   

Conversion technology: A complement to plastic recycling

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Executive Summary

The field of solid waste management continues to evolve and much of that evolution is driven by the adoption of new technologies that increase recovery capacity and processing capabilities. Despite all of the technological advances over the recent years in the reclamation of plastics, there remains a portion of the plastic waste stream that cannot be mechanically recycled due to contamination, lack of markets or the inability to separate plastics that can make recovery unfeasible. In the U.S., much of this non-recycled plastic then becomes landfilled. However, a new generation of conversion technology specifically designed to manage non-recycled plastics has been developed, and commercial scale facilities that use pyrolysis technology to convert plastics into oil and fuel are being established in Europe and Asia.

The benefits presented by plastic to fuel (PTF) technologies are two-fold: transforming non-recycled plastic into a valuable commodity, and creating a reliable source of alternative energy from an abundant, no-cost feedstock. This paper provides an overview of the newest generation of PTF technologies, explores how this technology can be used to compliment and support the existing mechanical recycling infrastructure for plastics, and discusses the opportunities and barriers that exist to commercializing this technology in the U.S.

1. Overview

In the U.S., the field of solid waste management is becoming more closely aligned with resource management, and this is occurring in large part because the way we view "waste" is dramatically shifting. New technologies are being developed that allow more materials to be recovered and new value created from those materials. Much more of our waste stream is considered to be valuable scrap material and new technologies such as automation for materials separation and major improvements in commercial composting are allowing the industry to tap into these resources and create value out of what was previously considered non-valuable material. Conversion technologies, specifically those designed for plastics, offer the same potential to create value for landfilled plastics that are not appropriate for mechanical recycling. And further, plastic to fuel (PTF) technologies offer the potential to manage landfill-bound plastics as a resource to create a valuable alternative fuel source.

At this time, a large portion of the plastic waste stream is still treated as "waste," and there is a large opportunity to recover more of the plastics we use in the United States. Factors that currently limit mechanical recycling include: contamination issues (e.g., food waste), technical challenges of separating resins in mixed resin products, and lack of markets for some plastics. While technically all thermoplastics can be recycled, the conditions identified above can make recovery through mechanical recycling economically impossible. The result is that many plastics still are not recovered at end-of-life.

Now, an end-of-life management option exists for non-recycled[1] plastics: conversion of scrap plastics to either chemical feedstock or fuel. These conversion technologies rely on the processes of depolymerization and pyrolysis, respectively. Those in the plastics industry may be familiar with the term pyrolysis, or plastic-to-fuel (PTF) technologies, and have some knowledge of past attempts that have been made to commercialize this technology. The technology has existed for decades, but challenges seemed to persist in making commercial-scale systems economically feasible, and the technology was limited and did not yield a desirable product. However, recent investment and innovation in pyrolytic technology has created a new generation of systems that may have overcome these previous challenges. And, these modern systems have been deployed in communities in Europe and Asia with a number of years of demonstrated success.

The recent evolution of conversion technologies for managing scrap plastics has given cause for a re-evaluation of how these systems might serve as a viable end of life option for scrap plastics, and better yet, how these systems might be used to complement the existing recycling infrastructure of plastics. In an effort to better understand the technologies that are available and how they might be used, the American Chemistry Council commissioned this study. This report covers the following items:

- Definition of conversion technology
- Existing technologies
- System feedstock
- Growth model for technology abroad
- Growth model for technology in North America
- Opportunities and barriers
- Policies that promote commercialization of PTF technologies
- Outlook for growth in the U.S.

The information in this report is a summary of findings gathered during interviews of plastic-to-fuel technology manufacturers, users of PTF technology, industry experts and solid waste managers. Because this information is aggregated from a number of sources, much of this information is presented as averages and general experiences. Specific technologies and economic scenarios will differ for each system and should be fully vetted. The information presented in this report is intended to inform the readers, including municipalities, government officials, plastics reclaimers, materials recovery facility (MRF) managers, investors, and other interested parties about the current state of conversion technology for scrap plastics, how these systems fit in community solid waste management plans and what conditions exist that could benefit, or hinder, the commercialization of these systems in North America.

[1] In this document, "non-recycled" refers to used plastics that are not mechanically recycled. ISO 15270 defines "mechanical recycling" as "processing of plastics waste into secondary raw material or products without significantly changing the chemical structure of the material." (Source: ISO 15270:2008(E). Plastics – Guidelines for the recovery and recycling of plastics waste. 2008)

2. Definition of conversion technology

The term "conversion technology" encompasses a broad range of technologies that are used to treat a wide variety of materials in the waste stream. Those technologies include incineration, gasification, hydrolysis, anaerobic digestion, pyrolysis and chemical feedstock recovery. This study only focuses on the latter two technologies of pyrolysis and depolymerization systems that are specifically designed to treat scrap plastics. The other technologies mentioned vary significantly from the technologies discussed in this report. An example of the capacity and outputs of these conversion technologies can be found in Table 1, which is an evaluation of conversion technologies for municipal solid waste (MSW) conducted by Los Angeles County.

It should be noted that under ISO 15270, conversion technologies, such as cracking, gasification and depolymerization are recognized as forms of recycling; specifically, they are classified as chemical or feedstock recycling. Pyrolysis is a synonym for cracking.

Table 1. Conversion technologies considered for treatment of MSW[2]

Technology Supplier	Technology Type	Proposed Capacity	Major Products
Arrow Ecology and Engineering	Anaerobic Digestion	300 tons/day	Biogas (Electricity) Digestate (Compost) Recyclables
Changing World Technologies	Thermal Depolymerization	200 tons/day	Renewable Diesel Carbon Fuel Metals
International Environmental Solutions	Pyrolysis	242.5 tons/day @ 58.9% moisture 125 tons/day @ 20% moisture	Syngas (Electricity)
Interstate Waste Technologies	Pyrolysis/High Temperature Gasification	312 tons/day (1 unit) 624 tons/day (2 units) 935 tons/day (3 units)	Syngas (Electricity) Mixed Metals Aggregate
NTech Environmental	Low Temperature Gasification	413 tons/day	Syngas (Electricity)

Table 1. Source: LA County 2007

As demonstrated in Table 1, pyrolytic and depolymerization systems can treat a wide variety of materials. Because these systems are used to treat MSW, there are vastly different permitting issues, economics and growth models, and very different levels of support for these technologies. MSW program managers who considered the technology options in Table 1 met with a great deal of resistance from environmental communities, very similar to the opposition to waste incineration technologies. Because the political and economic conditions and feedstock for these technology types in Table 1 vary

[2] Los Angeles County Conversion Technology Evaluation Report: Phase 2 Assessment. October 2007. http://dpw.lacounty.gov/epd/tf/attachments/LACo_Conversion_PII_Report.pdf.

so greatly from the conditions for plastics-to-fuel and plastics-to-chemical feedstock recovery, this report evaluates the latter category of technology as separate from the other conversion technologies. One of the most obvious examples of those differences is the capacity of the system. Most PTF systems are designed to manage about 20 tons per day. The vast capacity difference and the narrow treatment of plastics in PTF suggest these systems are very different in purpose and function.

Therefore, for the purpose of this study, "conversion technologies" refers to the pyrolysis and depolymerization technologies that are specifically designed to treat scrap plastics. Specifically, the use of the term "pyrolysis" refers to plastic-to-fuel (PTF) technologies that handle scrap plastic through a process of thermal treatment, and sometimes pressure, to convert these plastics to a fuel product. The term "depolymerization" refers to chemical feedstock recovery, or a process of turning scrap plastics back into monomers that can be used to rebuild resins that will have the properties and performance of virgin resins.[3]

3. Depolymerization technologies

While chemical feedstock recovery, or depolymerization, is not the primary focus of this study, it is important to recognize the positive impact that this form of plastic-specific conversion technology is having on the recovery of scrap plastics and other resin-based products. Depolymerization has successfully been employed to recover monomers from PET, polyamides such as nylons, and polyurethanes such as foam.

Depolymerization presents two unique advantages in recycling resin-based products, the ability to return a recovered resin to virgin resin-like quality, and the potential to recover a valuable feedstock from products that are economically challenging to recycle. When plastic is mechanically recycled, even small levels of contamination can compromise the performance of the resin. However, because depolymerization breaks scrap plastics back into the basic building blocks for resin, that contamination is removed. The resulting monomers, such as terephthalic acid, ethylene glycol, styrene and ethyl benzene, can be recovered and be remade into what is essentially comparable to virgin resins, free from impurities, and possessing virgin resin-like properties.

In terms of how depolymerization can be used to recover resin that would otherwise generally not be recovered, perhaps the best example is the recovery of nylon from scrap carpet. Carpet contains a number of resin components that can make mechanical plastic recycling and recovery difficult and economically challenging. However, a few firms have demonstrated the economic viability of nylon 6 recovery through chemical feedstock recovery methods, as depicted in Table 2.

Because these chemical feedstock recovery systems typically give manufacturers a competitive edge in their industry, much of the information about the function of these systems is proprietary. For this reason, detailed technology evaluations of these depolymerization systems are not available in this

[3] For additional information on depolymerization, visit the American Chemistry Council's site on advanced recycling technologies, http://www.americanchemistry.com/plastics/doc.asp?CID=1583&DID=6005.

report. However, Table 2 is a list of known firms employing the use of, or possessing, the technology to perform chemical feedstock recovery from scrap plastics and resin-containing products.

Table 2. Companies employing the use of depolymerization technologies

Company	Recycling performed through chemical feedstock recovery
Shaw	Nylon 6 recovery (separating nylon 6 from the rest of the carpet fiber)
Dupont Canada	Nylon 6 recovery
SABIC	PET to PBT chemical conversion process
GE Plastics	PET to PBT chemical conversion process
NURRC	Use of a partial depolymerization process for producing food-grade PET. The process breaks down the outer layer of the rPET flake into monomers.
Eastman	Holds a number of patents for chemical feedstock recovery processes
Polyflow	Has a unique pyrolytic process that converts plastics to fuel, natural gas and monomers, such as styrene and ethylbenzene.

The examples in Table 2 demonstrate just a few advantages that conversion technology can bring to the recovery and recycling of resin-based products. Chemical feedstock recovery can create significant added value to scrap material as well as create recovery options for resin-based products that otherwise may not be recycled. While these technologies are not the primary focus of this study, they are an important example of how conversion technologies can be used to enhance recovery and recycling alongside the existing recycling infrastructure.

4. Pyrolytic conversion technologies

A primary focus of this study is to identify technologies that use pyrolysis to convert scrap plastic to fuel sources. 4R identified 23 manufacturers of PTF technology. Each of these technologies is unique in terms of the type of scrap plastics the systems can handle, and the output, or fuel product. Common features of these systems include:

- Some level of pretreatment –this could be as minor as size reduction or as involved as cleaning and moisture removal.
- Conversion – pyrolytic processes are used to convert the plastic to a gas.
- Distillation – the gas is converted to liquid form
- Acid removal process – removal of acids that form in the breakdown of some scrap plastics. These acids require removal because they can be corrosive to the PTF systems as well as the engines that will consume the fuel.
- Separation/refining/final blending - the final steps required to make this product consumer ready can either be done on site or by a third party, depending on the system design.

A depiction of the process flow can be found in Appendix A.[4] While these systems vary in design, they have all been designed with the same purpose – create value from scrap resin that would otherwise be landfilled.

Although successful use of this technology has been demonstrated at PTF facilities around the world, no commercial-scale systems have yet been developed in North America. Despite the lack of adoption of PTF technologies in North America, there are a number of U.S. and Canadian-based technology manufacturers that have operational pilot facilities. And, some of the first reports are being made of orders being placed for commercial-scale systems. Table 3 contains a list of North American technology manufacturers.

Table 3. North American Technology Manufacturers

Company Name	Location	General output description (Fuel/Oil)	Technology form in Appendix B
Agilyx*	Tigard, Oregon	Oil	Yes
Climax Global Energy*	Allendale, South Carolina	Oil	Yes
Envion*	Washington, D.C.	Oil	Yes
GEEP*	Barrie, Ontario	Fuel	Yes
GreenMantra Recycling Technology	Toronto , Ontario	Wax/lubricants	No
Natural State Research (NSR)	Stamford, Connecticut	Fuel	Yes
Nexus Fuels	Atlanta, Georgia	Fuel	Yes
Northeastern University		Gas (skips distillation process)	No
Plastic2Oil (JBI, Inc.)*	Niagara Falls, New York	Fuel	No
PolyFlow	Akron, Ohio	Fuel	Yes
Recarbon corp.	Kingston, Pennsylvania	Oil	Yes
Vadxx*	Cleveland, Ohio	Oil	Yes

***Have a pilot scale facility in operation. Appendix B contains technology forms.**

The majority of these companies have pilot-scale facilities which tend to be about one-fifth of the size of the smallest recommended capacity for a commercial-scale facility. The others listed have "bench scale" systems which are even smaller demonstration systems. The difference in the scale of the facility is generally directly related to how long the technology has been in development. For example, one of the firms with a pilot scale facility is developing its sixth generation of the system. Each generation reflects improvements in processing and efficiency. However, development of pilot-scale facilities has generally taken most firms three to five years. The financial resources that have been made available to developing the technology will also have an impact on the size of the facility.

[4] Process flow courtesy of Cynar.

In addition to these North American technology manufacturers, a number of other international technology manufacturers have emerged, some of whom have made great strides in commercializing these systems. Those identified technology manufacturers are contained in Table 4.

Table 4. Conversion technology systems outside of North America

Company name	Company location	Facility location	General output description (Fuel/Oil)	Technology form in Appendix B
Anhui Oursun Environmental Technologies	China	Hefei in Anhui, China	Oil	Yes
Blest	Japan	Japan	Oil	No
Cynar Plc	Ireland	UK	Fuel	Yes
ECO – Int'l Marketing	Korea		Fuel	Yes
Klean Industries, Inc.	Vancouver, BC Canada	Asia and Europe	Fuel	Yes
P-Fuel, Ltd.	Australia	Australia , North Korea, South Korea,	Fuel	No
Plastic Advanced Recycling Corp.	Illinois	China	Fuel	Yes
PlastOil	Switzerland	Switzerland	Oil	No
Polymer Energy*	U.S.	Thailand, India	Fuel	Yes
Promeco/Cimelia	Italy/Singapore	Singapore	Oil	No
T Technology	Poland	Poland, Spain, Italy	Fuel	No

***Currently licensing technology**

As depicted in Table 4, a number of commercial scale facilities are in operation around the world. While investor uncertainty regarding the economic viability of these systems may exist in North America, investors abroad are seemingly more confident in this technology. Some of these commercial facilities have been in operation for three or more years, demonstrating the technological and economic feasibility for using pyrolytic technology to recover more scrap plastics. Section 6 of this report explores the adoption of this technology in North America and abroad.

5. System feedstock (Inputs)

There are a number of reasons why many scrap plastics and resin products are not recovered and mechanically recycled. According to the U.S. Environmental Protection Agency, in 2009 just seven percent of plastic in municipal solid waste stream was recovered for mechanical recycling.[5] Technically speaking, a majority of plastics produced can be mechanically recycled, however the economics of doing

[5] U.S. EPA, *Common Wastes & Materials – Plastics,* http://www.epa.gov/osw/conserve/materials/plastics.htm.

so often do not favor the mechanical recycling of contaminated plastics and/or multi-layer plastics. The condition of many plastics at end-of-life can make it economically unfeasible to mechanically recycle them, and in some cases, stable recovery markets for certain resins and products are lacking. However, because the latest generation of pyrolysis technologies are designed to accept a wide variety of resin types, can accommodate many forms of contamination and require little pretreatment before being fed into the system, PTF technology could present a potential alternative to landfilling non-recycled plastics.

In terms of identified feedstock for these systems, technology manufacturers claimed the following items as optimal sources of scrap material for fuel recovery:

- Nos. 2, and 4-7 (systems handle No.2 but are not designed to rely on HDPE), other contaminated plastics from MRFs.
- Contaminated films, rigids and other consumer plastics currently not being recycled
- Any other rigid plastics headed to the landfilll
- Non-recycled caps, labels and rejects from reclaimers
- Agricultural plastics
- Oil bottles
- Auto shredder residue (ASR) plastics
- Scrap carpet
- Engineering grade resins
- Mixed resin products and thermosets

However, not all systems can accommodate all of these types of material (see Appendix B for specific listing of optimal inputs for each system). The majority of the pyrolytic systems can accommodate consumer packaging of all types, including Nos. 1-7. It should be noted that while polyethylene terephthalate (PET, No. 1) and polyvinyl chloride (PVC, No. 3) are not listed as optimal feedstock for these systems, the majority of these systems can accommodate them in varying amounts. Usage of these systems envisions that feedstock materials will be pre-sorted, with valuable PET and HDPE removed for mechanical recycling. Therefore, PET levels will likely be low. The threshold levels for PVC, at 10%-15% are generally commensurate with the presence of PVC in the packaging waste stream.

In terms of fuel yield, PET and PVC are also less desirable because their fuel yield is considerably lower than other resins. The fuel yield for PET is just 30 percent compared to polystyrene (PS) at 90 percent, and polypropylene (PP) and low density polyethylene (LDPE), which yield about 70 percent. The yield for PVC is similar to that of PET, at about 30 percent, but PVC also breaks down into hydrochloric acid during the conversion process. Most systems are designed to capture and remove hydrochloric and other acids that might be present due to additives in the scrap plastic feedstock. Acids can be corrosive to both the conversion system and the combustion systems that the final product is ultimately used in. While it is generally the case that PVC should be limited in many of these systems, a few systems are available that can handle higher thresholds, such as the Agilyx system which can accommodate up to 70 percent PVC.

PTF technology manufacturers also were asked if systems could accommodate bio-based resins, such as poly lactic acid (PLA). Most responded that batches of PLA had not been specifically tested but it was likely that PLA had been present in the mixed Nos. 3-7 material that is run at pilot facilities. To everyone's knowledge, bio-resins had not yet presented any problems for the systems and in theory should breakdown in the conversion process.

6. Outputs

Each system evaluated in this study produces three outputs: natural gas, the fuel product and char.[6] The natural gas can be rerouted into the system to account for a portion of the system's energy needs, or it can be flared (clean burned). The majority of the systems do capture the energy from this gas, which can account for about one-third of the system's energy needs; however this will vary by system.

In terms of fuel output, the products derived from these pyrolytic systems can be quite different. Some of the systems produce a gasoline-diesel fuel blend that needs further refining. Some generate a product similar to sweet crude oil that needs to be refined, but can become a variety of products and other PTF systems produce diesel fuel ready for use in vehicles. One system, produced by Natural State Research, claims its technology can be customized to produce a product that will meet the buyer's needs, ranging from heating oil and gasoline, to naphtha or aviation diesel (all have been tested to meet ASTM standards). Most of the technology manufacturers that have pilot-scale facilities in place, and offering systems that have fuel outputs which require further refining or blending by a third party have had their products tested and processed to ensure that the output is indeed a usable product that will be in demand.

Char is the material that is left once the pyrolytic process is complete and the fuel recovered. Char contains the additives and contaminants that enter the system as part of the feedstock. The char can be a powdery residue or substance that is more like sludge with a heavy oil component. Glass, metal, calcium carbonate, clay and carbon black are just a few of the contaminants and additives that will remain after the conversion process is complete and become part of the char. In all cases, technology manufacturers said the char was a benign material that could be landfilled. In some cases, technology manufacturers are exploring applications for the char. Some of those exploratory end uses include road, carpet and roofing material. PTF technology manufacturers most often cited additional energy recovery as the management option for the char. Because there is a carbon component in the char, this material can be sent to an incinerator, or burned on site for additional energy recovery. These alternative uses for the char make the conversion process potentially a zero-landfill management option for non-recycled scrap plastics.

Fuel yield estimates will be different for each system, and each technology manufacturer notes that yields will vary from batch to batch depending on the quality of the feedstock being used. The more

[6] The only exception to this being the Northeastern University technology, which transforms the plastic into gas and does not move the gas through the distillation process to produce a fuel. Instead, the gas is diverted for energy use.

contamination and non-resin materials present, the less the fuel yield will be. Higher presence of PS, PP and LLDPE, the higher the yield will also be. Here is a breakdown of the average system outputs.

Table 5. Breakdown of system output

Output	Percentage of overall output
Char	Ranges on average from 2%-13% (one system claims negligible amounts of char when the system is run on a continuous feed versus a batch feed)
Natural gas	Ranges on average from 8% to 10%
Fuel/Oil	Ranges average from 80%-90%

7. System economics

The average recommended commercial-scale facility will have capacity of 7,500 to 10,000 tons per year, and all of these technologies can be easily scaled up by adding additional vessels or modules. Just as differences can be found in how these systems are designed, even greater differences can be found in system pricing. Quotes for systems ranged on average from $4 million to $5 million, however some systems were quoted as low as $1 million and as high as $11.5 million. Examples of system pricing are contained in Table 6.

Table 6. Example of quotes for pyrolysis systems

Company	Price	System capacity per year
System A	Just under $1 million	7,500 tons
System B	$4 million	10,000 tons
System C	$4-$5 million	7,500 tons
System D	$5 million	10,000 tons
System E	$7 million	10,000 tons

Return on investment (ROI) is generally quoted at two to five years if all cost conditions and product pricing hold steady. Factors that could impact the length of ROI include changes in energy costs, price of oil and fuel, and cost and availability of scrap plastic. However, due to the abundance of unrecovered and non-recycled scrap plastic, the last condition will likely not be a factor on ROI timeframe for some time.

Technology manufacturers offered very similar descriptions of economic models for PTF systems. The systems should be located at, or near, the source of the material at a MRF, collection facility, manufacturing facility generating non-recyclable scrap plastics, or even a landfill. All of the technology manufacturers said the economic forecast includes being able to obtain the scrap plastic material at no cost, and does not generally support paying for this material. The economics seem attractive, since currently the owners of this material have to pay a per-ton tipping fee to have this non-recycled, and therefore, unwanted material landfilled. This further supports the theory that scrap plastics, for which recycling markets currently exist, would not be diverted to a fuel recovery facility. Any scrap material that has even the slightest value as a marketable commodity would continue to be diverted into the mechanical recycling markets.

The fact that the calculated return on investment does not include charging the generators of plastic is important for several of reasons. First, because generators can avoid landfill fees, this will create a strong incentive to divert landfill-bound plastics to conversion systems. Second, in terms of the growth model for these systems in North America, because generators will not be charged a per-ton fee, PTF facilities can be located in any region of the U.S., independent of landfill disposal fees. For example, if the economic model required PTF system operators to charge a $40 per ton fee, siting a facility in a region with a $30 per ton landfill fee could threaten the ability to secure adequate volumes. The fact that landfill, and all other disposal fees, would be avoided by diverting non-recycled scrap plastics to a PTF facility makes it an ideal end-of-life option, regardless of how landfill tip fees vary across the nation. This will be further explored in section 9.

As discussed, fuel yields and production costs will vary based on the nature of the feedstock and labor and energy costs in the region. A general example of yield and production cost is offered below. One system manufacturer offered the following production yield and cost projections:

One ton of mixed scrap plastic = 264 gallons of consumer-ready fuel

Production costs (if plastic is obtained for free) = $0.75 per gallon

Economic returns are seen in either the sale of the fuel product, or the offset fuel costs if a company uses the fuel internally. When asked about the connection of ROI and the value of crude oil, a number of manufacturers said PTF-derived fuel is competitive to traditionally-derived fuel, even if the price of crude oil drops to about $40 per barrel.

A final point about the economics of PTF is a consideration of the “best and highest use” for non-recycled plastics. In terms of maximizing the inherent energy of plastics, pyrolysis also seems to be a better option than incineration with energy recovery. Using the above estimated production numbers, 5.6 pounds of scrap plastic would produce one gallon of diesel fuel. In terms of energy values:

One gallon of oil = 138,095 BTUs[7]

One pound of mixed plastic = 15,500 BTUs (when incinerated)[8]

[7] *Bioenergy conversion factors* Oak Ridge National Laboratory. http://bioenergy.ornl.gov/papers/misc/energy_conv.html.

Based on the calculation that one ton of scrap plastics would produce 264 gallons of consumer-ready fuel, it takes about 7.57 pounds of plastic to make one gallon of fuel.

The BTU value of 7.57 lbs. of plastic when incinerated would be about 117,424 BTUs. Compare that to the 138,095 BTU value of diesel, which also requires 7.57 pounds of plastic, and these calculations suggest that PTF yields better energy value from scrap plastics. If the BTU value of the char residual is then considered, which can be burned for further energy recovery, the BTU value of all products from the pyrolytic process will be even higher. While a further direct comparison and life cycle analysis also measuring the energy/resource inputs of pyrolysis and incineration will need to be conducted, initial numbers suggest that the fuel product from pyrolysis is likely a "higher and better use" for non-recycled plastics than incineration.

8. Examples of International Growth Models

Outside of North America, three key drivers have supported commercialization of PTF technology: rapidly diminishing landfill capacity, a strong push to increase diversion and materials recovery, and the drive to find value in non-recycled materials. In these examples below, all three factors were drivers in siting a facility. These examples highlight how companies have specifically leveraged one of these drivers and the technology has proven to meet an important need.

Shortage of suitable landfill space. Polymer Energy has two systems in place in Thailand and one in India. In Thailand, the PTF system is located at a landfill, where new landfill space is being created by mining and sorting the material in the landfill. The sorting, and in some cases the processing, is happening at the site of the landfill. Metals are recovered for recycling, organics are placed into a digester which creates biogas for energy, and plastics such as polyethylene (PE) and PP are fed into the PTF system to make oil. Because Thailand has limited future landfill options, significant efforts are being made to optimize existing landfill space. Conservation efforts are strong in Thailand, and financial incentives have been created for diversion of material. In terms of incentives for this specific technology, PTF companies are eligible to receive a subsidy of seven Bahts, or about $.023 U.S. for each liter of oil sold to a refinery.

Increased recovery goals. The United Kingdom continues to promote recovery of scrap plastics through increasing both recovery goals and funding, such as the Waste & Resources Action Programme (WRAP), to create recovery and end market opportunities for plastics. The current UK recycling goal for plastics is 32 percent for 2011 and 2012. This is up from up from 29 percent in 2010.[9] Even with aggressive recovery goals, 68 percent of plastic packaging will be headed to landfills or to energy recovery facilities in the UK. However, thanks to investment in PTF technology, a portion of the plastics that are not recovered will be converted to fuel.

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[8] Tennessee Solid Waste Education Project: Waste-to-energy incineration. http://www-tnswep.ra.utk.edu/activities/pdfs/mu-W.pdf.

[9] Bardelline, Jonathan. "UK's New Plastics Recycling Target Attached." In *Greenbiz.com*, October 28, 2010, http://www.greenbiz.com/news/2010/10/28/uk-new-plastic-recycling-target-attacked.

Cynar Plc., a PTF company, in partnership with Sita, one of Europe's largest waste management companies, will be building 10 PTF facilities throughout the UK in the next three years. Cynar has been operating a commercial-scale PTF facility in Ireland for a number of years and will be replicating that technology in the UK under contract with Sita. Sita's investment in this technology gives the company an avenue to further reduce the volume of material headed to landfills and thus give them a competitive edge in winning municipal solid waste management contracts. Sita now has a further competitive edge in being able to control their internal transport costs by using the fuel produced from end of life plastic in their collection fleet. Plastic recovered and converted into fuel currently counts toward diversion in the UK. And there is some support to redefine "recycling" to include plastics converted to fuel.

Finding value in Non-recycled plastics. China has a very robust plastics recycling industry. The dynamics of their rapidly growing economy has created opportunities to find value in scrap plastic material that does not have favorable economics for recycling in the U.S. and elsewhere. High demand for resources and relatively inexpensive labor costs has created new opportunities for the handling of some non-recycled plastics. And, PTF technology is one way new value is being found in otherwise non-recycled plastics. An example of this is the success that Plastic Advanced Recycling Corp. has had with two PTF systems, which are converting plastics into oil that have been rejected by paper mills and other recyclers in China.

Many paper recycling mills receive sizable volumes of mixed, contaminated plastics in the bales they purchase. The level of contamination that occurs during the paper pulping process leaves the plastics covered in ink. However, because most modern pyrolysis systems can tolerate a wide range of contaminants, these plastics make an ideal feedstock for fuel recovery. Since 2008, the Plastic Advanced Recycling Corp. has had two systems in place at paper mills and the company claims the systems have been a success. The mills avoid landfill fees, and the mixed-plastic product is a valuable resource. The company hopes to replicate this success in the U.S. in the next two years.

While these three factors that have led to investment in commercialization of pyrolytic technology abroad, these factors have played a smaller role in shaping the waste management landscape in North America. However, other drivers in the United States could play a role in increasing the commercialization of pyrolytic technologies for non-recycled plastics. These include an ample supply of non-recycled scrap plastics, economics of avoided landfill tipping fees, and the growing demand for less expensive, alternative fuel products.

9. Growth model for the technology in the U.S.

Pyrolytic technologies are not new and have a long history in the U.S. Dozens of companies have courted investors to finance plastic pyrolysis technologies. However, these companies failed to deliver economically viable, commercial-scale systems. Scaling the technology beyond bench scale proved problematic for decades, as did the quality of the fuel product. The history of this technology may cause some to be initially hesitant to invest in the technologies of today. However, the newest generation of pyrolysis technology manufacturers claim to have addressed most of those challenges, and appear poised to make the leap to commercial-scale installations. Confidence in the long-term viability of these systems is increasingly being bolstered by success stories of similar systems in other parts of the world.

While the U.S. does not have a landfill crisis, numerous mandates to increase diversion, or a particular collective ethic to find as much value in our waste streams as possible, the U.S. does have many of the same market dynamics that have made these systems a success abroad. And, North American technology manufacturers are offering a model of commercialization that utilizes these market advantages. Those positive market conditions are a consideration when evaluating optimal facility locations. First, close proximity to a collection or generation point for non-recycled scrap plastics (access to supply) is important. And if needed, proximity to a refinery (demand for product) should be considered. In many cases, systems producing a product needing additional treatment need not be located near a refinery, however the logistics for transporting the product to the refinery should be considered when factoring in production costs.

Two of the companies that have systems abroad have been actively seeking potential sites for systems in the U.S. These companies have had discussions with state and local governments about tax and business incentives, which can also be a compelling factor when deciding where to locate a facility. While these systems are not eligible to receive recycling grants or tax credits, there a number of other economic incentive programs that these systems may be eligible for, including job creation tax credits and potential eligibility for U.S. Department of Agriculture grants if the facility is built in a rural location.

While the U.S. generally lacks some of the economic, environmental, and policy drivers that have encouraged investment in commercialization abroad, it is important to consider the likely factors that could ultimately spur investment in North America. Some of those likely factors include: rising fuel costs; growing investment in “green” or “clean” technologies and, in particular, investment in alternative fuel production; as well as the pressure to increase the recovery of plastics.

Rising fuel costs. Fuel costs had been relatively stable over the past year; however increased political unrest in oil-producing nations has caused some price increases in 2011. For companies that have integrated waste hauling and waste sorting businesses, investment in PTF systems could be an ideal way to create a synergy between the abundant supply of non-recycled plastics being handled at MRFs and creating a long-term cost control strategy for fleet fuel costs. Alternatively, those companies looking to market the finished product from PTF facilities will be able to fetch higher prices for their product. Those companies running PTF systems that produce an oil product report the sale price of that product tracking just slightly lower than the NYMEX price of crude oil. As the price of crude rises, so could the sale price of the product, making ROI timeframe potentially shorter.

Alternative fuel. Because the health of the U.S. economy is so closely tied to fuel costs and the U.S. has little influence on the ability to control factors that contribute to those rising costs, alternative fuels are seen as an important investment. There is also a drive to produce more clean energy in the U.S.; specifically energy derived from alternative sources that do not require extraction of natural resources. PTF technology, like the development of ethanol and bio-diesel technologies, is an alternative fuel option. However, to date much of the focus on non-traditional fuels has been on developing "renewable" fuel sources. The ethanol and bio-diesel industries have seen sizeable investments made to build capacity in these two areas. These investments are sizable in large part due to the renewable fuel standards created through government initiatives. More decision-makers are recognizing that the scope of the focus for supporting non-traditional derived fuel should be expanded to include all alternative fuel sources. Creating demand for PTF products, similar to the demand created for renewable fuels, would be a likely catalyst for investment in commercialization of this technology.

Efforts to increase the recovery of plastics. The recovery rate for commodity scrap plastics has made just incremental gains over the past ten years. In 2009, it is estimated that 28 percent of PET bottles and 29 percent of HDPE bottles were recycled in the U.S.[10] Each year, reclaimers report one of the biggest challenges to their business is the constraint presented by collection rates. In a move to increase the volume of desirable HDPE and PET plastics, many communities have adopted "all bottle," or all plastic container collection programs. Many of the Nos. 3-7 containers that are collected in such programs are landfilled, or perhaps exported to Asia if domestic markets cannot be identified. If a stable and local solution for those Nos. 3-7 containers were available, many more communities might be able to expand to "all bottles," or all plastic container collection system systems in an effort to increase collection of PET, HDPE, and PP.

Many communities in the U.S. have not expanded recycling programs because either the technology is not in place to effectively separate a wide variety of plastics, or communities do not want to begin to collect material for which markets are uncertain. PTF technologies could afford municipalities an end-of-life solution they need for the non-recycled plastic that would be inevitably collected when recycling programs expand in an effort to increase recovery of PET and HDPE. The move to single-stream has been shown to both increase the volumes recovered for all recyclable commodities, but contamination tends to increase as well. Once the valuable plastics have been separated from the co-mingled mix of materials, MRFs are left with piles of plastics that are not suitable for recovery. Some of these plastics are films that are too contaminated for recovery at retail outlets. While these items cannot be mechanically recycled, they are the perfect feedstock materials for PTF systems.

10. Identified opportunities

A second goal of this study is to identify the opportunities that exist for creating favorable conditions for commercializing this technology in the U.S. Potential investors will want to know what favorable conditions exist that will support commercialization of this technology. A number of these opportunities have been touched upon in this report, including:

[10] *2009 United States National Post-Consumer Plastics Bottle Recycling Report.* Prepared by the American Chemistry Council and the Association of Postconsumer Plastic Recyclers, http://www.americanchemistry.com/s_plastics/sec_content.asp?CID=1593&DID=11513.

- There is ample supply of scrap material (feedstock) for these systems, as mechanical recycling currently captures seven percent of the plastics in the municipal solid waste stream (US EPA, 2009).
- Demonstrated fuel product is in demand and there are numerous buyers.
- In terms of permitting, only a basic air pollution permit is required, as the conversion process emits just a fraction of the allowable emissions under air permit standards. This is important in terms of the flexibility that exists for increasing the scale of a facility.
- Cost of tip fees is not a factor in siting facilities, so opportunity is ample.
- Economics of some of these systems are favorable, even if the price of oil drops down to $40 per barrel.
- Systems range in price from $1 million to $5 million for 7,500 -10,000 ton-per- year facility.
- According to technology manufacturers, ROI is relatively short, ranging from one to four years.
- For internal users of the end products, these technologies can present an opportunity to control fuel costs, which are projected to rise in the long-term.

One additional opportunity is the apparent widespread support for PTF technologies amongst the recycling industry. Perhaps the greatest fear by recycling proponents of PTF technologies is that highly recycled plastic such as PET and HDPE bottles, or growing plastics recycling such as rigid PP containers such as tubs and lids would end up as feedstock for these systems, reducing the amount of these plastics available for reclamation. PTF is certainly not the highest and best use for that plastic. Since the economics of these systems are designed around the strategy of obtaining scrap material for free, or nominal cost, large volumes of these plastics ending up in the PTF feedstock is not currently a valid concern.

To gauge support for PTF technologies amongst key sectors of the plastics recycling industry, Resource Recycling, publisher of *Plastics Recycling Update*, surveyed MRF operators and HDPE and PET reclaimers on the issue of PTF. Their responses are as follows:

Reclaimers	Do you support the development of plastics-to-oil systems as a complement to the current recycling infrastructure to manage plastics that are otherwise deemed “unrecyclable,” such as labels, bags or caps?	
	Yes - 80.0%	No - 20.0%
MFRs	One option for marketing the mixed, contaminated plastics generated at a MRF is to convert this material back into chemical feedstocks to make plastics again, or to convert this material into energy. Do you think conversion is a good idea?	
	Yes – 80.4%	No – 19.6%

11. Identified barriers

While it is important to understand the opportunities that might favor adoption of this technology, it is equally important, to identify some of the key barriers that could continue to present challenges for the commercialization of PTF technologies. Factors that present challenges are discussed below.

Classification of the technology is unclear. Some of the technology manufacturers that have built pilot-scale facilities have encountered some uncertainty as to how their PTF facility should be permitted. Most regulators do not have experience with this technology, and it does not neatly fall into a pre-existing category of a materials management facility. Currently a transfer station, recycling facility, or MRF are the common facility permitting options for materials management with which regulators are familiar. Sometimes PTF facilities are classified not so neatly under one of these groupings. In some instances, states such as New York, have a specific classification for pyrolysis facilities, but not all of these systems fit that category neatly, since some of pyrolysis systems operate at temperatures that are below the temperatures that traditionally have been used for pryolytic conversion. The result is that permitting a facility can take longer than expected and facilities might be required to obtain permits that had not been anticipated. As regulators become more familiar with siting these facilities, this challenge should diminish over time.

Conversion does not always count toward recovery rates. In most communities, the scrap plastic materials that could be recovered for PTF may not always count toward mandated recovery and recycling rates. For example, in California communities are mandated to "divert" 50% of material from disposal by 2000 based on 1990 disposal figures, "through source reduction, recycling and composting."[11] Diversion credit comes through reuse, recycling and recovery. Communities that had pre-approved waste to energy, and other conversion technologies in place before the passage of the law can claim a 10 percent credit toward the diversion goal. Since pyrolysis is considered a "transformation technology" in California, and no PTF facilities were sited in California before the passage of the diversion requirements, in many cases it does not count toward diversion rates.

The only exception to this would be for material that is managed at a facility that does not require a solid waste facility permit (SWFP). So, for example, if a PTF system were at the back end of a MRF, converting landfill-bound plastics to usable fuel, the material diverted from the landfill to the PTF system would count toward diversion credit. If that same type of landfill-bound feedstock for the PTF system were recovered at a transfer station or landfill, which does require a SWFP, then it would not count toward the diversion goal. This ambiguity can create a level of uncertainty around investment in, and adoption of this type of technology.

Ineligibility for recycling grants. At this time, pyrolytic conversion is not considered a form of recycling (see above), despite the fact that the technology could provide a "highest and best use" for

[11] *Guidance document: How conversion technologies fit current board regulatory structure*. California Integrated Waste Management Board, December 2007, http://www.calrecycle.ca.gov/lea/Mail/2007/ConversnTech/Guidance.pdf.

otherwise landfill-bound plastics. Federal, state and local grant opportunities exist to support the growth of recycling activities. However, because PTF does not fall into the category of "recycling", these projects are not currently eligible for recycling grants.

Alternative, not renewable fuel. As discussed in Section 10, considerable demand for renewable fuels has been created as a result of renewable fuel standards and government mandates. These fuel standards require that certain levels of fuel derived from renewable resources be blended with conventionally derived fuels. New demand for these fuels has created opportunity for investment in the alternative fuel industry. PTF products do not qualify as renewable; however they qualify as alternative. Work is being done at the federal level to replace "renewable" with "alternative" in regards to fuel standards.

PTF needs to be formally recognized as separate from incineration. While incineration or mass burn waste-to-energy (WTE) is commonly used to treat MSW in Europe and other parts of the world, WTE has met great opposition in the U.S. Concerns over environmental impacts and the impact incineration can have on material recovery rates have been voiced by those opposing expanded use of WTE. Environmental groups have voiced concerns over using other conversion technologies, such as gasification and pyrolysis systems, which they believe to be very similar to WTE incineration. In fact, Greenpeace lists pyrolysis as an incineration technology.[12] However, as discussed in Section 2 of this report, PTF technologies specifically treat plastics, have a different thermal treatment process that yields little emissions, and thus should be distinguished as a separate technology.

Many if not all of the barriers identified above could be addressed through broader recognition and/or adoption in the United States of ISO 15270, which includes cracking, gasification and depolymerization in its definitions of "chemical recycling" and "feedstock recycling." In addition, this ISO standard includes various forms of recycling and energy recovery in its definition of "recovery."

Systems treat just one fraction of the waste stream. While this is certainly a benefit in some regards, PTF technologies are designed to only treat scrap plastics. This could be a major detraction for a municipality that is faced with landfill constraints in the near future and needs to seek viable alternatives to treat the total of the MSW stream. According to the U.S. EPA, plastics only represent a total of 12.3% of the waste stream.[13] Communities like Los Angeles that face an impending landfill space shortage will need to invest in technologies that will provide much larger diversion potential to meet long-term solid waste management needs. PTF technologies are however a reasonable technology option for communities that are looking at long-term solutions for extending the life of landfills and finding new means to transform non-recycled plastics into a resource.

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[12] *Types of Incineration.* Greenpeace, http://archive.greenpeace.org/toxics/html/content/incineration/types.html#pyr.
[13] *Municipal Solid Waste.* U.S. EPA, http://www.epa.gov/epawaste/nonhaz/municipal/index.htm.

12. Policy options for promoting PTF technologies

A number of policy strategies can be employed to help mitigate the barriers to commercialization of PTF technologies in the U.S. These include creating aggressive recovery targets for plastics, making PTF installations eligible for federal and state tax credits, creating specific demand for PTF products and clearly defining PTF technology as separate from other conversion technologies that treat the entirety of the municipal solid waste stream. A number of these policy strategies have been successfully employed abroad.

Perhaps one of the most significant measures of this nature to be introduced in the U.S. was House Bill 3592, better known as the "Plastics Recycling Act of 2009." This federal measure would have created a $0.60 per gallon tax credit on the production of qualified synthetic oil derived from plastics at "qualified small conversion process recycling facilities." A qualified facility would have maximum processing capacity of 2,000 barrels of oil a day. Analysis of this bill suggests it could have addressed two of the primary barriers to commercialization of PTF technologies discussed in this paper – defining PTF as recycling and creating an incentive for investment. Unfortunately, this bill failed to move out of committee during the 111th Congress and is no longer an active measure. While many PTF technology manufacturers supported the measure as a means to spur investment and commercialization, attention to creating new demand for this product as an alternative fuel is reported to be of higher priority than subsidies at this time.

Two notable measures have been introduced at the state level, which address the definition of pyrolytic technologies. The first was Assembly Bill 1150, introduced in California in 2008. This measure would have removed pyrolysis from the definition of "transformation" technologies, which includes incineration. Currently the California Public Resources Code defines "recycling" as separate from "transformation." This code too would have addressed two barriers – changing the status of pyrolysis so it is not expressly omitted from the definition of recycling and defining pyrolysis as distinctly different from incineration. Assemblyman Ted Lieu (D-Torrance) eventually abandoned the effort, amending the bill to make it a health care measure.

The latest measure to be introduced that would attempt to redefine plastics pyrolysis as recycling is House Bill 3597, which was introduced in Oregon in 2011. This bill is currently under consideration.

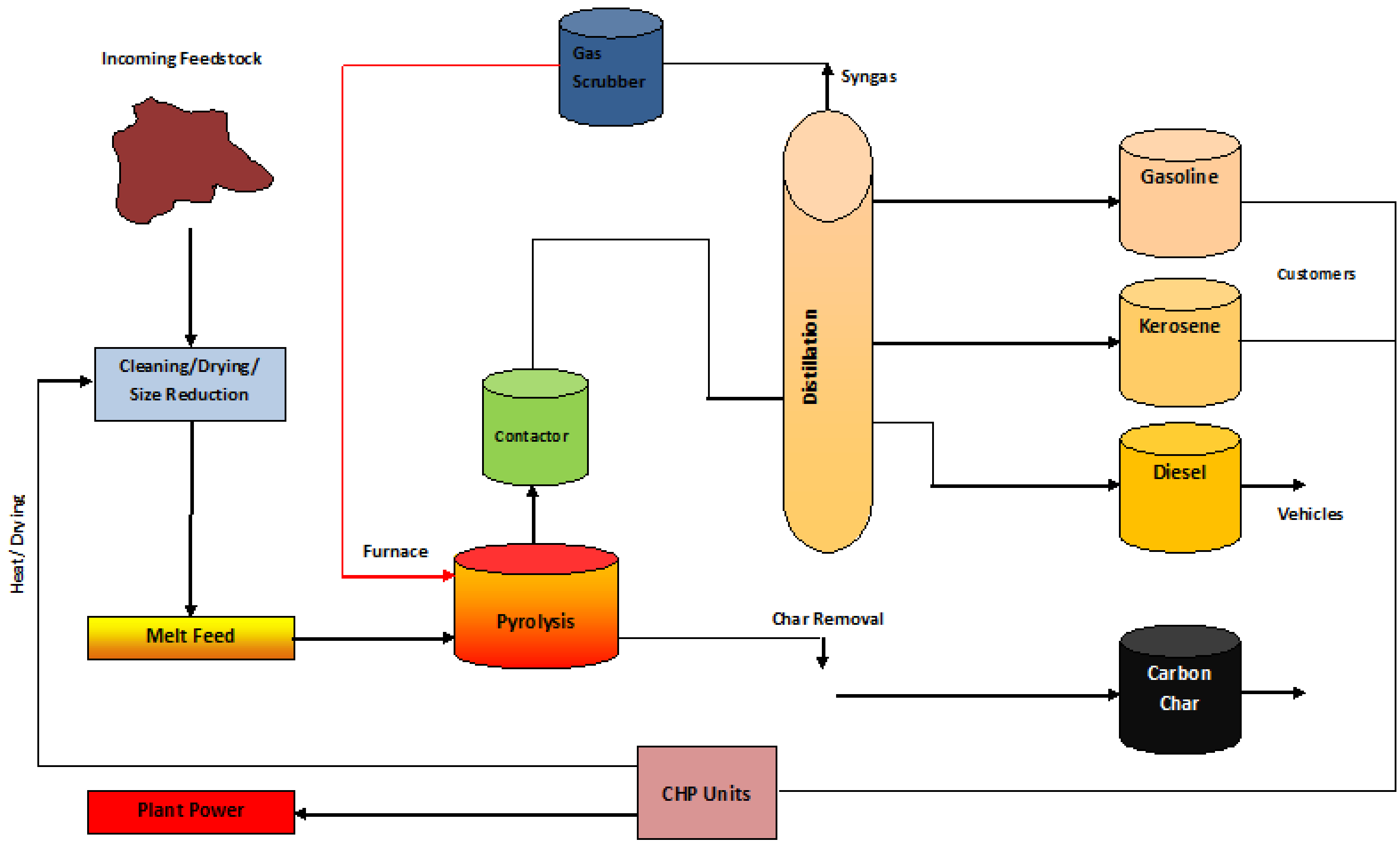
13. Outlook for commercialization for PTF technology in the U.S.

Many of the technology manufacturers in North America that have been operating pilot-scale facilities are hopeful that they will be able to secure investment for a commercial-scale facility in the next two or three years, if not sooner. A number of firms operating commercial facilities in other parts of the world have also expressed strong interest in bringing this technology to the U.S. Two firms with functional systems in place abroad have had serious discussions with state and local agencies about potential economic incentives that might be available for constructing a facility. The outlook for commercialization of PTF technology in North America in the near-term looks strong, as three operators of foreign systems are actively looking to site a facility in the U.S. and at least one U.S. PTF technology manufacturer has reported three systems slated for installation. Other PTF manufacturers reported being in active negotiations with potential municipal and private partners.

A recent development that demonstrates the growing interest in PTF technologies is the latest investment in the Agilyx plastic-to-oil technology. The $22 million investment includes financial support from Waste Management, the world's largest waste management firm and Total S.A., a major international oil company. A partnership of this nature is important as it supports the primary benefits that PTF technology offer – a recovery opportunity for non-recycled plastic which, through conversion, creates a valuable resource. An investment of this nature also adds validity to the use of this technology as a tool that the waste management and recycling industry can use to maximize material recovery and value. As Waste Management stated, the technology provides "a viable option for processing contaminated and hard to recycle plastic resins" and create "a high value commodity." For communities and their waste management partners, PTF technologies offer a double positive.

There is great optimism amongst other technology manufacturer's that Agilyx's success will not be unique. Additional investment in this area could lead to installation of the first commercial scale facilities in North America over the next few years. While drivers for investment in these systems vary based on political and environmental conditions, the sustaining factors of success seem to be universal, including ample supply of feedstock and demand for the fuel and oil product. Growing acceptance of this technology amongst the solid waste management community may also aid the movement toward favorable policies for PTF and the fuel products which will eliminate some of the current barriers for commercialization. These developments, coupled with the advances made by the latest generation of pyrolytic technology could create a bright future for PTF as a recovery opportunity for non-recycled plastics, and offer an enhancement to the existing plastics recycling infrastructure.

Appendix A: Pyrolysis process flow



Schematic courtesy of Cynar Plc, 2011

Appendix B: Technology forms from system manufacturers

These forms contained in Appendix B were collected from the technology manufacturers between February 2011 – April 2011. All information contained in the forms is self-reported information and appears as it was originally submitted.

Company Name: Agilyx

Company Location: Tigard, OR

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Currently running over a dozen sources, including: Ag lastics, some post-consumer, post-industrial and numerous customer samples from all over the world.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: Handling 3-7, primarily ☒ Engineering grade resins Comments: yields will vary with resin type ☐ PLA Comments: Should be OK, but have not tested it specifically. Others: Can handle loads up to 70% PVC, which is unique. System can handle a mix of rigids and films.
Resins not accepted by the system	List specific resins these system cannot handle Nylon 6 does not do well, so not a good solution for unprocessed carpet.
Toleration of contaminants	Is there a maximum contamination level, moisture level? system can handle any level of contamination and contaminants ranging from metal, glass, food, paper, water. Agilyx has run a load of up to 50% iron without any difficulty. The yield goes down with contamination, but the system can handle it.
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: 80% ☒ Natural gas; proportion of the output: 12% ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? 8% powdery carbon residual And, how is this residue treated (ex., landfilled)? Have been giving away the carbon residual which is being used in steel manufacutring. The material has BTU value so it could be burned. It could also be landfilled.
Description for the process	Brief description of the process Anaerobic thermal reclamation Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☒ Yes ☐ No
Process Yield	Conversion rate: 80% OR For one ton of plastic in, you get ~5 barrels of oil amount of usable product out. Other comments: yields depend on feedstock content
System capacity	Size of current system in operation (tons per year): 3,500 t/y

	System is scalable: ☒ Yes ☐ No If system is scalable: Min /Max most interest is in 20-30 t/d (about 10,000 t/y) (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments:
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 4 years or less
Number of facilities in operation	No. of facilities: 1 Years in operation 4.5 Location of facilities: Tigard, OR Size of facility: 10 t/day (3,500 t/year)

Company contact information:

Contact person: Chris Ulum
Address: 7904 SW Hunziker St., Tigard, OR 97223
Web address: www.agilyx.com
Phone: 503-217-3160
Email: culum@agilyx.com

Company Name: Anhui Oursun Environment &Technology Corporation

Company Location: Hefei,ANhui ,China

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place PPE.PE.PET.HDPE.LDPE.PP.PS.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: ☒ Engineering grade resins Comments: ☒ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle
Toleration of contaminants	Is there a maximum contamination level, moisture level? YES,IT WILL AFFECT THE AMOUNT OF THE OIL
Output/Product	Describe the product yielded from the process (check all that apply) ☒ Diesel (no gasoline), proportion of the output: 85% ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: 85% ☐ Natural gas; proportion of the output: % ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☒ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? carbon black And, how is this residue treated (ex., landfilled)? as a fuel
Description for the process	Brief description of the process Uses microwave frequencies to extract oil and gas from plastics. Uses a catalyst: ☒ Yes ☐ No Process conducted in a vacuum: ☒ Yes ☐ No
Process Yield	Conversion rate: OR For one ton of plastic in, you get 50-85% amount of usable product out. Other comments:
System capacity	Size of current system in operation (tons per year): 8000 System is scalable: ☒ Yes ☐ No If system is scalable: Min /Max 18000 (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments:
Estimated time frame for Return on	Based on projections with energy, labor and other costs remaining consistent over time.

Investment	it depends.but it ususally it will get net benefits in one year
Number of facilities in operation	No. of facilities: Years in operation 7 Location of facilities: HEFEI,Anhui,China Size of facility: two sites

Company contact information:

Contact person: Jane Tall
Address: hefei ,anhui
Web address: www.oursunchina.com
Phone: 0086+13965124132
Email: janegll@hotmail.com

Company Name: Climax Global Energy

Company Location: Allendale, South Carolina

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place MRF residue (muni and private); private recyclers
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: Post-consumer ☐ Engineering grade resins Comments: ☐ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle Have not tested engineered plastics
Toleration of contaminants	Is there a maximum contamination level, moisture level? Our feed can be mixed/dirty (e.g. paper, rocks, metals, etc) and wet; affects economics
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: 75% ☐ Natural gas; proportion of the output: % ☐ Monomers; proportion of the output: % Other: Can be refined into ULSD, wax/lubricants Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? Char And, how is this residue treated (ex., landfilled)? Landfilled or incinerated
Description for the process	Brief description of the process Uses microwave pyrolysis to break down plastics into syn-crude. Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: OR For one ton of plastic in, you get 5 bbl amount of usable product out. Other comments:
System capacity	Size of current system in operation (tons per year): 1,000 System is scalable: ☒ Yes ☐ No If system is scalable: Min /Max (tons per year)
Independent engineer's review available	☐ Yes ☒ No Comments: All engineering in-house. Product test results available.

Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 3 yrs
Number of facilities in operation	No. of facilities: 1 Years in operation 1 Location of facilities: SC Size of facility: 3 ton/day

Company contact information:

Contact person: John Griffith
Address: 450 Springfield Ave, Suite 201, Summit, NJ 07901
Web address:
Phone: (908) 277-2227
Email: johngriffith@climaxglobalenergy.com

Company Name: Cynar Plc

Company Location: Central Ireland

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place MAterial Recycling Facilities throughout Ireland
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: 2,4,5 and 6 ☒ Engineering grade resins Comments: ☐ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle PVC and PET
Toleration of contaminants	Is there a maximum contamination level, moisture level? 5% recommended but more contamination equals reduced output
Output/Product	Describe the product yielded from the process (check all that apply) ☒ Diesel (no gasoline), proportion of the output: 75% ☒ Diesel/gasoline mix , proportion of the output: 75/20% ☐ Product similar to crude oil; proportion of the output: % ☒ Natural gas; proportion of the output: 5% ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? 4% Char And, how is this residue treated (ex., landfilled)? Landfilled at the moment but being worked on for other applications.
Description for the process	Brief description of the process Pyrolysis of end of life plastics then specific distillation of the gases Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☒ Yes ☐ No
Process Yield	Conversion rate: 96% OR For one ton of plastic in, you get 750 litres of EN590 diesel and 200/250 litres of gasoline amount of usable product out. Other comments:
System capacity	Size of current system in operation (tons per year): 10 tons per day System is scalable: ☒ Yes ☐ No If system is scalable: Min 6000/Max 12000 (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments:
Estimated time frame for Return on	Based on projections with energy, labor and other costs remaining consistent over time.

Investment	£6m with an EBITDA of £1m
Number of facilities in operation	No. of facilities: 1 Years in operation 3 Location of facilities: Central Ireland Size of facility: 3000 tpa

Company contact information:

Contact person: Michael Murray
Address: Cynar Plc Portlaoise, Ireland
Web address: www.cynarplc.com
Phone: +353 86 608 1450
Email: michaelmurray@cynarplc.com

Company Name: Envion

Company Location: Washington, D.C.

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Scrap plastics from curbside mix, sourced directly from the MRF. Nos. 1-7, but have designed the system to run with Nos. 1-3 picked out (PET oil yield is very low).
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: Nos. 1-3 are sorted out. ☐ Engineering grade resins Comments: ☐ PLA Comments: Others: PVC is not acceptable but tolerated. Must be below 5 to less than 1% of the mix. Furthermore, human exposure to PVC type chemicals during the cracking process is a health hazard and not recommended .
Resins not accepted by the system	List specific resins these system cannot handle PVC and PVC related plastics are not desirable because of the corrosion factor and the product oil is also not good quality. PLA won't yield much oil, similar to PET.
Toleration of contaminants	Is there a maximum contamination level, moisture level? Moisture can be steamed out. Contamination like dirt and organics are not recommended. The system can accommodate paper the best. Because it's presorted plastics, the contamination should be relatively low.
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: 70% ☒ Natural gas; proportion of the output: 15%% ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? There is a heavy oil component that remains (aka char). 15% sludge. And, how is this residue treated (ex., landfilled)? Have tried to put it into asphalt but it’s not a binder. There is a carbon component to it, so it can be clean burned since it's mostly carbon, and generate electricty to feed back into the system (20% of electricity is coming from process gasses, clean burning the char could add another 25% of energy needs).
Description for the process	Brief description of the process Far-Infrared heating process. Catalysist is an electromagnetic wave. Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☒ Yes ☐ No
Process Yield	Conversion rate: about 70% OR For one ton of plastic in, you get 4.22 barrels of oil amount of usable product out.

	Other comments: About 10%-15% of material is the sludge/char, 15% process gases which are piped back into the system.
System capacity	Size of current system in operation (tons per year): 10,000 t/year is commercial System is scalable: ☒ Yes ☐ No If system is scalable: Min 10,000 t/y/Max just add multiple reactors for increased capacity (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments:
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 3-4 years if the system is integerated at the generators facility, longer ROI if the facility is at a stand alone site.
Number of facilities in operation	No. of facilities: 1 Years in operation 1.5 Location of facilities: Montgomery County, MD* Size of facility: demo faciltiy is 3,000 t/y

*Will be moved to a MRF by mid-2011 (permanent facility)

Company contact information:

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Company Name: GEEP

Company Location: Barrie, Ontario

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Plastics from electronics
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: ☒ Engineering grade resins Comments: ☐ PLA Comments: Others: mixed plastics, shredded-light fraction, can handle PVC
Resins not accepted by the system	List specific resins these system cannot handle None
Toleration of contaminants	Is there a maximum contamination level, moisture level? 40%
Output/Product	Describe the product yielded from the process (check all that apply) ☒ Diesel (no gasoline), proportion of the output: 100% ☐ Diesel/gasoline mix , proportion of the output: / % ☐ Product similar to crude oil; proportion of the output: % ☐ Natural gas; proportion of the output: % ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? carbon/oil sludge And, how is this residue treated (ex., landfilled)? centrifugated for recovery of oil into process, then compacted, disposed of at this point, when going into full production we will send material to steel mills as reducing agent and slag former
Description for the process	Brief description of the process Process converts waste Plastics from electronics (mainly PS, ABS, PC or blends thereof) into a usable diesel fuel at a yield of around 75%. Uses a catalyst: ☒ Yes ☐ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: 75% OR For one ton of plastic in, you get 750 kg amount of usable product out. Other comments: This is the yield for our average e-waste plastic mix. Can be higher or lower depending on the chemical structure of the plastic used (Example: for PE this can be 96%, for PVC only 12%.
System capacity	Size of current system in operation (tons per year): 6000 System is scalable: ☒ Yes ☐ No If system is scalable: Min /Max (tons per year)

Independent engineer's review available	☐ Yes ☒ No Comments: We havent done this yet (other than PSHR reviews to get our permits), but guests are welcome to have a look at the system if there is an interest.
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. For a production plant about 24 month
Number of facilities in operation	No. of facilities: 1 Years in operation 4 Location of facilities: Barrie, ON Size of facility: 500 liters/hour

Company contact information:

Contact person: Patrick Oberle
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Email: poberle@barriemetals.com

Company Name: JBI Global, Inc.

Company Location: Niagara Falls, Canada

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place 2,4 and 5 according to the Ontario Blue Box program, have the highest yield.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: 2,4 and 5 have the highest yield ☐ Engineering grade resins Comments: . ☐ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle The process accepts all types of engineering resins
Toleration of contaminants	Is there a maximum contamination level, moisture level? No
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☒ Diesel/gasoline mix , proportion of the output: 70/30% ☐ Product similar to crude oil; proportion of the output: % ☒ Natural gas; proportion of the output: 8.0% ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☒ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? carbon black, which is 1-5% of yield And, how is this residue treated (ex., landfilled)? The residue has a 10,600 BTU/lb heating value but can also be landfilled
Description for the process	Brief description of the process low-temperature thermal process. Uses a catalyst: ☒ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: 86.7% OR For one ton of plastic in, you get amount of usable product out. Other comments: 1kg of plastic in equals 1 Litre of fuel out
System capacity	Size of current system in operation (tons per year): aroximately 7000 T per year System is scalable: ☒ Yes ☐ No If system is scalable: Min 1T/Hour/Max (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments:
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. One year, or less

Number of facilities in operation	No. of facilities: 1 Location of facilities: Niagara Falls, NY

Company contact information:

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Company Name: Klean Industries Inc

Company Location: Headquarters, Vancouver, British Columbia, Canada

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place End of life plastics from municipal waste streams (MSW), material recycling facilities (MRF), agricultural scrap plastics, plastic films, post consumer, post industrial, automotive shredder residues (ASR), e-waste.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: Primarily processing PE, HDPE, LDPE, PS, PP ☒ Engineering grade resins Comments: Yields vary oil/char ratio ☒ PLA Comments: Others: System can handle loading of PVC and PET of up to 20% of in feed volume.
Resins not accepted by the system	List specific resins these system cannot handle The systems accepts all engineer resins, end yields will vary depending on the resins.
Toleration of contaminants	Is there a maximum contamination level, moisture level? Feedstock can be mixed, wet, dirty (i.e. metal, paper, soil etc) system integrated material handling systems that removes 95% of contamination. However it should be noted that more processed contamination means reduce yields by volume.
Output/Product	Describe the product yielded from the process (check all that apply) ☒ Diesel (no gasoline), proportion of the output: 70% ☒ Diesel/gasoline mix , proportion of the output: 70/30% ☐ Product similar to crude oil; proportion of the output: % ☒ Natural gas; proportion of the output: +/-10% ☒ Monomers; proportion of the output: +/-30% Describe state of the final product once it comes out of the system ☒ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? Continuous processing limits the production of char however less than 5% of infeed volume becomes char depending on feedstock. And, how is this residue treated (ex., landfilled)? It's pellitize, used and sold as a co-combustion fuel / coal replacement, used at steel mills and in CHP pellet boilers.
Description for the process	Brief description of the process A low temperature (less than 500 degrees Celsius) pyrolysis liquefaction based technology that produces high CV syn-gases at ambient pressure that are then processed using fractional distillation. Uses a catalyst: ☒ Yes ☒ No Process conducted in a vacuum: ☒ Yes ☒ No
Process Yield	Conversion rate: Depends on feedstock average 85% to 95% OR For one ton of plastic in, you get 650 litres to 950 litres (both gasoline & diesel)

	amount of usable product out. Other comments: Depending on how the system is configured and the plastic being processed specific volumes can be increased or decreased using specific controls not available with other systems.
System capacity	Size of current system in operation (tons per year): 35,000 System is scalable: ☒ Yes ☐ No If system is scalable: Min 1000/Max 75,000 (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments: The technology is in production for some of the world largest oil and chemical producers. Many reports and periodicals are available. It is one of the world's longest running, most commercailly proven technologies for processing mixed waste plastic on a largest scale.
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. Depends on the configuration of the plant, its location, balance of plant requirements, EPC requirements, infrastructure and other factors however most plants have a complete return on capital in 36 to 48 months. With consistent energy, labor and running costs.
Number of facilities in operation	No. of facilities: 7 Years in operation 12 Location of facilities: Asia/Europe Size of facility: Various sizes from 1000 tonnes per annum to 35,000 tonnes per anum.

Company contact information:

Contact person: Jesse Klinkhamer

Address: #903 - 1495 Richards Street

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Email: sales@kleanindustries.com

Company Name: KOREA ECO-System

Company Location: 439-3 Songnae-Dong Sosa-Goo

Buchon City, Kyonggi-Do, Korea

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Korea
Resins accepted by the system	List those that have been tested with success ☐ Nos. 1-7 Comments: ? ☐ Engineering grade resins Comments: ? ☐ PLA Comments: ? Others:
Resins not accepted by the system	List specific resins these system cannot handle N/A
Toleration of contaminants	Is there a maximum contamination level, moisture level? N/A
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: 7% ☐ Diesel/gasoline mix , proportion of the output: gasoline/10% ☐ Product similar to crude oil; proportion of the output: 0% ☐ Natural gas; proportion of the output: 0% ☐ Monomers; proportion of the output: 0% Describe state of the final product once it comes out of the system ☒ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? 3% of coke And, how is this residue treated (ex., landfilled)? selling to coal companies
Description for the process	Brief description of the process Uses microwave frequencies to extract oil and gas from plastics. Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: OR For one ton of plastic in, you get 1,000 liters of oil amount of usable product out. Other comments:
System capacity	Size of current system in operation (tons per year): 263,000 liters of oil System is scalable: ☒ Yes ☐ No If system is scalable: Min /Max (tons per year)
Independent engineer's review	☒ Yes ☐ No

available	Comments:
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. Net profit for year - USD 52,200
Number of facilities in operation	No. of facilities: 3 Years in operation Location of facilities: Korea Size of facility: 100 liters for 100 kg load each cycle for 4 ~ 5 hrs

Company contact information:

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Company Name: Natural State Research

Company Location: Stamford, CT

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Mix of plastics from municipal waste stream. Encourage propsective investors to send sample of materials to their labs to determine yeild and ROI.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: PVC and PET should be removed ☐ Engineering grade resins Comments: ☐ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle PVC and PET need some pretreatment for removal of chlorine and oxygen
Toleration of contaminants	Is there a maximum contamination level, moisture level? System can handle ag film, dirt and contamination does not seem to be a problem.
Output/Product	Describe the product yielded from the process (check all that apply) ☒ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☐ Product similar to crude oil; proportion of the output: % ☒ Natural gas; proportion of the output: % ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☒ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party Other: Product can be tailored to consumer's needs. The system can produce heating oil, gasoine, naphtha, aviation diesel, all which meet ASTM standards. Also produced No. 6 fuel, which is currently being tested.
Residue	What is the residue (ex., char)? If you run it in batches, you'll get char. With continuous operation you get little to no char. And, how is this residue treated (ex., landfilled)? Every three to six months you clean the sytem. Char has high carbon content and can be mixed in and used as road carpteting, roofing material. It could be landfilled if an alternative end use could not be found, but they haven't had to do that yet.
Description for the process	Brief description of the process Thermal liquification process that decomposes the hydrocarbon polymers of waste plastic, and converts them into the shorter chain hydrocarbons of liquid fuel. Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: 95%-98% OR For one ton of plastic in, you get amount of usable product out.

	Other comments:
System capacity	Size of current system in operation (tons per year): 6 kg/hour System is scalable: ☒ Yes ☐ No If system is scalable: Min /Max (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments:
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 1-2 years if the cost of fuel production is estimated at $0.75/gal.
Number of facilities in operation	No. of facilities: 1 Years in operation Location of facilities: Stamford, CT Size of facility: Demonstration lab, next facility will be 100 kg/h, and hope to have a commercial scale facility by 2012

Company contact information:

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Web address: www.naturalstateresearch.com
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Company Name: Nexus Fuels

Company Location: Atlanta, Georgia

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Bench scale system at this time, sourcing scrap as needed for testing. Commercial scale facilities would source post-consumer and post industrial plastics that are otherwise being landfilled or exported.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: Nos. 2, and 4-7, don't want much PVC or PET, will largely be going after LDPE film ☐ Engineering grade resins Comments: ☐ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle
Toleration of contaminants	Is there a maximum contamination level, moisture level? Paper contamination is an issue, testing way to remove paper before the plastics enter the system. Moisture is not a problem but increases energy cost to process.
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☒ Diesel/gasoline mix , proportion of the output: 70/80% ☐ Product similar to crude oil; proportion of the output: % ☒ Natural gas; proportion of the output: 8-12% ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? Residue, which is about 4-9% And, how is this residue treated (ex., landfilled)? Landfilled/ managed asphalt adjunct
Description for the process	Brief description of the process thermal cracking Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: 75-91% OR For one ton of plastic in, you get 1700 lbs amount of usable product out. Other comments:
System capacity	Size of current system in operation (tons per year): System is scalable: ☐ Yes ☐ No If system is scalable: Min /Max (tons per year)
Independent engineer's review	☐ Yes ☒ No

available	Comments:
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. NA at present
Number of facilities in operation	No. of facilities: 1 Location of facilities: Atlanta, Georgia Size of facility: Currently bench scale, hope to have a 10,000-20,000 t/year facility sited in the Atlanta area.

Company contact information:

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Email: jeff@iescylinders.com

Company Name: Plastic Advanced Recycling Corporation

Company Location: 7884 S.Quincy Street, Willowbrook IL 60527

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place partly from MSW after separation and another part is from paper mills.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: the oil yield will be different with different mixtures of resins. ☐ Engineering grade resins Comments: ☐ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle NO
Toleration of contaminants	Is there a maximum contamination level, moisture level? NO
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: 50%-70% fuel oil can be used directly as furnance fuel for power generation or can be further refined into diesel and gasoline% ☒ Natural gas; proportion of the output: 15-25% and is recycled back into the reactor used as fuel% ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☒ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? 15-25% of the output is residue, mostly carbon black And, how is this residue treated (ex., landfilled)? can be used as raw materials for regenerative carbon black and bricks
Description for the process	Brief description of the process The whole process is carried out in ambient pressure at temperature lower than 500 degrees celsius. Uses a catalyst: ☒ Yes ☐ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: OR For one ton of plastic in, you get amount of usable product out. Other comments: for 30 tons of plastic, we get 4605 gallons of oil and 4.5 tons of carbon black.
System capacity	Size of current system in operation (tons per year): 10,000 System is scalable: ☒ Yes ☐ No

	If system is scalable: Min 10,000/Max (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments:
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 2 and half years
Number of facilities in operation	No. of facilities: 2 Years in operation Location of facilities: China Size of facility:

Company contact information:

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Company Name: Polyflow

Company Location: Akron, Ohio

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place commercial and industrial generators, Akron zoo, building contractors, local MRF, residential collection, MSW, etc
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: 3-7 bales specifically ☒ Engineering grade resins Comments: ABS, SAN, PC, acetal, tires, carpet, SMC(70% inerts), etc ☒ PLA Comments: acceptable. other bio-polymers will be acceptable when available. Others: co-polymers, films, tires, carpet, multi-layer films, HDPE with calcium carbonate, snack bags, pouches, all thermoplastics and thermosets, e-waste polymer
Resins not accepted by the system	List specific resins these system cannot handle the process thrives on a mix. all polymers in the proportions produced by the polymer industry are acceptable in the feed mix. +/- 20% variation around this basaeline has been successfully demonstrated to date.
Toleration of contaminants	Is there a maximum contamination level, moisture level? the process can tolerate contaminants to 50%. to maximize product yield, we limit contaminants (including all materials compounded into the polymer) to less than 25%. we limit water to less than 5%.
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☒ Diesel/gasoline mix , proportion of the output: 33%/33% ☐ Product similar to crude oil; proportion of the output: % ☐ Natural gas; proportion of the output: % ☒ Monomers; proportion of the output: 33% Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? The bseline mix yeilds on average 13% char consisting of the contaminants, fillers glass, and metals in the feedstock. leaving out the tires and carpet reduce the char to 5-7% of the feedstock by weight. And, how is this residue treated (ex., landfilled)? landfilled. it passes the RCRA leachate tests.
Description for the process	Brief description of the process a unique, novel and patented application of pyrolysis Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: baseline polymer waste will yield 67-72% gasoline, diesel fuel and chemical intermediates. clean feedstock yields 78-83%.

	OR For one ton of plastic in, you get 67-72% amount of usable product out. Other comments: the process also produces a clean non-condensible off-gas that is sufficient to power the process.
System capacity	Size of current system in operation (tons per year): 420 lbs / batch pilot plant System is scalable: ☒ Yes ☐ No If system is scalable: Min 16,000/Max 150,000 typical plant (tons per year)
Independent engineer's review available	☒ Yes ☐ No Comments: process demonstrations are available by appointment
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 3-4 years
Number of facilities in operation	No. of facilities: 1 Location of facilities: Akron, OH Size of facility: Pilot facility, building a 16,000 ton/year facility in Akron

Company contact information:

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Company Name: Polymer Energy

Company Location: Circle Pines, MN

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Plasics mined from the landfill, industry scrap, or collected through recycling
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: ☒ Engineering grade resins Comments: ☒ PLA Comments: Others: System is designed for PP and PE plastic
Resins not accepted by the system	List specific resins these system cannot handle PVC
Toleration of contaminants	Is there a maximum contamination level, moisture level? Moisture and contamination levels should be under 15% for optimal yields
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☒ Diesel/gasoline mix , proportion of the output: / % ☐ Product similar to crude oil; proportion of the output: % ☐ Natural gas; proportion of the output: % ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☐ Product needs further refining by a third party
Residue	What is the residue (ex., char)? contaminants are cleaned out with the ash every four to five days And, how is this residue treated (ex., landfilled)? Residue is separted by size and density, Heavy metals are removed. Most of the residue can become a commodity.
Description for the process	Brief description of the process vaporizing waste plastic in an airless chamber with the addition of heat and a catalyst to produce oil Uses a catalyst: ☒ Yes ☐ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: OR For one ton of plastic in, you get 800 liters amount of usable product out. Other comments:
System capacity	Size of current system in operation (tons per year): 8.5 t/day System is scalable: ☒ Yes ☐ No If system is scalable: Min 8.5 t/day/Max (tons per year)
Independent engineer's review available	☐ Yes ☐ No Comments:

Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 3-5 years
Number of facilities in operation	No. of facilities: 14 Years in operation Location of facilities: Size of facility:

Company contact information:

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Phone: 763-225-6600
Email: kradosevich@ntic.com

Company Name: Recarbon Corp.

Company Location: Wilkes Barre, PA

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place waste plastics other than tires
Resins accepted by the system	List those that have been tested with success ☐ Nos. 1-7 Comments: ☐ Engineering grade resins Comments: ☐ PLA Comments: Others:
Resins not accepted by the system	List specific resins these system cannot handle possibly halogens containing plastics
Toleration of contaminants	Is there a maximum contamination level, moisture level? Can handle contamination without presorting.
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: cabout 50% ☒ Natural gas; proportion of the output: trace% ☒ Monomers; proportion of the output: trace% Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? fiber And, how is this residue treated (ex., landfilled)? filtered off and reused
Description for the process	Brief description of the process heating with Biodiesel Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: Unknown, in early bench scale phase OR For one ton of plastic in, you get about 1 ton of product and 0.5 ton of reusable fiber amount of usable product out. Other comments: the process will consume about 0.5 ton of BD
System capacity	Size of current system in operation (tons per year): System is scalable: ☒ Yes ☐ No If system is scalable: Min no limits/Max no limits (tons per year)
Independent engineer's review available	☐ Yes ☐ No Comments:
Estimated time frame for Return on	Based on projections with energy, labor and other costs remaining consistent over time.

Investment	Unknown, economics have not been explored
Number of facilities in operation	No. of facilities: 0 Years in operation 0 Location of facilities: Size of facility:

Company contact information:

Contact person: Howard Gonchar
Address:
Web address:
Phone: 570-262-0266
Email:

Company Name: Recarbon Corp.

Company Location: Wilkes Barre, PA

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Used tires
Resins accepted by the system	List those that have been tested with success ☐ Nos. 1-7 Comments: ☐ Engineering grade resins Comments: ☐ PLA Comments: Others: Rubber
Resins not accepted by the system	List specific resins these system cannot handle does not apply
Toleration of contaminants	Is there a maximum contamination level, moisture level? Can handle contamination without presorting.
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: close to 100% ☒ Natural gas; proportion of the output: trace% ☒ Monomers; proportion of the output: trace% Describe state of the final product once it comes out of the system ☒ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? valuable stainless steel wire, carbon black if needed And, how is this residue treated (ex., landfilled)? wires are filtered off and reused, carbon black can be left in suspension or filtered and reused after some refining
Description for the process	Brief description of the process Heting with cooking oil or biodiesel for 60 minutes Uses a catalyst: ☐ Yes ☒ No Process conducted in a vacuum: ☐ Yes ☒ No
Process Yield	Conversion rate: practically quantitative OR For one ton of plastic in, you get about 1.5 - 2 tons amount of usable product out. Other comments: the process will consume between 1/2 ton to 1 ton of BD
System capacity	Size of current system in operation (tons per year): System is scalable: ☒ Yes ☐ No If system is scalable: Min no limits/Max no limits (tons per year)
Independent engineer's review available	☒ Yes ☒ No Comments:
Estimated time frame for Return on	Based on projections with energy, labor and other costs remaining consistent over time.

Investment	Unknown, it depends on the scale and cost of crude
Number of facilities in operation	No. of facilities: 0 Years in operation 0 Location of facilities: Size of facility:

Company contact information:

Contact person: Howard Gonchar
Address:
Web address:
Phone: 570-262-0266
Email:

Company Name: Vadxx Energy

Company Location: Cleveland, OH

Criteria	System information
Source of feedstock	What is the current source of material for the systems in place Our business model is to form joint ventures with companies that already traffic in the desired feedstock (e.g. recycling company). They supply the feedstock, we supply the technology and operation and we share in the oil proceeds.
Resins accepted by the system	List those that have been tested with success ☒ Nos. 1-7 Comments: We have achieved consistent outputs of oil, hydrocarbon gas and char across varying mixes of municipal plastic waste from multiple waste management and recycling companies. The Nos. 1-7 mixtures have minimized content of No. 1 and No. 3. ☐ Engineering grade resins Comments: Not necessary to demand specific engineering grade resins; mixed post-consumer waste resins and spent industrial resins serve as good feedstock. ☐ PLA Comments: Poly(lactic acid) or polylactide (PLA) is an impurity in mixed feedstocks that is decomposed in the process without difficulty but it is not a primary feedstock. Others: Scrap tire, many grades of industrial waste rubber, polymer fraction of auto shredder residue (ASR)/auto fluff, polymer fraction of e-waste.
Resins not accepted by the system	List specific resins these system cannot handle Polysilanes & siloxanes, PVC & PVDC, polybrominated diphenyl ethers (PBDE), PTFE, polyurea (polycarbamate), and thermoset resins are not accepted as primary feedstocks but are minimized to contaminant levels.
Toleration of contaminants	Is there a maximum contamination level, moisture level? Contaminant-specific; minimum moisture level.
Output/Product	Describe the product yielded from the process (check all that apply) ☐ Diesel (no gasoline), proportion of the output: % ☐ Diesel/gasoline mix , proportion of the output: / % ☒ Product similar to crude oil; proportion of the output: 75% ☒ Natural gas; proportion of the output: 15% ☐ Monomers; proportion of the output: % Describe state of the final product once it comes out of the system ☐ It is ready to use by a consumer and needs no further refining ☒ Product needs further refining by a third party
Residue	What is the residue (ex., char)? Char. And, how is this residue treated (ex., landfilled)? We have confirmed multiple customers that will purchase our char output based on lab analyses of char composition that was provided to them.
Description for the process	Brief description of the process Continuous process pyrolysis. Uses a catalyst: ☒ Yes ☐ No Process conducted in a vacuum: ☐ Yes ☐ No

Process Yield	Conversion rate: 100% OR For one ton of plastic in, you get one ton amount of usable product out. Other comments: Practically all process outputs yield usable product in the form of synthetic crude oil (sold), hydrocarbon gas (used for process heat & electric power generation) and char (sold).
System capacity	Size of current system in operation (tons per year): If pilot plant was run continuously at near peak capacity, it would produce 2,000 barrels per year. We do not run it that often as its primary function is a research and development facility. System is scalable: ☒ Yes ☐ No If system is scalable: Min /Max 12,000 (tons per year)
Independent engineer's review available	☐ Yes ☒ No Comments: The details of the process involve trade secrets and proprietary information.
Estimated time frame for Return on Investment	Based on projections with energy, labor and other costs remaining consistent over time. 1 year
Number of facilities in operation	No. of facilities: 1 Years in operation 2 Location of facilities: Akron, OH Size of facility: Pilot plant

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