipping companies transport items from one location to another on behalf of their clients. These companies can give their clients the opportunity to purchase SAF through SAF partnerships for the carbon neutral transportation of the goods and improve sustainability across the supply chain. The amount of SAF purchased is tied to the weight of the shipment so clients can fuel their share of the flight with an environmentally friendly alternative. The clients are then able to deduct these savings from their scope three (indirect) emissions reporting. It is noteworthy that these types of partnerships can offer the option to purchase SAF on all cargo routes, despite the fact that SAF is not available at all airports. For example, cargo could be booked from airport A to airport B – both airports without a supply of SAF. If a client purchases SAF for the shipment, the SAF can be used in a flight on another route that departs from an airport with a supply of SAF.[20] Examples include:

- A recent partnership between Neste and CargoAi is testament to the power of securing partnerships with shipping companies. Through this partnership, SAF can be purchased from Neste immediately after a cargo booking is confirmed, or during the cargo tracking phase. Besides being better for the environment, third parties purchasing SAF during shipments can have a credible report of their CO2e emissions (calculated according to IATA standards) reductions and meet internal climate targets. CargoAi is now providing access to smaller quantities of SAF for smaller freight companies across 110 countries.[21]
- In 2022, United Airlines and Bolloré Logistics announced a partnership to satisfy consumer demand for "greener supply chain solutions." Through this partnership, 3 million liters of SAF will be purchased. It is instrumental in ensuring the logistic firm achieves its target of cutting its scope 3 emissions for transport by 30% by 2030, compared to a 2019 baseline. Bolloré Logistics expects this partnership to cut a minimum of 6,500 tons of CO2.[22]

20 Höglund, A. (2022, 24 September). Sustainable Aviation Fuels, a new pathway to decarbonize. Retrieved from GEODIS: https://geodis.com/blog/sustainability/sustainable-aviation-fuels-new-pathway-decarbonize.

21 Neste Corporation. (2022, November 07). Neste. Retrieved from Neste and CargoAi launch partnership offering freight forwarders and their clients an option to reduce the carbon emissions of their air cargo transports: https://www.neste.com/releases-and-news/renewable-solutions/neste-and-cargoai-launch-partnership-offering-freight-forwarders-and-their-clients-option-reduce.

22 Brett, D. (2022, August 31). Bolloré and United respond to shippers' green drive with SAF partnership. Retrieved from AirCargo News: https://www.aircargonews.net/policy/environment/bollore-and-united-respond-to-shippers-green-drive-with-saf-partnership/.

Table 5.2: Air Cargo Companies Operating out of SEA, or with a Base in Seattle, Demonstrating the Enormous Potential of Partnership Opportunities[23]

Operating out of SEA	Headquartered in Seattle[24]
Aer Lingus Cargo	Express Air Freight
Air Canada Cargo	Air Wave Express
Alaska Air Cargo	Lynden International
All Nippon Airways (ANA) Cargo	Saturn Freight Systems
American Airlines Cargo	Alaska Air Forwarding
Asiana Airlines Cargo	Sprint Forwarders
British Airways Cargo	Masterpiece International
Cargolux Airlines	World Cargo International
Cathay Pacific Cargo	Traffic Tech
China Airlines Cargo	Air Tiger Express
Condor Airlines Cargo	Amazon Air
Delta Air Lines Cargo	
DHL Express	
Emirates Sky Cargo	
EVA Air Cargo	
FedEX Express	
Hainan Airlines Cargo	
Hawaiian Airlines Cargo	
Icelandair Cargo	
Japan Airlines Cargo	
Korean Air Cargo	
Lufthansa Cargo	
Singapore Airlines Cargo	
Southwest Airlines Cargo	
Sun Country Airlines	
United Cargo	
Virgin Atlantic Cargo	

5.5.3. Partnerships with Pipeline and Blending Station Operators

Transporting renewable fuel through pipelines offers environmental benefits in comparison to conventional transportation via tanker trucks. As a result, forming partnerships to utilize existing pipelines (e.g., securing transportation slots) is advantageous, especially because building a new pipeline is a long, difficult, and sometimes impossible process today. Long-term partnerships can prove attractive to pipeline operators since operators charge a fee to transport materials in their pipeline.

23 *GoodFirms*. (2023, April 10). Retrieved from Air Freight Companies in the USA: https://www.goodfirms.co/supply-chain-logistics-companies/air-freight/usa.

24 *Air Freight Companies in Seattle*. (n.d.). Retrieved from Good Firms: https://www.goodfirms.co/supply-chain-logistics-companies/air-freight/seattle.

- For example, a partnership between TRAPIL, Neste, and Altens to achieve Europe's first transportation of renewable diesel via pipeline achieved a 92% reduction in CO_2 compared to conventional tanker trucks.[25]
- A partnership between Neste, Delta, Colonial Pipeline and Buckeye Partners delivered SAF to New York's LaGuardia Airport through an existing pipeline in 2022. Neste distributed the SAF from its refinery in Texas through the Colonial Pipeline across 11 states and 1,500 miles to New Jersey. Once within the state, the SAF entered the Buckeye Pipeline and transported to the airport.[26] This precedent demonstrates the possibility of transporting SAF to East Coast airports through existing infrastructure.

Operators of blending stations and pipelines transporting fuels from the blending stations to the airport may benefit from a partnership as they can participate in the growing market of renewable fuels and secure a long term business as part of the SAF supply chain.

5.6. Utilities and Required Infrastructure

This section explores the advantages of partnerships with utilities and infrastructure providers required for a renewable fuel facility. Amongst the many stakeholders, utility companies and other public entities would be crucial to getting services such as power, water, rail, road access, etc. A renewable fuel production facility is a large consumer of various utilities, and it may be required to expand the utility supply facilities and related infrastructure such as high voltage lines, pipelines, water treatments plants, etc. to meet the new demand. Partnerships with utility and infrastructure companies or public entities provide assurance that additional investments in this area would result in additional long-term revenue.

5.6.1. Renewable Energy Utilities

The Washington Clean Energy Transformation Act, adopted in 2019, will require the state's electric utilities to fully convert to clean, renewable power by 2045. Plans must be put in place to reduce their carbon emissions, or the utility companies will be heavily fined.[27] Currently, the state has established the Green Power Programs for utilities within Washington. RCW 19.29A.090(2) – The Revised Code of Washington (RCW), requires electric utilities to onboard a voluntary program where customers are eligible to purchase "qualified alternative energy sources." [28] The Washington Utilities and Transportation Commission states that the qualified alternative energy sources come from:

- Wind
- Solar
- Geothermal
- Landfill Gas
- Wave or tide action
- Wastewater treatment gas
- Qualified hydropower
- Certain biomass energy
- Dairy methane

Eligible investor-owned utilities (IOUs) adhering to the RCW, in the state of Washington and serving the regions identified in **Task 3** include:

1. **Avista Corporation**

   An energy company that produces, transmits, and distributes energy across four northwestern states. Avista has a diverse energy mix, positioning dependability with renewable energy sources.

25 Neste. (2022, April 06). Retrieved from Neste enabled the first-ever transport of renewable diesel by pipeline in Europe to help reduce emissions from fuel transports by 92%: https://www.neste.com/releases-and-news/renewable-solutions/neste-enabled-first-ever-transport-renewable-diesel-pipeline-europe-help-reduce-emissions-fuel.

26 Neste MY Sustainable Aviation Fuel. (2022, June 15). For the first time, Sustainable Aviation Fuel has been delivered to New York using existing petroleum pipelines. Retrieved from Neste: https://www.neste.com/releases-and-news/renewable-solutions/first-time-sustainable-aviation-fuel-has-been-delivered-new-york-using-existing-petroleum-pipelines.

27 "Washington's Energy Future." Washington Utilities and Transportation Commission, https://www.utc.wa.gov/regulated-industries/utilities/energy/conservation-and-renewable-energy-overview/washingtons-energy-future.

28 "Green Power Programs in Washington." Washington Utilities and Transportation Commission, https://www.utc.wa.gov/regulated-industries/utilities/energy/conservation-and-renewable-energy-overview/green-power-programs-washington.

2. Pacific Power & Light Company

Serving 243 communities and 800,000 customers across Oregon, Washington and California, Pacific Power is an energy company that aims to deliver sustainable energy solutions to its customers with Blue Sky products.

3. Puget Sound Energy

Puget Sound Energy serves a 6,000 square mile region in Western Washington. Having a rich history of energy leadership, PSE has established a present-day mission towards decarbonization and GHG emissions reduction, accompanied by various environmental goals, targets and commitments.

For the potential sites within the state of Oregon, it is dually noted that voluntary green programs are also put in place for their IOUs. Various alternative energy resources are in play; however, offshore wind (OSW) is a technology that is also being tested for widespread adoption to serve the qualified surrounding areas. Below is a breakdown of the participating IOUs and their respective alternative energy source programs. [29]

1. **Pacific Power** – Blue Sky (Wind and solar)

   Blue Sky products from Pacific Power are Green-e Energy certified meeting the standards established by the Center for Resource Solutions. These are environmental and consumer-protection standards that advocate for clean energy policies, markets and technologies.

2. **Portland General Electric** – Clean wind, Green Source, and Green Future Solar

   Serving approximately 900,000 customers, PGE has a 130-year history of powering people's lives. Leading the change to energy efficiency PGE is building smarter energy infrastructure, providing the demand for clean energy, and innovating new energy solutions for the future.

3. **Northwest Natural** – Smart Energy

   A natural gas company providing services to over 2.5 million people across Oregon and Southwest Washington for over 163 years. Northwest Natural is focused on decarbonization through energy efficiency, water conservation, and the expansion of renewable resources they can provide.

5.6.2. Benefits of Partnership for Utility Companies

In partnership with a renewable fuel production facility, a utility company could expect to onboard a resourceful client with an exceptional level of transparency and efficiency. Understanding the longevity a renewable fuel production facility provides, utility companies have been keen to secure long-term clients for consistent and reliable consumption of their supply.

By clarifying the necessary demand of the facility, the utility suppliers are also able to allocate the necessary resources without under-or-overestimating time and efforts required for their services.

The utilities industry as a whole is facing pressure to focus on ESG goals and public disclosures. By partnering with renewable fuel production facilities, utilities could expect to offset costs and withstand such pressure by partnering with sites that serve the regenerative sector.

Utility providers could benefit greatly from a partnership with a large consumer, such as a renewable fuel production facility, with an incentive to expand on land and within the market. If the facility were located on a brownfield site, grid connection may prove less expensive as the necessary infrastructure would already be in place. With the potential of the facility operating in a remote or rural area, it surfaces the incentive to expand the broadband utility systems to connect to other areas. This concept is typically called "middle mile." Some providers choose not to serve rural communities as they lack the presence of incentives or service requirements. Investor-owned utilities (IOUs) take on utility grid renovations to improve the efficiency and reliability of operations in these middle mile market areas. There are arrangements for IOUs to lease excess capacity on networks to providers in rural areas where all parties save money and provide or receive their essential services. By partnering with these types of entities, it is assuring

29 "Renewable Resources." Public Utility Commission: Renewable Resources: Utility Regulation: State of Oregon, https://www.oregon.gov/puc/utilities/Pages/Renewable-Resources.aspx.

the eligibility and intake of utility systems are accessible, efficient, clear, and well-coordinated.[30 31 32]

5.6.3. Benefits of Partnership for SAF Production Facility

In partnership with a single, or with various utility providers, a renewable fuel production facility could expect to receive all required resources needed for operation of the site. Furthermore, the required infrastructure to be implemented to feed the utility sources to the site could be fast-tracked under a respectable partnership with the provider.

Despite the potential risks of middle-mile market areas, a fuel production facility, with the longevity of its lifespan should also be presented with monetary incentives to save money under long-term and reliable contracts. Negotiations regarding current and future prices should aim to satisfy the opportunity costs of both entities. The ease of fiscal restraints in supplying utility to a relatively new and rural area could be achieved through partnering with the necessary companies. The additional provisions and services would accompany the partnership boosting the facility's overall operational efficiency, innovations, and value for money.

Overall, offloading risk, accessing alternative finances, capitalizing on efficiency savings and accelerating delivery are the key benefits of pursuing a partnership. A joint venture centered around design and implementation of utility supply should aim to meet the specific needs and objectives of the facility. The stakeholders involved can concoct a tailored approach to meeting this demand. [33, 34, 35]

5.6.4. Partnership Programs and Opportunities

The Grid Deployment Office has administered a $10.5 billion Grid Resilience and Innovation Partnership (GRIP) Program in 2023, as part of the Bipartisan Infrastructure Law. The grants under this program address Grid Innovation Programs, Smart Grids, and Grid Resilience Utility and Industry. Fast-tracking the deployment of projects to ensure reliable developments within the power sector which aim to reach all American communities, which is ideal for middle-mile sites to capitalize on. These opportunities are likely going to continue funding programs in the coming years.

The National Renewable Energy Laboratory (NREL) works with many types of organizations to broaden exposure of the clean energy economy. Their Strategic Public-Private Partnerships experience has shown to "bring together governments, communities, utilities, industry leaders, manufacturers, distributors, federal agencies—including the U.S. Department of Energy—and more."[36] Specific to sustainable aviation, the NREL's research "aims to not only permanently lower the carbon intensity of flight but also fundamentally improve the carbon footprint, mobility, and resiliency of the entire aviation ecosystem." Partnering with NREL could help to foresee important factors that ultimately help achieve decarbonization.[37]

30 Gong, L., & Read, A. (2022, March 29). Partnerships With Electric Utilities Can Help Expand Broadband Access. Retrieved from PEW: https://www.pewtrusts.org/en/research-and-analysis/articles/2022/03/29/partnerships-with-electric-utilities-can-help-expand-broadband-access.
31 Public private partnerships for central utilities. (n.d.). Retrieved from JLL: https://www.us.jll.com/en/views/central-utilities-public-private-partnerships.
32 Trabish, H. (2016, February 23). Utility Dive. Retrieved from Partnering for success: Utilities leverage innovative vendor relationships at the grid edge: https://www.utilitydive.com/news/partnering-for-success-utilities-leverage-innovative-vendor-relationships/413868/.
33 Gong, L., & Read, A. (2022, March 29). Partnerships With Electric Utilities Can Help Expand Broadband Access. Retrieved from PEW: https://www.pewtrusts.org/en/research-and-analysis/articles/2022/03/29/partnerships-with-electric-utilities-can-help-expand-broadband-access.
34 Public private partnerships for central utilities. (n.d.). Retrieved from JLL: https://www.us.jll.com/en/views/central-utilities-public-private-partnerships.
35 US Department of Treasury. (n.d.). Retrieved from Collaboration with Local Utility Companies & Other Utility Assistance Programs: https://home.treasury.gov/policy-issues/coronavirus/assistance- for-state-local-and-tribal-governments/emergency-rental-assistance-program/promising-practices/utilities.
36 NREL. (n.d.). Retrieved from Strategic Public-Private Partnerships: https://www.nrel.gov/workingwithus/strategic-partnerships.html.
37 Sustainable Aviation Research. (n.d.). Retrieved from NREL: https://www.nrel.gov/transportation/sustainable-aviation.html.

5.7. Contractor Access for Both MSW Drop-Off and Fuel Transport

In this section, existing partnerships, such as the airline fuel consortium, are studied to establish current access requirements for third party contractors. From there the contractor would work collaboratively with the stakeholders to refine and establish new requirements for access to both MSW drop-offs and fuel transportation sites.

5.7.1.MSW Drop-Off

The advantages of partnerships for MSW drop-off mirror those discussed in **Section 5.3.2 Logistical Benefits - Transportation**.

5.7.2. Fuel Transport

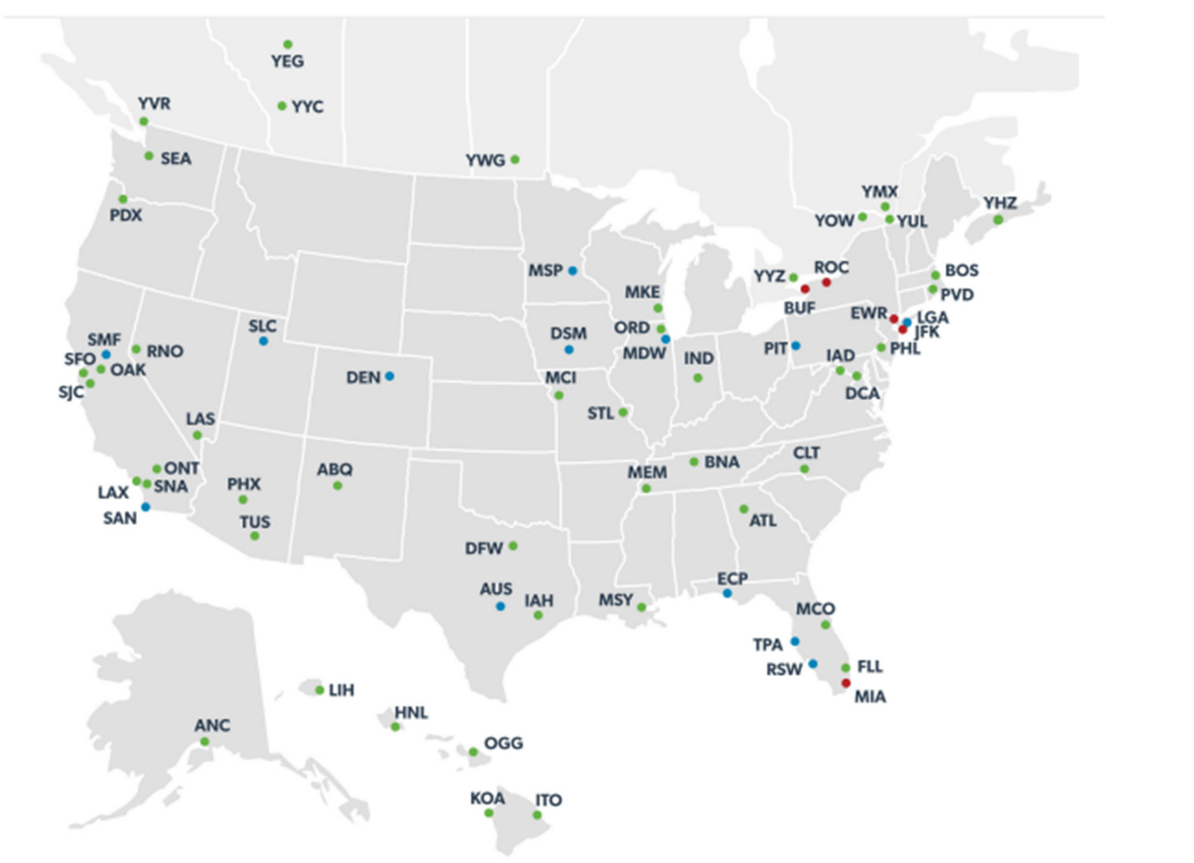
An airline fuel consortium is a partnership between airlines to manage, share, and finance a single fuel system at an airport instead of each airline having an independent system. A consortium can also concern itself with off-airport fuel facilities and distribution systems. Broadly speaking, a consortium can either govern the fuel system facility that is owned by an airport authority (indicated by the red and blue airport location markers on the map in **Figure 5.1**), or the airlines can collectively own the system (green location markers in **Figure 5.1**). The latter empowers airlines to engage with multiple suppliers to optimize its supply chain.[38]

Partnering with fuel consortiums offers logistical and financial benefits, evident through a case study of LAXFUEL's role in bringing SAF to Los Angeles International Airport (LAX). LAXFUEL is a fuel consortium representing airlines operating at LAX. It leases land at the airport to create jet fuel supply infrastructure. In 2022, Neste celebrated a SAF milestone after partnering with LAXFUEL because this agreement eliminated the need for Neste to deliver SAF to the airport via truck – which severely restricted the quantity of SAF supplied. Instead, the partnership ensured that greater quantities of a ready-made SAF fuel blend could be delivered to LAX via barges directly into existing fueling infrastructure.[39]

38 Management of Airport Fuel Systems. (2019, April). Retrieved from Airlines for America: https://airlines.org/wp-content/uploads/2019/04/Airport-Fuel-Systems.pdf.

39 Bodell, L. (2022, November 23). Neste's SAF Partnership with Los Angeles International Airport Sees500,000 Gallons Delivered. Retrieved from Simple Flying: https://simpleflying.com/neste-500000-gallons-saf-lax-airport/.

Figure 5.1: The Location of Three Types of Fuel Committees Across North America: Advisory, Committee, LLC Corporation[40]



Advisory

Airport authority has full ownership and control of the fuel system; it publishes and collects fuel system-related throughput fees from all airlines. Advisory committee – not a legal entity – is formed to help airlines communicate with the airport authority on fuel system-related issues, but typically lacks an interline agreement to define cost/liability allocation and step-up provisions.

Committee

Airport authority owns the fuel system but chooses to have a group of airlines manage/ operate without a fuel system lease; alternatively, the airport leases the fuel system to an airline and a fuel committee is formed to select the M&O operator, manage the system and share related costs. Not a legal entity, but often members sign an interline agreement to define cost/liability allocation and step-up provisions. Generally, the airport does not dictate the fuel system throughput fee charged to airlines.

LLC/Corporation

LLC is the most desirable modern structure, characterized by a legal entity that has signed a fuel system lease with the airport – key elements to obtaining financing for capital investment. Unlike LLCs, corporations may issue stocks to attract investment but offer less tax-return flexibility.

5.8. Permitting Requirements, Regulatory Standards, and Policy Framework

This section considers the role of partnerships in permitting requirements, regulatory standards, and policy framework. Building and establishing relationships with governing bodies such as the FAA, EPA, state and local environmental agencies, and others will be necessary to establish new infrastructure and operational costs and permitting timelines. Partnerships around permitting requirements will be more of relationship building, rather than firm partnerships.

40 Management of Airport Fuel Systems. (2019, April). Retrieved from Airlines for America: https://airlines.org/wp-content/uploads/2019/04/Airport-Fuel-Systems.pdf.

Failing to obtain the required permits may bring the entire project to a standstill. For example, Green Apple Renewable Fuels, LLC, planned to build a renewable fuels production facility that would have been co-located with the Phillips 66 Refinery in Ferndale, Washington. In 2020, the group announced that they would not move forward with the project due to "permitting delays and other uncertainties."[41] The project team was unaware of the need to complete an Environmental Impact Statement (EIS) in addition to other requirements. When the team realized it was mandatory, the long-duration required to obtain the EIS would have significantly delayed the project – jeopardizing the facility's competitiveness.[42] A second precedent is the state Department of Ecology's rejection of the Kalama methanol plant's request for a shoreline permit for a proposed facility in Washington state. The permit was denied after six years of expert review had been invested into the project, on the grounds that the project would emit GHGs for decades into the future, even though it was less harmful than alternatives.[43]

Developing good relationships with government agencies and the public will support the permitting process and can assist navigating through the oftentimes complex permitting process. This can be achieved by understanding and promoting the roles and responsibilities of the body, staff, and management. One avenue to maintain good relationships is by submitting timely and complete permit applications with accurate information instead of requiring government officials to request additional information to complete the application.[44]

In addition, developing partnerships with authorities will prove instrumental in meeting the needs of this facility since the process of converting MSW to jet fuel is a relatively new process and must be incorporated into future laws, regulations, policies, tax incentives, and investments. For example, the MSW to fuel process must be eligible to meet zero waste objectives, and the process of converting MSW should be favored over dumping waste in a landfill. Building strong relationships with local agencies could also play a role in reassuring local communities about the benefits of welcoming this emerging fuel production pathway into their homes. This is essential as evidenced by the backlash that Fulcrum BioEnergy experienced in Gary, Indiana, after selecting a site for a facility that will convert plastic and other garbage into SAF. Gary residents have challenged Fulcrum's air pollution permit (obtained from state regulators). The USEPA has also received a Civil Rights Act complaint.[45]

5.9. Siting Options and Planning Level Layouts and Costs

This section determines whether partnerships are recommended for siting options and planning level layouts and costs. The selection of a well-suited plant site has significant impact on the viability of the waste-to-fuels project. Siting options will be evaluated during the project development stage and will be done in close dialogue and cooperation with the Port and its stakeholders in order to achieve best results. Many parties are involved in the identification of potential sites up to selection of the best suitable site and the following land acquisition negotiations. The involvement of landowners and their partnerships has been discussed in Section 5.2 above. This study does not recommend partnerships but, rather the engagement of an experienced consultant to work cooperatively in this early phase of a project. Typical advantages and disadvantages of siting options that consultants would consider are as follows:

1. **Selecting a site close to an existing refiner that becomes a partner.**

- Pros:
  - An opportunity to utilize some of the refiner's existing infrastructure. Examples have already been discussed in **Section 4**, but are summarized as follows:
    - Since an existing refinery is already making fuel, a partnership would allow this facility to use some of the infrastructure (e.g., pipelines, storage tanks, loading racks - rail and truck - etc.). An additional benefit is the option to co-mingle the fuel (adding pure SAF to conventional jet fuel) at the refinery, before transporting it to the airport. A target of a 50-50% blend is common in the industry.

41 Whatcom News. (2020, January 26). Retrieved from Whatcom County responds to news of canceled Green Apple Renewable Fuel project: https://whatcom-news.com/whatcom-county-responds-to-news-of-canceled-green-apple-renewable-fuel-project_99250/.

42 Pearce, W. (03, March 2020). Green Apple Deal Goes Bad. Retrieved from Business Pulse: https://businesspulse.com/green-apple-deal-goes-bad/.

43 Bernton, H. (2021, January 19). Washington state Ecology Department rejects permit for Kalama methanol plant on Columbia River. Retrieved from The Seattle Times: https://www.seattletimes.com/seattle-news/state-ecology-department-rejects-permit-for-kalama-methanol-plant-on-columbia-river/.

44 Meyerhoff, M., & Whitmore, L. (2012, July 31). Building A Positive Relationship With Your Governing Body. Retrieved from CaseText: https://casetext.com/analysis/building-a-positive-relationship-with-your-governing-body.

45 Bruggers, J. (2022, December 12). A Gary, Indiana Plant Would Make Jet Fuel From Trash and Plastic. Provides 2023 CCUS Goals: https://www.businesswire.com/news/home/20230223005300/en/%C2%A0Denbury-Announces-New-CCUS-Agreements-and-Provides-2023-CCUS-Goals.

  - It provides access to utilities (e.g., power/natural gas). An example is that many facilities have a demand for steam. A renewable fuel facility co-located with a refinery might be able to tap into existing utilities. The two partners would draw up an agreement to divide the costs. Any further developments required by the facility (e.g., utility lines) under this type of partnership would be financed by the facility.
  - This partnership should guarantee access to good highways and rail.
  - A renewable fuel facility would benefit greatly from utilizing the laydown area belonging to the refinery during construction, thereby reducing the total acreage that must be purchased.
- Potentially subcontract operations.
  - As discussed in **Task 4**, a renewable fuel production facility is a complex operation, so a sophisticated operations & maintenance (O&M) team with a high level of training is required. Subcontracting with the refiner (who already has the talent in its experienced workforce) allows the refiner to operate and maintain the renewable facility instead of requiring the refiner to source untrained talent. Subcontracting to the refiner has an additional benefit of making financing much easier to obtain - a major advantage.
- Since brownfield sites are better prepared than greenfield sites (e.g., they already usually have a level site, access to roads and other infrastructure etc.), these sites are less costly to develop and less harmful to the environment.
- The project may have fewer NIMBY concerns because a refinery already exists, and the additional of a renewable fuel facility should not pose greater threats to the environment. Community acceptance is detailed in **Task 3, Section 3.7**.

- Cons:
  - The choice to locate a facility near a refinery is usually at the expense of being located near a feedstock supply. As a result, the feedstock must travel further to reach the facility, which negatively impacts the carbon intensity/index (CI) metric and makes the project less environmentally friendly.
  - A refiner in the vicinity may view a renewable fuel facility as a competitor and may not be willing to partner. However, if the facility offers the refiner's operators good compensation, it may be possible to persuade the talent to bring their expertise to the new facility, solving the O&M challenge.

2. **Selecting a site that is close to the feedstock and/or airport.**

- Pros:
  - Short transportation distances result in lower transportation costs and a lower carbon footprint.
  - A production site located near the feedstock source reduces feedstock transportation, resulting in lower costs compared to shipping an equivalent amount of fuel.
  - A site close to the airport can shorten the overall transportation distances if the waste feedstock is sourced from municipalities closer to the airport.
  - A SAF production facility close to the airport could include not only SAF storage capacity but also a blending facility if the site can be connected via pipeline to the airport.
  - Since the facility will not be sharing resources with another party (e.g., a refinery), all resources belong to the facility. As a result, there is no need to compromise with an existing facility's shared infrastructure.
    - For example, if a facility is located near a refiner with a truck rack, the operations of the new facility could interfere with refiners' operations. This is a disadvantage. If the facility does not share premises, there is no interference!
- Cons:
  - Revisit all the 'Pros' for being located near a refinery; now they are all cons. It is necessary to create new infrastructure to and ensure access to utilities. Furthermore, it is also necessary to generate the facility's own internal O&M group since using a co-located refiner's staff is not an option. The facility will have to seek and train new staff from scratch.
  - An existing refinery has usually already overcome the NIMBY opposition. Selecting an independent site for a facility now requires the facility to deal with the opposition from the start. Overcoming this challenge can take years – especially in

areas with strong active public involvement.

- Greenfield sites are generally much more expensive to develop because it requires more preparatory work prior to construction (e.g., moving more dirt around, mitigating water issues such as a creek on site, addressing wildlife concerns such as bald eagle hatchlings on site that cause costly delays, and building powerlines which include expensive substations and a few lines of high-power voltage lines requiring funding).

3. **Deciding between the Alternatives:** It takes time to locate and to complete an evaluation of potential sites. Each will have specific advantages and disadvantages, some of which were introduced above. A Risk Matrix and HAZOPS should be completed for each possible location. The risks and HAZOPS identified will differ for a facility co-located and an independent facility. Neither is better or worse – just different. Furthermore, additional criteria should be considered such as the ease with which negotiations between the proposed facility and landowner can occur, and the potential for NIMBY opposition. A thorough analysis could reveal that a more expensive site is preferred to avoid these long-term issues.

5.10. Potential for Carbon Sequestration, Greenhouse Gas Emission Reduction, or Similar Climate Strategies/Benefits Based on Different Options

This section identifies and summarizes potential partnership opportunities to support and enable carbon sequestration, GHG emission reductions, and other climate strategies/benefits. CO2 markets are generally smaller than the total quantity of CO2 generated.[46] However, the 45Q federal tax credit in the US (discussed in Section 12) is still an incentive to consider options relevant to this section. Possible avenues for partnerships may include the following.

5.10.1. E-Fuels

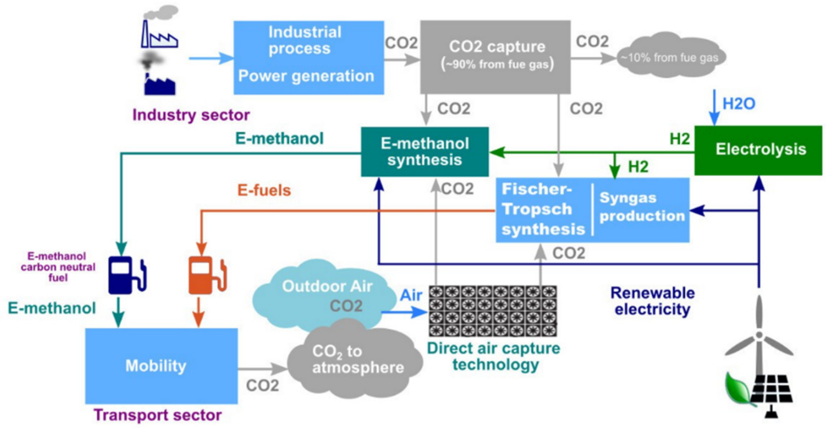
E-fuels are manufactured from captured CO2 emissions, making the fuel product carbon neutral (i.e., the CO2 released into the atmosphere is equal to the CO2 captured for production). CO2 is produced as a byproduct during industrial processes and can also be captured through direct air capture technology, as summarized in **Figure 5.2**.[47] CO2 produced as a byproduct at the proposed renewable fuel production facility could be sold to an E-Fuel producer. Even though it is an emerging technology, Highly Innovative Fuels (HIF) is a leading E-Fuels organization already producing E-Fuels in its demonstration plant in Chile. The company's "vision is to become the largest E-Fuels producer in the world, producing 140,000 barrels per day of E-Fuels by 2030, capturing over 25 million tons of CO2, and turning 5 million vehicles carbon neutral." HIF Global owns the following four subsidiaries: HIF Chile, HIF USA, HIF Asia Pacific, and HIF EMEA. HIF USA is headquartered in Texas. HIF recently entered into a partnership with Denbury to source 2 million metric tons per year (Mmtpa) of industrial-sourced CO_2.[48]

46 Ferreira, F., & Herzog, H. (2023, January 23). MIT Climate Portal. Retrieved from How much is captured CO2 worth: https://climate.mit.edu/ask-mit/how-much-captured-co2-worth#:~:text=It%20can%20either%20be%20injected,it%20for%20enhanced%20oil%20recovery.%E2%80%9D.

47 Abnett, K., & Waldersee, V. (2023, March 22). Explainer: What are e-fuels, and can they help make cars CO2-free? Retrieved from Reuters: https://www.reuters.com/business/autos-transportation/what-are-e-fuels-can-they-help-make-cars-co2-free-2023-03-07/.

48 Business Wire. (2023, February 23). Retrieved from Denbury Announces New CCUS Agreements and Provides 2023 CCUS Goals: https://www.businesswire.com/news/home/20230223005300/en/%C2%A0Denbury-Announces-New-CCUS-Agreements-and-Provides-2023-CCUS-Goals.

Figure 5.2: A Summary of the Process of Capturing/Channeling CO2 to Create E-Fuels[49]



5.10.2. Relationships for Carbon Sequestration

Organizations proactively focused on offsetting CO_2: Carbon offsetting is a growing market. This concept allows entities to reduce their impact by compensating for removal/reduction of carbon dioxide/emissions external from their own. By investing in the capture and storage of carbon from projects outside of their own business, they are able to maintain a compliant (or reduce their overall) carbon footprint. For this relationship, is important to determine the methods of sequestration that are eligible for carbon credits (i.e., defined, long-term and monitored). Below are some examples of carbon offsetting programs.

- International Civil Aviation Organization (ICAO)
  - CORSIA, Discussed in **Task 2, Section 2.7.2**
- NativeEnergy
  - A public benefit corporation that serves to address businesses sustainable operations such as GHG emissions and verified carbon offsets. Assessing financial risks and operational responsibilities, NativeEnergy will ensure compliance and project fulfillment based on catered demands and requirements.
- Sustainable Travel International (STI)
  - STI aims to transform the impact tourism has on nature and people within the planet's most vulnerable destinations. They are doing so through various actions including but not limited to carbon footprint measurements, climate awareness, carbon reduction, and carbon offsets.
- 3Degrees
  - A sustainability consulting company that helps organizations all over the globe achieve goals concerning renewable energy and transportation decarbonization.
- Airlines and shareholders
  - Alaska Airlines
  - Delta Airlines
  - United Airlines

United Airlines was the first to establish a commitment to investing in carbon capture and sequestration through 1PointFive.

49 Kmet, J. (2021, December 10). E-fuels and their potential role in decarbonizing transport in the EU. Retrieved from LinkedIn: https://www.linkedin.com/pulse/e-fuels-potential-role-decarbonizing-transport-eu-jaroslav-kme%C5%A5.

Partnering with Oxy Low Carbon Ventures and Rusheen Capital, a joint venture was put in place to plan the first industrial-sized Direct Air Capture plant in the US. The plant is presumed to be able to sequester one million tons of carbon dioxide annually.[50]

The following is a list of companies that have purchased carbon offsets. (Note: this is not a comprehensive list)

- Alphabet
- Cemex
- Delta
- Disney
- General Motors
- Honeywell
- JetBlue
- Microsoft
- PG&E
- Salesforce
- Shell
- Unilever

Relevant organizations and nonprofits: Partnering with accredited, professional organizations will provide opportunities for various informative criteria regarding climate strategies. It is in the interest of both parties to understand the efforts, investments, and potential outcomes of carbon sequestration, and other climate strategies, that may pose a risk to the economic, social, or health of surrounding areas. The following entities could bring knowledge of best practices, risk assessments, funding sources, connections to additional partners, business cases for strategic implementations, and a driving support for policy changes necessary to promote GHG reductions and carbon capture:

- Climate Solutions
  - A Northwest-based nonprofit focused on driving public policy to a clean energy economy.
- Airlines for America (A4A)
  - An organization that works directly with airlines and various governmental entities to improve the aviation industry's travel and shipping activity. Advocating for crucial policies to promote safe best practices for the environment, the public, and the economy.
- Local Clean Air Agency or Authority[51]
  - Governmental agency in charge of the enforcement of regulations on businesses air pollution and the outreach of air quality education to the public.
- Washington State Department of Natural Resources (DNR)
  - Carbon Sequestration Advisory Group (CSAG)
  - Carbon ESHB 1109
- Department of Ecology
  - *Agricultural and Forestry Carbon Capture & Sequestration Advisory Panel (AF-CCSAP)
- US Forest Service (USFS)
  - Forest Inventory and Analysis (FIA)
- National Risk Assessment Partnership
  - An entity that utilizes the DOE's capabilities to assess and manage environmental impacts of geologic carbon sequestration.
- National Energy Technology Laboratory
  - An energy laboratory that develops technologies to manage the full life cycles of carbon and creates solutions to sustainable energy.
- National Institute of Standards and Technology (NIST)
  - Part of the US Department of Commerce, NIST was established to advance measurement science, standards and technologies for innovation and industrial competitiveness for the US.
- Rusheen Capital Management, LLC

50 Polek, Gregory. "Promise of SAF Lies with Its Scalability, Cost Effectiveness." Aviation International News, 1 June 2021, https://www.ainonline.com/aviation-news/air-transport/2021-06-01/promise-saf-lies-its-scalability-cost-effectiveness.

51 WA DOE (2023). State of Washington Department of Ecology, Washington clean air agencies. Retrieved from: https://ecology.wa.gov/About-us/Accountability-transparency/Partnerships-committees/Clean-air-agencies.

- Private equity firm for carbon capture and utilization companies in the low-carbon and water sustainability sectors.

*The AF-CCSAP is a collaborative forum of experts offering input towards incentivizing and allocating credits for sequestering greenhouse gases relating to transportation fuel. The AF-CCSAP includes recommendations for:

- Accounting, incentivizing, and awarding Clean Fuel Standard credits on agricultural and forest lands that focus on serving the transportation fuels industry.
- Quantifying the current and future impact of carbon sequestration on production and conservation practices of agriculture and forestry.
- Establishing standards for efficient carbon sequestration based on practices with agricultural and forestlands.
- Developing strategies for calculating and allotting credits that incentivize carbon sequestration on agricultural and forestlands.
- Ecology's review of innovations and strategies that reduce emissions and increase credit opportunities, consulting for efforts needed to maintain a stable credit market.[52]

Local Influences: Boards & Commissions from each of the proposed regions are recommended partners to ensure transparency with the community. Connecting environmental, sustainable, airport, and solid waste leadership groups to the support of local carbon sequestration and GHG emissions reduction will strengthen potential approval processes within the counties. All parties are interconnected nodes in this system of developing a policy or agreement to enact on behalf of the local area. The following is a list of potentially relevant boards within each county, this is not a comprehensive list.

- Whatcom County, WA
  - Climate Impact Advisory Committee
  - Surface Mining Advisory Committee
- Skagit County, WA
  - The Community Energy Challenge
  - Sustainability Department
- Grays Harbor County, WA
  - Solid Waste Advisory Committee
- Lewis County, WA
  - Airport System Advisory Board
  - Solid Waste Advisory Committee (SWAC)
  - Lewis County Solid Waste Utility
    - Lewis County's Waste Widget
- Cowlitz County, WA
  - Solid Waste Advisory Committee
- Klickitat County, WA
  - Columbia River Gorge Commission
  - Columbia Gorge Regional Airport Board
  - Land and natural Resource Committee
  - Solid Waste Advisory Committee
- Gilliam County, OR

52 "Clean Fuel Standard: Agriculture and Forestry Carbon Capture & Sequestration Advisory Panel (AF-CCSAP)." Department of Ecology - Committees, Boards, and Workgroups, https://www.ezview.wa.gov/site/alias__1962/37752/agri_-forestry_carbon_capt__sequest_adv_panel.aspx.

  - Columbia Ridge Citizens Advisory Committee (CAC)
- Morrow County, OR
  - Airport Advisory Committee
  - Solid Waste Advisory Committee
- Franklin County, WA
  - Natural Resource Advisory Committee (NRAC)
  - Solid Waste Advisory Committee

Local Universities: The prospective future is reliant on what is accomplished in the present and how it is sustained in years to come. Universities are full of professionals working towards enhancing current operations, innovations, and processes for our communities. Several State of Washington and pacific northwest region universities are equipped with existing knowledge and ongoing research involving local carbon sequestration methods. It would be beneficial to establish relationships with universities for their funding support, fresh perspectives, facilities and equipment, in addition to their academic and commercial connections.

Landowners: Individuals or enterprises that own land along the Columbia River Basin, or other areas with naturally basaltic properties, can significantly benefit from a partnership with a facility. By paying landowners to utilize their property to sequester CO_2, it could provide a natural and cost-effective solution for mitigating emissions. Entering into a monetary agreement, they would be entering a profitable endeavor tied to renewables by allowing carbon to safely and securely be sequestered into their land while still maintaining significant preservation of it.[53]

The Wallula Basalt Pilot Project in Washington has proven the ability to capture and store carbon dioxide underground to mineralize, "making it impossible for escape." Additionally, the Big Sky Carbon Sequestration Partnership, based out of Montana State University's Energy Research Institute (supported by US DOE), successfully injected almost 1,000 tons of CO_2 into the Grande Ronde basalt formations.[54] With the proven experiences of successful sequestration in the local, basaltic areas, it is a notable option to consider a direct partnership with landowners of these properties containing the adequate geological composition.

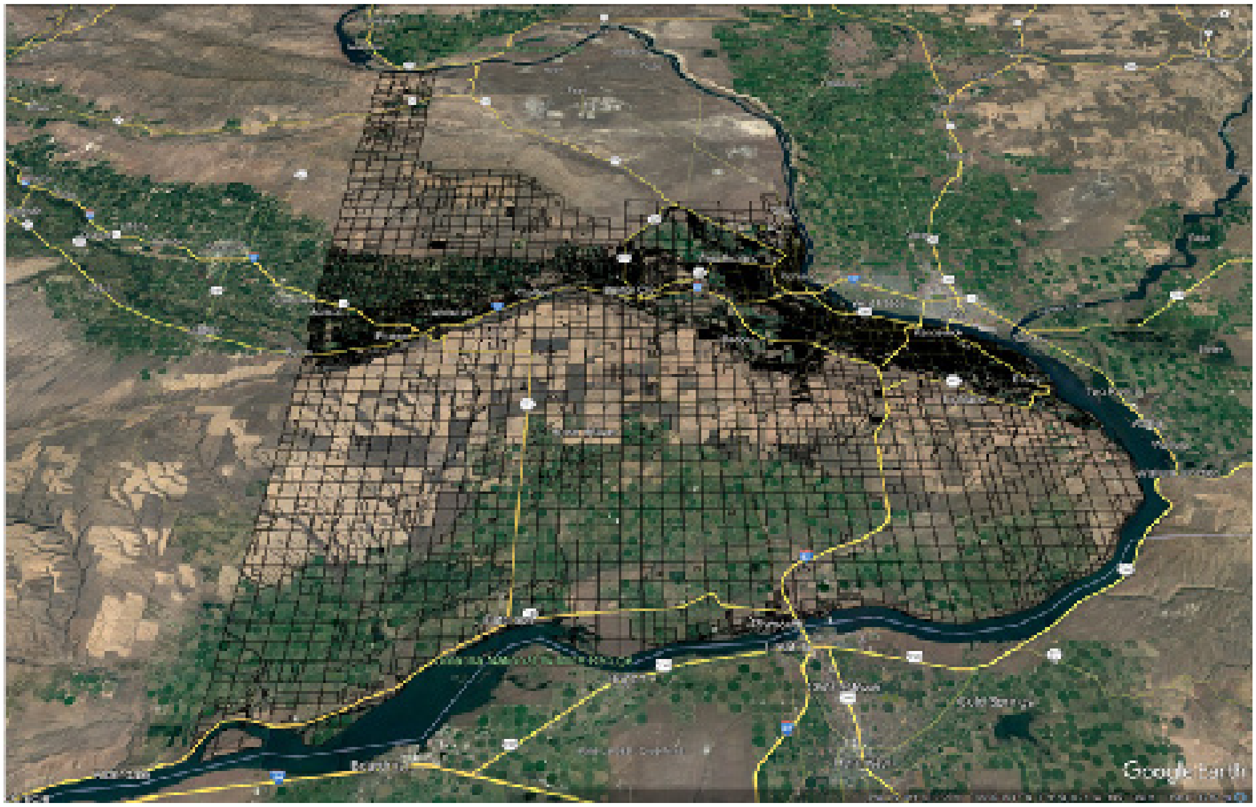
To identify potential landowners suitable and willing to engage in a carbon sequestering partnership with the facility, an analysis of accessible land plots would be put forward. Scraping GIS data online, Team EXP were able to extract KMZ (Keyhole Markup Language) files that can be imported to mapping software such as Google Earth. These files work best under smaller boundaries, which is why it is recommended that specific county KMZ files should be imported separately. See the below **Figure 5.3** for a representation on the KMZ file of Benton County, WA that has been loaded into Google Earth. This county was chosen as an example for its long range of accessibility to the Columbia River.

Each allotted parcel of land can be selected to provide a variety of data ranging from ownership, market value, acreage, and other geographic identifiers. The variable criteria for each land parcel should have set standards desired for the facility. For instance, understanding the required geologic composition for carbon sequestration, it would be ideal to identify plots that are within the parameters of basaltic properties identified in our preliminary site assessment. It is known that the Columbia River Basin is a main contributor to such parameters. Once determining the various geographical selection standards, based on the chosen SAF facility site location, the land plots can then be further investigated and contacted for partnership agreements.

53 Texas Climate News (2021, April 15). Paying landowners to store CO2 in soil a promising climate mitigation tool. Retrieved from: https://texasclimatenews.org/2021/04/15/paying-landowners-to-store-co2-in-soil-a-promising-climate-mitigation-tool/.

54 Walton, Robert. "Washington Carbon Capture Project Says It Has Permanently Sequestered CO2." Utility Dive, Industry Dive, 22 Nov. 2016, https://www.utilitydive.com/news/washington-carbon-capture-project-says-it-has-permanently-sequestered-co2/430935/.

Figure 5.3: A Representation on the KMZ File of Benton County; Each Allotted Parcel of Land can be Selected to Provide a Variety of Data Ranging from Ownership, Market Value, Acreage, and other Geographic Identifiers.



Buyers of CO_2 byproducts – Companies and industries interested in purchasing CO_2 byproducts can retract the need of sequestering all produced carbon from generating SAF. The entities involved may be sources of GHG's, but they can in turn act as a sink for their respective production and operations. Partnering with entities within the following list can repurpose the generated CO_2 from the SAF facility in hopes of continuous emissions mitigation.

- Agriculture and Forestry
- Fertilizer Industry
- Food and Beverage Production
- Greenhouses-plantgrowth
- Metal Fabrication
- Enhanced Oil Recover

The USEPA reported that fifty-nine percent (59%) of CO_2 produced from industrial processes was utilized towards enhanced oil and gas recovery. The next largest end-use was directed towards the food and beverage manufacturing industry; followed by metal fabrication and so on.[55]

Carbon capture and storage companies – Working with carbon capture and storage companies directly eliminates the need for relying on others to take on the produced carbon byproducts. Instead, these companies efficiently manage the full life cycle of carbon emissions by permanently storing the produced carbon. Having experts with accredited and successful projects in this process will ensure the appropriate technologies and methods are put in place for the facility to be fully capable of capturing and sequestering the carbon produced onsite. The following is a non-exhaustive list of example carbon capture and storage companies working in this space or similar field:

55 "Supply, Underground Injection, and Geologic Sequestration of Carbon Dioxide." EPA, Environmental Protection Agency, 1 Dec. 2022, https://www.epa.gov/ghgreporting/supply-underground-injection-and-geologic-sequestration-carbon-dioxide.

- SLB
- Climeworks
- CO2 Solutions by SAPIEM
- LanzaTech
- Carbon Clean
- Aker Carbon Capture
- Carbon Engineering
- Carbon Engineering Ltd.
- Global Thermostat
- Quest Carbon Capture & Storage (SHELL)
- CarbonFree
- CarbFix
- Chevron Corp.
- Dakota Gasification Company
- Fluor Corporation
- FuelCell Energy (FCEL)

5.11. Effective Policies/Regulations from Other Jurisdictions that Could be Adopted in KC to Support the Recommended Outcome

This section considers effective policies and regulations that could be adopted in KC or Washington state to support the recommended outcome. In addition to the requirements already described in Section 5.8, tapping into communities outside the State of Washington or even the United States may yield precedents for accelerated policy and regulation development here at home. This is not an uncommon phenomenon and has been demonstrated through recent changes such as the Low Carbon Fuel Standard (LCFS) that has roots in California but later spread to Oregon, Washington and across the border to British Columbia, Canada, due to its positive impact.[56] One example of a local and international policy is presented.

Effective Policies/Regulations Within the US

The city of San Francisco has a demonstrated history of successfully achieving its zero waste goals. In 2002, the city set a 75% diversion target for 2010 and achieved its goal two years early, partly attributed to its 'Environmental Code' initiated in 2003. In 2009, the city passed the 'Mandatory Recycling and Composting Ordinance' which required a further reduction of 50% by 2030.[57] Developing effective policies and implementing this type of target and regulation encourages waste utilization e.g., as feedstock for a renewable fuel facility rather than disposal of said waste in a landfill; this alternative promotes the use of locally sourced feedstocks for SAF production.

Effective Policies/Regulations Internationally

A noteworthy precedent is Japan's 3R initiatives (Reduce, Reuse, Recycle + Renewable) which encourages resource circulation of plastics across a product's lifecycle. In 2022, the Act on Promotion of Resource Circulation for Plastics (as part of the 3R initiative), came into effect. Under the 'discharge, collection, and recycling' category of the act, businesses are required to minimize the generation of plastic wastes and must recycle through measures facilitated by the act.[58] For example, manufacturers and municipalities that successfully collect and recycle products made from plastics receive 150,000 yen from the ministry.[59] Implementing a similar policy which compensates businesses for successfully meeting targets (e.g., collecting and sending materials for recycling or to a renewable fuel facility etc.) could yield desirable results in the US.

56 States with Low Carbon Fuel Standards or Considering a LCFS-Like Program. (2020, November 16). Retrieved from The Jacobsen: https://thejacobsen.com/news_items/states-considering-lcfs/.
57 Zero Waste Case Study: San Francisco. (2021, September 04). Retrieved from EPA: https://www.epa.gov/transforming-waste-tool/zero-waste-case-study-san-francisco.
58 Concerning the Act on Promotion of Resource Circulation for Plastics. (2022, May). Retrieved from Government of Japan Public Relations Office: https://www.gov-online.go.jp/eng/publicity/book/hlj/html/202205/202205_09_en.html.
59 ARTECH. (2023, January 10). Retrieved from Food Packaging & New Plastic Recycling Law in Japan: https://www.artechpms.com/news-detail/food-packaging-new-plastic-recycling-law-in-japan.htm#:~:text=The%20new%20law%20encourages%20municipalities,150%2C000%20yen%20from%20the%20ministry.

5.12. Potential Funding Sources Such as Grants, Incentives, and/or Credits

Although not directly related to partnerships, this section considers potential funding sources such as grants, incentives, and/or credits to guarantee the feasibility of the waste-to-fuels project. Team EXP has worked with the Port to explore funding sources in previous phases of this study: **Task 2, Section 2.7.2** details MSW to SAF incentives at an international, federal, state, and municipal level; **Task 4, Section 4.7** lists Federal and State financial support for similar projects; **Task 4, Section 4.8** highlights strategic partnership opportunities from private sector investments; and **Task 4, Section 4.9** introduces sources of traditional and non-traditional project financing applicable to this facility. From these past works it can be concluded that multiple opportunities exist for this facility to secure funding from the public and private sector. Depending on the source, the funding provider might request or be interested in a financial partnership.

Further exploration of potential funding sources related to **Task 5, Section 5.6** revealed that the Grid Deployment Office administered a Grid Resilience and Innovation Partnership (GRIP) Program, as part of the Bipartisan Infrastructure Law, could be applicable to this project. Tax credits pertaining to carbon sequestration (**Task 5, Section 5.10.2**) are also obtainable under the Inflation Reduction Act's (IRA) recent expansion of Section 45Q of the United States Internal Revenue Code. Under the IRA, tax credits of up to USD 60 per ton of CO2 used for enhanced oil recovery (EOR) or other industrial uses of CO2 and USD 85 per ton of CO2 permanently stored are available, on the condition that emission reductions are clearly demonstrated.[60]

5.13. Conclusion

Partnerships are formed between entities that have an area of mutual interest. While other aspects of their business may not be related, the entities may align in one or more defined areas. Each entity contributes (e.g., money, time, resources, long-term contracts, facilities, etc.) to advance the area of common interest. An easily understood example of a partnership in the aviation industry is when an airline agrees to a long-term offtake agreement for SAF and/or provides seed capital which helps to finance the early phases of project development. Both entities in that scenario recognize their common goal – a working SAF production facility providing fuel to the transportation industry.

Entering into a partnership is not taken lightly as misalignment of interest can occur, resulting in damage to one or both partners (i.e., financial or reputational damage which ultimately results in financial damage too). Risks must be clearly understood and carefully evaluated by each party. This takes an extended period of clear communication to mitigate risks and ensure each party is truly aligned with the end-goal.

Table 5.3 provides an overview of partnership benefits across the entire SAF supply chain.

60 Section 45Q Credit for Carbon Oxide Sequestration. (2022, November 04). Retrieved from IEA: https://www.iea.org/policies/4986-section-45q-credit-for-carbon-oxide-sequestration.

Table 5.3: Partnership Benefits Across the SAF Supply Chain

Supply-Chain Component	Potential Partners & Partnership Opportunities
1) Feedstock Source and Pre-Processing	Renewable fuel facilities, landfills, transportation partners, waste haulers, and RNG producers.
2) Facility Land Acquisition or Purchase, Funding, Ownership, Development, Co-Location, and/or Operation	Brownfield sites offer existing infrastructure. Co-locating a facility with a petroleum refinery or by sharing landfill sites offers financial benefits.
3) Product Development, Marketing, and Sales	Offtake agreements, partnerships with air cargo carriers and operators of blending stations and pipelines.
4) Utilities and Required Infrastructure	Utility companies
5) Contractor Access for Both MSW Drop-off and Fuel Transport	Partnerships for MSW drop-off and fuel transport through an airline fuel consortium.
6) Permitting Requirements, Regulatory Standards, and Policy Framework	Develop and maintain strong relations with government agencies to efficiently navigate the permitting process. MSW to jet fuel conversion is a relatively new process and must be incorporated into future laws, regulations, policies, tax incentives, and investments.
7) Siting Options and Planning Level Layouts and Costs	Siting considerations offer unique benefits, e.g., site adjacent to landfill is close to a feedstock source and a site adjacent to a brownfield site or refinery may potentially utilize existing infrastructure.
8) Potential for Carbon Sequestration, GHG Emission Reduction, or Similar Climate Strategies/Benefits based on Different Options	Organizations offsetting CO2, nonprofits, local universities, and landowners. Selling CO2 to E-Fuel producers could also be a future option.
9) Effective Policies or Regulations from Other Jurisdictions that could be Adopted in KC to support the Recommended Outcomes	The City of San Francisco's 'Mandatory Recycling and Composting Ordinance' and Japan's Act on Promotion of Resource Circulation for Plastics are examples that could be applied in KC to enhance the utilization of MSW as valuable feedstock for SAF production and promote locally sourced feedstocks.
10) Potential Funding Sources (Grants, Incentives, and/or Credits)	Washington Senate Bill 5447, Inflation Reduction Act (SAF Credit) and the expansion of Section 45Q of the United States Internal Revenue Code.

Identification of partnership opportunities from the entire supply chain are essential for growing SAF supplies and meeting aviation decarbonization goals. CAAFI, or the Commercial Aviation Alternative Fuels Initiative, is a coalition of aviation stakeholders formed to facilitate the development and deployment of SAF in commercially meaningful quantities and to reduce aviation-related emissions while also improving price stability and supply security. This partnership is co-sponsored by the Aerospace Industries Association, Airports Council International, Airlines for America, and the FAA. In addition, CAAFI membership consists of approximately 600 organizations and 1800+ stakeholders (e.g., U.S. and non-U.S. government agencies, trade associations, energy producers, university faculty, nongovernmental organizations, and consultants). The success of CAAFI and their partnerships with industry stakeholders is illustrated through their achievements to date and include:

- Fuel Specification Approvals (e.g., establish processes to help move promising alternative aviation fuels through industry evaluation to approval by ASTM International).
- Fuel and Feedstock Readiness Tools (e.g., developed a collection of tools to facilitate assessment and advancement of fuel and feedstock readiness with respect to ASTM approval).
- Stakeholder Coordination and Communication (between all stakeholders listed above).
- Strategic Thought Leadership (e.g., participates with the SAF Grand Challenge, FAA's Aviation Sustainability Center, etc.)

- State Initiatives (e.g., facilitated formation of supply chains for SAF deployment through the CAAFI State Initiatives).[61]

At a regional level, SEA, Portland International Airport (PDX), and Vancouver International Airport (YVR) have established a Joint Cascadia Airport's Statement of Goals for Decarbonizing Aviation with a shared focus on four key categories, the first being SAF. Together, this partnership:

- Advocates to state/provincial and federal governments to provide appropriate policy and funding to support SAF.
- Works with air travelers – particularly industry associations and large corporate employers with significant employee travel – to increase passenger demand for SAF uptake.
- Supports airlines in their efforts to invest in and adopt SAF.
- Encourages appropriate infrastructure investment, feedstock development, and public-private partnerships to facilitate affordable and sufficient SAF implementation.[62]

To meet the Port of Seattle's goal to power every flight fueled at SEA with at least a 10% blend of SAF by 2028, partnerships will be required up the entire SAF supply chain. With strategic, win-win relationships to benefit all parties involved, the transition to alternative fuels can help further decarbonize the aviation industry, and bear fruit for those involved.

61 CAAFI (2023). Commercial Aviation Alternative Fuels Initiative. Retrieved from: https://www.caafi.org/default.aspx.

62 Joint Cascadia Airports' Statement of Goals for Decarbonizing Aviation . (n.d.). Retrieved from Connect Retrieved from: https://connectcascadia.com/wp-content/uploads/2022/09/Joint-Cascadia-Airport-Statement-of-Goals-for-Decarbonizing-Aviation-FINAL.pdf.

5.14. References

Abnett, K., & Waldersee, V. (2023, March 22). Explainer: What are e-fuels, and can they help make cars CO2-free? Retrieved from Reuters: https://www.reuters.com/business/autos-transportation/what-are-e-fuels-can-they-help-make-cars-co2-free-2023-03-07/.

Air Freight Companies in Seattle. (n.d.). Retrieved from Good Firms: https://www.goodfirms.co/supply-chain-logistics-companies/air-freight/seattle.

Alaska Airlines (2023, March 23). Alaska Airlines announces agreement with Shell Aviation to help expand sustainable aviation fuel market in Pacific Northwest. Retrieved from: https://news.alaskaair.com/newsroom/alaska-airlines-announces-agreement-with-shell-aviation-to-help-expand-sustainable-aviation-fuel-market-in-pacific-northwest/.

ARTECH. (2023, January 10). Retrieved from Food Packaging & New Plastic Recycling Law in Japan: https://www.artechpms.com/news-detail/food-packaging-new-plastic-recycling-law-in-japan.htm#:~:text=The%20new%20law%20encourages%20municipalities,150%2C000%20yen%20from%20the%20ministry.

Barrett, J. (2022, May 15). Evolution 5. Retrieved from The benefits of brownfield sites: https://evolution5.co.uk/the-benefits-of-brownfield-sites/.

Bernton, H. (2021, January 19). Washington state Ecology Department rejects permit for Kalama methanol plant on Columbia River. Retrieved from The Seattle Times: https://www.seattletimes.com/seattle-news/state-ecology-department-rejects-permit-for-kalama-methanol-plant-on-columbia-river/.

Beurteaux, D. (2022, March 23). Is jet fuel from waste finally ready for takeoff? Retrieved from Waste Dive: https://www.wastedive.com/news/waste-jet-sustainable-aviation-fuel-fulcrum-bioenergy-saf/620365/.

Bodell, L. (2022, November 23). Neste's SAF Partnership With Los Angeles International Airport Sees500,000 Gallons Delivered. Retrieved from Simple Flying : https://simpleflying.com/neste-500000-gallons-saf-lax-airport/.

Brandt, K., Garcia-Perez, M., Stockle, C., Tanzil, A., Wolcott, M., & Zhang, X. (2021). Production of Sustainable Aviation Fuels in Petroleum Refineries: Evaluation of New Bio-Refinery Concepts. Frontiers in Energy Research, Volume 9. Retrieved from: https://doi.org/10.3389/fenrg.2021.735661.

Brett, D. (2022, August 31). Bolloré and United respond to shippers' green drive with SAF partnership. Retrieved from AirCargo News: https://www.aircargonews.net/policy/environment/bollore-and-united-respond-to-shippers-green-drive-with-saf-partnership/.

Brownfields Program Environmental and Economic Benefits. (2023, February 22). Retrieved from United States Environemntal Protection Agency : https://www.epa.gov/brownfields/brownfields-program-environmental-and-economic-benefits.

Bruggers, J. (2022, December 12). A Gary, Indiana Plant Would Make Jet Fuel From Trash and Plastic. Provides 2023 CCUS Goals : https://www.businesswire.com/news/home/20230223005300/en/%C2%A0Denbury-Announces-New-CCUS-Agreements-and-Provides-2023-CCUS-Goals.

Business Wire. (2023, February 23). Retrieved from Denbury Announces New CCUS Agreements and Provides 2023 CCUS Goals : https://www.businesswire.com/news/home/20230223005300/en/%C2%A0Denbury-Announces-New-CCUS-Agreements-and-Provides-2023-CCUS-Goals.

CAAFI (2023). Commercial Aviation Alternative Fuels Initiative. Retrieved from: https://www.caafi.org/default.aspx.

Concerning the Act on Promotion of Resource Circulation for Plastics. (2022, May). Retrieved from Government of Japan Public Relations Office: https://www.gov-online.go.jp/eng/publicity/book/hlj/html/202205/202205_09_en.html.

Delta Airlines (2023, April 20). Delta, Shell Aviation SAF agreement to fuel LAX hub and accelerate aviation decarbonization. Retrieved from: https://news.delta.com/delta-shell-aviation-saf-agreement-fuel-lax-hub-and-accelerate-aviation-decarbonization.

Federal Energy Management Program . (n.d.). Retrieved from Utility Program Utility Partners: United States Energy Association . (n.d.). Retrieved from Improving Utility Performance and Energy Security by Enhancing Institutional Knowledge : https://usea.org/program/energy-utility-partnership-program-eupp.

Ferreira, F., & Herzog, H. (2023, January 23). MIT Climate Portal . Retrieved from How much is captured CO2 worth?: https://climate.mit.edu/ask-mit/how-much-captured-co2-worth#:~:text=It%20can%20either%20be%20injected,it%20for%20enhanced%20oil%20recovery.%E2%80%9D.

Gong, L., & Read, A. (2022, March 29). Partnerships With Electric Utilities Can Help Expand Broadband Access. Retrieved from PEW: https://www.pewtrusts.org/en/research-and-analysis/articles/2022/03/29/partnerships-with-electric-utilities-can-help-expand-broadband-access.

GoodFirms. (2023, April 10). Retrieved from Air Freight Companies in the USA: https://www.goodfirms.co/supply-chain-logistics-companies/air-freight/usa.

Hawaiian Airlines to buy sustainable aviation fuel. (2023, March 27). Retrieved from Yahoo! News: https://news.yahoo.com/hawaiian-airlines-buy-sustainable-aviation-160300337.html?guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAHa3L4JQf1ylvrSXGsMODpxLtErAz3NGdV3gCXlXcDpVTMrJeBeFgIxws6_hl_-PvvqywiWXNJtFyGEDm9me-FebnF7db7B3rK9CE6pHH4.

Höglund, A. (2022, 24 September). Sustainable Aviation Fuels, a new pathway to decarbonize. Retrieved from GEODIS: https://geodis.com/blog/sustainability/sustainable-aviation-fuels-new-pathway-decarbonize.

In Support of Municipal Zero Waste Principles and a Hierarchy of Materials Management. (n.d.). Retrieved from The United States Conference of Mayors: https://www.usmayors.org/the-conference/resolutions/?category=b83aReso050&meeting=83rd%20Annual%20Meeting.

Joint Cascadia Airports' Statement of Goals for Decarbonizing Aviation . (n.d.). Retrieved from Connect Retrieved from: https://connectcascadia.com/wp-content/uploads/2022/09/Joint-Cascadia-Airport-Statement-of-Goals-for-Decarbonizing-Aviation-FINAL.pdf.Kmet, J. (2021, December 10). E-fuels and their potential role in decarbonizing transport in the EU. Retrieved from LinkedIn: https://www.linkedin.com/pulse/e-fuels-potential-role-decarbonizing-transport-eu-jaroslav-kme%C5%A5.

Management of Airport Fuel Systems. (2019, April). Retrieved from Airlines for America: https://airlines.org/wp-content/uploads/2019/04/Airport-Fuel-Systems.pdf.

Meyerhoff, M., & Whitmore, L. (2012, July 31). Building A Positive Relationship With Your Governing Body. Retrieved from CaseText: https://casetext.com/analysis/building-a-positive-relationship-with-your-governing-body.

Neste. (2022, April 06). Retrieved from Neste enabled the first-ever transport of renewable diesel by pipeline in Europe to help reduce emissions from fuel transports by 92%: https://www.neste.com/releases-and-news/renewable-solutions/neste-enabled-first-ever-transport-renewable-diesel-pipeline-europe-help-reduce-emissions-fuel.

Neste Corporation . (2022, November 07). Neste. Retrieved from Neste and CargoAi launch partnership offering freight forwarders and their clients an option to reduce the carbon emissions of their air cargo transports: https://www.neste.com/releases-and-news/renewable-solutions/neste-and-cargoai-launch-partnership-offering-freight-forwarders-and-their-clients-option-reduce.

Neste MY Sustainable Aviation Fuel. (2022, June 15). For the first time, Sustainable Aviation Fuel has been delivered to New York using existing petroleum pipelines. Retrieved from Neste: https://www.neste.com/releases-and-news/renewable-solutions/first-time-sustainable-aviation-fuel-has-been-delivered-new-york-using-existing-petroleum-pipelines.

NEXT Renewable Fuels and BP enter into renewable feedstock supply agreement. (2019, June 11). Retrieved from F+L Daily: https://www.fuelsandlubes.com/renewable-fuels-bp-products-north-america-enter-renewable-feedstock-supply-agreement/#:~:text=(NEXT)%20and%20BP%20Products%20North,facility%20in%20the%20United%20States.

NREL. (n.d.). Retrieved from Strategic Public-Private Partnerships: https://www.nrel.gov/workingwithus/strategic-partnerships.html.

Pearce, W. (03, March 2020). Green Apple Deal Goes Bad. Retrieved from Business Pulse: https://businesspulse.com/green-apple-deal-goes-bad/.

Promoting Renewable Natural Gas in Washington State, A Report to the Washington State Legislature. (2018, December). Retrieved from Department of Commerce and Energy Program Washington State University : https://www.commerce.wa.gov/wp-content/uploads/2019/01/Energy-Promoting-RNG-in-Washington-State.pdf.

Public private partnerships for central utilities. (n.d.). Retrieved from JLL: https://www.us.jll.com/en/views/central-utilities-public-private-partnerships.

Re+ Strategic Plan: Reimagining a waste-free King County. (2022). King County.

SAF Grand Challenge Roadmap. (2022, September). Retrieved from Department of Energy: https://www.energy.gov/sites/default/files/2022-09/beto-saf-gc-roadmap-report-sept-2022.pdf.

SAF Offtake Agreements . (n.d.). Retrieved from ICAO Offtake Agreements: https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx.

Sapp, M. (2023, March 15). The Digest. Retrieved from JetBlue and Shell Aviation agree to SAF offtake agreement for LAX: https://www.biofuelsdigest.com/bdigest/2023/03/15/jetblue-and-shell-aviation-agree-to-saf-offtake-agreement-for-lax/#:~:text=Within%20the%20terms%20of%20the,other%20airports%20in%20JetBlue's%20network.&text=Thank%20you%20for%20visting%20the%20Digest.

Seattle Airport. (n.d.). Retrieved from Airlines Operating at Seattle Tacoma Airport -SEATAC (SEA): https://www.seattle-airport.com/seatac-airlines.

Section 45Q Credit for Carbon Oxide Sequestration. (2022, November 04). Retrieved from IEA: https://www.iea.org/policies/4986-section-45q-credit-for-carbon-oxide-sequestration.

Segal, T. (2023, January 29). What Is an Offtake Agreement in Project Financing? Retrieved from Investopedia: https://www.investopedia.com/terms/o/offtake-agreement.asp.

Solid waste. (n.d.). Retrieved from State of Washington Department of Ecology: https://ecology.wa.gov/Waste-Toxics/Solid-waste-litter/Solid-waste.

States with Low Carbon Fuel Standards or Considering a LCFS-Like Program. (2020, November 16). Retrieved from The Jacobsen: https://thejacobsen.com/news_items/states-considering-lcfs/.

Surgenor, C. (2021, December 03). Phillips 66 to start supplies of UK-produced SAF to British Airways within months. Retrieved from GreenAir: https://www.greenairnews.com/?p=2223.

Sustainable Aviation Research. (n.d.). Retrieved from NREL: https://www.nrel.gov/transportation/sustainable-aviation.html.

Texas Climate News (2021, April 15). Paying landowners to store CO2 in soil a promising climate mitigation tool. Retrieved from: https://texasclimatenews.org/2021/04/15/paying-landowners-to-store-co2-in-soil-a-promising-climate-mitigation-tool/.

Trabish, H. (2016, February 23). Utility Dive. Retrieved from Partnering for success: Utilities leverage innovative vendor relationships at the grid edge: https://www.utilitydive.com/news/partnering-for-success-utilities-leverage-innovative-vendor-relationships/413868/.

United States Energy Association . (n.d.). Retrieved from Improving Utility Performance and Energy Security by Enhancing Institutional Knowledge : https://usea.org/program/energy-utility-partnership-program-eupp.

US Department of Treasury. (n.d.). Retrieved from Collaboration with Local Utility Companies & Other Utility Assistance Programs: https://home.treasury.gov/policy-issues/coronavirus/assistance- for-state-local-and-tribal-governments/emergency-rental-assistance-program/promising-practices/utilities.

Utility Program and Utility Energy Service Contracts for Federal Agencies. (n.d.). Retrieved from Federal Energy Management Program: https://www.energy.gov/femp/utility-program-and-utility-energy-service-contracts-federal-agencies.

WA DOE (2023). State of Washington Department of Ecology, Washington clean air agencies. Retrieved from: https://ecology.wa.gov/About-us/Accountability-transparency/Partnerships-committees/Clean-air-agencies.

Whatcom News. (2020, January 26). Retrieved from Whatcom County responds to news of canceled Green Apple Renewable Fuel project: https://whatcom-news.com/whatcom-county-responds-to-news-of-canceled-green-apple-renewable-fuel-project_99250/.

Zero Waste Case Study: San Francisco. (2021, September 04). Retrieved from EPA: https://www.epa.gov/transforming-waste-tool/zero-waste-case-study-san-francisco.

Zero Waste Washington. (n.d.). Retrieved from Mission and vision: https://zerowastewashington.org/about/mission-and-vision.

EXP | 451 Montgomery Street, Suite 300 | San Francisco, CA 94104
t: +1. 954.999.8292

exp•com

TASK

6

MUNICIPAL SOLID WASTE TO LIQUID FUELS STUDY

Port of Seattle + King County Solid Waste Division

Report Name:

Task 6 – Final Recommendations

2023-06-30

prepared by

EXP

451 Montgomery Street, Suite 300 | San Francisco, CA 94104

Principal, Marcos Souza: marcos.souza@exp.com

Project Manager, Joseph Gale: joseph.gale@exp.com

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

6

TASK 6 – FINAL RECOMMENDATIONS

6. Task 6 - Final Recommendations

6.1. Executive Summary

The United States Environmental Protection Agency (USEPA) determined the transportation sector to be one of the most significant contributors to national greenhouse gas (GHG) emissions.[1] Due to the extensive geographic expanse of the United States and the significant role of aviation in both passenger and freight transportation, aviation accounts for 11% of transportation-related GHG emissions within the country, whereas on a global scale, this contribution is 2%. As a leader in the mission to decarbonize the transportation sector, the Port of Seattle (POS) established a goal for all flights at Seattle-Tacoma International Airport (SEA) to have a blend of 10 percent sustainable aviation fuel (SAF) by 2028. In addition, a rapid transition to clean energy is required to avoid the large-scale impacts of climate change to the State of Washington.[2]

ASTM International D7566 has approved seven pathways to produce Sustainable Aviation Fuel (SAF). Annex A1 and Annex A4 with Fischer-Tropsch (FT) synthesis and further hydro-processing, and Annex A5 - the conversion of alcohols to jet fuel (ATJ) - define the pathways for conversion of MSW and other solid waste into SAF.

Task 6 concludes this report with final recommendations for developing a facility to convert regionally sourced MSW into SAF. The final recommendations for this report derive from comprehensive evaluations from Task Reports 1 to 5.

Task Reports 1-5 include the following:

- **Task 1:** Evaluation of feasible technologies for converting municipal solid waste and other solid waste into liquid fuels, particularly sustainable aviation fuel.
- **Task 2:** Evaluation of existing waste feedstocks from the Cedar Hills Regional Landfill and populated regions of western Washington and Oregon.
- **Task 3:** Identification and evaluation of potential facility siting locations.
- **Task 4:** Identification and evaluation models for project financing.
- **Task 5:** Identification and evaluation of financial and logistical partnerships.

A summary of the results is listed in Table 6.1 and of recommendations in Table 6.2 below.

Table 6.1: Summary of Study Results

Technology	• Renewable jet fuel conversion technologies, approved by ASTM International, offer promising solutions for solid waste transformation. The Fulcrum Sierra BioFuels plant in Nevada stands out as the first commercial-scale facility of its kind, employing the FT process and commencing operations in late 2022. • LanzaJet, a sustainable fuels technology company, is set to commission the first large-scale ATJ process later this year. Meanwhile, Enerkem, a clean technology company, has successfully operated a demonstration-scale waste gasification and ethanol synthesis plant in Edmonton for several years. Presently, they are constructing a large-scale facility, with commissioning scheduled for 2025. While the ATJ process route provides greater flexibility by utilizing ethanol from diverse bio-sources, its viability at a commercial scale still requires validation.

1 Port of Seattle. (n.d.). Retrieved from Sustainable Aviation Fuels: https://www.portseattle.org/page/sustainable-aviation-fuels#:~:text=The%20Port%20of%20Seattle%20set, fuel%20(SAF)%20by%202028.

2 Washington State Legislature, House Bill 1216. (2023, April 14). Certification of Enrollment, Engrossed Second Substitute House Bill 1216, Chapter 230, Laws of 2023, 68th Legislature, 2023 Regular Session, Clean Energy Project Siting, Effective July 23, 2023. Retrieved from: https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Session%20Laws/House/1216-S2.SL.pdf#page=1.

MSW	• Five landfills in Washington State and northern Oregon receive sufficient MSW each to support SAF production. • The projected MSW volume received exclusively in King County at the Cedar Hills Regional Landfill is sufficient to support SAF production. • The projected and combined MSW generated in populated regions in western Washington and Oregon is sufficient to support the development of a large-scale, cost-effective renewable fuels production facility.
Project Financing	• Project financing for waste-to-fuel conversion projects as well as for other renewable fuel projects is more challenging compared to established industrial projects. These projects face higher risks which must be addressed and mitigated to attract investors. A regulatory regime can support SAF production, provide incentives and tax credits, act as credit guarantor, and make MSW eligible as a renewable feedstock source. Strategic partnerships along the whole supply chain from waste hauling to SAF offtake, are beneficial for obtaining project financing. A risk mitigation plan which also addresses technology, performance, and siting risks provides additional confidence to investors.
Capital Cost	• A high-level cost estimate developed for this project revealed that SAF's Minimum Sales Price (MSP) might exceed \$10 per gallon without subsidies. The Total Plant Costs (TPC) for a 25 million gallons per year facility can reach or even exceed the \$1 billion mark.
Policies	• MSW is a significant and essential feedstock for SAF production to meet the goals of GHG emission reduction in the aviation industry. GHG emission reduction, net-zero waste, and other policies call for changes in the current landscape for waste handling and for the transportation and aviation industry. • Public agencies can promote this project and reduce project risks by offering incentives, providing credits or credit guarantees, supporting the permitting process, providing the required infrastructure, and other measures.
Partnerships	• Partnerships with public and private entities are essential due to the project's complexity, the financing demand, the various entities in the supply chain, the marketing and sales needs for products and by-products, the challenges in regulatory and permitting, and GHG emission reduction measures and credits.

Table 6.2: Summary of Recommendations

Plant Locations	The study identified and assessed suitable plant sites in Washington and Northern Oregon. Three regions were shortlisted as suitable for a new plant: • Landfill Proximity: Columbia River arearegion (near the Washington and Oregon border) with proximity to large landfills • Industrial Area: Industrial areas in central Washington along the I-5 corridor with various brownfield areas • Refinery Proximity: Northwest Washington with proximity to refineries.
Plant Size	This report recommends a plant with a capacity of producing 25 million gallons of SAF per year. This capacity is larger than current operational plants but a scale-up from today's capacities is technically feasible with low risk of non-performance.

The following tasks identify the immediate next steps to develop a waste-to-fuels project to meet the target date of 2028 for SAF production and delivery to the Seattle-Tacoma International Airport:

1. A dedicated stakeholder coordination team is recommended to coordinate upfront activities for the project's development and identify potential stakeholders and interested parties. The team should also connect with similar organizations in Europe or Canada to:

- Learn about their experience, best practices and lessons learned.
- Understand how to accelerate an MSW-to-SAF project for Washington and the Port of Seattle
- Co-operate successfully with government entities and other public organizations for regulations, laws, and code changes.

2. Local governments and economic development agencies with interest in developing an MSW-to-fuels project may already identify suitable sites based on the information provided in this Study.

3. Local, state, and federal authorities can support the project with grants, incentives, and assistance with applications for these funding types.

4. Create a fund with money from stakeholders and other interested parties to provide seed money for the initial project phase.

5. Public agencies such as the Port of Seattle or King County Solid Waste Division could support the project:

- Champion the dedicated stakeholder coordination team.
- Proactively communicate with the public to inform them about the project's benefits.
- Coordinate with stakeholders and address changes in rules and regulations.
- Identify changes required in their organizations to include the use of by-products from the SAF production process for their fleets, mandates for personnel to fly responsibly, modify facilities for handling SAF, assess the installation of a waste separation system at Cedar Hills Landfill to separate suitable materials for SAF production, and also improve the recycling of waste arriving at the landfill.

6. Attract project developers through marketing and presentations at public events.

6.2. Introduction

The Port of Seattle and King County Solid Waste Division conducted this Municipal Solid Waste (MSW) to Liquid Fuels Study (the Study) to provide insights into the potential costs and benefits of the development and operation of a renewable fuel production facility that uses regionally generated MSW.

Using MSW as a feedstock for fuel production could reduce the amount of methane and CO_2 emitted through the decomposition of landfill waste, reduce landfill site expansion, provide a steady stream of feedstock supply, and keep fossil fuels in the ground. This report evaluated the feasibility of directing MSW and other material received in King County and other regional (western WA or OR) solid waste facilities to a potential renewable fuel production facility. This joint initiative funded by the Port of Seattle and King County Solid Waste Division intends to achieve the entities' goals of greenhouse gas emission reduction, economic vitality, and waste reduction.

Task 6 provides conclusions of the findings in Task Reports 1 – 5 and recommends a path forward with next steps to develop this renewable fuel production facility.

6.3. Technologies and Waste Components

6.3.1. Technologies

ASTM International's D7566 "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons"[3] has approved seven pathways to produce SAF as a drop-in fuel, as well as the percentage of SAF allowed for blending with conventional aviation jet fuel. Two methods are applicable for municipal solid waste (MSW) to fuel conversion (Figure 6.1):

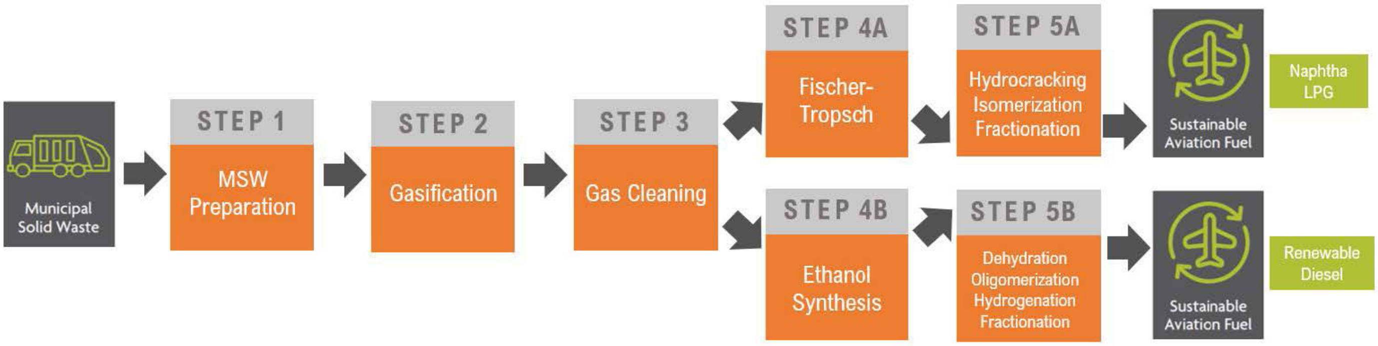
1. Annex A1 and Annex A4 with gasification followed by Fischer-Tropsch synthesis and further hydro-processing
2. Annex A5 with the conversion of alcohols to jet fuel

Annex A5 does not define a pathway to alcohol production, which offers a diversity of choices, whether fermentation of sugars (first-generation biofuels), gasification of solids followed by catalytic conversion, or fermentation of solid waste. The only commercially proven production route for solid waste to alcohol conversion is through gasification, followed by catalytic conversion, or by fermentation of syngas into ethanol.

The Fischer-Tropsch technology for fuel production is well established. The combination with syngas from MSW was first applied at the Fulcrum plant. The plant was commissioned in 2022, and the long-term operational results are still outstanding. Other MSW processing plants produce only syngas or convert syngas into methanol (GIDARA) or ethanol (Enerkem).

Whereas the gasification and syngas conversion into alcohol is in commercial operation, the ATJ process itself, i.e., the conversion of alcohols, in particular ethanol, into jet fuel, is in the validation phase with the first commercial operation starting in 2023/2024 at LanzaJet's Freedom Pines Fuels facility.

Figure 6.1 Pathways for MSW to SAF Conversion



3 ASTM (2022 November, 4). ASTM International. Retrieved from, https://www.astm.org/d7566-22.html.

If built as stand-alone plants, the FT and the ATJ routes are similar in production costs. However, importing lower-cost ethanol and blending it with MSW-derived ethanol, as well as building a larger ethanol-to-jet fuel plant could achieve significant cost and economy-of-scale advantages.

Both FT and ATJ routes could achieve further cost advantages by reducing carbon emissions through carbon capture, utilization and storage (CCUS), or feeding green hydrogen from renewable energy (solar, wind, or hydro) into the system. Regardless, both process options would reduce lifecycle GHG emissions, improve carbon efficiency and result in a higher product output for a given amount of MSW.

6.3.2. Design Scenarios

EXP developed four (4) facility scenarios and compared relevant concepts to understand the impact of the chosen technology, capacity and added measures to reduce the carbon intensity, product yield, costs, and plot space.

The Study evaluates two scenarios considering the minimum feasible design capacities of the individual process units for the FT and ATJ pathways and two methods for FT and ATJ pathways to produce 25 million gallons per year of SAF. A plant size with capacity production of 25 million gallons per year of SAF is cost-effective and technically feasible, with larger landfills in Washington and Oregon capable of providing sufficient MSW feedstock for this capacity. The four (4) scenarios are as follows:

Scenario 1: Process plant using Fischer-Tropsch synthesis and hydro-processing with a capacity like the Fulcrum Nevada plant.

Scenario 2: Process plant based on ethanol production followed by the ethanol to jet fuel conversion through the ATJ process. The waste gasification and ethanol synthesis are based on a capacity built by Enerkem, and the ethanol-to-fuels conversion (ATJ process) for similar capacity will go onstream soon.

Scenario 3: Conventional process plant similar to Scenario 1 but scaled-up to a production capacity of 25 million gallons per year of SAF.

Scenario 4: Optimized process plant for 25 million gallons per year capacity based on ATJ pathway with optimized yield and reduced CO_2 emissions. The added measures include a CO_2 into CO conversion (reverse water gas shift reaction) and additional hydrogen production from renewable energy through water electrolysis. While we have based Scenario 4 on the ATJ process as more data was available, the results apply to both process pathways.

Table 6.3 lists the key data for the four scenarios.

Table 6.3: Key Data for Four (4) Technical Concepts assessed in this Study

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Key data	FT pathway RDF: 500 mtpd SAF: 8.6 mmgpa Naphtha + LPG: 2.15 mmgpa	ATJ pathway RDF: 720 mtpd SAF: 12.7 mmgpa Renewable diesel: 1.6 mmgpa	FT pathway RDF: 1,450 mtpd SAF: 25 mmgpa Naphtha + LPG: 6 mmgpa	ATJ pathway RDF: 720 mtpd Hydrogen: 80 mtpd SAF: 25 mmgpa Renewable diesel: 3 mmgpa

Note:
mtpd - metric tons per day
mmgpa - million gallons per year
RDF - Refuse Derived Fuel, the suitable portion of MSW
SAF - Sustainable Aviation Fuel
LPG - Liquid Petroleum Fuel, mainly propane and butane

A commercial application for processing MSW to SAF should focus on the robustness of the chosen pathway, technologies, and vendors with experience in these applications. Larger capacities provide benefits for costs and plant size. Additional measures to increase yield and reduce CO_2 emissions, as shown in Scenario 4, allow for higher tax incentives and other subsidies which lower production costs.

6.3.3. Waste Components

Municipal solid waste, as shipped to a landfill, consists of various materials such as food waste, paper, glass, plastics, yard waste, metals, wood, demolition materials, textiles, and plastic film (foil). The composition depends on various factors such as recycling programs, seasonality, industrial collection, and residential structures. MSW suitable for conversion into fuel is called Refuse Derived Fuel (RDF) and consists mainly of paper, demolition wood, cardboard, plastics, and textiles. Only small amounts of food and yard waste may be mixed into the RDF as it typically has a moisture content of approximately 50% and must first be dried. Glass, metals, and other non-combustibles should also be separated to keep their content below 1.5% as they would negatively impact the process and energy balance.

This assessment analyzed MSW from households and commercial sources in Washington and northern Oregon. The assessment excluded other wastes delivered to landfills, including contaminated soil, asphalt, brick, soil, rock, gravel, construction, demolition debris, or special and toxic waste.

The MSW sorting process is essential for the success of a waste-to-fuel facility. The conversion process allows only specific waste components to be processed. Regulatory requirements further reduce the amount and type of suitable materials to enable the facility to generate RIN certificates. In particular a low content of plastics derived from fossil fuel in RDF is beneficial for RIN credit generation. A RIN – short for *Renewable Identification Number* – is a credit generated each time a gallon of renewable fuel (ethanol, biodiesel, etc.) is produced. However, the two are not inextricably linked, as the RIN can be split from the gallon when bought on the open market. The credit alone can then be sold to businesses interested in purchasing RIN credits.[4]

EXP recommends a centralized and mostly automated Material Recovery Facility (MRF) for best sorting results. An automated process allows for the recovery of valuable materials such as glass, metals, recyclable plastics, and food residues for composting. According to Renewable Fuel Standard (RFS) regulations, MSW-derived feedstock may qualify as renewable biomass and be used in renewable fuel production pathways authorized to generate RIN credits. The USEPA provides an approval process to renewable fuel producers by reviewing development plans to remove recyclable materials from their MSW-derived feedstock. USEPA determination is based on whether the MSW separation plan demonstrates that paper, cardboard, plastics, rubber, textiles, metals, and glass that can be recycled will be separated and removed from the MSW stream to the extent reasonably practicable.[5]

The remaining portion of MSW suitable for fuel production, RDF, will be shredded, pelletized, or milled into fine particles before feeding it into the processing plant. The RDF portion of the MSW arriving at a landfill is only about 40% to 50%, depending on the waste composition and the regulatory requirements.

6.3.4. Determination of MSW Demand for Fuel Production

Technical evaluations revealed that the smallest feasible amount of RDF is 500 mtpd which can be extracted from approximately 350,000 metric tons per year of MSW. A cost-efficient facility to produce 25 million gallons per year (mmgpa) of SAF needs approximately one million metric tons of municipal waste annually.

6.3.5. Volume of MSW from Washington State and Northern Oregon

6.3.5.1. Current Waste Volume

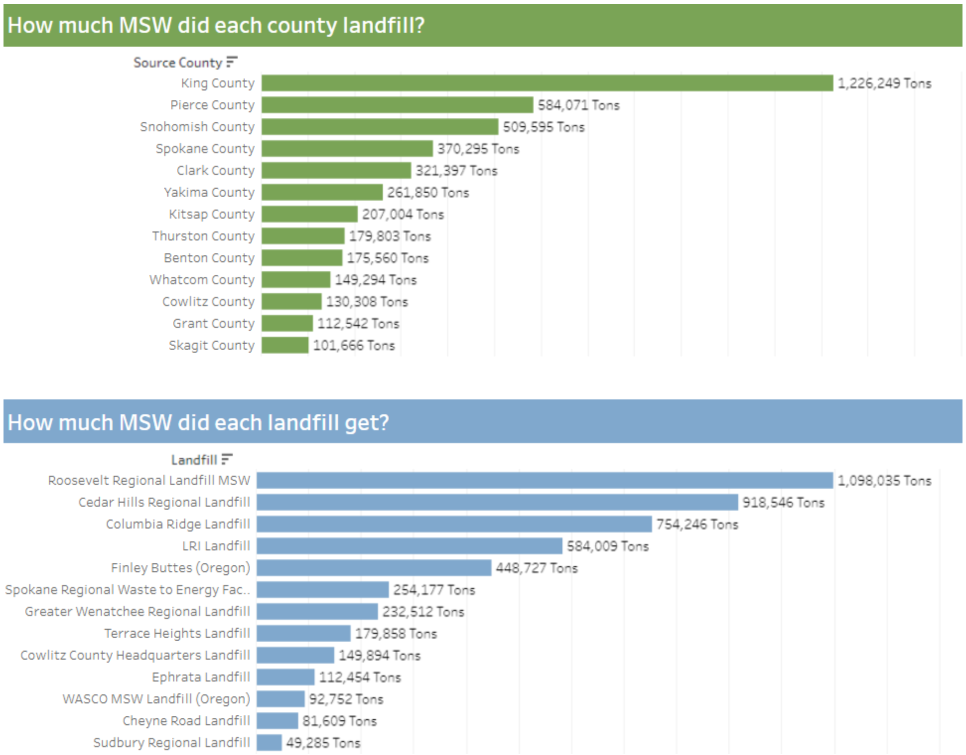
The State of Washington produces more than 5 million tons of MSW that ends up in landfills annually. Each county has waste collection, sorting and recycling programs, and disposal agreements.

Figure 6.2 shows the waste producer and receiver for MSW generated in Washington.

4 Targray (2023). What are RIN credits? Retrieved from: https://www.targray.com/biofuels/rin-credits.

5 United States Environmental Protection Agency. (n.d.). Retrieved from Waste Separation Plans for Renewable Fuel Standard Program: https://www.epa.gov/renewable-fuel-standard-program/waste-separation-plans-renewable-fuel-standard-program.

Figure 6.2 Waste Producer and Receiver[6]



Five landfills in Washington State and northern Oregon receive sufficient MSW to support SAF production:

- Roosevelt Regional Landfill in Washington
- Columbia Ridge Landfill in Oregon
- Finley Buttes in Oregon
- Cedar Hills Landfill in Washington
- LRI Landfill in Washington

The three landfills near the Columbia River and Washington/Oregon border are Roosevelt Regional Landfill, Columbia Ridge Landfill, and Finley Buttes. These landfills collect waste from Washington State and parts of Oregon, with waste traveling 500 miles or more to reach the landfill. Cedar Hills Landfill and LRI Landfill receive locally produced waste.

Roosevelt Regional and Columbia Ridge Landfill are the only two landfills that can deliver sufficient MSW to a potential large-scale fuel production plant that produces the recommended 25 million gallons per year.

6.3.5.2. Future Waste Volume Projection

EXP analyzed data from 2000 to 2018 to identify trends in population growth, waste generation, and recycling behavior. This period was not impacted by unusual disruptors such as the COVID-19 pandemic, which could change trend patterns and lead to misinterpretations of long-term trends.

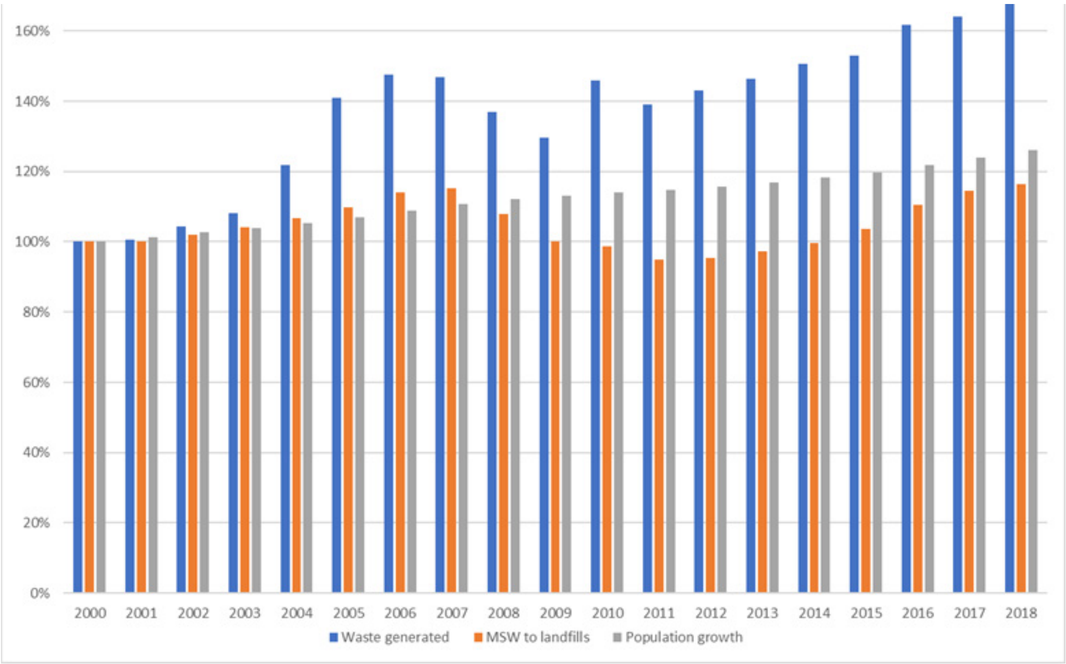
Over the last two decades, the amount of waste from households and commercial sources has increased significantly. Recycling programs starting during this period slowed down the increase in waste sent to the landfills but not the growth in quantities.

Figure 6.3 compares population growth, produced waste, and MSW sent to landfills. An increase is expected for MSW generated and MSW arriving at landfills. Introducing additional recycling and reuse programs and policies such as zero-waste could reduce the amount of waste. A predictive model was used to understand the impact on MSW quality and quantity for a waste conversion

6 State of Washington Department of Ecology (2016). Department of Ecology State of Washington, Municipal Solid Waste Flows. Retrieved from: https://public.tableau.com/app/profile/solidwastemgmt/viz/MunicipalSolidWasteFlow2016/Dashboard1.

project. The model confirmed that of the five landfills, only Roosevelt and Columbia Ridge sustainably meet the 20 million gallons per year threshold to feed a large facility alone.

Figure 6.3: Population and Waste Growth Trends in Washington State



6.3.6. Transportation and Logistics

Transportation and logistics planning could be complex depending on the final plant site location. Their carbon footprint could be reduced by using renewable energy with lower carbon intensity for transportation, such as renewable diesel, electric or hydrogen-powered trains or trucks.

Rail is the preferred solution for solid waste transportation for medium- and long-haul distances. Several counties that ship their waste to Roosevelt or Columbia Ridge landfills use this mode of transportation. Unit trains or larger groups of rail cars minimize track slot requirements and operate at lower costs.

Truck transportation supplies the highest routing and capacity flexibility but comes with the highest costs per ton and mile. Larger plant capacities do not result in lower truck transportation costs, and the cost spread to other transportation modes further increases if due to longer distances the trucks cannot return to their base within one day. Conversely, truck transportation might be beneficial when a site location has other significant cost advantages that offset truck transportation costs.

Barge transportation is not a stand-alone solution. Its use depends on coordinated efforts with trucks or rail. Intermediate storage, to buffer the different transportation capacities of barges, trucks, rail, and intermodal transfer stations, significantly increases capital costs.

6.3.7. Site Selection

Potential plant sites must fulfill various criteria such as sufficient plot space, zoning requirements, permitting regulations, infrastructure for construction and operations, logistics, geological conditions for potential carbon sequestration, environmental aspects such as minimizing emissions and effluents, avoiding unnecessary noise and odor, community acceptance, and availability of operations and administration personnel.

As shown in **Figure 6.4**, three regions are shortlisted and assessed for suitability.

Landfill Proximity – A SAF production facility near a landfill would minimize the need for added MSW or RDF transport, which is less efficient and costlier than shipping the final fuel product. A large landfill is easily accessible for waste sorting to optimize RDF composition as feedstock for fuel production. The five landfills in Washington State and northern Oregon receive sufficient MSW each to support SAF production.

Industrial Area – An existing or a demolished industrial facility (e.g., brownfield) already zoned as industrial would simplify the permitting process. Access to infrastructure and transportation connections is more likely in an industrial area. These sites may require additional logistics planning for MSW delivery and fuel transport. Various areas along the I-5 corridor, south of Seattle's metropolitan area, have been identified and further assessed.

Refinery Proximity – A refinery and its surroundings are a form of an industrial area. A refinery has existing utility systems, inert gas, and water treatment plants to reduce capital costs for a renewable fuels production facility. Added advantages of a refinery are storage and blending opportunities. Conversely, logistics for MSW, environmental aspects, and community acceptance are critical tasks to be solved.

Figure 6.4: Viable Facility Site Locations in WA and OR

6.3.8. Cedar Hills Landfill

This study placed significant consideration on the Cedar Hills landfill facility as the MSW supplier for a SAF production plant.

The incentives recently announced by WA state request a plant with a minimum annual production of 20 million gallons. King County's Zero-Waste goal requires further sorting and recycling, resulting in an amount of suitable waste from Cedar Hills that could just be sufficient to produce 20 million gallons per year. However, there would be limited spare capacity if the recycling quota exceeds the expected amounts.

A solution to benefit from the delivered municipal solid waste and reduce the amount of waste landfilled at Cedar Hills may be sorting the incoming waste at Cedar Hills, getting more recyclables out (metals, plastics, paper), sending the remaining RDF to a waste-to-fuels facility located elsewhere in Washington or Oregon, and landfilling only the remaining waste. This would reduce landfilled waste by at least 50% and provide an alternative revenue stream for King County.

Partnering with a SAF facility owner/operator could secure the offtake or usage of their RDF and lower transportation costs than shipping waste to other landfills. This allows the Cedar Hills landfill to operate for an extended period.

The amount of MSW arriving at the Cedar Hills Landfill does not favor a SAF production facility near this location. The proximity to residential areas, limited community acceptance, added environmental measures to reduce effluents, emissions, or noise, and limited plot space availability are additional factors that validate this site not serving as a potential location.

6.3.9. SEA Airport Fuel Delivery

Rail or truck transportation remain viable options to deliver SAF from identified, potential sites. The cost differentials are significant, depending on modes of transportation, and the distance of a site to the blending point. The study discussed three potential blending stations for SEA airport for shipping by rail, road, or barge:

- Renton Terminal
- Port facility close to SEA such as Port of Tacoma or Harbor Island
- NW Washington Refinery.

The blending station's storage capacity size also depends on the type of transportation. Renton Terminal can be connected by rail, whereas the refineries in northwest Washington already have access to all three transportation modes and possibly have sufficient storage and blending capabilities available. Harbor Island is the closest barge unloading point for the Seattle-Tacoma International Airport but comes with the penalty of requiring trans-loading the fuel onto a truck or rail and shipping it to a blending point.

6.3.10. Other Customers (for SAF and by-products)

SAF would be the main product of a potential renewable fuels production plant for the scenarios provided in this study. Depending on the production route, a maximum of 80% of the produced fuel is SAF, the remaining balance being naphtha and LPG for the FT route, or 90% with 10% renewable diesel for the ATJ route. The plant could also be designed for lower SAF content if economics favor diesel or naphtha over SAF. As the Port's goal is to produce a certain amount of SAF starting with approximately 75 million gallons annually to meet their 10% goal in 2028 and constantly rising over the following years, the study focused on maximizing SAF production.

Airports in the U.S. are not allowed to market and sell jet fuel. They only provide the infrastructure; jet fuel will be traded between fuel producers or traders, and airline companies. This limits the control of an airport over the SAF production and trade and the amount of SAF delivered to a specific airport. SAF produced at one of the proposed locations in Washington can also be shipped to Oregon or California or even be exported internationally.

Naphtha, renewable diesel, and LPG are all low-carbon by-products that can easily be sold on the market. Their demand is high and forecasted for further growth. Several traders specialize in these products. As the quantity of by-products is much lower than that of SAF, they can be shipped to trading hubs or to clients in the same manner as SAF, i.e., by rail, truck, or ship. If the fuel production plant is located close to a larger fuel terminal or refinery, the by-products may also be sold directly to the terminal or refinery operator.

6.3.11. Economics

Capital costs and yield, i.e., the amount of fuel produced per ton of MSW, govern the economic impacts of SAF production. Another critical factor is the capability to capture and sequester CO_2 to avoid carbon emission costs and to increase incentives by reducing the lifetime GHG emissions. The availability of renewable energy instead of fossil fuels for driving motors and producing heat is an additional measure to reduce GHG emissions and improve the carbon footprint. Having sufficient renewable energy to produce green hydrogen simultaneously increases the yield and reduces CO_2 emissions.

The cost model developed by EXP demonstrates the following:

- Production costs for MSW, and other solid waste, to SAF conversion are higher than from other non-solid feedstock sources.
- Incentives are required to convert and make MSW to SAF competitive.
- Additional measures to improve the overall carbon balance could reduce the production costs per gallon of fuel, despite higher capital costs. These are increasing the yield by adding renewable hydrogen and/or reducing the CO_2 emissions by carbon capture and sequestration.
- Low-cost renewable energy is required if additional hydrogen is used to improve the yield.
- Conventional jet fuel has a carbon intensity of between 85 and 95 g CO_2eq/MJ[7]. The Carbon Intensity for an SAF plant can be expected to be approximately 40 g CO_2eq/MJ based on current MSW composition with further reductions possible to 20 or 30 g CO_2eq/MJ when implementing additional measures such as carbon capture, improving the yield or optimizing the MSW feedstock composition. This carbon intensity would allow for various incentives.

6.4. Financing, Ownership/Operational Model

6.4.1. Financing

An MSW-to-SAF project is complex in many ways. It is not only a technological challenge. Project financing calls for multiple finance sources, innovative ways to develop new funds, and a regulatory regime that supports SAF production and, moreover, makes MSW eligible as a renewable feedstock source.

This report evaluated suggested pathways for financing a renewable fuels production facility by exploring seven (7) factors:

1. Technology selection
2. Performance guarantees
3. Facility siting
4. Commercial agreements
5. Federal and State financial support for renewable fuel projects,
6. Strategic partnerships
7. Financing sources

Financing opportunities for traditional projects, including mature industrial plants are not always readily available to high-risk projects such as a renewable fuels facility. Over the past few years, new, creative models have been developed to support such novel processes and projects.

Renewable fuels projects in the U.S. to date have focused on bioethanol production due to federal incentives. During the last decade, a few plants processing canola and other vegetable oils into renewable diesel and naphtha were built and are under construction. So far, only one plant is in operation that converts MSW into renewable diesel. A few others process MSW but produce methanol, ethanol, or renewable natural gas (RNG). The lack of existing facilities and the low maturity of the technologies makes financing challenging for MSW-to-SAF plants.

Institutional investors are traditionally risk-averse and profit-oriented. SAF projects do not meet these criteria and call for measures to de-risk and provide incentives to attract investors.

SAF production from renewables is not profitable without incentives and not competitive with fossil fuel-based jet fuel. Plants processing solid waste face one of the highest costs of all renewable fuel processes. Mandates to reduce GHG emissions and even reach net zero in the coming decades force the aviation industry to replace conventional jet fuel with SAF. There is no indication of achieving alternative options, including hydrogen, carbon-free fuels, or battery-electric options, over the next 20-30 years.

7 Pavlenko, Nikita and Searle, Stephanie (2021, March 4). The International Council on Clean Transportation, Assessing the Sustainability Implications of Alternative Aviation Fuels. Retrieved from: https://theicct.org/publication/assessing-the-sustainability-implications-of-alternative-aviation-fuels/.

Therefore, SAF is the only pathway for the aviation industry to reduce their GHG emissions, and the high demand for SAF requires the industry to utilize all available sources of feedstock, not only biomass, vegetable oil, and used cooking oil but also solid waste.

A cost model developed for this Study confirms peer-reviewed literature showing the higher costs of SAF compared to conventional petroleum-based jet fuel. Incentives are required to compensate for this disadvantage and to make SAF projects attractive to investors.

Support for renewable fuels projects from the federal- and state-level contributes to financial feasibility and makes the renewable fuel price attractive to potential buyers. Policy development to support the advancement of global SAF supplies and utilization of MSW as feedstock are categorized into five broad categories:

1. Government funding for SAF research and development, demonstration, and deployment (RDD&D).

2. Targeted incentives and tax relief to expand SAF supply infrastructure (e.g., capital grants, loan guarantee, making SAF projects eligible for tax-advantaged business status, allowing for the accelerated depreciation/'bonus' depreciation, Business Investment Tax Credit (ITC) for SAF investments, performance-based tax credit, and bonds/green bonds).

3. Targeted incentives and tax relief to assist SAF facility operation (e.g., blending incentives such as the Blenders Tax Credit (BTC), production incentives such as the Producer's Tax Credit (PTC), excise tax credits for SAF, support for feedstock supply establishment and production).

4. Recognition and valorization of SAF environmental benefits (e.g., recognizing SAF benefits under carbon taxation or cap-and-trade systems).[8]

5. Recognition of MSW as renewable feedstock and calculating lifecycle GHG emissions accordingly instead of treating it as waste and penalizing it for avoided landfill carbon utilization.

The United States provides federal and state financial support for renewable fuel projects through several of policy options. Achieving sustainable aviation is a top priority under the 2023 *National Aeronautics Science & Technology Priorities*, which replaces the 2006 *National Aeronautics and Research Development Policy*. SAF production and supply are critical to achieving this priority, and increasing this production domestically directly aligns with the United States' *SAF Grand Challenge Roadmap*.

Washington State passed new legislation in 2023 that provides incentives of up to $2 per gallon of SAF produced depending on the amount of GHG emission reduction.[9]

SAF is not yet listed as a renewable fuel for incentives and grants in several programs, and it does not have the same position as renewable diesel regarding GHG emission calculations. Some programs even consider MSW as landfilled waste and not as a renewable feedstock which results in significantly different calculated lifetime GHG emissions when using the respective formulas for calculating the carbon intensity. The GREET model which is used in the U.S. does not have yet a published procedure with respective formulas for the MSW-to-SAF conversion process.

Strategic partnerships are critical to secure project financing for a renewable fuels production facility. Industry examples are provided as precedents and references to investigate further. This could serve as a source of capital for this facility.

Strategic partnerships mitigate risk through:

- Commercial agreements (e.g., securing feedstock supply, product offtake).
- Leveraging expertise (e.g., operations/maintenance partners).
- Reducing capital requirements and increasing performance expectations (e.g., technology & EPC partners).

A partnership with well-known entities provides significant project validation. Partnerships can also open doors to other financial institutions and possibly streamline the Due Diligence (DD) timeframe – partly due to the preparation required to onboard partners.

8 ICAO Committee on Aviation Environmental Protection. (2022). Guidance on Potential Policies and Coordinated Approaches for the Deployment of Sustainable Aviation Fuels. https://www.icao.int/environmental-protection/Documents/SAF/Guidance%20on%20SAF%20policies%20-%20Version%201.pdf: ICAO.
9 Washington State Legislature, Senate Bill 5447. (2023 April). Retrieved from: https://app.leg.wa.gov/billsummary?BillNumber=5447&Year=2023&Initiative=false.

SAF projects have many potential partners, including airlines, energy companies, and waste handlers – all of which have demonstrated their willingness to partner for renewable fuel projects.

Public sector banks can de-risk a project further through blended finance, concessional loans, capital grants, or long-term guarantees.

Cross-industry partnership models that have been in development or are already employed are the Fly Green Fund or Board Now Program, where corporations can buy SAF from dedicated SAF producers without involvement in the SAF supply chain. This secures a certain offtake of SAF and enables the buyers to reduce their carbon footprint.

6.4.2. Ownership and Operational Model

The financial and logistical benefits of partnerships with entities, including private industry and public agencies, across the entire supply chain for the fuel production process are noteworthy, spanning from feedstock sourcing to transporting fuel to an airport. For example, the following entities involved in feedstock sourcing and pre-processing benefit from partnerships: Renewable fuel facilities (feedstock security), landfills (extended lifespan and zero waste support), transportation partners (logistical benefits), and waste haulers (diversifying waste drop-off destinations).

The financial strength of the project developer and financing requirements are factors that impact the ownership and ownership structure of the project. Shareholders from the whole supply chain are beneficial, as they would be more interested in supporting the project and providing their services and supplies. In a pure customer relationship, the risk of impacting profitability and interrupting the supply chain is higher when a supplier moves to another client.

Commercial fuel production facility technologies require a sophisticated operational, maintenance, and management team. If the project developer has limited operational experience, obtaining a strategic partner or subcontractor early on in development for operations and maintenance (O&M) will win the confidence of project financers. In addition, partnering with an experienced operator, e.g., a refiner, and subcontracting O&M to the refiner with an existing talented workforce would prove advantageous.

6.5. Risk Mitigation

Risk mitigation is critical for project success. Particularly, projects that are not fully mature and combine technologies in a new way and disrupt existing supply chains and waste processes, face a lot of risks which need to be identified and addressed. Risks may be expected from all project areas, not only the technical risks but also scheduling, permitting, or financing risks.

The types of risks and mitigation measures are typical for large projects. To avoid major disruptions, it is essential to have good risk management, risk identification, and mitigation plans during all project phases.

6.5.1. Scheduling Risk

A project's life has two phases. The first phase is project development until the plant becomes operational, followed by plant operations and productions as a second phase. During the project development phase with design, permitting, and construction, a project is cash negative and bears high scheduling risks.

Partners for such large projects should be identified and actively involved from early on. They may have special wishes and those should be addressed before or in the early design phases. The later the changes in a project, the more expensive they are. Special wishes of partners could be logistics topics such as feedstock delivery, type and size of material sorting, size of feedstock (MSW) storage, additional recycling facilities on site, utility delivery, fuel intermediate storage, and loading facilities (rail, truck, barge), etc. A more seamless planning and design process can occur when they are fully involved.

Various factors impact a project schedule. The permitting process must be integrated into engineering and design. Regulators need to understand the technology and the technological challenges to provide informed feedback and reasonably define the regulatory requirements. Long lead items are often on the critical path of a project, a careful selection of the vendors and good expediting is essential to deliver these items on schedule. The past several years have shown that disruptions in the supply chain and logistics make careful material sourcing and determination of the origin of materials essential to avoid schedule delays.

Once a site is selected, construction planning may begin. Construction planning must start early in the design phase and continue into procurement to ensure that the construction sequence meets the design and delivery dates of equipment and materials.

6.5.2. Permitting Risk

A renewable fuel production plant project may come to a halt if the required permits are not obtained. Establishing relationships with government agencies and the public can support this permitting process, assist in navigating complex permitting processes, and reduce risks. To achieve beneficial relationships, a developer must understand and promote the roles and responsibilities of the organization, staff, and management team. Additionally, strong relations can develop by submitting timely, complete, and accurate permit applications. This aids in reducing the requests to complete an application with additional information from government agencies.

Developing relationships with authorities will empower parties to participate in the process of developing future laws, regulations, policies, tax incentives, permits, and investments required in this relatively new process of converting MSW into renewable fuel.

6.5.3. Performance Risk

A positive revenue stream creates financial success. A cost model is required to determine the incoming and outgoing flow of funds. Significant parameters for a cost model are the plant's performance data, including the yield and quality of the product and the energy and utility consumption. Revenue is affected if these parameters are not achieved in later operations. As the technology is not fully mature, licensors and contractors should design the plant with higher design margins to compensate for possibly lower availability during the first years. They also provide performance warranties, considered to cover the differences for a certain time. Still, each licensor and contractor cover only their services and supplies, which typically do not satisfy investor requirements. Additional performance insurance is available to cover this gap. Despite being expensive, this is often required to secure project financing.

6.5.4. Financing Risk

Investors prefer to invest in later stages of project development. Once a project has reached the level for making the Final Investment Decision (FID), and the cost model shows favorable numbers, many investors are willing to invest in the project. The early project phase, with project definition and development of alternative project concepts, has the highest risks and financing difficulties.

Higher Technology Readiness Levels (TRL) are associated with lower investor risk and enhance project financial feasibility. Financing risk may also be reduced through partnerships with or subcontracting out O&M for the facility.

Financing terms such as interest rates, duration of loans, or securities may change during the lifetime of a project. Such risks for change need to be addressed in a detailed cost model to understand the impact. Due to project status and early techno-economic feasibility staging, this report did not incorporate a specific cost model.

6.6. Project Impact on Supply Chain Related Entities

6.6.1. Estimation of a Pro Forma

The cost model developed for this potential project revealed that the Minimum Sales Price (MSP) may exceed $10 per gallon of SAF. The Total Plant Costs (TPC) for a 25 million gallons per year facility can reach or even exceed the $1 billion mark. However, MSW is a significant and essential feedstock for SAF production to meet the goals of GHG emission reduction in the aviation industry. Policies such as GHG emission reduction and net-zero waste request changes in the current landscape for waste handling as well as for the transportation and the aviation industry.

6.6.2. Waste Hauling

Current waste hauling, from collecting the waste to delivery to transfer stations for landfill waste and separate collection of compostable, yard waste, and recycling material, is decentralized with multiple waste hauling and local recycling concepts in place. Moving towards zero waste could modify the business model of waste haulers and include them in the supply chain with potential partnership opportunities for a renewable fuel facility. This transition enables waste haulers to be part of this transition and secure a solid business model even under changing conditions.

6.6.3. Long-Range Waste Transportation

The MSW transportation landscape will change in the next years. Landfills reaching their capacity, zero waste policies, and the need for more recycling and reuse affects the amount of waste transportation and transportation routes. This could lead to larger shipping distances for the landfilled waste and the separate and additional shipments of recycled materials, including MSW and RDF, the need to use different transportation modes such as barge or trucks where rail was dominant, and to optimize transportation with the aim to minimize GHG emissions.

6.6.4. Landfill

The waste models forecasting future waste quantities and waste composition show a further increase in landfilled waste. This trend can only be stopped by introducing more stringent waste reduction regulations. A large renewable fuels facility could reduce the amount of waste being landfilled significantly and would, under current conditions, negatively impact the landfill business unless other financial partnership arrangements are made. Landfills that are reaching their capacity in the next two decades could benefit by diverting about half of their waste to a SAF production plant and thereby extending their life and their revenue streams.

6.6.5. Recommendations to Mitigate Negative Impacts

Task 5 detailed the potential partnership benefits of stakeholder involvement in the waste supply chain from waste collection to landfills for an MSW-to-SAF plant.

A reorganization of the waste management process with a more centralized waste management organization could improve results and reduce costs. An analysis of waste arriving at landfills showed that waste composition still includes a larger amount of potentially recyclable materials. Several communities in other U.S. states and other countries have moved away from separating waste at the source and collect all household and commercial waste in common bins or containers and separate it in a larger central facility into compostables, recyclables and landfill waste. Semi-automated or fully automated MRFs allow for more efficient sorting and higher recycling rates. The market power would also increase, and the prices achieved for recycling materials improve, benefiting all parties involved in the waste logistics supply chain. A MRF could also separate the material required for SAF production and even optimize it with regards to material composition to gain maximum benefits and GHG emission credits.

A change in the tipping fee structure and amount of tipping fees could help landfills to compensate for some of these modifications. Landfills may increase their tipping fees as compensation for a reduced amount of waste that they receive. As future laws will require further improvements in recycling and waste reduction, landfill operators could diversify their business and generate additional revenue through waste sorting and additional recycling. Managing materials handling for an SAF production facility would actively involve them in the renewable fuels business and enhance their environmental profile.

Higher costs on conventional fuels such as a higher carbon tax or similar policies could generate more revenue which could be used to support the renewable fuels production and would also narrow the price gap between conventional and renewable fuels.

6.7. Code Changes, Policies, Incentives, or Amendments

Code changes, policies, or amendments must be adopted by the Comprehensive Solid Waste Management Plan and at government level, and incentives need to be provided by the government in order for MSW-to-fuel plants to be profitable. Developing partnerships with government authorities will prove instrumental in meeting the needs of this type of facility since the conversion of MSW to jet fuel is a relatively new process and must be incorporated into future laws, regulations, policies, tax incentives, and investments. For example, the MSW to fuel process must be eligible to meet zero waste objectives, and the process of converting MSW should be favored over dumping waste in a landfill.

The Washington State Sustainable Aviation Biofuels Work Group has issued a report[10] that supplements the policy recommendations made in this section.

10 Sustainable Aviation Biofuels Work Group (2022 December) Sustainable Aviation Fuel Updates and Recommendations (Opportunities for Washington), December 2022 Final Report. Retrieved from: https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=2022-12-01%20SABWG%20REPORT_9cd2afd3-8606-46d2-aa90-42b98fe62972.pdf.

6.7.1. Comprehensive Solid Waste Management Plan Suggestions

- The Cedar Hills Landfill is rapidly approaching its useful end-of-life; the next disposal method must be identified and incentivized. Alternative disposal solutions, like converting waste into fuel, could be a viable solution that aligns with King County's Re+. Re+ shifts the region's current solid waste system from a disposal-based system to one focused on reduction, recovery, recycling, and regeneration, creating more of a circular economy in the process.
- Most contracts between waste haulers and counties expire between now and 2028. A waste-to-fuel conversion facility needs four to five years for construction and, therefore would not be commissioned before 2028. This provides sufficient flexibility to renegotiate contracts and divert collected waste from landfills to SAF production.
- Japan's 3R initiatives (Reduce, Reuse, Recycle + Renewable) require businesses to minimize plastic wastes generation and must recycle through measures facilitated by the act. For example, manufacturers and municipalities that successfully collect and recycle products made from plastics receive 150,000 yen from the ministry.[11] As discussed in Task 5.11, implementing a similar policy which compensates businesses for successfully meeting targets (e.g., collecting and sending materials for recycling or to a renewable fuel facility etc.) could yield desirable results in the United States.

6.7.2. Government Incentives

Multiple tax credits and other incentive programs are available to support the development of renewable fuels facilities. These might change during the development of this project, but examples of programs currently available are:

- Low Carbon or Clean Fuel Standards like those implemented in WA, CA, OR and BC
- Washington State's new SAF incentive tax credit
- The Carbon Offset and Reduction Scheme for International Aviation (CORSIA)
- Renewable Identification Number (RIN)
- Inflation Reduction Act (IRA)
  - SAF Blenders Credit (BTC) and the Clean Fuel Production Credit (CFPC)
  - Section 4007 (grant)
  - Section 1703 Loan Guarantee
  - New Section 1706 Loan Programs Office Title 17 Energy Infrastructure Reinvestment
  - Fueling Aviation's Sustainable Transition (FAST)
- The Grid Deployment Office administered a Grid Resilience and Innovation Partnership (GRIP) Program, as part of the Bipartisan Infrastructure Law
- Carbon sequestration tax credits are also obtainable under the IRA's recent expansion of Section 45Q of the United States Internal Revenue Code.

6.7.3. SAF

SAF is the only renewable jet fuel available today. Electric or hydrogen powered propulsions are still in development and need decades before they can be used in commercial aircraft. As SAF demand increases, prioritization of its production must be met with amended rules and regulations, tax incentives, government grants, and other subsidies.

SAF is not yet listed as a renewable fuel for incentives and grants in several programs and does not have the same position as renewable diesel regarding GHG emission calculations. There is an abundance of bioethanol in the market which receives subsidies and tax credits. The demand for bioethanol as a gasoline blend will shrink over the coming years as more cars switch to carbon-free fuels, either electric, or hydrogen. Tax policies should change and favor SAF production over bioethanol and renewable diesel.

11 ARTECH. (2023, January 10). Retrieved from Food Packaging & New Plastic Recycling Law in Japan: https://www.artechpms.com/news-detail/food-packaging-new-plastic-recycling-law-in-japan.htm#:~:text=The%20new%20law%20encourages%20municipalities,150%2C000%20yen%20from%20the%20ministry.

SAF must be produced from multiple feedstocks and with different technologies to meet the demand of the aviation industry. Investors may be reluctant to invest in capital-intense processes with high production costs, such as the solid waste processing pathway.

Governments could develop regulations supporting the usage of local resources and provide more grants, and incentives to cover the cost gap to cheaper production routes. Local resources would also secure the feedstock supply and avoid price competition for feedstocks competing for international offtakers.

Another solution to keep the supply chain from feedstock sourcing to product offtake local is to create an SAF pool where SAF from the various approved feedstocks and production processes flows in. This pool could take defined amounts of SAF from local feedstocks, ensuring a market for solid waste based SAF production facilities. Alternately, SAF consumers or blenders could commit to offtake specific amounts of SAF from this pool. The pool could be owned by public agencies or by SAF stakeholders.

6.7.4. MSW and GHG Emission Calculations

MSW and other solid waste as feedstock for SAF production still face various hurdles in policies, rules and regulations which have an impact on the ability to receive incentives and subsidies.

Washington and the Pacific Northwest produce sufficient solid waste and forestry waste to feed several large scale SAF production plants. However, some current rules and regulations for GHG emission calculations have not yet considered the use of MSW and focus on vegetable oils, used cooking oil or animal fat.

Some calculation models consider MSW, which is used as feedstock for SAF as waste and not as a recycled material. Lifecycle GHG emission calculations as e.g., used by CORSIA[12] are currently based on a model for waste management practices instead of waste recycling. EPA describes both models in their Waste Reduction Model (WARM) documentation,[13] and their definition for recycling as a "process that takes materials or products that are at end of life and transforms them into the same product or a secondary product,"[14] would fit much better the intended purpose.

Most laws and regulations require that SAF needs to achieve a GHG emissions reduction of 50% or more compared to conventional jet fuel to be eligible for grants and tax incentives.

In the CORSIA model, despite containing a high biogenic carbon content, the calculated lifecycle GHG emissions for MSW could even surpass those for petroleum-based jet fuel with up to 105g CO_2e/MJ instead of conventional fossil fuel with 91g CO_2e/MJ. Additional measures such as carbon capture and sequestration, which could provide a potential carbon credit of 60 to 80g CO_2e/MJ, and other carbon reducing measures must be implemented to just reach the 50% threshold. The Argonne National Laboratories[15] utilized CORSIA's formula[16] in a recently published paper. This formula calculates the GHG emissions of MSW for fuel production, and the results are up to 10% higher lifecycle GHG emissions for MSW as feedstock than for petroleum jet fuel depending on the process, the waste composition and additional measures taken for carbon reduction. A significant factor that contributes to this high CI factor results from the above mentioned consideration of MSW as waste and is the penalty for avoided alternative use of the MSW and the corresponding carbon emissions, a calculation method that is not used elsewhere.

Canada's GHGenius model sees the conversion of MSW into fuels as waste recycling and gives credit for the avoided landfill methane emissions. This results in significantly lower lifecycle GHG emissions of around 40g CO_2e/MJ and is in line with EXP's model and the CI factor that the California Air Resource Board published for the Fulcrum Sierra Nevada plant[17].

12 ICAO (2022 June). CORSIA Methodology for Calculating Actual Life Cycle Emission Values, ICAO document. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO document 07 - Methodology for Actual Life Cycle Emissions - June 2022.pdf.

13 USEPA (2020 November). U.S. Environmental Protection Agency Documentation for Greenhouse Gas Emission and Energy Factors Used in Waste Reduction Model (WARM), Management Practices Chapters. Retrieved from: https://www.epa.gov/warm/documentation-chapters-greenhouse-gas-emission-energy-and-economic-factors-used-waste.

14 Ibid.

15 Lee, Uisung, Cai Hao, Ou, Longwen, Thatiana, PAhola, Wang, Yixuan, Wang, Michael (2023, January 1). Journal of Cleaner Production, Life cycle analysis of gasification and Fischer-Tropsch conversion of municipal solid waste for transportation fuel production, Journal of Cleaner Production, Volume 382, 135114. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0959652622046881.

16 ICAO (2022 June). CORSIA Methodology for Calculating Actual Life Cycle Emission Values, ICAO document, June 2022, https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO document 07 - Methodology for Actual Life Cycle Emissions - June 2022.pdf.

17 California Air Resource Board (2023, June 12)., Spreadsheet of all certified pathways published on the web, r. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx.

GREET has not published a model for MSW-to-SAF lifecycle GHG emission calculations yet, and the pathway for Fulcrum's calculation methodology has retired. MSW continues to encounter significant risks as long as the GHG emission calculation methodology and the resulting eligibility for grants and incentives associated with GHG emission reductions is not known.

6.8. Beneficial Partnerships among Government Entities

This potential project would involve coordination with multiple permitting authorities and regulators. Public agencies could be involved as direct stakeholders, such as the Port of Seattle as airport owner and operator, King County Solid Waste Division (KCSWD) as a feedstock provider, or utility providers for power, water, and natural gas. Partnerships among government entities could enhance the economics, logistics, or efficiencies of the project.

This type of project is unique in various ways, from feedstock sourcing to processing, shipping, and blending of SAF, logistics and supply chain. It is imperative to include governmental organizations, public agencies, and also elected officials in the development process. Development of an MSW-to-fuel project requires an understanding of the importance of waste reduction, GHG emission reduction, improved air quality, and creating new jobs. Discussions should also pertain to this project's economic impacts and community benefits.

The utilization of MSW as feedstock for renewable fuel production is still new, with a handful of projects around the world that process MSW to create syngas, methanol, ethanol, or other derivatives. To date, only one plant has been commissioned to convert MSW into renewable diesel and later potentially to SAF. Permitting authorities are mandated to ensure that all relevant laws and regulations are met and the health and wellness of the population at large and the neighborhood in particular is protected. Current laws and regulations may not even cover the MSW-to-SAF pathway, and others do not handle MSW as a valuable feedstock instead of just waste.

EXP recommends the Port of Seattle and/or KCSWD champion this potential project and connect with relevant authorities, public agencies and other governmental and non-governmental organizations. It would be important to educate all stakeholders about the proposed project and the processes and logistics involved, the economic and social benefits, and the environmental impact. Through a workshop style task force, positive project impacts and benefits as well as risk mitigation should be communicated to all stakeholders, ensuring an expedited permitting process for a future developer.

This study describes in various sections the importance of financing and also the difficult economics which require public support. The rules of how to accept MSW as a renewable feedstock, the thresholds for waste composition, or calculation methods for lifecycle GHG emissions are not consistent between government levels, but they determine whether and how much subsidies, tax incentives, or grants a project will receive. Clear rules, acceptance of waste as a feedstock, SAF eligibility as renewable fuel, and policy discrimination of SAF versus renewable diesel or other renewable fuels is relevant to receive the maximum possible subsidies and hence reduce the amount of funding needed from investors.

This project relies on strong and reliable infrastructure. Involvement of utility providers and garnering their support could make siting selection a more simplistic solution. The same is true for road / rail access and obtaining right of way for new access roads or rail branch lines. Communication and coordination with local authorities, utility providers, economic development agencies, and chambers of commerce could pave the way for early site selection.

Relationships with politicians on all levels could create a supportive environment for SAF projects, they can relay information and knowledge received to their constituency and to governmental organizations.

The cooperation with other public entities and organizations on state, national and international level in the deployment of SAF production facilities accelerates the learning curve, strengthens the promotion of SAF as a renewable fuel and may avoid competing incentives and subsidies from jurisdiction to jurisdiction as it is important to support SAF production in all regions and for all airports.

6.9. Next Steps

The State of Washington has passed new SAF incentives to be available once there is at least 20 million gallons annually of SAF production in the state.[18] In addition, the Washington State Legislature proposed House Bill (HB) 1216 on January 10, 2023, to enable

18 Washington State Legislature, Senate Bill 5447. (2023 April). Retrieved from: https://app.leg.wa.gov/billsummary?BillNumber=5447&Year=2023&Initiative=false.

more efficient and effective siting and permitting of clean energy projects. On May 3, 2023, Governor Jay Inslee signed HB 1216 into law. Effective July 23, 2023, HB 1216 will help to accelerate permitting and environmental review for construction of clean energy plants in Washington state.[19]

The state of Washington does not currently have a facility with continuous SAF production. The findings of this Study support the development of a commercial scale plant utilizing technology with higher maturity which will be able to capitalize on the new SAF incentive for the State of Washington.

The complexity of such a project, the impact on the supply chain and changes of existing supply chain structures, mandates to reduce GHG emissions and landfill waste, goals to reach zero waste and net-zero emissions, the conversion of waste into a valuable feedstock, and other environmental and social impacts will require development of an entirely new eco-system and involve all potential stakeholders in this development. A dedicated team (Team) should coordinate all activities and identify all potential stakeholders and interested parties. It should also connect with similar organizations in Europe or Canada to:

- Learn about their experience and how to avoid missteps.
- Understand how to accelerate an MSW-to-SAF or liquid fuel project for Washington
- Deal with government entities and other public organizations for changes in regulations, laws, and codes.

The Commercial Aviation Alternative Fuels Initiative (CAAFI) on large scale and Washington's Sustainable Aviation Biofuels Work Group (SABWG) are good examples for such a Team.

One or more suitable site locations need to be identified that meet as many of the client specific requirements and needs as possible. Local governments and economic development agencies who might be interested in developing an MSW-to-fuels project may already identify suitable sites based on the information provided in this Study.

A project developer needs to be found and attracted for this project. For every developer the most difficult phase of a project is early development. The cost to get the project to a stage where a project developer can obtain money from normal sources involved is not high, but these initial dollars are the highest risk dollars spent. $5-10 million initial development is needed to get to actual development. The Port of Seattle or the Team could liaise with airlines and other potential well capitalized stakeholders, and help these entities create a fund to cover the costs for the first development phase. The fund administrator could also do a pre-screening of potential developers to select the most promising one. The availability of initial development money could accelerate the development of the project as potential project developers see a higher chance of project realization and are more willing to spend time and effort for this project.

MSW-to-fuel production is a quite new production pathway; however, the single process steps are available and most of them are already mature. First large operational production plants provide insight into the MSW sorting and processing steps and in the downstream more refinery type processes.

A first step in project development is the project definition. Key parameters to define are the source and available quantity of feedstock (MSW). These determine the maximum capacity of a new plant. A plant concept with the process steps and possible options and alternatives is required to develop a high-level cost estimate and to identify utilities and offsites needs. The required plot space is also an outcome of the plant concept development.

Local, state, and federal authorities could support the project by providing grants and incentives and by helping to apply for such money.

Once the feedstock source is known, it is recommended that samples of MSW be shipped to an existing facility or licensor test facility to verify the suitability of the waste and optimize the most critical front-end portion before starting the design. It is not recommended to design and build a pilot plant first however, the plant design should be based on an existing and operational plant design, such as e.g., Fulcrum for the FT pathway or Enerkem and LanzaJet for the ATJ pathway.

19 Washington State Legislature, House Bill 1216. (2023, April 14). Certification of Enrollment, Engrossed Second Substitute House Bill 1216, Chapter 230, Laws of 2023, 68th Legislature, 2023 Regular Session, Clean Energy Project Siting, Effective July 23, 2023. Retrieved from: https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Session%20Laws/House/1216-S2.SL.pdf#page=1.

Going forward, public entities may support this project in the following ways:

- Champion a dedicated stakeholder coordination team.
- Proactively communicate with the public about the project's benefits.
- Coordinate with stakeholders and address changes in rules and regulations,
- Identify changes required in their organizations to include:
- Use of the SAF by-products, i.e., renewable diesel or LPG, for their fleets.
- Encourage private sector companies to create internal requirements for personnel to fly responsibly, use SAF certificates or similar if available.
- Modifications required to process SAF blends, additional storage tanks, separate metering stations, etc.
- Installing a waste separation system at the landfill that meets the requirements for a SAF facility,
- Identify waste (MSW or RDF) logistics options to get the waste to the SAF facility.
- Attract project developers through marketing and presentations at public events.

6.10. Conclusion

This study assessed various aspects of using MSW and other solid waste to produce SAF and other renewable fuels. The intent of this study is to support the Port of Seattle's goal to fuel each flight out of Seattle-Tacoma International Airport (SEA) with a minimum of 10% blend of sustainable aviation fuel by 2028. This study also supports King County's long-term MSW disposal planning. Due to the limited capacity at King County's Cedar Hills Landfill, it will be unable to receive added waste after about 2040.

Alternative propulsion fuels such as hydrogen or electricity for the aviation industry will not be readily available in large quantities over the next twenty to thirty years. SAF is the only renewable jet fuel that can be utilized in the short term for reducing carbon emissions. MSW is a local source and is available in abundant quantities for the conversion to renewable fuel. Its use as a renewable fuel source can also reduce the amount of landfilled waste.

This study investigated potential technologies for converting MSW into SAF. Our evaluation includes identifying potential vendors and considering the commercial availability based on the TRL and the existence of reference plants. ASTM International has approved two pathways for producing SAF from MSW.

Currently, the Fischer-Tropsch pathway stands out as the only one with a commercial-sized reference plant, operated by Fulcrum Bioenergy in Nevada. While the individual process steps within this pathway are well-proven, their combination presents a unique challenge. Our experience suggests that even under these circumstances, a period of two to three years should be anticipated from the initial start-up phase to achieve smooth and full-capacity of operations.

The initial segment of a SAF production plant utilizing the Alcohol-to-Jet fuel pathway, the second ASTM-approved pathway, is currently operational at a smaller commercial scale through Enerkem's Edmonton plant. This facility is dedicated to processing MSW and produces methanol and ethanol. However, it's important to note that the further conversion of ethanol into SAF remains in demonstration phase, with the first commercial-sized plants currently under construction.

Scaling up technologies and equipment presents significant challenges, particularly when transitioning from a demonstration-sized operation to a full-scale commercial plant. Such scale-ups can be complex and even prone to failure. It's important to recognize that the SAF production from solid waste is a nascent industry with limited operating experience. A plant set to commence operations by the end of this decade should be founded on technology and design with the highest TRL and as much operating experience as possible. This approach is essential to mitigate potential process, schedule, and cost risks.

An analysis of MSW in Washington and Northern Oregon identified sufficient MSW is available for this plant type. A list of potential sites for the facility have been identified, as well as the required logistics assessment comparing rail, truck, and barge transportation from potential sites to possible blending stations where SAF could be blended into conventional jet fuel.

Comprehensive evaluations of financing options, high-level cost estimates, and discussions on partnerships were conducted to address the commercial aspects of this project. A project of this size requires at least five years to become operational, including planning and construction. The suggested first steps shall support the development of this type of plant, reduce schedule risks and permitting delays, and may guide interested parties in taking appropriate measures to bring the project to fruition in a timely manner.

Through techno-economic evaluations, development of an MSW to SAF production plant is feasible in the pacific northwest region, and presents a path forward to meet Port of Seattle and King County GHG reduction, economic development, and zero waste goals.

6.11.References

ARTECH. (2023, January 10). Retrieved from Food Packaging & New Plastic Recycling Law in Japan: https://www.artechpms.com/news-detail/food-packaging-new-plastic-recycling-law-in-japan.htm#:~:text=The%20new%20law%20encourages%20municipalities,150%2C000%20yen%20from%20the%20ministry.

ASTM (2022 November, 4). ASTM International. Retrieved from, https://www.astm.org/d7566-22.html.

California Air Resource Board (2023, June 12). Spreadsheet of all certified pathways published on the web. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx.

ICAO (2022 June). CORSIA Methodology for Calculating Actual Life Cycle Emission Values, ICAO document. Retrieved from: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO document 07 - Methodology for Actual Life Cycle Emissions - June 2022.pdf.

ICAO Committee on Aviation Environmental Protection. (2022). *Guidance on Potential Policies and Coordinated Approaches for the Deployment of Sustainable Aviation Fuels*. https://www.icao.int/environmental-protection/Documents/SAF/Guidance%20on%20SAF%20policies%20-%20Version%201.pdf: ICAO.

Lee, Uisung, Cai Hao, Ou, Longwen, Thatiana, PAhola, Wang, Yixuan, Wang, Michael (2023, January 1). Journal of Cleaner Production, *Life cycle analysis of gasification and Fischer-Tropsch conversion of municipal solid waste for transportation fuel production*, Journal of Cleaner Production, Volume 382, 135114. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0959652622046881.

Pavlenko, Nikita and Searle, Stephanie (2021, March 4). The International Council on Clean Transportation, Assessing the Sustainability Implications of Alternative Aviation Fuels. Retrieved from: https://theicct.org/publication/assessing-the-sustainability-implications-of-alternative-aviation-fuels/.

Port of Seattle. (n.d.). Retrieved from Sustainable Aviation Fuels: https://www.portseattle.org/page/sustainable-aviation-fuels#:~:text=The%20Port%20of%20Seattle%20set, fuel%20(SAF)%20by%202028.

SFO (2019). Sustainable Aviation Fuel Feasibility Study, Final Report 2019, SFO. Retrieved from: https://www.flysfo.com/about/sustainability/reducing-carbon-emissions/sustainable-aviation-fuel.

State of Washington Department of Ecology (2016). Department of Ecology State of Washington, Municipal Solid Waste Flows. Retrieved from: https://public.tableau.com/app/profile/solidwastemgmt/viz/MunicipalSolidWasteFlow2016/Dashboard1.

Sustainable Aviation Biofuels Work Group (2022 December) *Sustainable Aviation Fuel Updates and Recommendations (Opportunities for Washington)*, December 2022 Final Report. Retrieved from: https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=2022-12-01%20SABWG%20REPORT_9cd2afd3-8606-46d2-aa90-42b98fe62972.pdf.

Targray (2023). *What are RIN credits?* Retrieved from: https://www.targray.com/biofuels/rin-credits.

United States Environmental Protection Agency. (n.d.). Retrieved from Waste Separation Plans for Renewable Fuel Standard Program: https://www.epa.gov/renewable-fuel-standard-program/waste-separation-plans-renewable-fuel-standard-program.

Washington State Legislature, House Bill 1216. (2023, April 14). Certification of Enrollment, Engrossed Second Substitute House Bill 1216, Chapter 230, Laws of 2023, 68th Legislature, 2023 Regular Session, Clean Energy Project Siting, Effective July 23, 2023. Retrieved from: https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Session%20Laws/House/1216-S2.SL.pdf#page=1.

Washington State Legislature, Senate Bill 5447. (2023 April). Retrieved from: https://app.leg.wa.gov/billsummary?BillNumber=5447&Year=2023&Initiative=false.

USEPA (2020 November). U.S. Environmental Protection Agency Documentation for Greenhouse Gas Emission and Energy Factors Used in Waste Reduction Model (WARM), Management Practices Chapters. Retrieved from: https://www.epa.gov/warm/documentation-chapters-greenhouse-gas-emission-energy-and-economic-factors-used-waste.

EXP | 451 Montgomery Street, Suite 300 | San Francisco, CA 94104
t: +1. 954.999.8292

exp.com