Pyrolysis System Feasibility Study for the Port of Port Townsend

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PRESENTED TO

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EXECUTIVE SUMMARY

The following study was conducted under a Recycling Development Center grant received by the Port of Port Townsend (the Port) from the Washington State Department of Ecology. Tetra Tech, Inc. (Tetra Tech) was retained by the Port to assess if the conversion of waste plastics via pyrolysis is an effective alternative to the current waste disposal practices in Jefferson County. The overall goal of the Washington State grant is to develop local markets and processing for Washington's recyclable products via transforming or remanufacturing rather than sending them to landfill for disposal.

An overview of the findings and evaluation is presented below:

Feedstock

- In 2020, 21,819 tons of solid waste and 3,951 tons of mixed recyclables were collected and disposed by Jefferson County
    - Of the 3,951 tons of mixed recyclables, 467 tons was comprised of source separated comingled Tin, Aluminum and Plastic (TAP). It is estimated that only 25% or ~120 tons is plastic recyclables
- In 2020, the estimated overall plastic waste generated by Jefferson County was approximately 2,100 tons (this includes non-recyclable and non-marked plastics) based on regional data and characteristics presented in Washington State Department of Ecology's 2018 Waste Characterization Study (Group, 2018). The marked plastic (#1-#7) which is suitable for pyrolysis feedstock is estimated at approximately 500 tons of the total plastic waste generated
- The estimated potential feedstock available (Plastic Types #1-7, excluding 3) for pyrolysis is a minimum of 200 tons/year and a maximum of 500 tons/year

Pretreatment

- Currently recyclable plastics (#1, #2 and some #5) are comingled with tin and aluminum and collected curbside and at drop off locations throughout Jefferson County
- The creation of a Material Recovery Facility (MRF) is costly and not desired by the County, therefore, it is assumed that source separation practices would require modification to remove comingling of tin and aluminum with the plastic and that marked plastics #1-#7, excluding #3, may be accepted
- The primary equipment required for pretreatment is a manual sorting conveyor, infeed conveyor, shredder, and outfeed conveyor
- System sizing would likely be 500-1000 pounds per hour (lb/hr) throughput capacity, smaller sizing is limited based on equipment availability/scalability

Pyrolysis System

- Ten (10) vendors of Pyrolysis technologies were contacted for this study
    - Two (2) vendors declined to participate, four (4) vendors did not respond, and four (4) were evaluated
- Of the four (4) evaluated, only PDO Technologies offered technology packages which could be scaled down to the amount of feedstock available (200-500 tons). This offering includes a stationary system (maximum system process capacity of 5,000 lbs/day) and a mobile system (maximum system process capacity of 1,500 lbs/day)
- Products include Pyrolysis Oils (Diesel & Naptha), Char, and Incompressible gas which is recycled back into the process

Financial Evaluation (Based on 200 tons/year feedstock)

- Total project capital and operational costs is approximately $2.5M and $223K/year.
- Estimated revenue is $138K/year from sale of 55,500 gallons of fuel at $2.50/gallon
- A minimum tip fee of $0.70/lb is required to break even

Financial Evaluation (Based on 500 tons/year feedstock)

- Total project capital and operational costs is approximately $2.2M and $280K/year.
- Estimated revenue is $278K/year from sale of 111,420 gallons of fuel at $2.50/gallon

- A minimum tip fee of $0.18/lb is required to break even

1.0 INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) was retained by the Port of Port Townsend (the Port) to conduct a study to evaluate the technological, economic and environmental feasibility of developing a Pyrolysis project for the final use of the recycled plastics waste stream available in Jefferson County, Washington. The goal of this project is to assess if the conversion of waste plastics via pyrolysis is an effective alternative to the current waste disposal practices. The current practice includes collecting recyclables including plastics in Port Townsend and trucking them to Material Recovery Facility (MRF) in Tacoma, Washington.

This study was conducted under a Recycling Development Center grant received by the Port from the Washington State Department of Ecology. The overall goal of the Washington State grant is to develop local markets and processing for Washington's recyclable products via transforming or remanufacturing rather than sending them to landfill for disposal.

3.1 BACKGROUND

In 2017 an estimated 466,749 tons of plastic packaging and products was generated by residents and commercial operations in the Washington State (Group, 2018). This equates to approximately 10.2% of the total statewide disposed waste stream. The estimated plastic waste generation (recyclable and non-recyclable) in Jefferson County is between 1,800-2,500 tons/year. Through their current waste management practices, Jefferson County collects and ships approximately 400-470 tons/year of comingled tin, aluminum, and plastic (TAP) to Pioneer Recycling Services' MRF in Tacoma. The plastic component of the TAP is comprised of Plastics #1, 2, and limited types of #5. It is estimated that approximately 25% of the total TAP or approximately 100-120 tons/year is comprised of these plastics (estimate provided by Jefferson County Department of Public Works). This equates to approximately 20% of the total marked plastic, types #1-7 (refer to **Error! Reference source not found.** for definition), waste stream generated in Jefferson County.

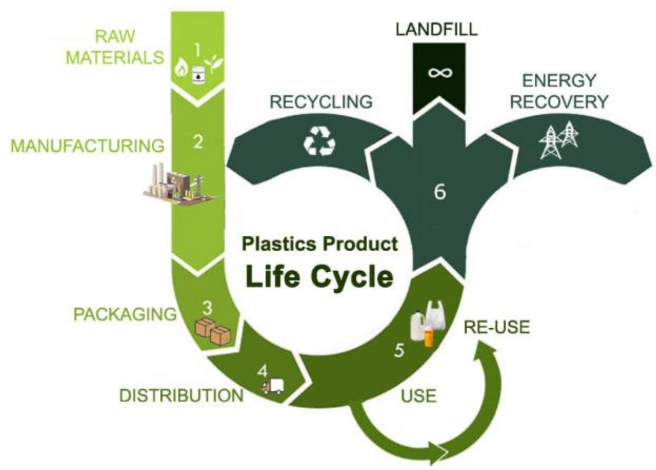


Figure 1 - Plastic Products Life Cycle (What Does It Mean to Be Environmentally Friendly?, 2020)

Figure 1 provides a representation of the life cycle of plastic products. Plastic products at their "end-life" or phase 6 of the diagram have three pathways; (1) recycle, (2) dispose in a landfill, or (3) use for energy recovery/fuel generation. The scope of this feasibility report is to consider the third pathway, energy recovery/fuel generation, and more specifically to investigate the thermal chemical conversion pathway known as pyrolysis. **Figure 2** provides an illustration of the primary thermochemical conversion pathways, their products, and applications.

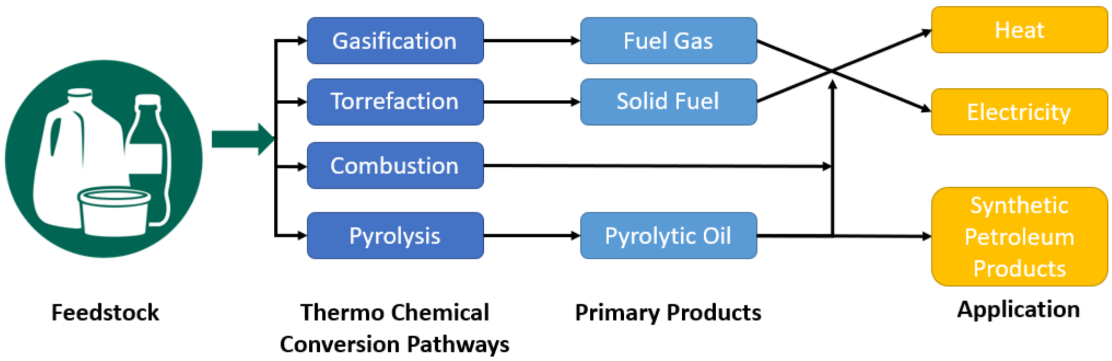


Figure 2 - Thermochemical Conversion Pathways

The objectives of the feasibility study are as follows:

- Identify, analyze, and evaluate available and potential future feedstocks
- Evaluate appropriate pyrolysis technologies and provide recommended option
- Identify offtake market applicability and options for pyrolysis outputs
- Develop an economic assessment for the recommended option
- Develop a preliminary permitting matrix

The findings of this study are discussed in the following sections.

2.0 FEEDSTOCK ASSESSMENT

Jefferson County, WA located on the Olympic Peninsula of Washington State and is due west of Seattle. The County features locations with the potential and historical census data for steady, continuous growth over the studied period of time analyzed for the feedstock analysis. Currently an estimated population of 30,856 reside in the 2,183 square mile county that houses a coast on the east and west sides (Deloitte & Datawheel, 2021). Port Townsend is the county seat and the only incorporated city located in Jefferson County, home to approximately one-third of the county's citizens. The following section describes Tetra Tech's findings on the feedstock available and to be considered for the basis of the feasibility study.

3.2 EXISTING FEEDSTOCK OVERVIEW

The Jefferson County solid waste program is managed by Jefferson County's Department of Public Works (Public Works) and operates following the Solid Waste Management Plan (SWMP) issued in 2016. The County has the following facilities as part of their program:

- **Transfer Station**
  - 325 County Landfill Rd, Port Townsend, WA 98368
- **Solid Waste Drop Box**
  - 295312 Highway 101, Quilcene, WA 98376
- **Household Hazardous Waste Facility**
  - 282 10th Street, Building 19, Port of Port Townsend Boat Haven

- **Compost Facility (Operated by Port Townsend)**
  - 325 County Landfill Rd, Port Townsend, WA 98368
- **Recycle Drop Off Locations**
  - Jefferson County Recycling Center; 301 County Landfill Road, Port Townsend, WA 98368
  - Quilcene Drop Box Facility; 295312 Highway 101, Quilcene, WA 98376
  - Port Hadlock; 202 Elkins Road
  - Kala Point; 20 Village Drive
  - Port Ludlow Village Center; 40 Village Way.
  - Household Hazardous Waste Facility; 282 10th St., Port of Port Townsend Boat Haven.

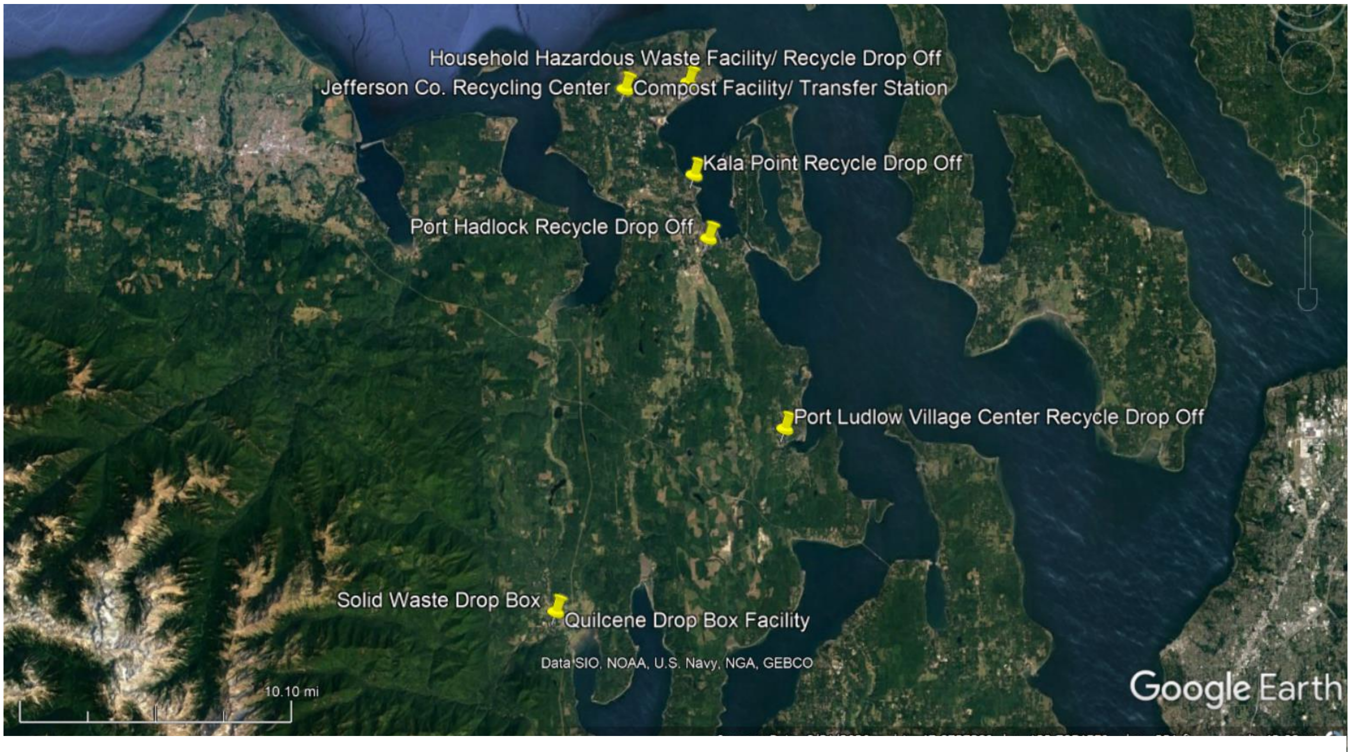


Figure 3 - Jefferson County Facilities Overview

2.1.1 Overview of Current Practices for Jefferson County Municipal Solid Waste and Recyclables Collection and Transfer

Municipal Solid Waste (MSW) and recyclables are collected by privatized collection companies from the source (e.g. curbside residential or commercial pickup) and deposited at the Jefferson County Transfer Station. Residents and business operations can also self-deposit waste and recyclables at the County's drop off facilities. Self-hauled recyclables are currently accepted at the six drop locations for free, while other wastes are accepted based on a published fee schedule. The facilities listed above are operated and maintained via tip fees and a small allocation of grants from the Washington Department of Ecology (WA DOE).

Non-recycled waste disposed through the County's waste transfer system is packed into trans modal containers in Renton and shipped to Roosevelt Regional Landfill located in Klickitat County; over 300 miles away. Recycled waste is currently contracted out to Skookum Contract Services. A Request for Proposal for Recycling Services was issued by Public Works on June 15, 2021 for a revised contract and/or contractor. Skookum currently manages the collection of all recyclables from the drop off locations, sorting, consolidating, and transfer out of Jefferson County. An illustration of the current curbside collected recyclables is shown below (**Error! Reference source not found.**).

Figure 4 - Jefferson County Recycling Flyer (Works, 2021)

Plastics are currently comingled with tin and aluminum products. This is referred to as TAP (Tin, Aluminum, Plastics) and tracked/managed as such by Skookum. The plastic portion of the TAP primarily consists of plastics types #1, #2, and #5. The TAP is currently consolidated into 2.5 ft by 5 ft bales with an average weight of 1,200 lbs., which are then trucked to Pioneer Recycling Services' Material Recovery Facility (MRF) located in Tacoma, WA. The TAP is further sorted and sold to external buyers. The revenue from the TAP sales, as reported by Jefferson County, has been variable over the past three years: $51K in 2018, $15K in 2019, and $23K in 2020.

The following charts (**Figure 5**) illustrate the total tonnages of Solid Waste and Recyclables collected annually from 2018 through April of 2021 as provided by Jefferson County Department of Public Works.

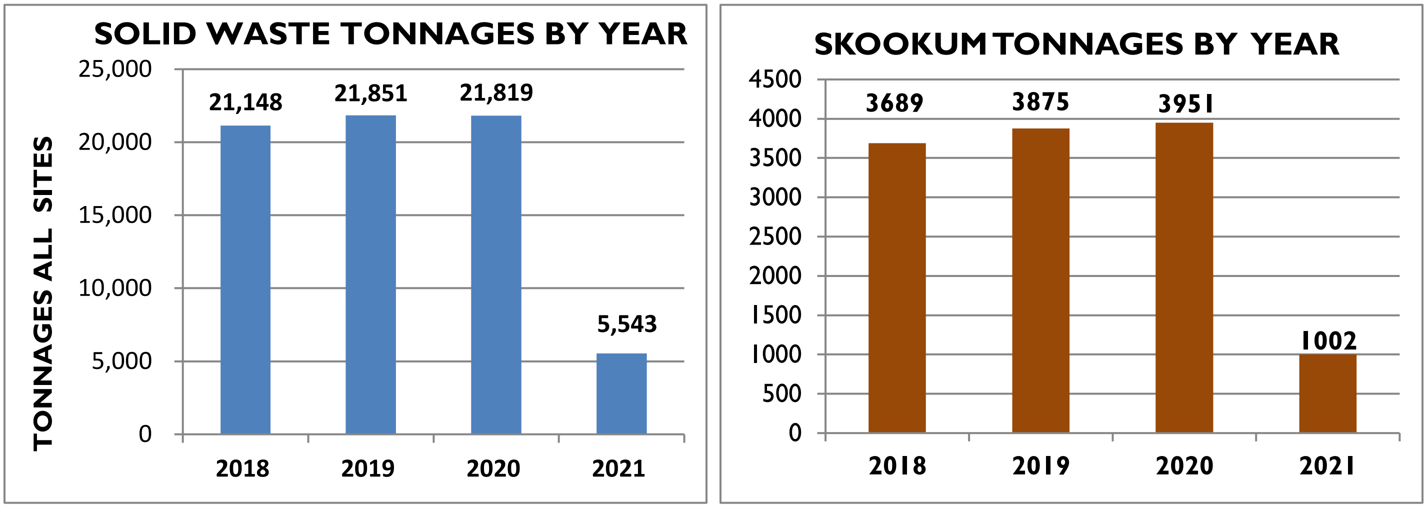


Figure 5 - Jefferson County Solid Waste and Recycling

The TAP portion of the "Skookum Tonnages By Year" is approximately 400-470 tons/year. It is estimated that the plastic portion of the TAP ranges between 100-120 tons annually.

2.1.2 Jefferson County Potential Future Recycling Practices

Tetra Tech has been made aware by Public Works that Jefferson County is considering discontinuation of plastic collection as part of the recycling program and launch an education campaign to help customers reduce their consumption of single-use plastics.

Further, Public Works, noted that drop box recyclables have high contamination rates (up to 30%) mostly stemming from the plastics, which may further incentivize the discontinuation of plastic collection as part of the recycling program.

2.1.3 Jefferson County Plastic Waste Characterization

The State of Washington Department of Ecology and Cascadia Consulting Group completed a statewide waste characterization study in 2015-2016 and was updated in 2018. In this study the detailed composition of waste disposed was determined and reported. The characterization of Plastic Waste by Type for Washington's "West" region, which includes Clallam, Jefferson, Mason, Grays Harbor, and Pacific Counties, is presented in **Figure 7**. The definition of the different plastic waste categories and examples of the types of products within each category is presented in **Error! Reference source not found.**.

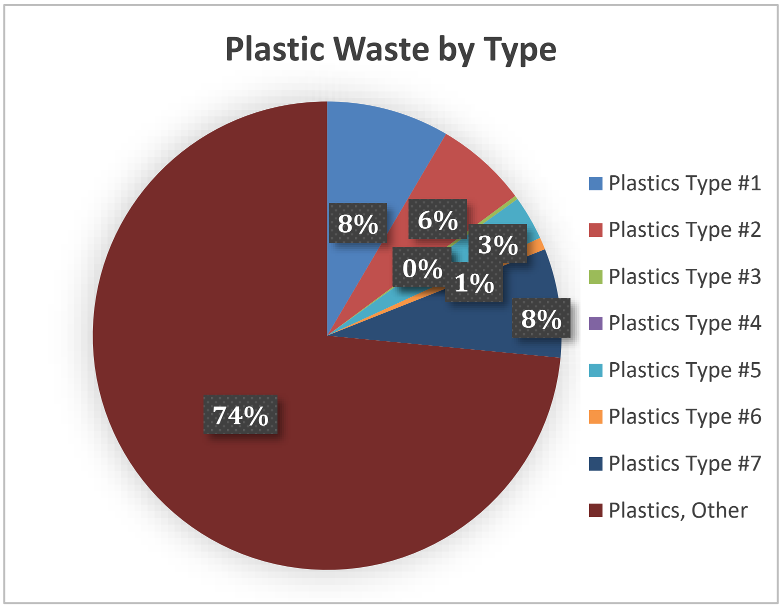


Figure 7 - Washington West Region Plastic Waste Characterization (Group, 2018)

1 PETE	2 HDPE	3 PVC	4 LDPE	5 PP	6 PS	7 OTHER	OTHER PLASTIC
Polyethylene terephthalate	High-density polyethylene	Polyvinyl chloride	Low-density polyethylene	Polypropylene	Polystyrene	Other plastics including, acrylic, polycarbonate, polyactic fibers, nylon, fiberglass	Other non-marked plastic products
Plastic drink bottles, fruit juice containers, cooking oil bottles	Milk jugs, dairy containers, water jugs, shampoo and washing soap containers	Trays for fruit and sweets, plastic packing (bubble foil) and food foils, some shower curtains & toys	Plastic bottles and containers, shopping bags, highly resistant sacks and wrappings	Plastic packaging, straws, reusable food containers	Rigid packaging, CD cases, vending cups, toys, plastic tableware	Baby bottles, toys, household products, durable plastic products	non-numbered plastic products such as toys, reusable containers, furniture, etc.

Figure 6 - Plastic Recycling Numbering System Definition

For the purpose of understanding the potential quantity of waste plastic available by plastic type, Tetra Tech has assumed that the characterization of the waste in Jefferson County is similar to the characterization of waste for Washington's West Region as defined in the Waste Characterization Study. Therefore, the estimated plastic waste generated in Jefferson County in 2020 is presented in **Table 1**.

Table 1 - Jefferson County 2020 Estimated Plastic Waste by Type

Waste Type	% of Total Waste Stream	2020 Tonnage (Estimated)
Solid Waste	**100%**	21,819*
Plastic Waste	**10.0%**	2,171
#1	***0.8%***	*184*
#2	***0.6%***	*138*
#3	***0.0%***	*6*
#4	***0.0%***	*0*
#5	***0.3%***	*66*
#6	***0.1%***	*18*
#7	***0.7%***	*163*
Other	***7.3%***	*1,596*

Note: *Solid Waste tonnage is reported value from Jefferson County Department of Public Works

The total value of Plastics #1, #2, and #5 based on this estimation is approximately 388 tons. If by estimation 120 tons of this type of plastic was collected in the TAP in 2020, then only 30% of this total waste stream was collected via the recycling program.

For this feasibility study, the plastic waste for feedstock only considers Types #1-7, excluding #3. Other plastic that is not categorized by recycling number or is not recycled as noted were not included in the following feedstock projections.

2.3 POTENTIAL AVAILABLE FEEDSTOCK PROJECTIONS

The projected population and potential generation of MSW are expected to steadily increase over the next 20 years. **Error! Reference source not found.** depicts the historic and projected population growth and MSW generation of Jefferson County. Through the trend over the last 10 years of recorded population status for Jefferson County, it is predicted that the population with continue to increase at a steady 1.0% increase of the next 20 years and will directly coordinate with the projected increase of MSW following consumption and disposal trends. The MSW generation assumes approximately 0.7 tons/year per capita based on historic data and studies (Group, 2018). Along with the increased MSW production lies the significant chance of increase in recycled plastic disposal and collection as well. However, this may be impacted by local, state and federal policies that focus on reduction and/or elimination of single use plastic production and consumption. Therefore, Tetra Tech has provided two projections: (1) assuming no change in single-use plastic habits, and (2) assuming a steady decline in single-use plastic habits (types #1, #2, and #5).

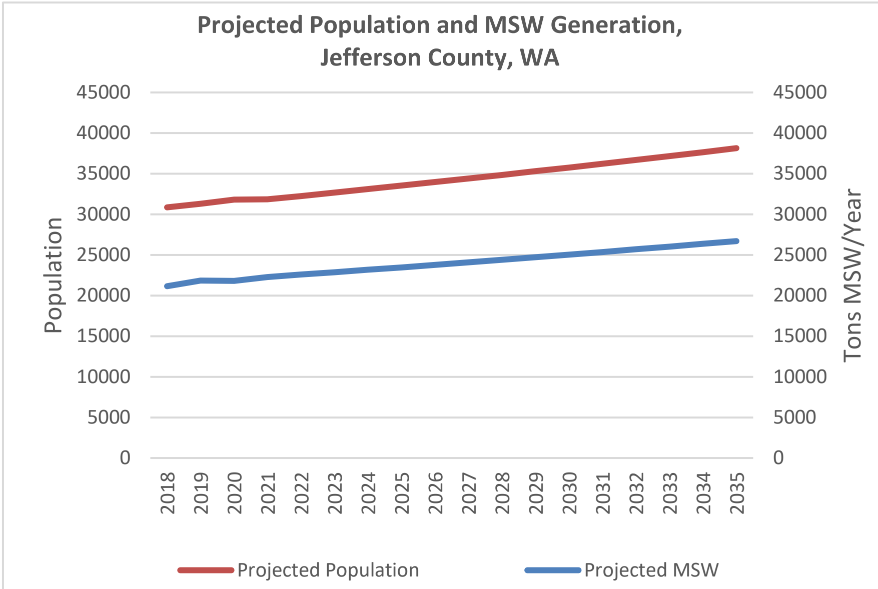


Figure 9 - Population and MSW Generation

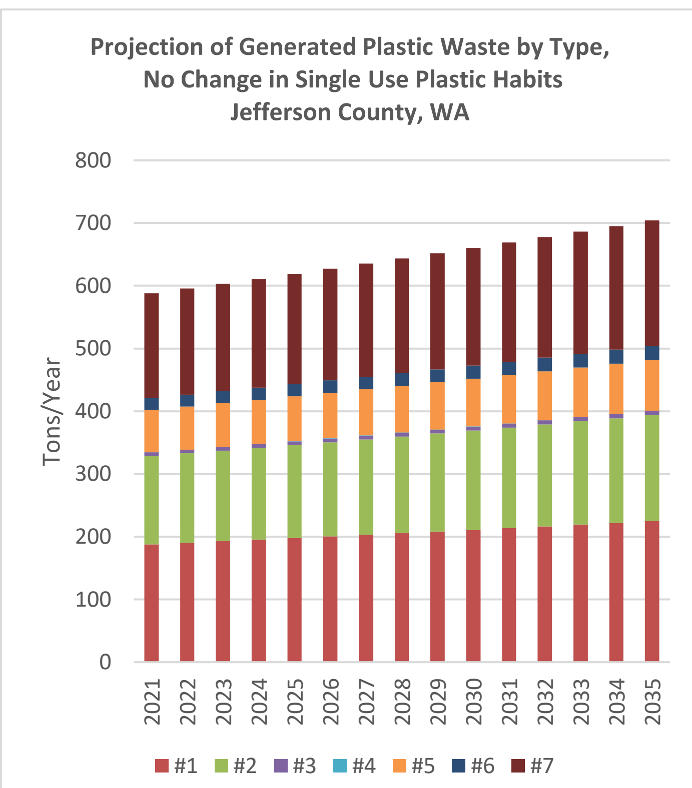


Figure 10 - Plastic Waste Generation, No Change in Habits

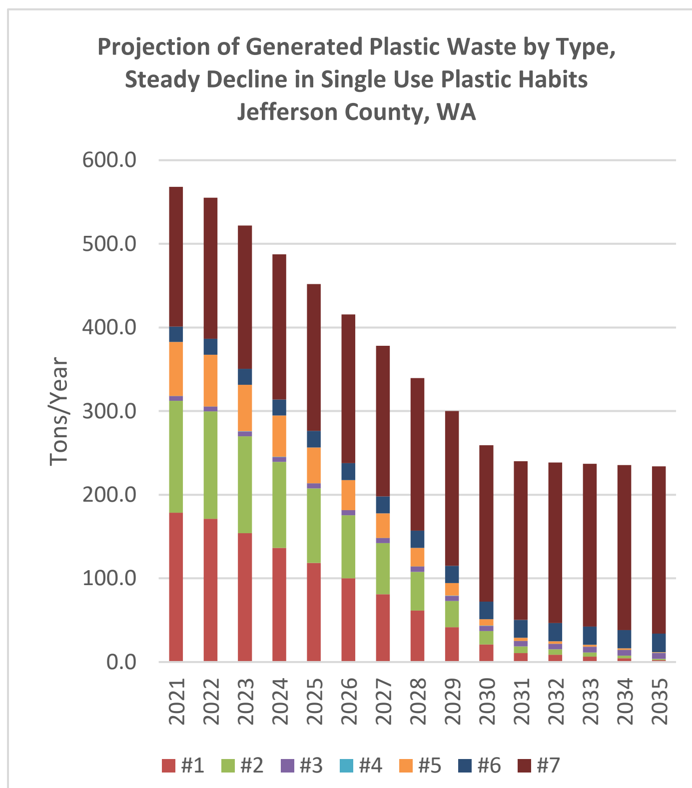


Figure 8 - Plastic Waste Generation, Decline in Single Use Plastic Habits

Based on the projections presented above the total potential feedstock available (plastics types #1-7, excluding #3) may range to be as high as 700 tons/year and as low as 230 tons/year.

2.3 PYROLYSIS SCENARIO FEEDSTOCK ASSUMPTIONS

Based on discussions with Public Works, Tetra Tech understands that the following limitations may impact the feasibility of sourcing the feedstock within Jefferson County:

- Curbside services within the City of Port Townsend is currently a three-bin system which is contracted. It is unlikely that the provider would provide a separate bin for plastics.
- Curbside services for unincorporated Jefferson County are by subscription with a private sector hauler. This hauler is unlikely to adjust service to provide a separate bin for plastics.
- Drop box services have high contamination rates (up to 30%) mostly stemming from plastics.
- Public Works is not presently interested in financing or siting on County property a MRF to separate plastics from MSW
- As state and federal legislative action is trending towards reducing the production and consumption of single use plastics, Jefferson County has been considering discontinuation of plastic collection as part of its services

Understanding the above limitations, the following options may need to be considered to make feedstock available:

- Locate the plant near the existing MRF in Tacoma and source material for fee from Pioneer Recycling Services. This could provide greater economy as a larger and more efficient system may be able to be employed; however, the amount of feedstock available and the costs associated with sourcing material has not been determined as it was outside of the scope/parameters of the study.
- Engage a private sector hauler to collect plastic feedstock directly from residential and commercial customers. This would be by subscription and/or contract for commercial customers. This scenario would likely add more truck traffic within Jefferson County, which Tetra Tech understands is not favored by residents.

For a pyrolysis project to be considered without employing an MRF source separation must occur. For the purpose of this study, Tetra Tech assumes that either an additional bin is added to current curbside services to stop comingling of tin, aluminum and plastic and drop off recycling is also separated accordingly OR a privatized subscription/contract service is employed to source feedstock directly from residents and commercial businesses and these services are discontinued by Public Works.

From the feedstock projections provided in section 2.3, the maximum potential feedstock available is up to ~700 tons/year and the minimum potential feedstock available is ~230 tons/year. It is unlikely that all of the potential feedstock available will be able to be sourced. It is estimated that only 30% of all currently collected recyclable plastics (#1, 2, & 5) are captured through the existing systems. Since the pyrolysis process will accept a wider range of plastics and will not require separation into individual types, Tetra Tech will assume that capture rate will improve to 75%. Therefore, Tetra Tech will consider a minimum pyrolysis system size of 200 tons/year and a maximum system size of 500 tons/year.

3.0 PRETREATMENT SYSTEM

As part of this feasibility study, Tetra Tech assessed the feedstock and determined the degree of pretreatment required to support an effective waste conversion system. Based upon this assessment, Tetra Tech contacted pretreatment technology providers to conceptually develop and size a suitable pretreatment process train. This section provides an overview of pretreatment processes, summary of vendor discussions, and the development of conceptual block flow diagram and system requirements based on the proposed feedstock scenario.

4.1 PRETREATMENT OVERVIEW

For all waste conversion technologies to be effective, feedstock requires pretreatment to ensure effective conversion. The amount and type of pretreatment is determined by the operating requirements of the conversation technology. In the context of MSW handling, pretreatment includes sorting, separation, size reduction, drying, or conveying necessary to prepare the collected waste streams for subsequent conversion. The goal of pretreatment is to concentrate the valuable feedstock that can be converted and separate it from inert material or other contaminants that cannot be converted. Complex multi-step pretreatment is required to separate comingled or non-source separated waste streams using various technologies depending on the desired end-uses of the separated streams. Source separated waste streams refers to separation and segregation of waste by the generator. This is the most cost-effective means of sorting because the waste is separated at origination. While effective, typically source separated waste still requires some pre-treatment as it will inevitably contain a degree of contaminants and may require some preparation for downstream processing. Pretreatment for non-source separated and source separated waste streams is described further in the following sections.

4.2 NON-SOURCE SEPARATED PRETREATMENT

MSW not separated at the source (i.e., household) requires segregation prior to waste conversion. This often occurs at a waste transfer point or immediately before a waste conversion facility. Post-consumer refuse separation occurs in a MRF. This is commonly referred to as a mixed waste MRF. There are several factors that are used to determine the effectiveness of mixed waste MRFs. The primary question is whether a community uses these mixed waste MRFs as its primary form of recycling and waste diversion or as a supplemental step to take out the remaining recyclable and divertible materials before the residuals or garbage stream is disposed. In the case of Jefferson County, source separation occurs voluntarily and is already capturing approximately 20% of the total usable plastic waste stream. It has also been expressed by Public Works that this type of facility is not desired. Therefore, it has been assumed that an MRF will not be considered for separation.

The principles of recycling and organic waste diversion are imbedded in the community. In communities where recycling and organic waste diversion are not imbedded a mixed waste MRF would be used to enhance waste diversion for those who choose not to divert waste. The target waste stream is the disposal/garbage stream and the objective is to reduce the amount of material requiring disposal, increase the amount of recyclables, and utilize the organics for energy generation, thereby diverting material from the landfill.

Mixed waste MRFs typically consist of conveyor systems, bag splitters, screens and/or trommels to separate the waste into different size fractions. The waste stream then travels through a series of magnets, eddy current separators, air classifiers and hand sorters to divide the waste stream into the required constituent streams. **Figure 11** illustrates the various components and stages in a mixed waste MRF. The mixed waste MRF process does not produce the same quality of commodities as a “clean MRF” because of contamination from compostable materials (food waste and liquids). A “clean MRF” generally refers to a facility that already has compostable organics removed and therefore separation of materials results in better efficiency. The market value for commodities from a mixed waste MRF is typically less than that of a clean MRF.

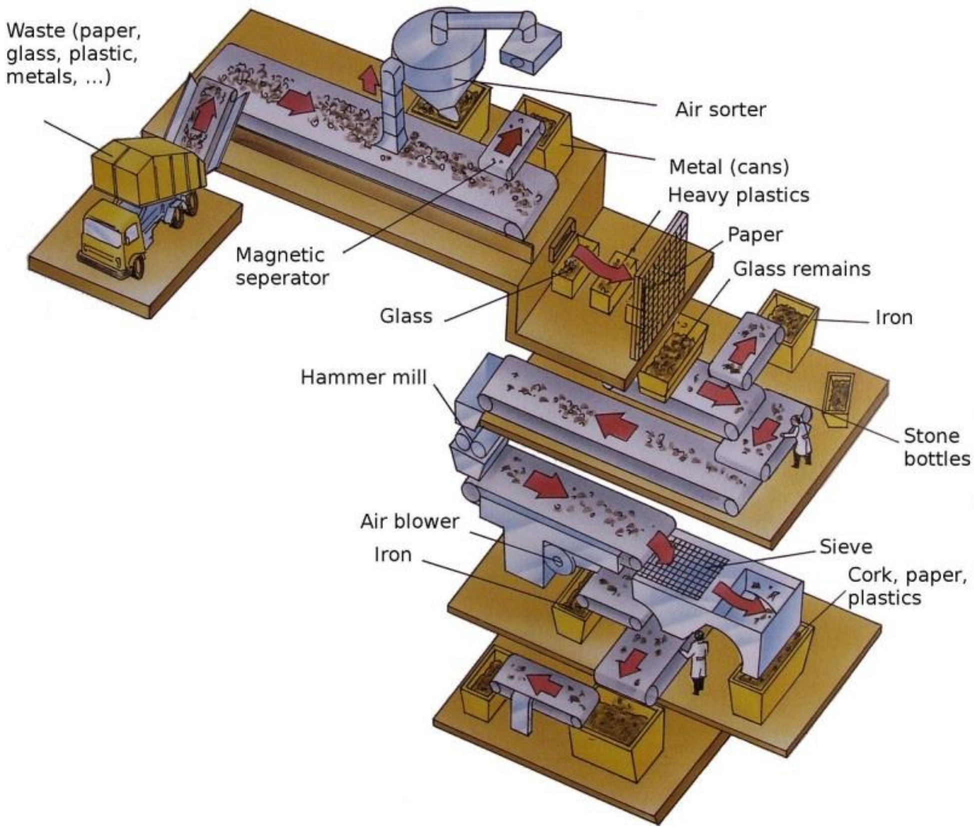


Figure 11 - MRF Schematic

Source: Based on "Energie en grondstoffen in de toekomst" by Robbin Kerrod

The majority of MRF's, even in large metropolitan areas, are effectively operated with a combination of mechanical and manual sorting, with employees separating various contaminants and other recyclable materials from the waste stream. Although an MRF is not being considered as part of the pretreatment train, a manual sorting step is recommended and included in our proposed process train.

4.3 SOURCE SEPARATED PRETREATMENT

As previously stated, Tetra Tech assumes that the material will be source separated and an MRF will not be considered as part of the pretreatment requirements for the defined scenario. Tetra Tech worked with providers of solid waste handling technology and infrastructure in parallel with the pyrolysis technology suppliers to develop a general definition of the feedstock pretreatment required to implement a plastics-to-pyrolysis project.

The exact feedstock specifications and resulting additional pre-treatment required, including feedstock particle size, bulk density, moisture content, and non-plastic material content will need to be refined as the preferred pyrolysis technology vendor and uses of the pyrolysis products are further developed for this project.

Tetra Tech prepared the following block flow diagram representing the minimum feedstock pretreatment anticipated to be required as part of the plastics pyrolysis project.

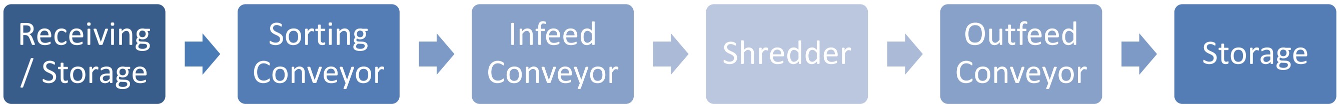


Figure 12 - Pre-Processing Block Flow

It was determined that the plastics will likely, at a minimum, be received, unloaded, and stored for a brief period before being manually sorted and then mechanically shredded to a particle size of 2" or smaller. Shredding of the feedstock provides a more homogenized and easily handled material stream going into the pyrolysis process, as well as allows for some drying and liquids removal. The shredded material must then be staged and stored before being transferred to the pyrolysis process.

It was also recommended by the shredding technology vendors that a manual sorting conveyor be included as part of the shredder infeed equipment to remove contaminated materials and any other non-plastic materials that may cause damage or downtime to the shredding equipment. As an alternative, if inclusion of manual sorting is not preferrable, a larger more robust, and more easily repaired shredder could be installed to account for the occasional damage and downtime caused by extraneous non-plastic items.

3.3.1 Pretreatment Vendors

Vecoplan LLC of Archdale, NC (Vecoplan), was the most responsive pretreatment technology vendor. Vecoplan specializes in industrial shredding equipment and systems for the plastics, paper, wood, and waste industries and claims experience providing equipment to several plastics pyrolysis projects.

Tetra Tech also contacted Machinex Industries, Inc. of Plessisville, Quebec, Canada (Machinex) and Bulk Handling Systems of Eugene, OR (BHS). Machinex provides sorting, waste management, and recycling machinery specifically for the recycling and solid waste industries. Machinex initially expressed interest in this project, however, later declined to participate in the feasibility study due to the scale of the project and lack of demand for high-end sorting technology. BHS provides processing technology and systems to extract recyclables from a composite solid waste stream. No response was received from BHS regarding participation in this feasibility study.

3.3.2 Pretreatment System Sizing

For the approximate project throughput range of 200-500 tons per year of waste plastics, Vecoplan recommended either their 60-horsepower model VAZ1100XL shredder with a throughput capacity of 500-1000 pounds per hour ($85k), or their 125-horsepower model VAZ1300M shredder with a throughput capacity of 1500-2000 lbs/hr ($150k), depending on whether the manual sort conveyor is included to remove items that could damage the shredder and cause downtime. The larger VAZ1300M model is configured to replace wear components more easily and would provide excess throughput capacity to make up for downtime spent making repairs or clearing jams.

The shredding system would require infeed and outfeed belt conveyors to transfer material in and out of the shredder. Vecoplan can provide these conveyors and suggested a budgetary allowance of $25k each.

4.0 PYROLYSIS TECHNOLOGY

As part of this feasibility study, Tetra Tech screened several Pyrolysis technology providers to determine which technologies may be applicable for implementation. This section provides an overview of Pyrolysis technology, summary of vendor screening, evaluation of vendors, and the development of conceptual block flow diagram and system requirements based on the proposed feedstock scenario.

5.1 PYROLYSIS OVERVIEW

Pyrolysis is defined as the thermal breakdown of higher chain organic molecules (cracking) into smaller organic components. This thermal cracking is done in the absence of oxygen, sometimes with the addition of a catalyst.

The resulting products from the pyrolysis process are:

- Char: Consists of high carbon content solids. Also, any inorganics that might be contained in the waste stream and catalysts that were added and carried through the process.
- Non-condensable Gas: Made up of hydrogen, methane, carbon monoxide and other non-condensable gases. Can be burned similar to natural gas.
- Condensable Liquids: Sometimes referred to as Pyrolysis Oils. Made up of dozens of organic chemicals. Can be exported as-is or separated via distillation or other processing methods.

Most organic compounds can be broken down to basic components using the pyrolysis process. As a result, many experimental and pilot plant programs have been done using pyrolysis to process products such as animal offal, used tires, agricultural field residue, and manure. The process is endothermic, requiring significant support fuel to maintain the temperature for the reaction, and can be difficult to control because of variations in feed make-up. Therefore, the product quality has a tendency to be inconsistent.

Commercially, when compared to combustion processes, there have not been many successful pyrolysis ventures. Capital costs and operating costs tend to be higher than combustion projects due to the complexity of the process, varying feedstock quality, and additional processing requirements.

5.2 PYROLYSIS VENDOR SCREENING

Tetra Tech contacted the eleven (11) pyrolysis technology vendors with locations, web pages, and responses as listed in below:

Table 2 - Pyrolysis Vendor Summary

Vendor	Location	Web Page	Response	Evaluated
Agilyx	Tigard, OR	https://www.agilyx.com/	Yes	Yes
Alterra	Akron, OH	https://alterraenergy.com/	Yes	Yes
Braven Environmental	Yonkers, NY	https://bravenenvironmental.com/	No	No
Encina	The Woodlands, TX	https://www.encina.com/	No	No
Enerkem	Edmonton, AB	https://enerkem.com/	Yes	Declined
Nexus Fuels	Atlanta, GA	https://www.nexusfuels.com/	Yes	Yes
PDO Technologies	Brooks, OR	https://www.pdotech.com/	Yes	Yes
Recycling Technologies	Swindon, United Kingdom	https://recyclingtechnologies.co.uk/	Yes	Declined

ThermoChem Recovery International	Baltimore, MD	https://tri-inc.net/pyrolysis/	No	No
Weiss-Linka	Denmark	https://www.weiss2energy.eu/	No	No

No response was received from Braven Environmental, Encina, ThermoChem Recovery International, or Weiss-Linka. As such, these vendors and their technologies were not included in further components of this study.

In addition, Enerkem declined to participate further in the study with the explanation that their current target market is projects on a much larger scale (their design processes about 5 tons of feedstock per day, employs 50-80 people per facility, and has a capital cost of about $400-$500 million).

Recycling Technologies stated that they are in the process of developing their first commercial-scale plant in Scotland and will be investing in- and operating the first plants themselves. As such, they declined to participate further in the study, however, they did provide that their process is designed to process 1.1 tons per hour at 80% uptime for a total of 7,700 tons per year of dried plastic waste, with their target feedstock being polyolefins and some tolerance for PU and PET plastics. Recycling Technologies also provided the basic process flow diagram as shown in **Figure 13** indicating that they expect approximately 75% of the feedstock mass to be converted into the Plaxx pyrolysis oil product, with the remaining non-condensable gas used to provide heat to the process.

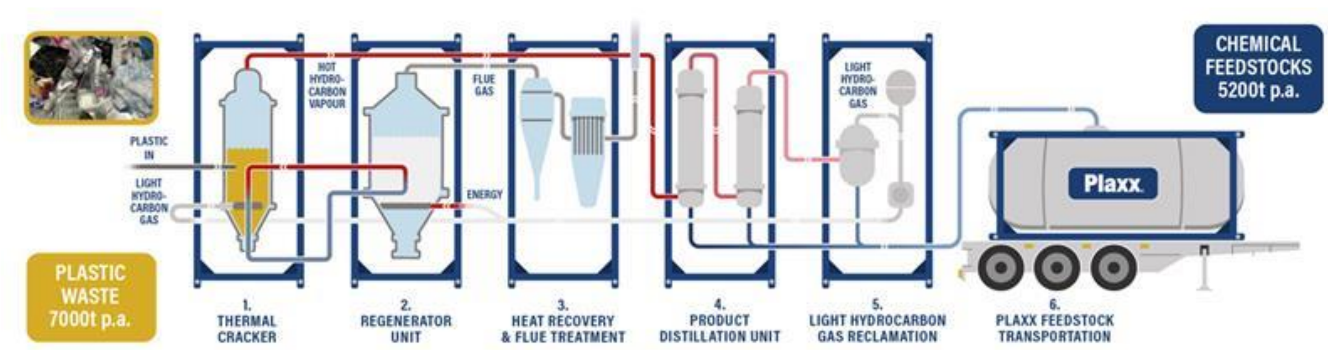


Figure 13 - Recycling Technologies Process Flow

5.3 PYROLYSIS VENDOR EVALUATION

The following is a summary of the information gathered from Tetra Tech's discussions with the following vendors: Agilyx, Alterra, Nexus Fuels, and PDO Technologies.

Table 3 - Pyrolysis Vendor Evaluation

Vendor	Summary of Technology	Suitable for Application
Agilyx	• Can use material in most forms without much sorting/shredding, PVC is not preferable but can work with some levels; sister company Cyclyx provides feedstock sorting/shredding if needed. • Continuous process flow: Prep/pre-melt > reactor > Processing and storage. Outputs can bees waxes, fuel products, plastic intermediaries.	Not a likely candidate for this project due to scale of projects and

	• Standard design 50-250 tons/day. Above 50tpd makes most economic sense. • Operates one facility in Tigard, OR focused on reclaiming polystyrene. • Cannot disclose further operational or costing information without an NDA and paid feasibility study.	expertise (50-250x the scale)
Alterra	• Visited Akron OH commercial-sized demonstration facility. • Have ran everything from pelletized mixed MSW to cleanly sorted plastics. Generally, want #2-7 with minimal #3. Equipment can handle all plastics, but feedstock impurities will impact pyrolysis oil product. Can handle PVC and PETE. Can achieve 80% Chlorine (from PVC) reduction by preprocessing Feedstock must be shredded to <1" and densified to >15 lb / cubic foot. • Continuous process flow: Preprocessing > Extruder > Kiln > Condensing Train. • Akron ran at up to 4000 lb/hr. Akron designed for 60 tpd. Standardizing design to 180 tpd (using 2 Akron-sized x 1.5 reactors). Stated that the European market is triangulating around 180-240tpd designs as they are most economical. • Currently accounting for a 2-week annual shutdown, plus 5-days of downtime per quarter, with 95% uptime during the remaining periods. • Expect a staffing level of 4-shifts, 5-people per shift. • Estimated capex of $50-60 MM all-in for 120tpd greenfield facility in OH/PA, no building or property, includes first-time engineering, 2-process trains, fully redundant. Expect $30-40MM for a 60tpd facility.	Not a likely candidate for this project due to scale of projects (50-250x the scale)
Nexus Fuels	• Has a commercial scale 50tpd plant operating in Atlanta for 3-years. • Process accepts #2, 4, 5, 6 plastics. • Process train is designed in modules with throughput capacity of 50tpd each. • Capex stated to be 25-50% of the competitors. • Cannot disclose further operational or costing information without an NDA.	Not a likely candidate for this project due to scale of projects (50-250x the scale)
PDO Technologies	• Claims to have fixed (stationary) systems in operation. Plastic Recycler facility located in Brooks, OR. • Feedstock requirements are very flexible with limited amounts of #3 plastics acceptable. Output products also have flexibility dependent upon final processing. • Semi-Batch process. Stationary system is designed for 10tpd. Also have a mobile unit designed to process 1tpd. • Designed in multiple "reactor pots", throughput is stated to be very flexible. Typical design of 4 reactor pots.	Most likely candidate for this project due to scale, flexibility of feedstock, and modular design. Warrants further discussion and investigation as/if project proceeds. Mobile unit might

	• Uptime is flexible due to multiple reactor pots (more can be added to reduce downtime). The semi-batch operation allows for a more flexible production schedule. • Staffing estimated to be ~20ppl depending on schedule. • Capex estimated to be $5-6 million for one 4-reactor process train, dependent upon end-products desired.	also be of interest as it has the ability to be transported to a particular site then relocated as needed.

Based on Tetra Tech's discussions with the Pyrolysis Technology Vendors, the most likely candidate for implementation would be PDO Technologies.

A high-level summary of PDO's stationary and mobile unit technologies is provided in below:

TECHNOLOGY INFORMATION	1-UNIT - STATIONARY	1 UNIT - MOBILE
Number of batches per Day	4 batches	3 batches
Feedstock Types	Homogenous ***or*** Heterogeneous feedstocks Best yield: #2, #4, #5, #6, some #7 Limited/no yield: #1, #3	Homogenous ***or*** Heterogeneous feedstocks Best yield: #2, #4, #5, #6, some #7 Limited/no yield: #1, #3
Feedstock preparation requirement	Separation from non target plastics <10% contaminants (dirt, metal, wood). Feedstock Densification to ≥ 20 lbs./ft3	Separation from non target plastics <10% contaminants (dirt, metal, wood). Feedstock Densification to ≥ 20 lbs./ft3
Feedstock loading	Continuous batch cartridge processing w/ganged, asynchronous processors	Continuous batch cartridge processing
Single batch size	1,250lbs.	500lbs.
Batch cycle time	5 hours, 30 minutes	3 hours, 15 minutes
Electricity consumption per batch	About 200-250 kwh	About 80-100 kwh
Burner fuel consumption per batch	About 4.1 MMBTU	About 1.7 MMBTU
% yield of plastic-to-fuel	ca. 80%	ca. 80%
Naphtha output per batch	About 50 gallons	About 20 gallons
Diesel output per batch	About 100 gallons	About 40 gallons
Char output per batch	85lbs. (energy content 8,000 BTUs/lb.)	35lbs. (energy content 8,000 BTUs/lb.)
Process emissions	Deminimus	Deminimus

Figure 14 - PDO Technologies Unit Summary

For the maximum feedstock capacity of 500 tons/year (3,500 lbs/day) a single unit stationary system would be suitable to meet the project requirements. For the minimum feedstock capacity of 200 tons/year (1,500 lbs/day) a single mobile unit would be suitable to meet the project requirements.

5.4 PYROLYSIS SYSTEM SCENARIO

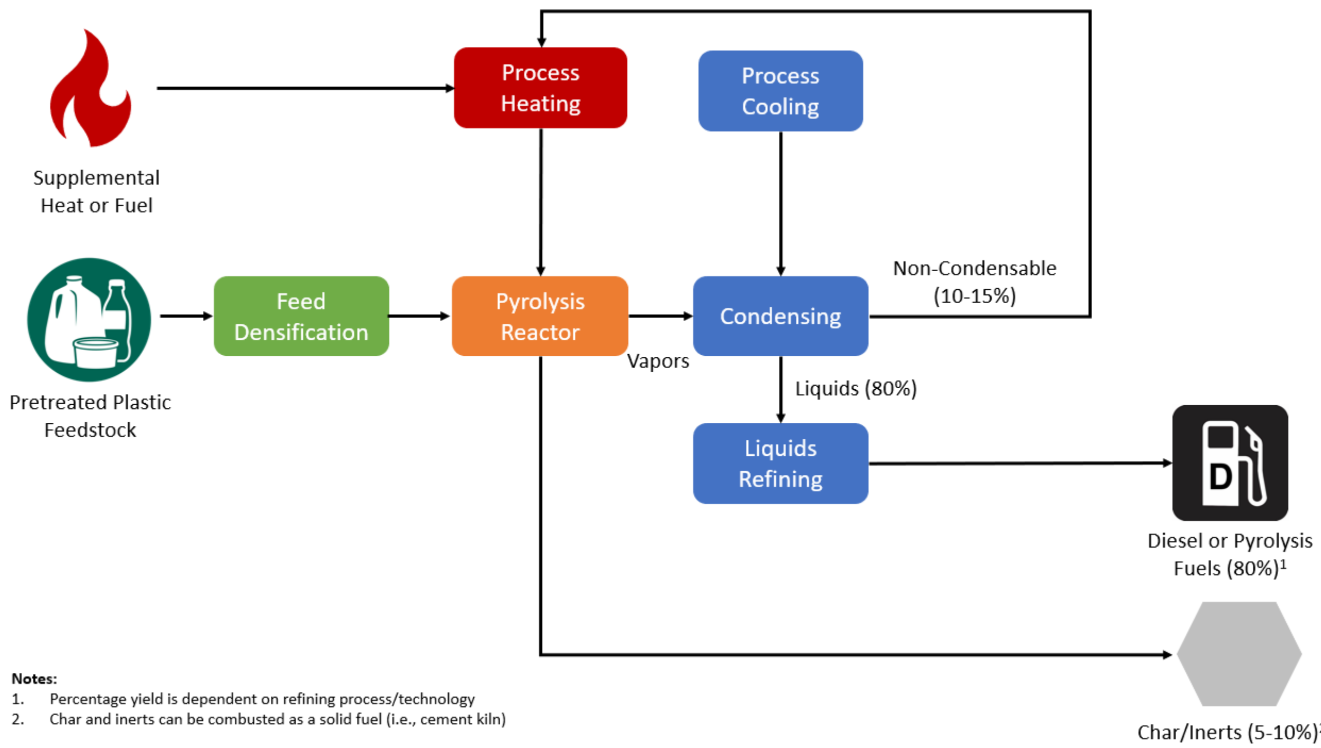
Based on the feedstock information presented in earlier sections of this report, Tetra Tech anticipates that the plastics pyrolysis project high-level system requirements will be as presented in **Table 4** below:

Table 4 - Pyrolysis System Requirements

Parameter	Requirement
Feedstock Throughput	Maximum System: 500 tons / year; 3,500 lbs/day Minimum System: 200 tons / year; 1,500 lbs/day
Operation Schedule	5 days per week (assuming batch process)
Feedstock Types	ASTM Resin Identification Code #1-7
Feedstock Contamination	Some levels as present in source-separated municipal waste
Feedstock Pre-Processing	To be defined by pyrolysis technology provider
Pyrolysis End-Products	Non-Condensable Gas, Pyrolysis Oil, Char
Project Design Life	25-years

4.4.1 System Block Flow Diagram

A typical block flow diagram for the Pyrolysis system is provided in **Figure 15**. Pretreated plastic feedstock, as described in the section "Pretreatment System" of this report, first under goes a densification process prior to entering into the Pyrolysis Reactor. In the case of PDO's technology, the plastic is densified and added into a load cartridge which is feed into their Thermal Processing System, e.g. reactor, in batches. A thermal heat source is applied to the Thermal Processing System, this heat is absorbed by the plastic, which melts and eventually cracks into smaller molecular fragments. Char and inerts are the solid product of this reaction and a gaseous vapor stream is produced. The resulting vapor stream undergoes a condensing process which may utilize a catalyst to assist in



Notes:
1. Percentage yield is dependent on refining process/technology
2. Char and inerts can be combusted as a solid fuel (i.e., cement kiln)

Figure 15 - Pyrolysis System Block Flow Diagram

condensing the vapors into liquids and non-condensable light gases. The lights gases are recycled back to the process heater, while the liquids are further refined into the desired pyrolytic fuel (e.g., Diesel, Naptha, etc.).

4.4.2 Pyrolysis System Site Requirements

Assuming the selected system is PDO Technologies, for a single stationary unit, the following site requirements are needed:

- 3,500 square feet of building space for 1 unit, cleaning and cartridge filling areas
- 2,500 square feet of building space for pretreatment of plastics
- 3,000 square feet for utilities
- 24 feet of clearing height for crane operation
- 480-volt, 3-phase power
- Natural gas connection or 5,000-gallon propane tank
  - 1,250 lb load requires 4.13 MMBTU or ~45 gallons of propane without light gas recycling and 2.9 MMBTU or 32 gallons of propane with light gas recycling

For a PDO Technologies, the real-estate required can be reduced by approximately 20%.

5.0 PYROLYSIS OFF-GAS UTILIZATION

Based on input from the pyrolysis vendors and previous project experience, Tetra Tech anticipates that approximately 60-80% of the feedstock will be converted to pyrolysis oils, 10-20% will be converted to non-condensable gases, and 10-20% will be converted to char. This is reflected in **Table 5** below. These values are approximate and will be refined by the pyrolysis technology vendors as the details regarding the composition and purity of the plastic feedstocks, pyrolysis process selected, and desired end product uses are developed as part of the project. At this stage of the project, the heat required to support the pyrolysis process cannot be quantified as this is highly dependent on the feedstock composition, specific pyrolysis technology, and desired end-products and their uses.

Table 5 - Preliminary Material Balance

Category	Inputs	Outputs
Unit	Tons / Year	Tons / Year
Waste Plastics	Maximum - 500 Minimum - 200	
Pyrolysis Oils		Maximum: 300 – 400 Minimum: 120 - 160
Non-Condensable Gases		Maximum: 50– 100 Minimum: 20 - 40
Char		Maximum: 50 – 100 Minimum: 20 - 40
Total	**Maximum - 500**	**Maximum - 500**

	Minimum - 200	Minimum - 200

Power generation via combined heat and power (CHP) methods are not suitable for consideration based on the employable technologies for this project. For example, PDO Technologies is a batch process, meaning that the pyrolysis products including the non-condensable gases, the potential fuel source for CHP generation, will not be produced on a continuous basis. Non-continuous processes are not ideal for CHP projects as the fuel would need to be stored during the time between batches, or the generator would need to be operated on a periodic basis. In order to store the non-condensable gases, they would need to be compressed and contained in a pressure vessel, which is both capital and operating cost intensive. Operation of a gas-fired CHP generator on a periodic basis is possible but not advisable as the electric power interconnection and the thermal energy users would need to be set up to receive energy on a start-stop basis. In addition, frequent startup and shutdown of the generator system would lead to premature failure of the equipment. Moreover, PDO Technologies has specifically designed their system to recycle the non-condensable gases to provide an offset to the thermal heat load required in the reactor process.

7.1 PYROLYSIS PRODUCTS

The composition and characteristics of the products of the Pyrolysis process are highly dependent on both the feedstock composition and the pyrolysis technology employed. Due to the emerging and rapidly evolving nature of the industry, the diverse and proprietary nature of the technologies, and the widely variable feedstock possibilities, published literature values for the expected composition and characteristics of pyrolysis products from source separated plastics from municipal solid waste are generally unavailable. Confirmation of the product quantities and compositions for a particular pyrolysis project is only possible via pilot-scale testing of the specific feedstock and technology selected for the project. This section presents general information on the potential pyrolysis products from the feedstock identified for this project.

Pyrolysis Oil

The condensed liquids, or pyrolysis oil, can be transported to a refinery as it is produced with minimal processing. Typically, some particle filtration is required to remove fine char particles. This product is sometimes called "Syn-Crude" and can be used as a supplement for crude oil. The pyrolysis oil must be stored and transported at higher temperatures (greater than about 150°F) for flowability as it does typically contain heavier hydrocarbons similar to what would be recovered as vacuum residual product in a conventional refinery.

Alternatively, pyrolysis oil can be distilled on-site and separated into various cuts that may include those listed below, depending on the specific distillation (i.e. atmospheric or vacuum) and/or separation technology employed. This technology and the resulting cuts are typically selected based on the most economical demand for the pyrolysis oil products in the local market and the buyer's specifications:

a. Waxes and heavy hydrocarbons with pour points greater than about 150°F.

b. Diesel and gasoline fuel blend stocks with pour/cloud points and density similar to conventional off-road diesel. The distillation characteristics including boiling range and volatility are a product of the specific distillation technology employed and can be tailored accordingly. Typically, these products contain sulfur and other contaminants such as chlorine in higher concentrations than is allowed in on-road fuels and as such, they are not suitable for direct drop-in replacements for on-road diesel or gasoline without further processing and refinement.

c. Naptha products with pour/cloud points and boiling range characteristics similar to the light and heavy naptha produced in a conventional refinery. Generally, these cuts are sold into the petrochemical market for blending with conventional petroleum prior to further upgrading via isomerization or catalytic reforming.

Pyrolysis oil generally is highly odorous and contains compounds that are volatile under atmospheric conditions. Depending on the scale of the project, the location of the facility, the volume of the liquid storage vessels required, and the location-specific environmental permitting requirements - odor control, vapor recovery, and/or vent gas treatment may be required.

Non-Condensable Gases

The non-condensable gases (NCG) typically contain a mixture including butane, propane, methane, ethane, and a small amount of hydrogen with a higher heating value in the range of 1,200 – 1,500 Btu per Standard Cubic Foot. The NCG can be combusted on site to provide heat to the pyrolysis process or to provide electricity to the pyrolysis process or for export. As discussed in previous sections, the PDO technology utilizes the NCG to provide heat to the pyrolysis process. Care must be taken in materials and process selection during the pilot and design phases of a project to account for constituents of the feedstock such as chlorine or sulfur that can produce corrosive compounds in the NCG.

Char

The residual solids or char typically requires processing including particle size reduction, metal removal, and densification or packaging in bulk bags or containers to facilitate handling and transportation. Depending on the local market and demand, the char can be further refined and marketed as a Carbon Black substitute or other manufacturing constituent, it can be sold and used as a solid fuel supplement to operations such as a solid-fuel boilers or cement kilns, or it can be disposed of as a solid waste product. Considerations must be taken in the char handling and processing technology to account for dust collection and fire protection.

6.0 EXISTING PYROLYSIS SYSTEMS EVALUATION

To accurately portray the reality of installing and operating a pyrolysis system as a viable option for recycled plastic disposal, Tetra Tech has visited and interviewed an existing and functioning pyrolysis plant of one of the vendors evaluated during the screening process. This allowed insight into the potential benefits and roadblocks that could be experienced with the maintenance and operation of a pyrolysis plant.

As previously discussed, the composition of the feedstock and its pretreatment play an important role in the products received. Within the feedstock certain plastic categories and items need to be minimized to prevent damage to the system and spoiling the product for future consumption. Category #3 plastics tend to be minimized due to the chlorine content and the release of such content during the process. Even looking aside the hazardous and corrosive properties of chlorine, it will cause the syn-gas end product to become unusable for combustion and increase the chances of an air permit issue as chlorine (and many associated compounds) are listed as Hazardous Air Pollutants. Similar to the same way category #3 plastics cause damage to the syn-gas, other recycled items such as chip or snack bags are also to be limited since there is a presence of silicon between the layers which could cause issues in the later processing of the syn-crude product. Testing and knowledge of the feedstock greatly aid in the predictability of the product composition and potential usage. Additional costs for feedstock may be added if a pure plastic additive will need to be used to “dilute” the impurities caused by the gathered feedstock. As well the pretreatment of the feedstock also plays a role in the size of feedstock chips and the temperatures prior to and entering the reactor to ensure the best product yield. Consultation with the vendor on recommended temperatures will be important along with proper temperature instrumentation will need to be purchased and installed along the process.

As temperature is important with the feedstock and pyrolysis, it will also play a role with the products. Syn-crude by nature has a waxy texture that will need to be maintained at certain temperature to prevent and line clogging and build up potentially causing a disruption to production. Heat tracing and heat-controlled storage will be additional costs as the Port experiences winter conditions.

The final insight into potential additional maintenance costs lie in any additional separation equipment for the product, specifically for the syn-crude and char. Depending on the syn-crude product intended use, further separation of the syn-crude and char may be needed which will entail additional equipment and maintenance as the initial separation process will not remove all char from the syn-crude. This may pose a maintenance and cost issue for the device directly combusting the syn-crude and potential buildup within any storage tanks and trucks.

In summary, the additional costs could potentially lie in the feedstock and product handling. Preventative measures in composition and care aid to increase the predictability of the process and thereby decreasing the potential for additional costs.

7.0 PERMITTING ASSESSMENT

Tetra Tech has completed preliminary research based on the project information provided by the Port along with the initial assessment in order to complete the proposed matrix. In person or virtual meetings may be required with the agencies once a decision and additional information is provided from the Port. The following matrix has been prepared based upon previous experience with various federal, state, and local permits for similar complex projects. This following outline is not comprehensive project-specific view of all the permitting required, rather it is shared as a guide for the Port of Port Townsend on the permitting efforts typically required. The applicable permitting is highly dependent on the specific technology selected (including feedstocks processed and products created) and the specific location of the site. As a site has not been selected, nor the quality and characterization of the feedstock been thoroughly analyzed and therefore the specific design of the employed technology has not been developed, the project-specific permitting and project specific permitting issues cannot be determined at this phase.

Specific to PDO Technologies, they have indicated that air emissions are deminimus for both their stationary and mobile units. Requirements for emergency flare or thermal oxidizer cannot be determined at this phase and would require further investigation in later development phases of a project.

Tetra Tech understands that projects of this nature can also be sensitive or in favorable in certain localities. It was not in the scope of this feasibility study to gauge the acceptance of such a project by the potentially affected communities; however, it should be appreciated that sensitivity to this type of project may affect approval of land development permits.

In a future phase of development, the list of permits below will be reviewed against the available project information to assess applicability and provide a preliminary determination of which specific permits will be needed. Permit turnaround time varies by agency and if any meetings are required previous to any submittals.

Federal Permits

Permit	Authority	Triggers/Notes
Coastal Zone Management (CZM) Federal Consistency	State of Washington - Department of Ecology	Federal agency activities and developments and projects requiring a federal license or permit, and which are proposed within any of Washington's 15 coastal counties (including Jefferson County). This is expected to be done State of Washington as the issuing authority.
Discharge of Dredge or Fill Material into Water – US Army Corp of Engineers (USACE) – Section 404 Nationwide Permit	USACE	If you plan to conduct ground-disturbing activities in waters of the US, including wetlands, you may need authorization from the USACE. A variety of activities typically require Department of the Army authorization when they occur in waters of the United States. They include, but are not limited to, placement of fill material,

		grading, mechanized land clearing, and redeposit of excavated/dredged material.
Section 7 Consultation under the Endangered Species Act (ESA) – Terrestrial Species	U.S. Fish and Wildlife Service (USFWS)	Disturbance of land managed by a federal agency or other; federal permit or approval required.
Section 7 Consultation under the Endangered Species Act (ESA) – Marine Species	National Oceanic and Atmospheric Administration (NOAA)	Project construction may disturb marine species (mammals, fish, invertebrates) species listed under the Endangered Species Act or their habitat.
Marine Mammal Protection Act Incidental Take Authorization or Letter of Authorization	US FWS	Project construction and operation may harm, harass, or kill marine mammals.
Fishery Conservation and Management Act (Magnuson-Stevens Act)	NOAA	If the Project is located within Essential Fish Habitat (EFH) for commercially important species, NOAA must evaluate whether Project construction and operation may adversely affect EFH.
Section 106 Consultation under the National Historic Preservation Act (NHPA)	Washington Department of Archaeology and Historic Preservation (DAHP)	Disturbance of land managed by a federal agency; federal permit or approval required.
Consultation and due diligence under the Migratory Bird Treaty Act (MBTA) and the Bald and Golden Eagle Protection Act (BGEPA)	USFWS	Potential impacts to migratory birds and eagles.
Section 10 of the Rivers and Harbors Act of 1899	USACE	Placement/removal of structures, work involving dredging, disposal of dredged material, filling, excavation, or any other disturbance of soils/sediments or modification of a navigable waterway.
Private Aids to Navigation (PATON) Review	U.S. Coast Guard	If the pier is located in federally recognized navigable waters and is not directly managed by the state, modifications to lighting, buoys, and other features could require this permit.
Spill Prevention, Control, and Counter-measure (SPCC) Plan	U.S. Environmental Protection Agency (EPA)	Exceedance of aggregate aboveground storage capacity of 1,320 gallons or a completely buried storage capacity greater than 42,000 gallons; required in conjunction with other permits or plans.

State Permits

Permit	Authority	Assumptions/Notes
Construction Stormwater General Permit – NPDES (National Pollutant Discharge Elimination System	State of Washington - Department of Ecology	Construction site operators are required to be covered by a Construction Stormwater General Permit if they are engaged in clearing, grading, and excavating activities that disturb one or more acres and discharge stormwater to surface waters of the state.
Clean Air Act, Prevention of Significant Deterioration Review (if over PSD threshold for CO2e or other pollutants; otherwise, New Source Review	Olympic Region Clean Air Agency	If Project equipment (fire-pump, emergency generators, etc.) emits greenhouse gases and criteria pollutants, this permit may be required. The Clean Air Act (42 USC 7401) requires that EPA review new emissions sources with a potential to emit quantities of criteria pollutants greater than certain standards.
CWA Section 401 Water Quality Certification	State of WA– Department of Ecology	Project construction will alter drainage in existing drainage channels that may be considered waters of the US.
Hydraulic Project Approval	Washington Department of Fish and Wildlife	Pier modification may involve disturbance of the sea floor that could affect fish and shellfish.
Electrical Work Permit	State of Washington - Department of Labor and Industries	Any electrical installation or alteration described in RCW 19.28.101 and WAC 296-46B-901.
Drinking Water Operating Permit	State of Washington - Department of Health	Operating a public water system that has 15 or more services or serves more than 25 people a day for more than 60 days a year.
Water Right	State of Washington – Department of Ecology	A water right is required for use of any amount of surface water (from a river, stream, spring, or lake) for any purpose, or for use of groundwater for domestic or industrial purposes of greater than 5,000 gallons per day. Water obtained from public utilities does not require separate individual water rights.
General Permit Coverage - NPDES	State of Washington - Department of Ecology	Construction of project facilities has the potential to discharge sediment in storm water and will involve disturbance of more than five acres.
Industrial Stormwater General Permit Coverage – NPDES	State of Washington - Department of Ecology	Industrial Facilities: Public or private operation of an industrial facility with a stormwater discharge to surface waters or a storm sewer.

Large On-Site Sewage Disposal Permit	State of Washington - Department of Ecology	Large On-site Sewage Systems with any of the following characteristics require s coverage under this permit: • Residential-strength sewage treatment with a design flow exceeding 100,000 gallons per day; • Systems whose discharge includes industrial/commercial process wastewater or stormwater; • Systems that discharge to the land surface (such as wetlands or infiltration lagoons without a drainfield); or • Systems that discharge to surface water (including those that discharge to ground, where groundwater is in hydraulic continuity with surface water).
Small On-Site Sewage Disposal Permit	State of Washington - Department of Health	A permit or approval is needed before the installation, repair, modification, connection to, or expansion of an on-site sewage system with a peak daily flow of greater than 3,500 gallons but less than 100,000 gallons of residential-strength sewage.
State Wastewater Discharge Permit – Industrial to Ground Water	State of Washington - Department of Ecology	Facilities that discharge wastewater pollutants to land must apply for a State Wastewater Discharge Permit to Discharge Industrial Wastewater to Ground Water by Land Treatment or Application.

Local Permits

Permit	Authority	Assumptions/Notes
Site Plan Approval	Local Government – City of Port Townsend (within city limits), Jefferson County (outside city limits)	Approval from the local township that the project meets zoning requirements and local ordinances.
Building Permits	Local Government – City of Port Townsend (within city limits), Jefferson County (outside city limits)	Construction of permanent buildings or additions to existing facilities.
On-Site Sewage Permit	Local Government – City of Port Townsend (within city limits), Jefferson County (outside city limits)	Construction or modification of on-site septic system with a peak daily flow of less than 3,500 gallons of residential-strength sewage.
Noise Ordinance	Local Government – City of Port Townsend (within city limits), Jefferson County (outside city limits)	Local governments set maximum intruding sound level limits or adopt statewide statute.
Air Quality Notice of Construction (NOC) Permit	Local Government –Jefferson County	Releasing pollution to the air from a new or modified business or industrial source, unless the source or activity is exempt.

8.1 ENVIRONMENTAL CONSIDERATIONS

PDO Technologies shared the following information regarding the environmental benefits of their system:

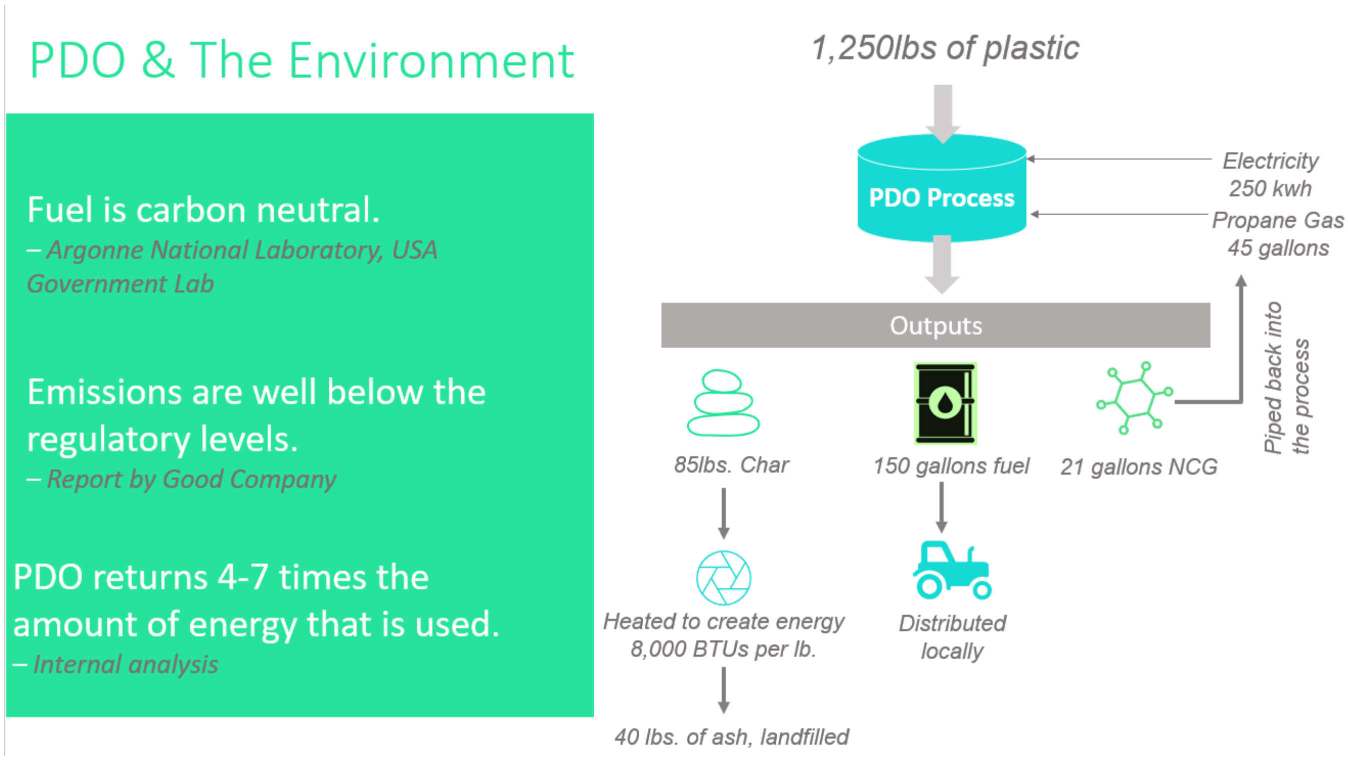


Figure 16 - Environmental Benefits, PDO Technologies

The following references were also provided:

- Good Company report on emissions profile: https://plastics.americanchemistry.com/Plastics-to-Fuel-Manufacturing-Emissions-Study.pdf
- Argonne Labs report on carbon neutral fuel and the reduction in GHG, Water usage & Energy: https://www.osti.gov/servlets/purl/1353191
- The Chem Council released this report on how Plastic to Fuel sites are regulated: https://plastics.americanchemistry.com/Product-Groups-and-Stats/Plastics-to-Fuel/Regulatory-Treatment-of-Plastics-to-Fuel-Facilities.pdf

8.0 ECONOMIC ASSESSMENT

Tetra Tech has conducted an economic assessment of a pyrolysis project for the minimum and maximum potential feedstock scenarios presented.

8.1 200 TON PER YEAR FEEDSTOCK RATE

The following assessment was contemplated using an average 200 ton/year feedstock rate and PDO Technologies Mobile Unit.

PDO Technologies provided the following financial data presented in **Figure 18** below:

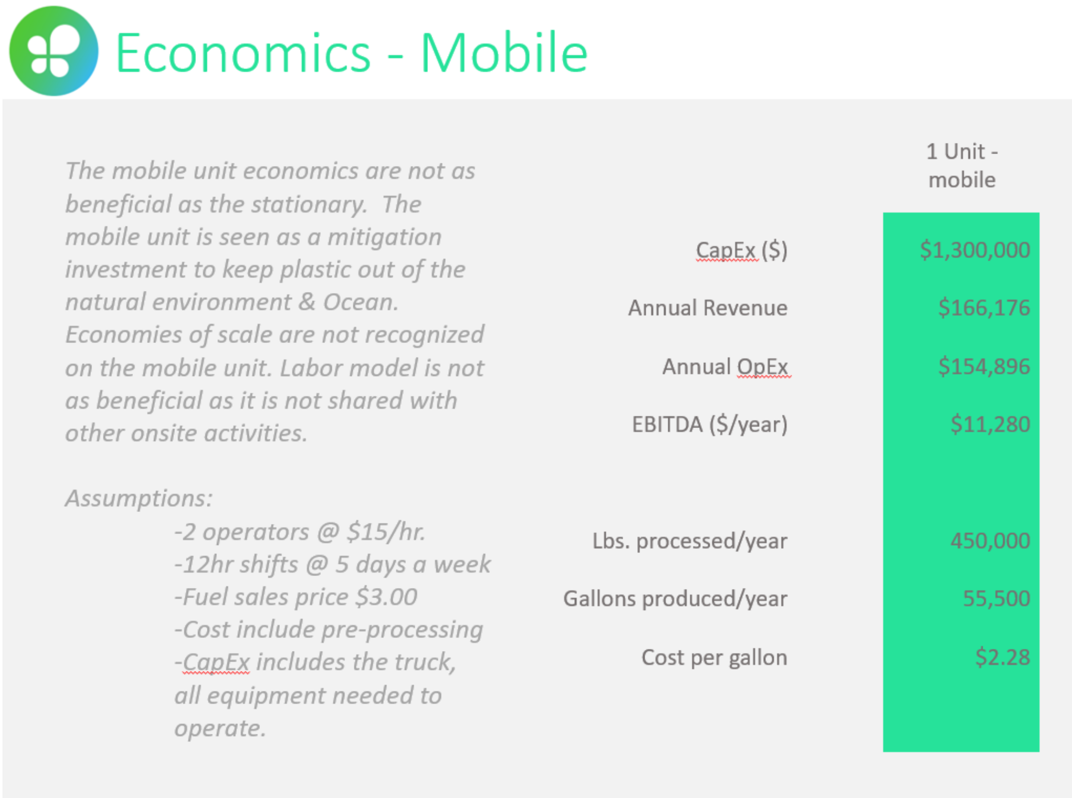


Figure 18 - PDO Technologies Mobile Unit Economic Summary

The capital expenditures presented do not include the pretreatment system, pre-engineered building, site preparation, permitting or balance of plant engineering. Tetra Tech developed the following comprehensive Capital and Operational cost estimate and revenue projection:

PROJECT FINANCIAL SCENARIO 200 Tons/Year Process Capacity			
Type	**Item**	**Description**	**Cost**
CAPEX	General	Contract Conditions & General Requirements, Mob/Demob, Site Preparation	$120,000
CAPEX	Pretreatment Infeed/Outfeed Conveyors	Vecoplan (1) each infeed and outfeed belt conveyors	$70,000
CAPEX	Pretreatment Shredder	Vecoplan 60-horsepower model VAZ1100XL shredder	$119,000
CAPEX	PDO Technologies Mobile Unit	PDO Technologies (1) Mobil Unit including; Thermal Processing & Condensing Unit, 2 cartridges, cleaning machine, associated infrastructure, platforms, lifts (as quoted by PDO)	$1,300,000
CAPEX	Building	Pre-Engineered Building (4,000 SF) including plumbing, HVAC, fixtures and furnishes	$300,000
CAPEX		Subtotal Direct Capital Costs	$1,909,000
CAPEX		Permitting & Engineering Fees (15%)	$190,900
CAPEX		Contingency (20%)	$381,800
CAPEX		Total Capital Costs	$2,481,700
OPEX	Pretreatment System	Annual Operating Cost (power usage, maintenance, consumables, manual sorting labor)	$67,700
OPEX	PDO Technologies Stationary Unit	Annual Operating Cost (as quoted by PDO Technologies)	$154,896
OPEX		Total Operational Costs	$222,596
REVENUE	Pyrolysis Oil	55,500 gallons produced per year (200 tons/year plastics processed); fuel price of $2.50/Gallon	$138,750
REVENUE	Cost Avoidance	Tipping Fees at Roosevelt Regional Landfill avoided for (200 tons/year)	$14,330

Figure 17 - 200 Tons/Year Financial Summary

A tip fee would be required to make this project economically viable. Assuming a project lifespan of 20 years, 6% interest rate, and a 10-year dept tenor, it was determined that a minimum tip fee of $0.70 per lb is required to break even. A tipping fee of $1.00/lb provides a pre-tax IRR of ~10% and project IRR of 5%; while a tipping fee of $1.50/lb provides a pre-tax IRR of ~17.5% and project IRR of 12%.

The estimated cost to operate the plant is approximately $4.01/gallon of fuel produced. The revenue projection does not include sales of char. It is estimated that approximately 28,000 lbs of char would be produced annually.

8.2 500 TON PER YEAR FEEDSTOCK RATE

The following assessment was contemplated using an average 500 ton/year feedstock rate and PDO Technologies Stationary Unit.

PDO Technologies provided the following financial data presented in **Figure 22** below:

PDO Customer Economics - Stationary

The range of customer benefit will vary primarily based on labor costs and price of fuel. For these models we have used labor rates and fuel prices in the US. We would expect some of the markets these units would run in given where plastic has been shipped to would have lower labor rates providing additional benefit in those locations.

	1 Unit	4 Unit
CapEx ($)	$975,000	$3,550,000
Annual Revenue	$520,900	$2,083,700
Annual OpEx	$276,900	$886,300
EBITDA ($/year)	$244,000	$1,116,700
Payback Period	5.8	4.8
IRR 15 yrs	19%	26%
lbs processed/year	1.87 M	7.4 M
Gallons produced/year	208,360	833,465
Cost per gallon	$1.68	$1.35

* Assumes price for fuel $2.50

Figure 19 - PDO Technologies Stationary Unit Economic Summary

The capital expenditures presented do not include the pretreatment system, pre-engineered building, site preparation, permitting or balance of plant engineering. Tetra Tech developed the following comprehensive Capital and Operational cost estimate and revenue projection:

PROJECT FINANCIAL SCENARIO 500 Tons/Year Process Capacity			
Type	**Item**	**Description**	**Cost**
CAPEX	General	Contract Conditions & General Requirements, Mob/Demob, Site Preparation	$150,000
CAPEX	Pretreatment Infeed/Outfeed Conveyors	Vecoplan (1) each infeed and outfeed belt conveyors	$70,000
CAPEX	Pretreatment Shredder	Vecoplan 60-horsepower model VAZ1100XL shredder	$119,000
CAPEX	PDO Technologies Stationary Unit	PDO Technologies (1) Stationary Unit including; Thermal Processing & Condensing Unit, 2 cartridges, cleaning machine, associated infrastructure, platforms, lifts (as quoted by PDO)	$975,000
CAPEX	Building	Pre-Engineered Building (5,000 SF) including plumbing, HVAC, fixtures and furnishes	$375,000
CAPEX		Subtotal Direct Capital Costs	$1,689,000
CAPEX		Permitting & Engineering Fees (15%)	$168,900
CAPEX		Contingency (20%)	$337,800
CAPEX		Total Capital Costs	$2,195,700
OPEX	Pretreatment System	Annual Operating Cost (power usage, maintenance, consumables, manual sorting labor)	$71,600
OPEX	PDO Technologies Stationary Unit	Annual Operating Cost (assume 75% quoted by PDO Technologies due to less processing)	$207,675
OPEX		Total Operational Costs	$279,275
REVENUE	Pyrolysis Oil	111,420 gallons produced per year (500 tons/year plastics processed); fuel price of $2.50/Gallon	$278,550
REVENUE	Cost Avoidance	Tipping Fees at Roosevelt Regional Landfill avoided for (500 tons/year)	$35,825

Figure 20 - 500 Tons/Year Financial Summary

A tip fee would be required to make this project economically viable. Assuming a project lifespan of 20 years, 6% interest rate, and a 10-year dept tenor, it was determined that a minimum tip fee of $0.18 per lb is required to break even. A tipping fee of $0.50/lb provides a pre-tax IRR of ~19% and project IRR of 12%; while a tipping fee of $1.00 provides a pre-tax IRR of ~35% and project IRR of 26%.

The estimated cost to operate the plant is approximately $2.50/gallon of fuel produced. The revenue projection does not include sales of char. It is estimated that approximately 68,000 lbs of char would be produced annually.

DISPOSAL IN ROOSEVELT REGIONAL LANDFILL

The current tip fee paid by Jefferson County Department of Public Works in 2021 for Roosevelt Regional Landfill is $71.65/ton. This equates to an annual cost of$14,330 for 200 tons and $35,825 for 500 tons disposed.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Keys to a successful pyrolysis system fundamentally lie in the feedstock quantity and quality in comparison to the technology costs and product gains. Jefferson County possesses a general location with potential for a steady increase in population and therefore recyclable plastic feedstock. Prime feedstock requirements generally lie in the collection of clean plastics while minimizing category #3 plastics. Upon review of the currently available and operating pyrolysis technologies one vendor emerged as the most likely candidate, PDO Technologies. PDO shows potential for operational success with the current and projected state of feedstock production from Jefferson County and overall design for pyrolysis. Their technology is feedstock flexible, able to shift products, and allows for greater operational flexibility due to the batch operation of the pyrolysis reactor. However, a limitation is that the economics do not appear to be fruitful at the proposed feedstock rates.

Tetra Tech has identified the following conclusions which generally detract from the feasibility of a pyrolysis project:

- Tetra Tech is aware of State and Federal legislative action presently underway that is intended to curb single use plastic production and place the financial burden of collection on the producers. At the local level, Jefferson County may discontinue the collection of plastics as part of the recycling program and launch an education campaign to reduce residential single-use plastic consumption.
- Tetra Tech is aware that the Jefferson County Department of Public Works anticipates adopting a different service delivery model that would not deliver feedstock to a pyrolysis project and would prefer to discontinue the drop box service for recyclables due to high (up to 30%) contamination rates. In addition, the Department of Public Works has stated that they have no intention of adjusting service to include a plastic-only bin.
- Tetra Tech is aware that the current three-bin curbside service in the City of Port Townsend is considered to be problematic by the Jefferson County Department of Public Works and that it is unlikely that an additional plastics bin would be provided under this service.
- Tetra Tech is aware that the Jefferson County Department of Public Works presently has no ambition to finance or site on County property a pretreatment facility.

Tetra Tech recommends the following to provide further insight into the viability for a PDO Technologies based project:

- Contact PDO Technologies for a more detailed discussion/presentation of their process considering the now known parameters of the Port of Port Townsend application. The discussion should include possible financing options and potential off-take scenarios, which may improve project economics from the preliminary estimates completed during this phase of the study.
- Confirm the feasibility of implementing a plastics-only source separation program (inclusion of another collection bin), voluntary drop off, or subscription service.
- Conduct a waste composition study to better quantify the type and composition of plastic feedstock available for a pyrolysis project.
- Investigate the feasibility of combining the Jefferson County's waste plastics with the waste plastic from neighboring counties to support a larger scale pyrolysis project, or, consider a project located near Pioneer Recycling's MRF facility to offtake feedstock from the MRF.
- Perform a local/regional market assessment to quantify the market potential and pricing for pyrolysis products including the char as a manufacturing additive or solid fuel replacement, the syn-crude as a diesel fuel blendstock, and the naptha and heavy hydrocarbons as petrochemical additives.

Should the Port of Port Townsend choose another method for recyclable plastic disposal, it may prove to be beneficial to combine efforts and waste with surrounding areas and to encompass the pyrolysis technology at a centralized location to gain the full benefits of the process and increase product output and feedstock diversity options. With the current location and population of surrounding areas, it may be suggested to explore the option of a centralized location close to the Tacoma, WA area. This would be a prime location to maximize the number of participants and efficacy of the pyrolysis technology.

Tetra Tech presents the above feasibility study to the Port of Port Townsend for the consideration of the future of plastics recycling for Jefferson County and once a decision has been made the next steps will entail contacting and further analyzing equipment necessary to proceed, in which, Tetra Tech may provide further assistance.

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