CLOSED LOOP partners

ACCELERATING CIRCULAR SUPPLY CHAINS FOR PLASTICS:

—

A LANDSCAPE OF TRANSFORMATIONAL TECHNOLOGIES THAT STOP PLASTIC WASTE, KEEP MATERIALS IN PLAY AND GROW MARKETS

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INTRODUCTION

LAY OF THE LAND

Plastics are ubiquitous. Found in packaging, textiles, hardware, and consumer products, they offer performance at low cost, often with environmental benefit, for countless uses. Yet most plastic packaging and too many plastic products are eventually discarded after one use.

In the U.S. and Canada, current recycling infrastructure recovers less than 10% of post-consumer plastics, and today's supply of recycled plastics meets just 6% of real demand [1], [2]. When poorly managed, plastics waste fills our landfills and our environment. If current trends continue, global demand for plastics is forecasted to triple by 2050 [3]. At the same time, there may be more plastics than fish in oceans by 2050 [4].

Many large corporations are making commitments to use more recycled plastics in their products and their packaging, and to reduce their carbon emissions - signaling demand for solutions that keep plastics in play. Suppliers are scrambling to meet this increasing demand, but the options today are limited.

For the petrochemical industry, there is a lot at stake, too. The threats of being blamed for contributing to the problem or left out of the picture are increasingly driving change among the largest petrochemical companies and plastics manufacturers in the world.

To address the current challenges - and the current demand - transformational technologies that keep plastics in play are needed at scale.

There are at least 60 technology providers developing innovative solutions to purify, decompose, or convert waste plastics into renewed raw materials. With these available technologies, there is a clear opportunity to build new infrastructure to transform markets. These solutions can also help to decrease the world's reliance on fossil fuel extraction, lower landfill disposal costs for municipalities, and reduce marine pollution.

All of these factors indicate an inflection point for plastics.

THE PROBLEM

A majority of the plastics used are never recovered: today, in the U.S. and Canada, about 90% of plastic waste ends up in a landfill or incinerated [1]. When plastics are collected, many regions do not have the recycling infrastructure to properly and profitably sort, process and market much of this material. Manufacturers are further challenged to use recycled plastics in their current form because they often do not perform as well as prime, or virgin, plastics, due to degradation or contamination issues. Without a bold shift in approach, the mismanagement of plastics waste will worsen, resulting in the loss of valuable materials and missed opportunities to recover and harvest the value of these resources.

THE OPPORTUNITY

The good news is that innovative technologies exist - with even more emerging and scaling - to solve these challenges. These technologies are transforming waste plastics into building blocks for new materials.

If these technologies are more widely adopted and scaled, tremendous economic value can be realized. According to our analysis, there is an existing $120 billion addressable market in the U.S. and Canada for plastics and petrochemicals that could be met, in part, by recovering waste plastics. This renewed resource could displace fossil fuels being used in these markets today. Furthermore, there are environmental benefits from recycling waste plastics back into a myriad of useful products, including reducing or avoiding environmental pollution, significant amounts of CO_2 emissions and potentially hazardous chemical pollutants.

To reach this potential, more investment is urgently needed to support and scale these transformational technologies. We are calling on brands and investors to seize the opportunities presented by today's landscape of innovators and the growing demand for recycled materials.

WHERE ARE WE COMING FROM?

The Center for the Circular Economy at Closed Loop Partners is committed to accelerating solutions for more circular supply chains at scale. Over the past year, the Center has been exploring innovative technologies that effectively transform waste plastics into like-new materials. While many have tremendous potential, they also challenge us to expand our current definition of recycling.

Closed Loop Partners undertook this project to learn more about technologies and their potential role in scaling circular supply chains, transforming markets, and stopping plastics waste in the US and Canada. **The goal of this report is to reflect the current landscape of technology providers focused on converting waste plastics into a variety of safe and high-quality materials, as well as the scale of opportunity for these providers to meet demand.**

We want to share these learnings with the many actors who participate in the system today. For consumer brands, chemical companies, and investment firms like Closed Loop Partners, this report is the first in an ongoing effort to shape investment strategies and infrastructure over the next five to ten years.

By developing a shared landscape and understanding of next steps, this report aims to make a complex topic more approachable and accessible, while also building on current momentum, and generating excitement about the opportunities ahead of us.

EXECUTIVE SUMMARY

This report offers a survey of the current technology landscape and opportunities for repurposing waste plastics into a variety of safe and high-quality materials.

Recommendations include:

1. Invest: Investors, brands, and industry must urgently invest to bring transformational technologies to scale.

2. Educate: Increasing awareness and adopting shared terminology and understanding of these technologies will make them more accessible to a wider audience.

3. Collaborate: Brands and industry need to develop partnerships with technology providers to create new business models that will match the current technologies with the infrastructure of plastics and petrochemical manufacturing, waste management and recycling.

KEY FINDINGS

1. TECHNOLOGIES THAT KEEP PLASTICS IN PLAY MUST BE PART OF THE SOLUTION TO END PLASTICS POLLUTION.

+ **Demand for plastics is strong and growing**, yet the supply of recycled plastics available to meet demand is stuck at 6% [2]

+ There are an estimated 34+ million metric tons of plastics landfilled or incinerated in the U.S. and Canada each year [1], [5].

+ Current infrastructure and technologies are limited in their ability to transform all of the diverse types of plastics used today into high-value feedstocks that compete with prime, or virgin, materials.

+ Technologies exist to repurpose these plastics into valuable materials; **purification, decomposition, and conversion technologies** can all play a role.

2. THERE IS REAL DEMAND FOR PLASTICS AND OTHER MATERIALS ACROSS THE SUPPLY CHAIN.

+ Analysis indicates that if these technologies can meet market demands, they have potential revenue opportunities of **$120 billion in the U.S. and Canada alone.**

+ The world's largest brands, retailers and plastics manufacturers are making commitments around plastics recycling, recycled and recyclable content, and recovery. **Current projections indicate new demand for recycled plastics of 5 to 7.5 million metric tons by 2030** [2], [6].

+ Beyond plastics, markets also exist for chemicals and fuels - creating even more opportunity for waste plastics to be repurposed into materials that can continue to flow through our economy.

3. THIS IS POSSIBLE. THE INNOVATION EXISTS TO MEET THE DEMAND.

+ This study identifies **60 technology providers**, nearly all of them at least at the lab stage of maturity, with significant potential to grow and scale. Although many are in the early stages of securing the capital needed to scale and meet demand, more than 40 solution providers are operating early commercial scale plants in the U.S. and Canada today, or have plans to do so in the next two years.

+ **There is money to be made.** Technology providers are operating profitably with higher margins as they mature and scale.

+ **250 investors and strategic partners**, including the world's largest brands, private investors, petrochemical companies and plastic manufacturers, and government and NGO partners, are already engaging with the companies profiled in the study.

+ **Going from "possible" to "probable"** will require: new solutions and business models that integrate innovations with existing infrastructure, flexible technology platforms that can evolve over time, and market incentives driven by public and private policies.

KEY FINDINGS

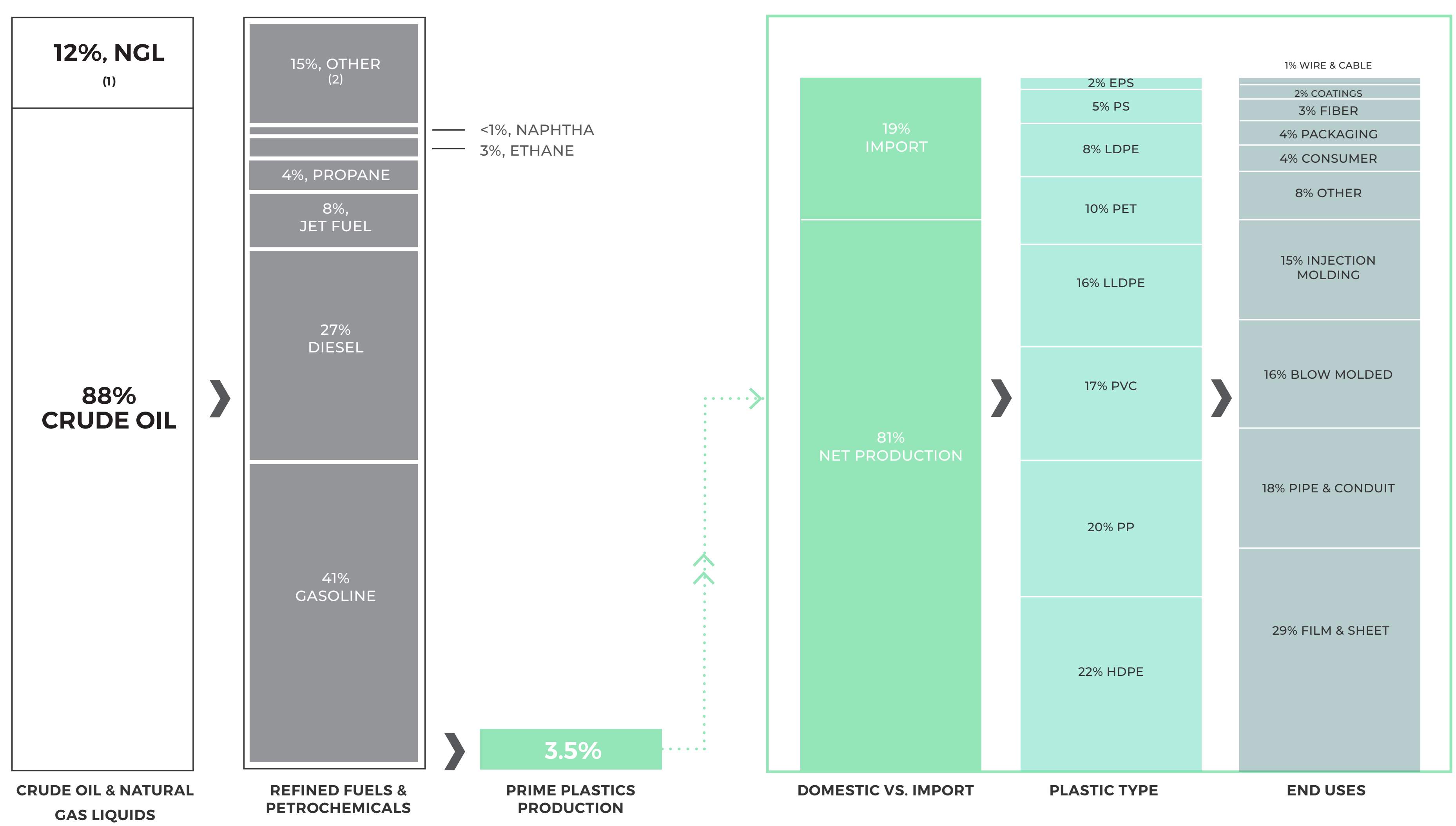
1. TECHNOLOGIES THAT KEEP PLASTICS IN PLAY MUST BE PART OF THE SOLUTION TO END PLASTICS POLLUTION.

The very public issue of ocean plastics has put consumer brands and their suppliers on notice by governments and consumers. For an increasing number of brands, this monumental challenge can be solved by becoming buyers of their own products and packaging. Closing the loop on resources means reducing fossil fuel extraction and exposure to volatile oil prices, earning credit for responsible behavior from government and NGOs, and building brand loyalty with consumers. As brands commit to and shift toward circular supply chains, there is friction between existing infrastructure and the future state. The current supply of recycled plastics is far less than the demand suggested by these publicly stated goals.

It is essential that society stops thinking of plastics as waste, and starts treating them as resources. Today, our options for recycling plastics are limited and low value. With current infrastructure, a small portion - less than 10% - of plastics waste from many consumer packages and products is recovered and recycled [1]. Consumers, governments, brands, chemical companies, and investors want to change that. But it is clear that real change must include new solutions at a broader scale. Transformational technologies that allow us to keep plastics in play must be part of the solution.

In 2018, nearly 42 million metric tons of plastics were produced in North America, driving revenues of $47 billion [2]. The raw materials used in plastics production represent 3-4% of crude oil and natural gas liquid (NGL) production in North America, not including the energy used to make plastics. These raw materials can be made into many different types of plastics, such as polystyrene (PS), polypropylene (PP), and polyethylene terephthalate (PET). These plastics serve various end uses beyond packaging, including pipes, films, and coatings.

AGGREGATE MATERIAL FLOW 2018



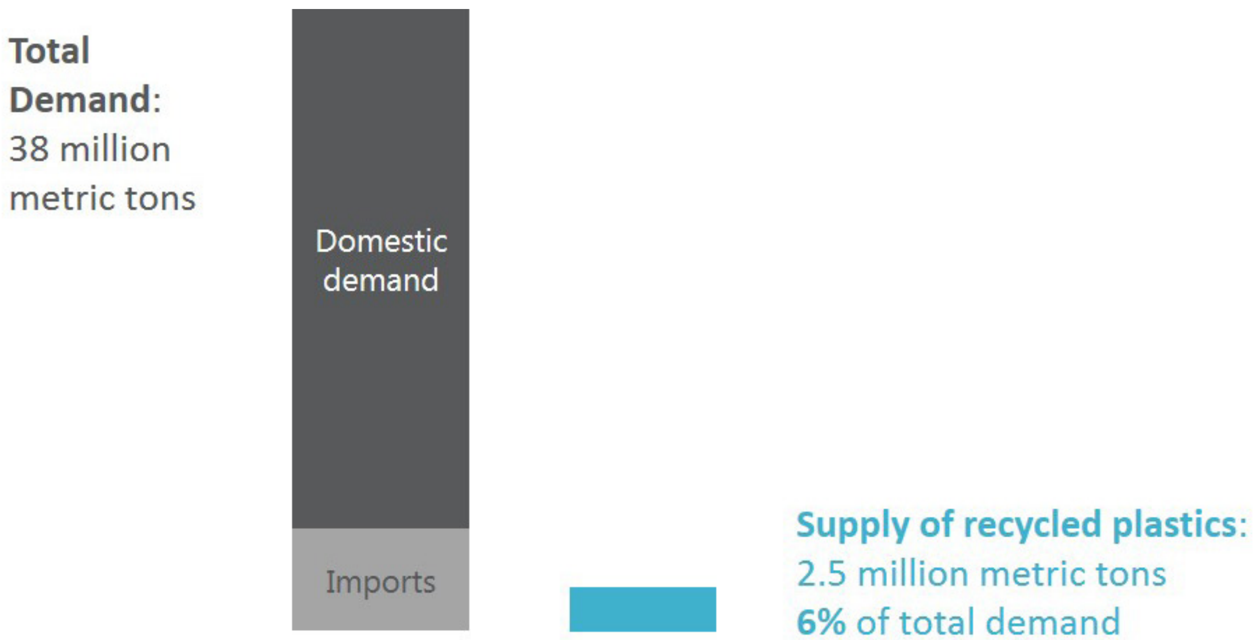
(1) 91% of raw materials used in prime plastics production in North America comes from natural gas liquids (e.g., ethane, propane).
(2) "Other" includes residual fuel oil, butane, kerosene

Source: IHS Markit, AFARA

Demand for plastics is strong and growing, but current supply of recycled plastics meets just 6% of demand. In the U.S. and Canada, 2.5 million metric tons of post-use recycled plastics were available in 2018. This represents only 6% of the 38 million metric tons of demand for the most common plastics.

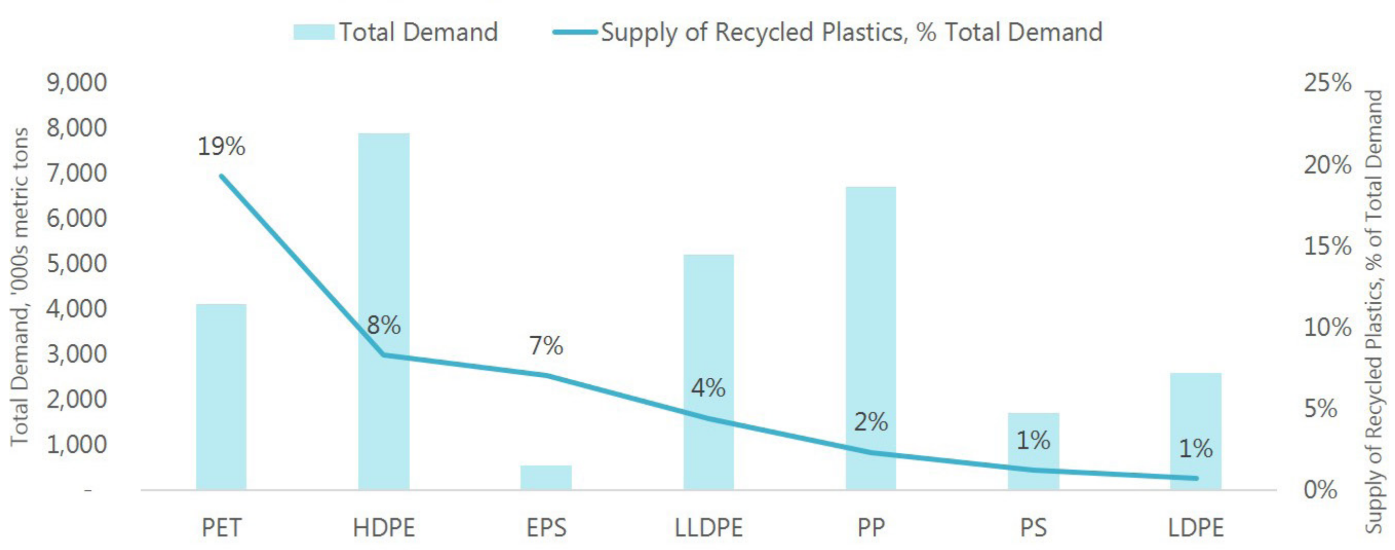
Six percent doesn't tell the whole story. The supply of the most commonly recycled plastic, PET, represents less than 20% of total demand, as shown in the chart below. The gap between demand and recycled supply is even greater for other common plastics, such as high density polyethylene (HDPE), polypropylene (PP), polystyrenes (PS/EPS), and films (LLDPE/LDPE).

2018 AGGREGATED PLASTICS DEMAND + RECYCLED SUPPLY, U.S & CANADA



Source: IHS Markit

2018 SUPPLY OF RECYCLED PLASTICS AND TOTAL DEMAND IN U.S. & CANADA



Source: IHS Markit

Plastics waste is a huge untapped resource. Using recycled plastics has benefits in many applications: it can be cheaper than prime plastics; pricing is less volatile than prime; and using it does not depend on new extraction of non-renewable fossil fuel resources.

With global demand for plastics projected to triple by 2050 [3] and an increase in demand for recycled plastics of at least 5 million tons in the next five to ten years, the overall contribution of plastics waste to this supply chain must change dramatically.

Where is the rest?

The U.S. and Canada sends 34 million tons of plastics to landfills or incinerators each year. This costs communities more than $2.2 billion in disposal fees [5], [7]. The lost commodity value from plastics that are not recycled is even greater. For example, 6.6 million metric tons of polypropylene were produced in the U.S. and Canada in 2018. Mechanical processing yielded just 150,000 metric tons (2%) of recycled PP returned to the supply chain at a value of $1,100/ton. If all production was replaced with recycled PP, this differential would translate into $4.2 billion in revenues [2], [7], [8].

We're throwing valuable material away every day. Why is this happening?

- Plastics aren't recovered effectively. Consumers are confused by messages on how to recycle, or do not have convenient services at home, work or school. These barriers translate into low capture and high contamination rates, the primary reason China and India have banned imports of recycled plastics from North America [9], [10].

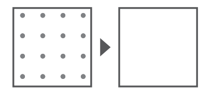
- "Chop-and-wash" processing technologies were not designed to deal with the complex and highly variable plastics coming through our waste streams today. Mechanical recycling works well for certain grades of PET and HDPE, but are limited in their ability to sort and process films and labels, chip bags, pouches, consumer electronics and hardware, synthetic fibers, and other "mixed plastics". Contamination and degradation prevent the material from continuously staying in play.

- The embedded costs today cannot compete with world-scale plastics manufacturing. The cost structure of mechanical recycling from bale to pellet can exceed $1,000/ton [11].

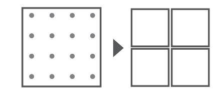
The challenges of the current system are likely to get worse. The complexity of plastics entering the waste stream will continue to increase as more consumer products and packaging take advantage of material innovations. For example, flexible packaging is the fastest growing segment of the packaging industry [12]. At the same time, demand for recycled plastics is expected to increase dramatically, as consumer packaged goods companies and packaging producers go after recycled content goals. Current reprocessing capabilities have difficulty meeting quality specifications

Technologies exist to repurpose plastics waste into valuable materials.

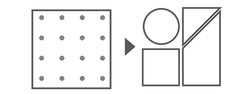
This study identifies 60 technology providers that can be broadly categorized as using one (or more) of three processes today. Detailed profiles of each provider can be found in the Appendix.



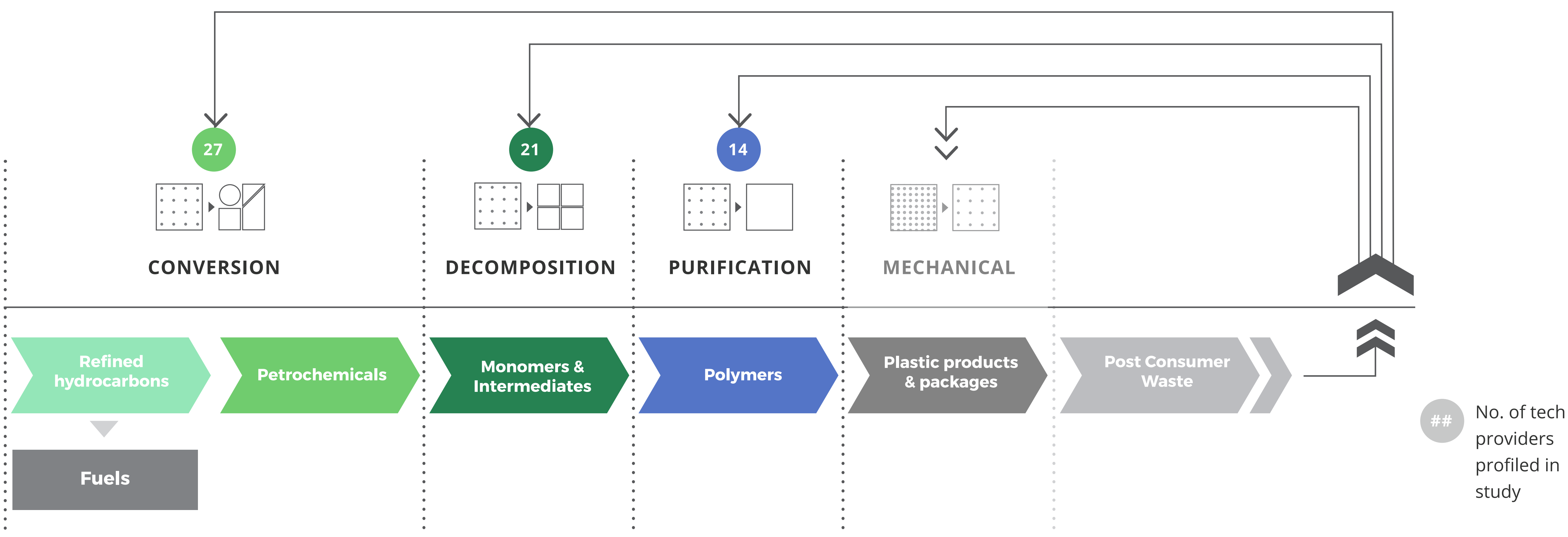
PURIFICATION is a process that involves dissolving plastic in a solvent, then separating and purifying the mixture to extract additives and dyes to ultimately obtain a "purified" plastic. The purification process does not change the polymer on a molecular level.



DECOMPOSITION is a process that involves breaking molecular bonds of the plastic to recover the simple molecules ("monomers") from which the plastic is made. Monomers may be single molecules or short fragments of molecules bound together called "oligomers," both of which are often reconstructed into plastics. This process, sometimes referred to as "depolymerization", can be biological, chemical, or thermal, and in some cases, a combination of two or three of these methods.



CONVERSION is similar to decomposition in that the process involves breaking the molecular bonds of the plastic. A key difference is that the output products from conversion processes are often liquid or gaseous hydrocarbons similar to the products derived from petroleum refining. These raw materials may enter different supply chains, such as fuels for combustion, and/or petrochemicals (e.g., naphtha) that can be made into intermediates and monomers for new plastics.



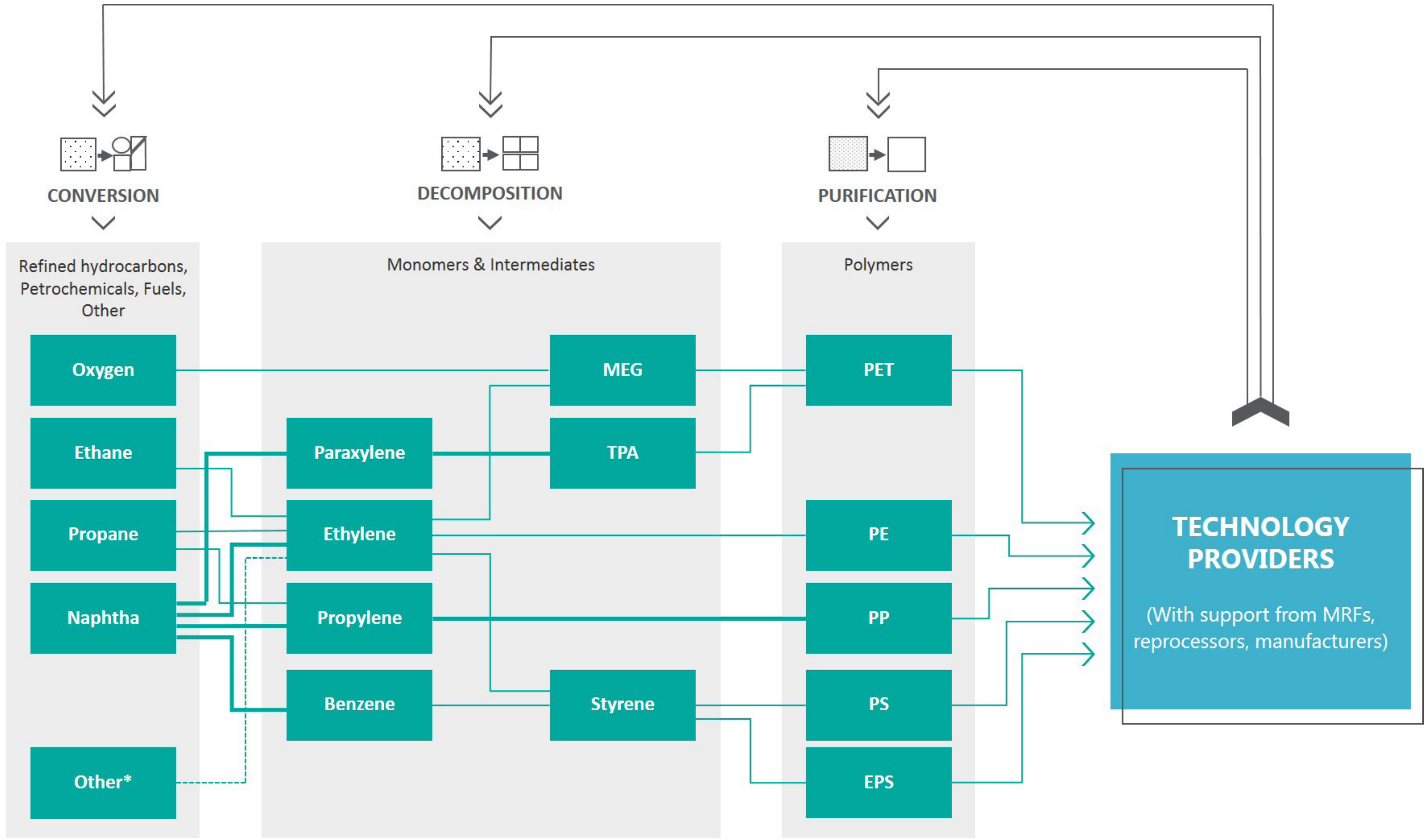
In the illustration above, "Monomers" includes other intermediates, such as paraxylene. In the current landscape, these intermediates are often made from petrochemicals produced by the conversion process.

While these processes are not new, technology providers are applying them in innovative and exciting ways. **Investors and brands have an opportunity to influence and accelerate solutions that repurpose plastics waste and keep materials in play.**

Technology providers are transforming the plastics supply chain. The technology providers profiled in the landscape demonstrate real opportunities to reduce our reliance on fossil fuels and start transforming plastics waste into a renewed resource throughout the supply chain.

Technology providers have the ability to select how and where they will re-enter the plastics supply chain. The pathway of possibilities for creating new products with conversion are endless (but generally require more energy), while the pathways with decomposition and purification are more restricted (but generally require less energy).

The illustration below shows where the different processes impact many of the chemicals, monomers, and intermediates that become the most common plastics in use today.



*Note: "Other" includes butane and gas oil.
Source: IHS Markit, AFARA

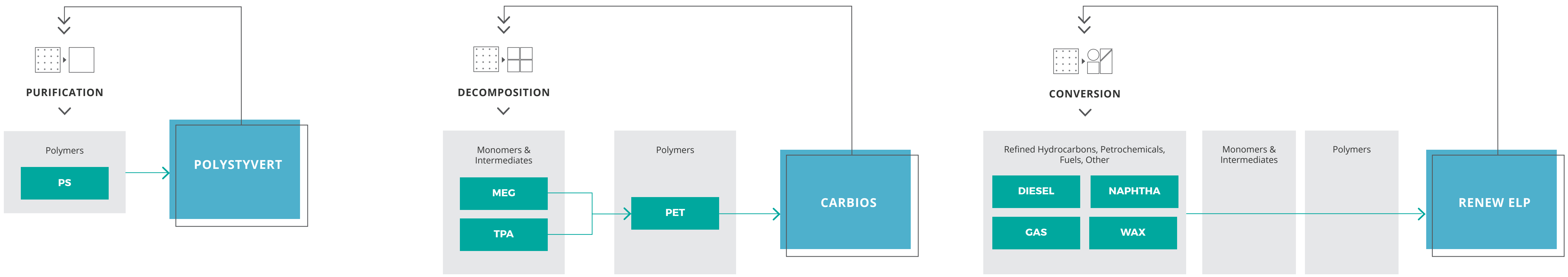
Decomposition technology providers in the landscape are largely focused on producing monomers such as MEG, TPA, and styrene. One conceptual technology provider is planning to produce ethylene and propylene through decomposition. Other chemical intermediates, such as paraxylene, are referenced here to demonstrate the pathway for refining conversion products (e.g., naphtha) back into monomers and eventually to polymers.

Our research looked at 60 technology providers working with different material types and at different stages of maturity. Below are examples that illustrate some of the exciting applications of technologies being developed today.

Canada-based **Polystyvert** applies a combination of filtration, dissolution, and purification using an essential oil to process all forms of polystyrene (PS), including expanded PS, extruded PS, and high-impact PS, back into PS polymer that can be remade into plastics.

Carbios, based in France, is using an enzymatic process to biologically recycle PET back into the monomers MEG and TPA to make PET polymer again.

Nearly half (27) of the providers surveyed are using conversion technologies to produce diverse outputs. **Renew ELP**, as one example, is focused on recovering the most contaminated mixed plastics coming from municipal solid waste and using a chemical conversion process to produce naphtha (which is a key ingredient in many plastics), as well as fuels (diesel, gas), and other petrochemicals (waxes).



Profiles of the technology providers reviewed in this landscape are provided in the Appendix.

AVERAGE TIMELINE TO MATURITY

Source: Primary Research
Note: Based on 62 (in scope) technologies, as of January 2019

Of the 60 technology providers surveyed, **it has taken, on average, 17 years to reach growth scale.**

Furthermore, the more mature companies are typically those that produce fuels and petrochemicals from plastics waste. Those that produce polymers are at an earlier stage, on average.

Why?

Technology providers cite challenges as they try to engage with investors, partners and customers who do not understand the technology or the business models. *"[Our biggest challenge is] education that plastics can be used as feedstock and building awareness that we have solutions on what to do with it. It's more than "who is Agilyx?" says Chris Faulkner, Vice President of Technology Group, at Agilyx [13].*

Making these technologies more accessible is critical to fundraising. Approximately 25% of technology providers included in the landscape shared that they were fundraising when surveyed. Although there is a wide range of funds depending on the stage of maturity (pilot through early commercial), the average raise for provider is $15 million, or more than $200 million in aggregate. The time spent building awareness and educating to open the door to these conversations is time that cannot be spent on execution at scale.

One relative success story, **Pyrowave**, has accelerated the timeline for bringing technologies from the lab to early commercial scale. Based in Oakville, Ontario in Canada, Pyrowave decomposes post-consumer PS into styrene monomers, using microwave technology. The diverse range of input plastics that can be processed allows for flexibility in their portfolio to adapt to market needs and tap into diverse supply chains.

After a few years in development, Pyrowave became a company in 2014 and has reached commercial scale within 5 years. Pyrowave has been backed by a strong team of executives and investors, including high profile board members and advisors who have a strong understanding of the market, and developed a strategy that fits the market need. The company has taken on predominantly non-dilutive capital, including from Export Development Canada (EDC) and Business Development Bank of Canada (BDC), allowing the team to control decision making.

As CEO Jocelyn Doucet describes it: *"We've put 10 years of work into bootstrapping the technology at a time when plastic pollution was not very much debated, but still a fast growing environmental crisis. Our initial vision 10 years ago is now giving us a very good shot at solving this problem."* [14]

Many of these technologies are founded by technologists, i.e., scientists and chemists who are not necessarily experienced CEOs or marketers. Therefore, partnerships are critical for complementing their core expertise to build a successful business. **For those who have been successful, they attribute their strategic partnerships as key to accelerating their growth.**

One example of a technology provider successfully forming key partnerships is **Loop Industries.** Founded in 2015, the company decomposes PET back into monomers, and then partners to produce a like-new recycled PET pellet. Loop has engaged with cross-industry stakeholders and established partnerships that can drive impactful change to the recycling supply chain. Partnerships have taken many forms. Loop has signed investment term sheets with Danone/Evian, Nestlé Waters, and L'Oreal. They have secured offtake agreements with Gatorade, PepsiCo, Coca-Cola, L'Occitane and Drinkworks. Loop has also established strategic partnerships, including a joint venture with one of the world's largest manufacturers of prime PET resin Indorama, and a global alliance agreement with thyssenkrupp.

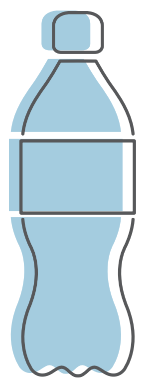
Technology providers must scale faster with support from key partners. These technologies all have the potential to scale, but their growth and commercialization needs to be accelerated in order to meet growing demand. With better access to investment capital and increasing demand from brands and supply chain partners, **technology providers may soon be able to accelerate the pace of growth.**

What are the technologies and outputs that work for a specific type of plastic?

The following pages summarize the technology providers working with different plastics waste streams and the processes they are using to generate different output products.

WASTE STREAM	TECHNOLOGY TYPE		OUTPUTS

PET - POLYETHYLENE TEREPHTHALATE



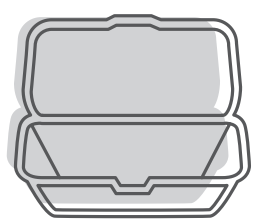
33 TECH PROVIDERS

PET - POLYETHYLENE TEREPHTHALATE
(Packaging, textiles)

Technology type	Tech providers
THERMAL CONVERSION	14
CHEMICAL DECOMPOSITION	9
PURIFICATION	6
BIOLOGICAL DECOMPOSITION	3
THERMAL DECOMPOSITION	1

Output	Example	Count
POLYMERS (PET, PBT)	E.G., AMBERCYCLE	12
DIESEL	E.G., GOLDEN RENEWABLE ENERGY	12
NAPHTHA	E.G., RECYCLING TECHNOLOGIES	11
LIQUID CRUDE	E.G., RES POLYFLOW	11
MONOMERS (TPA, EG, DMT, BHET)	E.G., IONIQA	7
SYNGAS	E.G., GOLDEN RENEWABLE ENERGY	6

PS - POLYSTYRENE



29 TECH PROVIDERS

PS - POLYSTYRENE
(Packaging, insulation)

Technology type	Tech providers
THERMAL CONVERSION	21
CHEMICAL DECOMPOSITION	3
THERMAL DECOMPOSITION	3
PURIFICATION	2

Output	Example	Count
DIESEL	E.G., POLYCYCL	22
NAPHTHA	E.G., RESYNERGI	20
LIQUID CRUDE	E.G., AGILYX	19
SYNGAS	E.G., VADXX	9
POLYMERS (PS)	E.G, GREENMANTRA	4
MONOMERS (STYRENE)	E.G., PYROWAVE	4

PE - POLYETHYLENE

28 TECH PROVIDERS

PE - POLYETHYLENE
(Packaging. Films)

Technology type	Tech providers
THERMAL CONVERSION	21
PURIFICATION	3
CHEMICAL DECOMPOSITION	3
THERMAL DECOMPOSITION	1

Output	Example	Count
DIESEL	E.G., NEXUS FUELS	21
NAPHTHA	E.G., NEW HOPE ENERGY	18
LIQUID CRUDE	E.G., KLEAN INDUSTRIES	16
SYNGAS	E.G., VADXX	9
POLYMERS (PE)	E.G., CADEL DEINKING	5
MONOMERS* (ETHYLENE)	E.G., KARLSRUHE INSTITUTE OF TECHNOLOGY	2

*CURRENTLY CONCEPTUAL/LAB SCALE DATA LAST UPDATED: JAN 2019

WASTE STREAM	TECHNOLOGY TYPE	OUTPUTS

PP - POLYPROPYLENE

28 TECH PROVIDERS

PP - POLYPROPYLENE
(Packaging, pipe, textiles)

Technology type

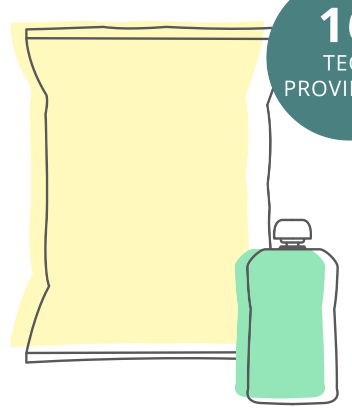
- THERMAL CONVERSION — 21
- PURIFICATION — 3
- CHEMICAL DECOMPOSITION — 3
- THERMAL DECOMPOSITION — 1

Outputs

- **DIESEL** — E.G., JBI PLASTICS2OIL — 21
- **NAPHTHA** — E.G., RENEW ELP — 18
- **LIQUID CRUDE** — E.G., KLEAN INDUSTRIES — 16
- **SYNGAS** — E.G., PLASTIC ENERGY — 9
- **POLYMERS** (PP) — E.G., PURECYCLE TECHNOLOGIES — 5
- **MONOMERS*** (PROPYLENE) — E.G., KARLSRUHE INSTITUTE OF TECHNOLOGY — 2

MIXED PLASTICS

16 TECH PROVIDERS



MIXED PLASTICS
(Packaging, other)

Technology type

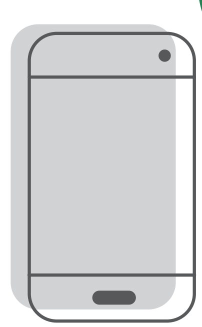
- THERMAL CONVERSION — 14
- CHEMICAL DECOMPOSITION — 1
- THERMAL DECOMPOSITION — 1

Outputs

- **DIESEL** — E.G., RENEWLOGY — 15
- **NAPHTHA** — E.G., RECYCLING TECHNOLOGIES — 13
- **LIQUID CRUDE** — E.G., RES POLYFLOW — 13
- **SYNGAS** — E.G., GOLDEN RENEWABLE ENERGY — 9
- **MONOMERS*** (ETHYLENE, PROPYLENE) — E.G., KARLSRUHE INSTITUTE OF TECHNOLOGY — 1

ELECTRONICS

7 TECH PROVIDERS



ELECTRONICS
(Cell phones, electronic hardware)

Technology type

- THERMAL CONVERSION — 4
- PURIFICATION — 3

Outputs

- **DIESEL** — E.G, KLEAN INDUSTRIES — 5
- **NAPHTHA** — E.G, SIERRA ENERGY — 5
- **LIQUID CRUDE** — E.G., JEPLAN — 4
- **POLYMERS** (PC, ABS, HIPS) — E.G., GEO-TECH POLYMERS — 3
- **SYNGAS** — E.G., KLEAN INDUSTRIES — 2

*CURRENTLY CONCEPTUAL/LAB SCALE DATA LAST UPDATED: JAN 2019

2. THERE IS REAL DEMAND FOR PLASTICS AND OTHER MATERIALS ACROSS THE SUPPLY CHAIN.

The technologies in this landscape produce a portfolio of materials that can meet demand for plastics and beyond. Currently, there is a significant and growing market for recycled plastics, as brands continue to make public commitments to use more recycled content and better manage plastics pollution. Beyond this, there is real demand for plastics, chemicals, and fuels that could be met by these transformational technologies.

In aggregate, the relevant market opportunity in North America -- including polymers, monomers, intermediates, and other chemicals -- totals $120 billion annually.

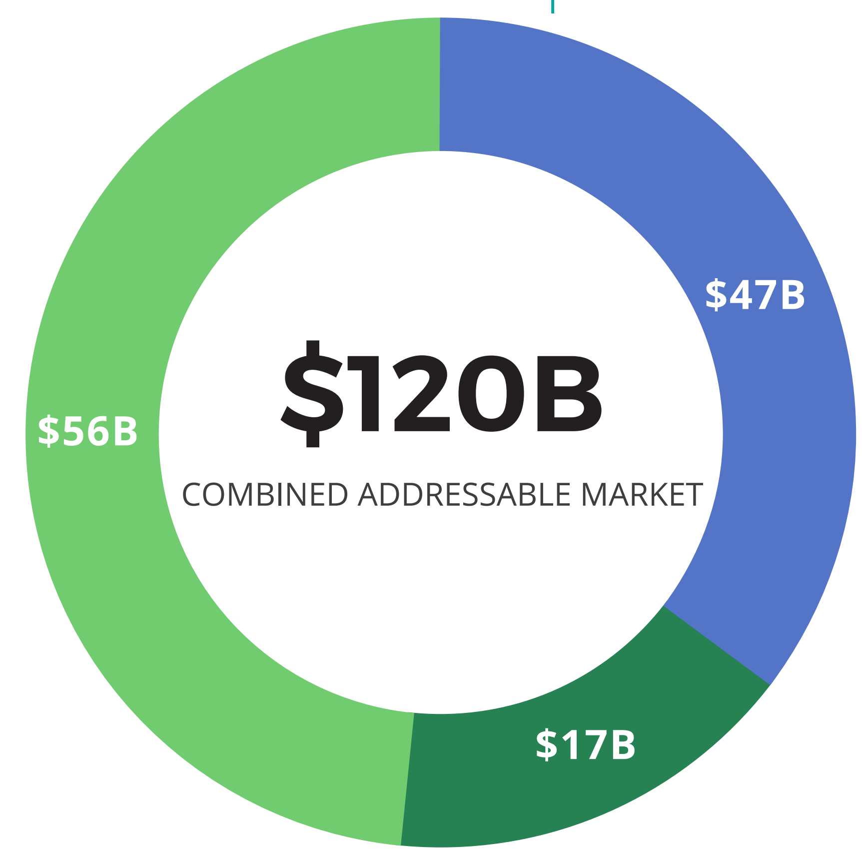
A $120 billion addressable market reflects those outputs that have a pathway back to plastics. However, including other outputs, such as diesel and gasoline, jet fuels, and liquid oils, would significantly increase the market opportunity.

SIZE OF THE PRIZE

POLYMERS

$47B, including:

- Polyethylene
- PET
- Polystyrene



MONOMERS & INTERMEDIATES

$56B, including:

- Ethylene
- Propylene
- Styrene

REFINED HYDROCARBONS, PETROCHEMICALS & FUELS

$17B, including:

- Naphtha
- Ethane
- Propane

Brands, retailers, and manufacturers are driving demand for recycled plastics with commitments.

Thirty-seven (37) of the world's largest consumer brands and retailers , including Coca-Cola [15], Danone [16], Nestlé [17], PepsiCo [18], Unilever [19], Walmart [20], and others [6] have made public commitments to use recycled plastics in their packaging within the next 10 years, signaling the opportunity to shift billions of dollars from the "take, make, waste" linear supply chain to circular supply chains. Current projections indicate new real demand of 5 million to 7.5 million metric tons by 2030 , requiring an increase of supply of 200-300% [2], [6].

Beyond plastics, the demand also exists for chemicals and fuels - creating even more opportunity for waste plastics to be repurposed into materials that can continue to flow through our economy. Other industries, including automotive and textiles/carpets, are already large, active end users of recycled plastics today.

Signals from large buyers are translating into contracts and offtake agreements.

TABLE 1: EXAMPLES OF RECENT OFFTAKE PARTNERS

Technology Provider	Known Offtake Partners
Agilyx	Monroe Energy (a wholly owned subsidiary of Delta Airlines), Americas Styrenics, and INEOS Styrolution
Aquafil	Adidas, Volcom, Stella McCartney, Interface, Milliken, Mannington, and Tarkett Group
GreenMantra Technologies	Sun Chemical
Ioniqa	Unilever and Indorama Ventures
Loop Industries	Indorama, PepsiCo, Coca-Cola's Cross Enterprise Procurement Group, Danone/Evian, L'Oreal, Nestlé Waters, Gatorade, L'Occitane, and Drinkworks
perPETual	Adidas, H&M, Zara, Puma, Vero Moda, and Decathalon
Plastic EnergyTM	SABIC
PureCycle	P&G
Pyrowave	INEOS Styrolution
Recycling Technologies	Interchem, Kerax
RES Polyflow	BP, AM Wax
Sierra Energy	State of California and the US Army

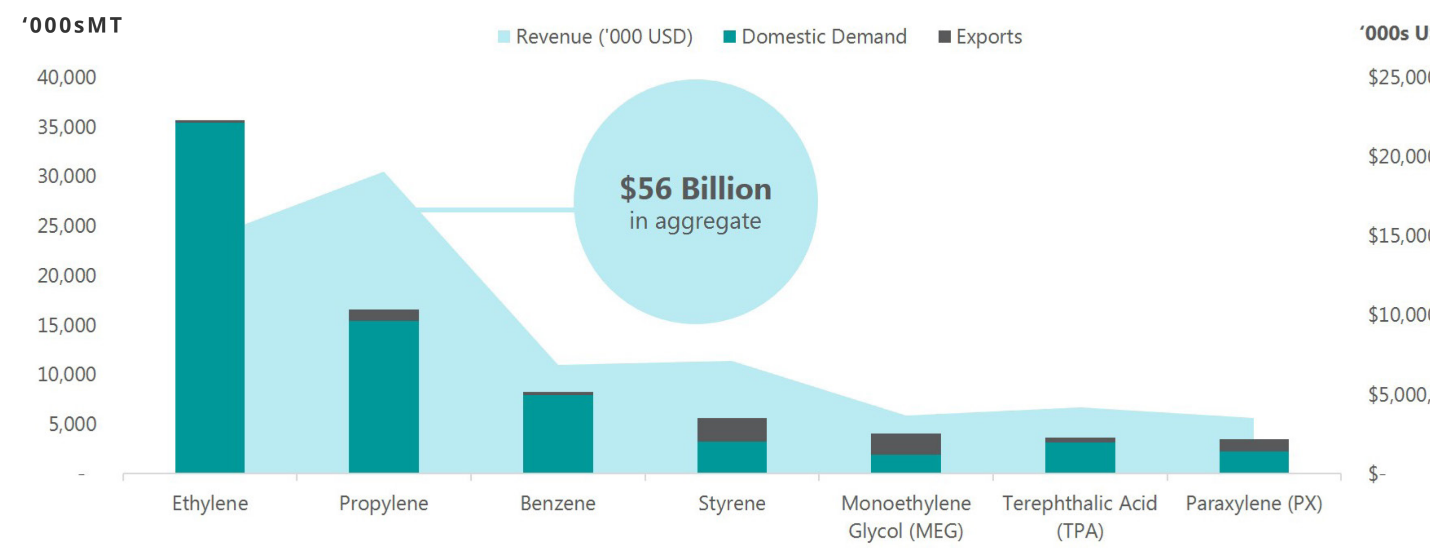
Plastics manufacturers such as Indorama [21] and SABIC [22] are making strategic investments in plastics-to-plastics solutions. Chemicals companies, such as BASF [23], Eastman Chemicals [103], and LyondellBasell [24], are integrating advanced technologies in their own manufacturing and supply chains. As an industry, plastics resin producers in the U.S. have announced ambitious goals [25] to responsibly manage plastics packaging, including to recover and recycle all plastics packaging by 2040. The top 20 global resin makers have also recently announced a $1.5B commitment to infrastructure and innovation through the Alliance to End Plastic Waste.

Addressable markets exist beyond plastics.
Many technology providers assessed in the landscape are able to transform plastics into many useful building blocks, creating co-products beyond raw materials for plastics. Technologies that convert mixed plastics, such as LDPE film, PP pots/tubs/trays, HDPE piping with varying material properties, levels of contamination and moisture content, such as Renew ELP, will yield naphtha (a chemical feedstock used to make plastics) and other end products. Looking at the spectrum of outputs across the supply chain, it is clear that technology providers today see a broader opportunity in addition to the plastic to plastic supply chain.

The polymers market on its own is $47 billion in annual revenue for the U.S. and Canada. Purification processes make it possible to safely transform carpet into yogurt cups -- greatly increasing the value of plastics waste and expanding the opportunities for technology providers and investors.

Decomposition and conversion technologies offer new opportunities to access petrochemical markets that have not typically been accessible to traditional plastics recyclers. The following chart shows a sampling of monomers and intermediates that represent raw materials and feedstocks used to make plastics and other useful materials. Above and beyond the market for polymers, **many of the monomers and intermediates used in the most common plastics collectively represent an addressable market of $56 billion.**

2018 DEMAND AND REVENUES FOR SELECT MONOMERS & INTERMEDIATES, U.S, & CANADA



Based on average spot prices (USD)
Source: IHS Markit

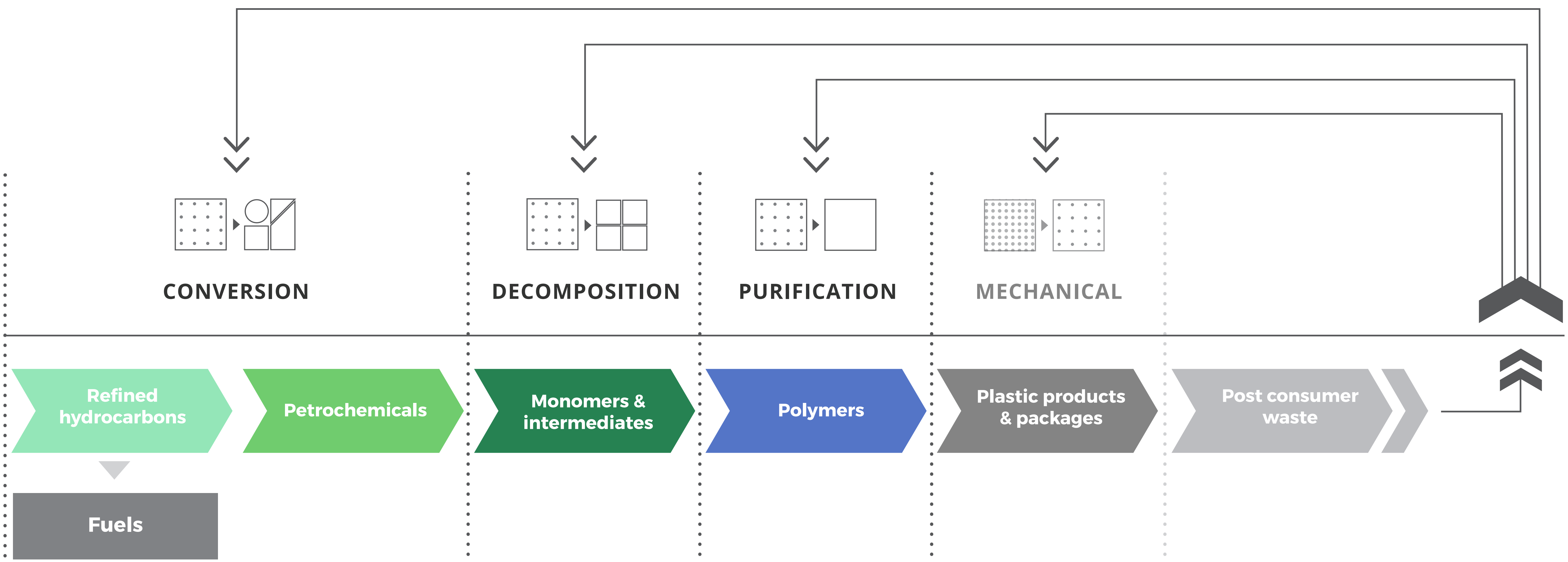
The economics of producing low-cost, more contamination-tolerant outputs has driven many technology providers to produce fuels. However, this may be changing. As illustrated by the biofuels industry [26], technology providers that solely followed a fuel-based model did not survive in that market over the long term. In the case of biofuels, many operators ultimately transitioned towards higher value chemical products for the cosmetics or pharmaceutical industries. In order to sustain their business as markets evolve, it is important for technology providers to build flexible platforms that allow for greater optionality.

Recent shifts in demand for plastics-to-plastics solutions has encouraged innovators, such as Agilyx, to build more circular business models over time.

Founded in 2004, **Agilyx** began as a thermal conversion technology provider that takes mixed plastics and converts them into liquid oil products. Volatile and low oil prices inspired Agilyx to pursue additional revenue streams, leading them to adapt their existing technology to develop a Polystyrene-to-Styrene Monomer (PSM) System that creates chemical feedstocks for plastic. While never losing their roots in the fuel business, Agilyx has expanded their portfolio to a dual revenue model of producing both chemicals and fuels.

3. THIS IS POSSIBLE. THE INNOVATION EXISTS TO MEET THE DEMAND.

If the opportunity and demand is there, the current landscape of technologies indicates that producing the supply is possible. This assessment surveyed more than 60 technology providers; all had significant potential to grow and scale. There is also increasing momentum building among different players. The innovation exists to meet the demand.



REFINED HYDROCARBONS, PETROCHEMICALS, FUELS, OTHERS

+ Agile Process Chemicals LLP
+ Agilyx
+ Anhui Oursun Environmental Technologies
+ Blest
+ Climax Global Energy
+ EcoFuel Technologies
+ Enerkem
+ Enval
+ Fulcrum BioEnergy
+ Global Electric Electronic Processing
+ Golden Renewable Energy
+ GreenMantra Technologies
+ Illinois Sustainable Technology Center
+ JBI Plastic2Oil
+ Jeplan
+ Klean Industries
+ New Hope Energy
+ Nexus Fuels
+ Plastic Energy
+ Polycycl
+ Pyrowave
+ Reclaimed EcoEnergy
+ Recycling Technologies
+ ReNew ELP
+ Renewlogy
+ RES Polyflow
+ Resynergi
+ Sierra Energy
+ The Pennsylvania State University
+ Vadxx

MONOMERS & INTERMEDIATES

+ Agilyx
+ Axens
+ Biocellection
+ Carbios
+ Gr3n
+ Ioniqa
+ Jeplan
+ Karlsruhe Institute of Technology
+ Loop Industries
+ perPETual
+ Pyrowave
+ Tyton BioSciences
+ University of Massachusetts-Lowell
+ University of Portsmouth & U.S. Department of Energy's National Renewable Energy Laboratory

POLYMERS

+ APK
+ Aquafil
+ Cadel Deinking
+ CreaCycle
+ Ecopek
+ Equipolymers
+ Galactic
+ Geo-Tech Polymers
+ GreenMantra Technologies
+ Illinois Sustainable Technology Center
+ Natureworks
+ Next Generation
+ Polystyvert
+ PureCycle Technologies
+ Resinate Materials Group
+ RESYNTEX
+ SABIC Innovative Plastics
+ TRASH2CASH
+ University of Massachusetts-Lowell
+ University of Ulsan
+ Worn Again Technologies

PLASTIC PRODUCTS & PACKAGES

POST CONSUMER WASTE

More than 40 technology providers are operating pilot and commercial scale plants in the U.S. and Canada today, or have plans to do so in the next two years. The scale of operations may still be very small (and highly distributed) relative to existing petrochemical infrastructure, but the potential to scale is real.

Many technology providers have spent the last decade optimizing their technology and, in collaboration with critical partners, are emerging beyond the lab to scale up. Planned facilities include:

- **PureCycle Technologies** will be commissioning Phase 1 of their plant (the Feedstock Evaluation Unit) with support from P&G and Closed Loop Partners.
- **Recycling Technologies** is building their first commercial scale plant in Scotland with support from InterChem, Kerax, and Swindon Borough Council, and may soon look to expand to North America.
- **Worn Again** is planning to establish their first industrial demonstration plant to be operational by 2021 with support from H&M, Kering, Sulzer Chemtech, Himes Corporation among others.

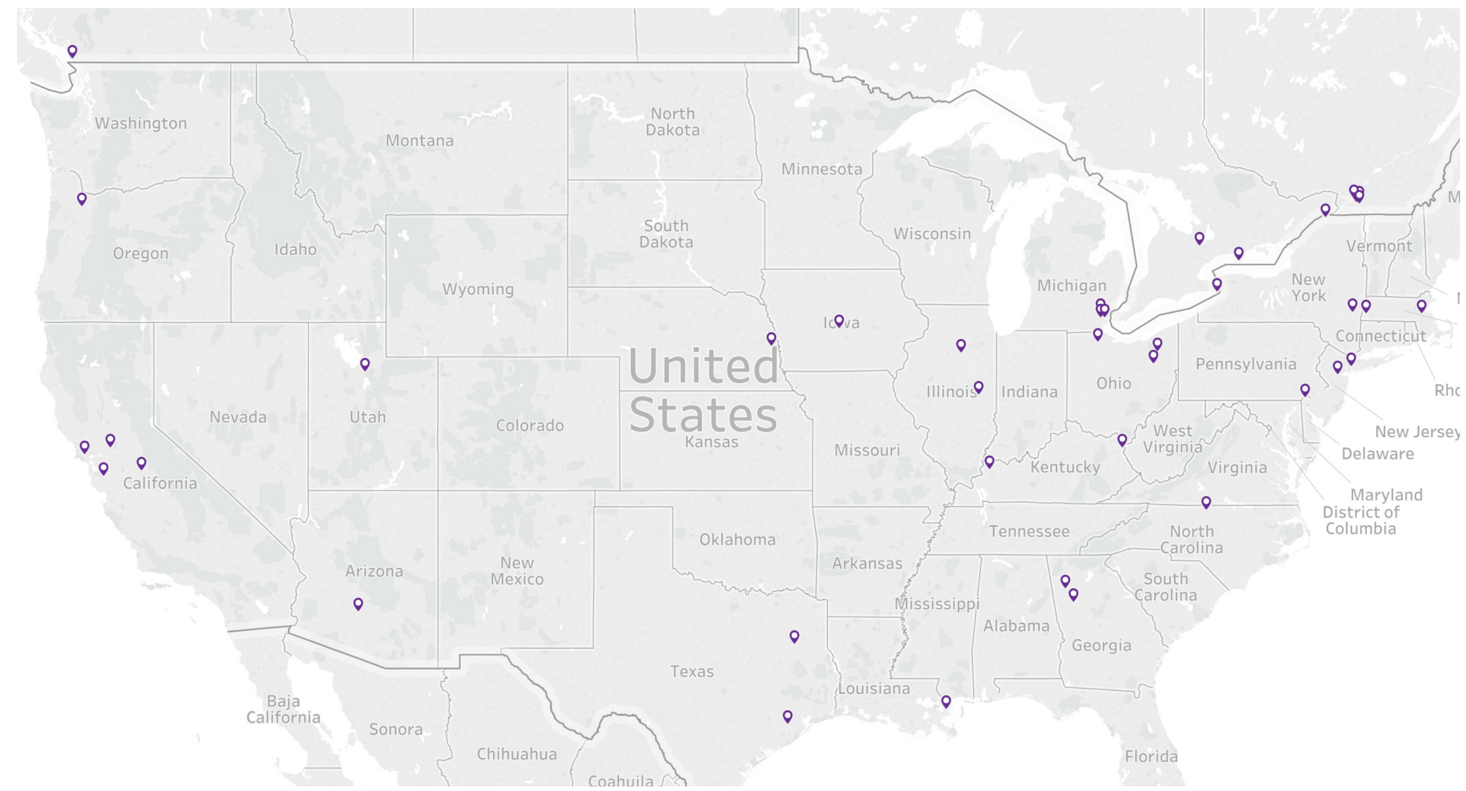
There's a critical need to replicate and scale operating facilities to process enough waste plastics to make a meaningful impact on current supply.

There is money to be made.
The landscape shows that technology providers can profitably transform waste plastics through conversion, decomposition, and purification technologies.

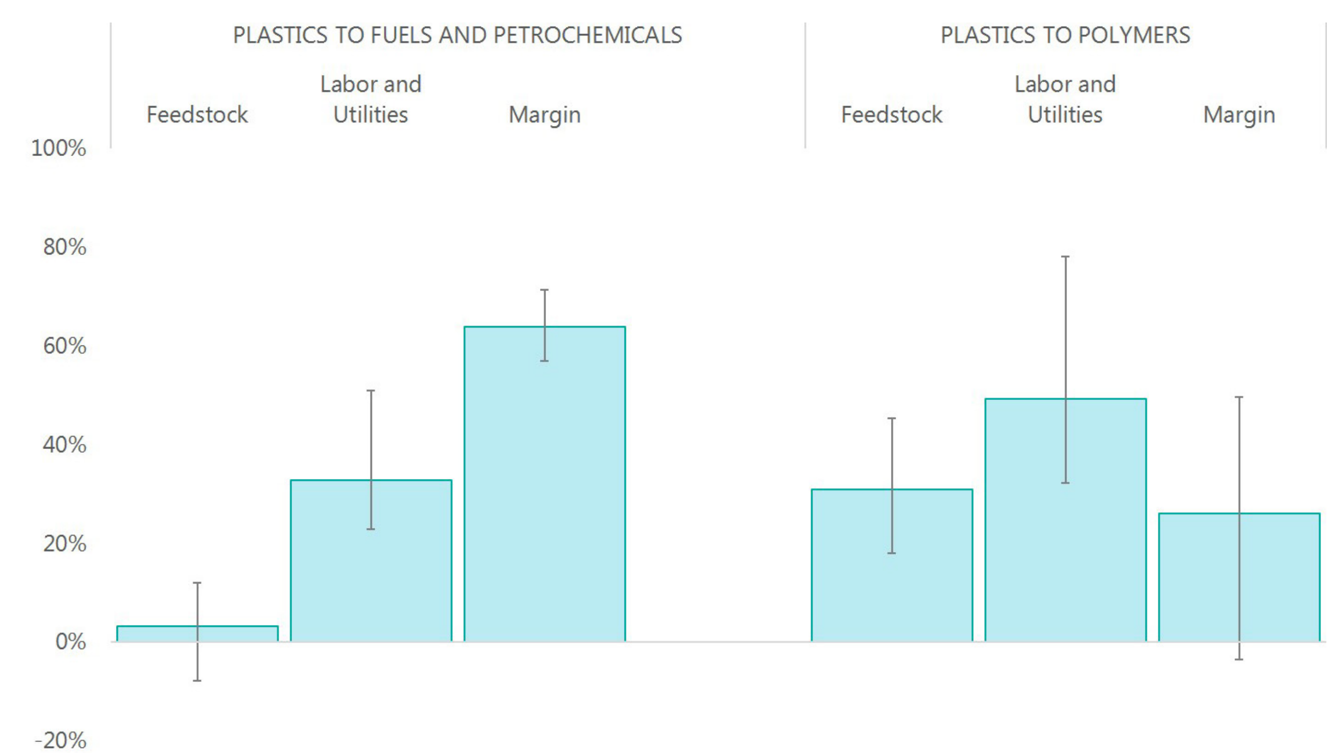
Today, the business case is stronger for providers producing petrochemicals and fuels, with **consistently positive margins, ranging from 60-70%** (Operating Expenses [OpEx] only, based on EBITDA - see figure to the right). Overall, the 27 providers converting plastics in this way are further along on the maturity scale, which contributes to higher margins and stronger economic performance.

Note: The margins presented in the figure represent EBITDA on technology providers' OpEx (Operating Expenses) only. These margins will be impacted by the cost of servicing debt and relevant taxes. Data presented is based on information shared by a subset of technology providers. Closed Loop Partners has not conducted financial due diligence on this information.

TECHNOLOGY PROVIDERS



OPERATING EXPENSES AND GROSS MARGINS, WITH RANGES



Source: Technology providers, AFARA, team analysis

These investments represent the first wave of opportunities, but not the only ones. The 14 providers in the landscape that are producing polymers have less track record and a longer time horizon to scale. For these technology providers, expected margins are still mostly positive today, ranging from -4% up to 50% (OpEx only, based on EBITDA), but highly variable.

Investing in both pathways can keep materials in play. While diverting waste plastics into fuels gives the material an additional "loop" in the economy, transforming waste plastics into petrochemicals or back into plastics can keep material flowing through the economy over multiple generations.

In reality, the two pathways are not mutually exclusive. Some technology providers generate a mix of outputs creating petrochemicals for plastics and fuels simultaneously. Ultimately, investment is needed in this space to mature all the technologies that can capture the economic opportunity. Technology providers who produce predominantly fuels are, on average, more mature, and require later stage investment, while the technology providers who produce predominantly plastic polymers are, on average, an attractive opportunity for earlier stage investors. A mix of financial instruments and strategies is needed to capture the full market opportunity.

Investors and strategic partners are already getting on board.
In the survey, we identified some 250 unique investors, suppliers, customers, and other partners that are engaged with these technology providers. We expect technology providers are enlisting help from many more partners and capital providers that are not yet publicly named as well.

Among those included in the landscape are:

- **National and local government agencies**, quasi-governmental capital providers, **research institutions, and support organizations**, including (in the U.S.) NASA, NREL (the National Renewable Energy Lab), REMADE Institute, state economic development agencies, and (in Canada) BDC, BIC, and Sustainable Development Technologies Canada; notable examples outside of North America can be found in the EU and UK, e.g., Ellen MacArthur Foundation

- **Private capital providers,** including Blackrock, Breakthrough Energy Ventures, Closed Loop Partners, Cycle Capital Management, Kleiner Perkins, Rabobank, and Royal Bank of Canada

- **Brands** and their venture funds, across categories including: consumer packaged goods (e.g., Coca-Cola, Danone, Kraft, Nestlé, PepsiCo, P&G, and Unilever), airlines (e.g., Cathay Pacific, Delta, Japan Airlines), cosmetics (e.g., L'Occitane, L'Oreal), fashion and apparel (e.g., Adidas, H&M, Levi Strauss & Co.), consumer electronics (e.g., Samsung), and furnishings (e.g., IKEA)

- **Most promisingly, petrochemicals and plastics industry** investment and partnerships, such as DAK, Dow, DSM, Indorama, Lyondell Basell, SABIC, TOTAL, and others

Momentum is growing

Over the course of our research, which began in earnest in October 2018, **there has also been an uptick in the pace of research** on plastics waste, the future of the petrochemical industry, and solutions that include many of these technologies. This in and of itself is notable, as perspectives and data are emerging to inform decision-making in markets, policy, infrastructure, and investment capital. See Appendix for additional resources.

With growing interest and engagement coming from many different players in the system, **there is clear momentum for adopting and scaling** purification, decomposition and conversion infrastructure for waste plastics. Every sector of society is engaged in the broad challenges of climate change and the visible problem of plastics waste. The world's largest and most influential brands are taking ownership of the problem and looking at their own supply chains. Technology development is happening. There are solutions that are tackling key material types, producing materials in an environmentally beneficial way, attracting partners and capital, and becoming commercially viable.

We have reached an inflection point.

GOING FROM “POSSIBLE” TO “PROBABLE”: IMPORTANT CONSIDERATIONS

In this moment of technology transition from a linear to circular system, a fundamental question is: **How fast and how far can we go?** For investors, brands, and industry, the answer depends upon four key shifts that will be critical to success.

We need to match up the scale of plastics manufacturing with the distribution of municipal solid waste.

Our linear patterns of consumption have been very good at creating infrastructure that goes from big (petrochemical pipelines) to little (single-use packages), but we now need to go from little (municipal recycling programs and curbside carts) to big (back to pipe). A few models, such as Renewlogy and Recycling Technologies, illustrate what more distributed infrastructure could look like. Fixing this mismatch will be key to achieving scale and market transformation over time.

We need more vertically integrated models to bring down cost structures and make sure the economics work to turn more material back to plastics.

While these models have been proven in the mechanical recycling space, the same cannot be said of more advanced technologies, which may require a very low-contamination stream of feedstock. For a technology provider, that may mean adding pre-processing capabilities to do advanced sorting of mixed materials or co-locating with a supplier or customer. Additional integration, whether through strategic partnerships, such as Ioniqa's partnership with Indorama, or bolt-ons to the core business model, will bring cost structures down as well.

We need to invest in technology platforms that are flexible and can evolve over time.

The benefits of going "upstream" to producing chemicals and fuels that meet many non-plastic markets needs to be considered carefully against the costs of switching as markets evolve. In the interest of scaling these technologies quickly, we risk locking in to technologies that incentivize more "single-use" behavior (i.e., optimizing for fuel production over feedstocks for plastics). Solutions with flexible platforms, such as Agilyx, are demonstrating process agility, allowing them to adapt as feedstocks and end markets shift.

We need market incentives to change.

In the EU and UK, policies have created incentives for scaling these technologies, and a clear framework within which different actors and innovators are developing infrastructure. However, policies in the U.S. and Canada today do not recognize or incentivize the use of these technologies for recycling. As one example, certain conversion technologies are understood as waste combustion, rather than recycling, in jurisdictions such as California and Quebec. Policies, both public and private, can help catalyze action and further scale. Supportive policy mechanisms in other markets have included: landfill bans, minimum recycled content requirements for production and manufacturing, credit schemes for tracking materials in the system, and resources dedicated to more comprehensive collections and recovery of post-use plastics. Models that can be adapted in the U.S. and Canada need to be better understood to shape adoption of these technologies across North America.

Where Are We Going?

By recognizing the opportunities to invest in and scale the technologies highlighted in this landscape, brands, investors and the plastics industry can dramatically impact plastics pollution and waste, create new value in markets and reduce carbon impact of plastics and petrochemical production. But the technologies alone will not solve these problems. Changing the system will only be successful if investments in transformational technologies are made alongside shifts in behavior, infrastructure, and economic incentives of multiple actors. If all of these shifts occur, **we can accelerate solutions at scale in North America.**

CALL TO ACTION: Investors, brands, and industry need to take action now to bring solutions to scale.

The demand for expanded capacity and technologies to recycle plastics is clear. The landscape indicates that it is possible to return far more waste plastics to supply chains than is currently in play today, thanks to the innovation being developed and scaled by technology providers. Now, we are calling on investors, brands, and industry partners to invest in innovative technologies that will accelerate the recycling of plastics. These investments will build capacity, expand to new markets, and scale current infrastructure.

This section outlines recommendations and tangible next steps. It is a call to action to work together to end plastics pollution and create a more circular plastics supply chain.

OUR RECOMMENDATIONS INCLUDE:

Invest: Investors, brands, and industry must urgently invest to advance the recycling of plastics and bring these solutions to scale.

Educate: Clearly define terminology to create shared understanding while making these technologies and processes more accessible to a wider audience.

Collaborate: To build on these findings, brands and industry need to work together to develop partnerships with technology providers to create new business models and agreements, and match the very small scale of current technologies with the very large scale infrastructure of plastics and petrochemical manufacturing.

INVEST

Investors: We need to engage a range of investors, including strategic investors, private equity, venture capital, impact investors, and public or philanthropic funders, to put more capital to work. These investments will help:

- **Accelerate scale and growth of current technology providers.** We can't afford to wait 17 years for new solutions to reach maturity.
- **Create value across the system.** We know successful models are likely to serve multiple end markets. By incentivizing continued recovery and return of plastics to material supply chains, we can prioritize models that create a throughline for materials to exist over multiple generations.
- **Deploy capital toward overall collection and recovery of plastics.** Scaling existing infrastructure or innovating new collections solutions can support the growth of many of these solutions. Closed Loop Fund, The Recycling Partnership and others are investing in collections infrastructure around the country, in close partnership with municipalities and independent operators. Innovation in this space, such as developing new collections models, are strongly needed. Public infrastructure financing schemes can help evolve the system too.

Brand & Industry: Large supply chains have a tremendous amount of influence to solving the plastics waste problem. At this moment, we are seeing significant alignment and opportunity to act. In order to propel the development of technologies and models forward, brands and industry must:

- **Continue to signal strong demand for recycled material.** Further commitments to secure feedstocks through long-term offtake agreements ensure that technology providers will have capital to scale. In the near-term, this may mean allowing for more flexible or premium pricing as technologies mature.
- **Support new business models and partnerships** (e.g., Ioniqa has received support from The Coca-Cola Company, Unilever and Indorama [27]). We need technology providers to have better access and feedback from downstream partners. Strategic investments will ensure that solving plastics waste is now core to a company's competitive advantage. Likewise, we need brands and their suppliers to invest together to help experiment and develop technology providers.

EDUCATE

- **Make the technology accessible.** One of the key challenges that technology providers expressed was the difficulty of explaining the technical side of their solution - whether to potential investors, municipalities, regulatory and permitting agencies, or brands. These technologies are not well understood by decision makers and influencers outside of the industry and academia. This landscape study has been a first attempt to make the issue accessible to a non-technical audience. There is still much work to be done to educate investors, brands and industry about these technologies, and clarify many other terms being used, e.g., chemical recycling, pyrolysis, gasification, or depolymerization.
- **Use shared language.** Intermediaries should make efforts to create common frameworks and definitions to help non-technical decision makers better understand how technologies apply to different supply chains and waste streams.
- **Share what we know.** Research needs to be shared widely. We suspect that much of the data exists, but has been held privately. A knowledge hub would help to consolidate and interpret the latest research.

COLLABORATE

- **Convene stakeholders to create opportunities for feedback and collaboration.** If we are interested in seeing a plastics supply chain in which more recycled plastic is reintroduced into plastic resin manufacturing, chemicals manufacturing, and even farther upstream to refining operations, then we have to bring more operators in the system to the table.
- **Learn from each other.** In the course of our research, we also recognize that technology providers do not have the benefit of learning from others in the field. A pre-competitive community of practice could help spread successful strategies at each stage of maturity.
- **Create syndicate investment opportunities.** Likewise, while it is remarkable that we identified so many investors already investing in individual companies, a forum for investors to share knowledge and syndicate investment into individual companies could increase deal flow and reduce the time technology providers must spend fundraising.

It’s time for bold action.

There is a clear and achievable opportunity to expand the role of transformational technologies that return waste plastics to material supply chains in the United States and Canada. To build on the progress made thus far, the system must drive investment in these solution providers, build awareness to make this work more accessible and encourage collaboration across stakeholders. Doing so will lead to a dramatic shift in plastics and chemicals supply chains over the next ten years - one that keeps plastics in play.

What's next?

This landscape introduces the current state of play for technologies that transform waste plastics and keep materials in play.

For more information: Additional research, articles, and an interactive map of existing infrastructure in the US and Canada are available on the Closed Loop Partners website: [www.closedlooppartners.com/plastics].

To contribute or update information: We invite technology providers and researchers to contribute to the data collected in late 2018/early 2019 by providing updates and add to the landscape: admin@closedlooppartners.com

Future topics
There are further topics that must be explored in greater depth, including:

- An **investment roadmap** that defines the aggregate capital needed to scale solutions across North America and outlines the breadth of investment and other strategies to achieve impact and scale.
- The **role and impact of policies**, credit or certification schemes and standards as incentives to stimulate market demand in North America.
- The **role of alternative materials that would lead to deselection of extraction-based plastics** in accelerating circular supply chains, including how alternatives would perform within existing prime production and recycling infrastructure from both economic and environmental perspectives.
- An **assessment of impacts**, both positive and adverse, on health, safety and environment associated with existing or emerging technologies.

Join us: If you are interested in participating in our ongoing research, convening, and investment in this area, we encourage you to introduce yourself to the Center for the Circular Economy: admin@closedlooppartners.com

APPENDIX

APPENDIX TABLE OF CONTENTS

I. Plastics 101

What are plastics? All plastics are polymers. A polymer is a large molecule made of repeating units of smaller molecules, called monomers, that are linked together by chemical bonds to form long chains.

Polymers can be made by connecting a single type of monomer, such as those commonly found in packaging, pipes, and toys (e.g., polyethylene, polypropylene, polystyrene, or polyvinyl chloride); or by the reaction between two different types of monomers, such as those commonly found in carpets and clothes (e.g., polyethylene terephthalate, nylon).

Furthermore, plastics can be characterized as thermosets or thermoplastics. Only thermoplastics are recyclable.

- Thermoset plastics are hard and durable and cannot be recycled into new polymers due to irreversible chemical bonds between polymer chains called crosslinks. Examples include polyurethanes and epoxy resins.
- Thermoplastics, by contrast, do not contain crosslinks and are less rigid than thermosets, allowing the material to soften when heated and can be reshaped. Thermoplastics are easily molded and extruded into films, fibers, and packaging. Examples of thermoplastics include polyethylene (PE), polypropylene (PP) and polystyrene (PS).

Plastics bio-degrade slowly, over hundreds and even thousands of years, so dealing with post-consumer and post-industrial plastics is a global imperative.

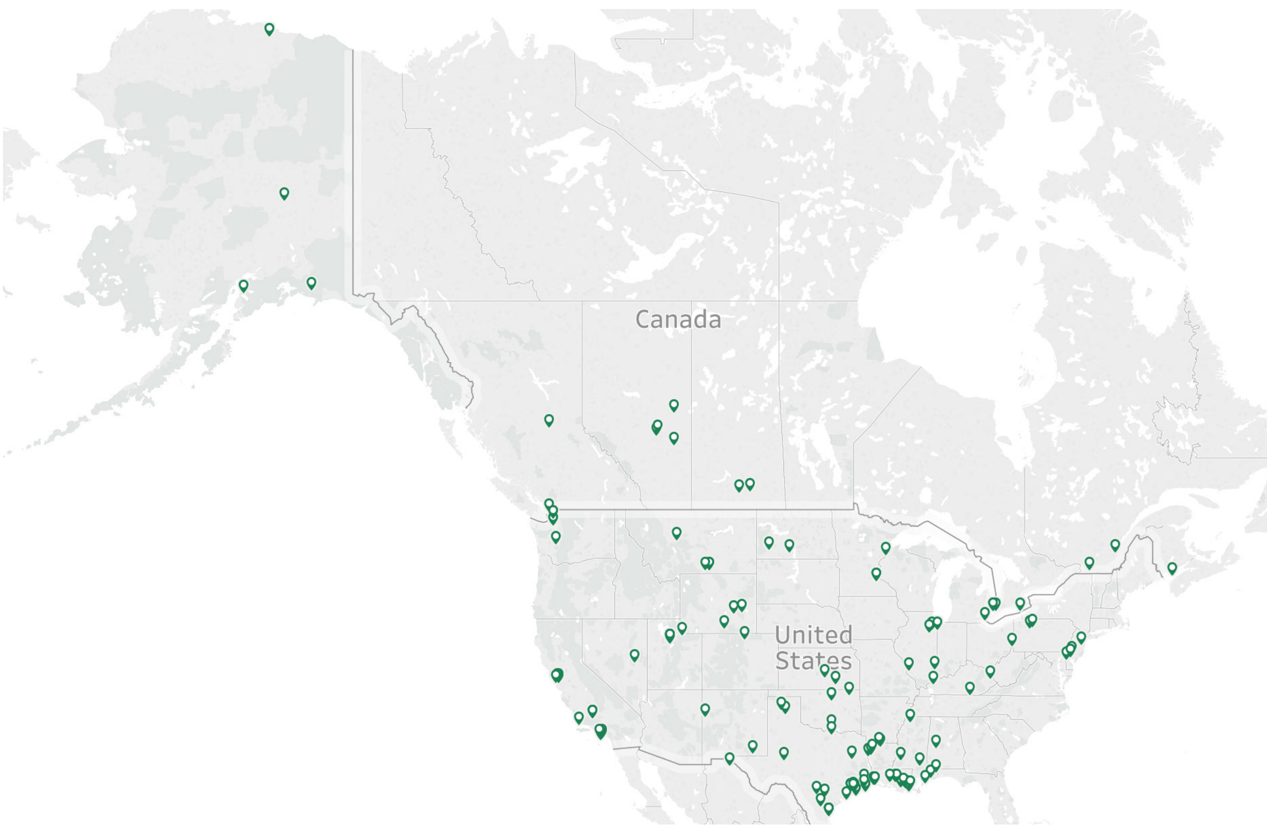
CHEMICAL NAMES/ABBREVIATION SIDEBAR

Term	Description or Example	
Intermediates	Paraxylene	Chemicals which are precursors to the production of monomers and/or polymers
MEG	Monoethylene Glycol	Monomer used in PET
PCR	Post-consumer resin	Waste plastics coming from residential or commercial consumer sources
PE (incl. HDPE, LDPE)	Polyethylene High-Density Polyethylene Low-Density Polyethylene	HDPE: Milk jugs, detergent containers LDPE: Sandwich bags, cling wrap
PET	Polyethylene Terephthalate	Water bottles, soda bottles
PP	Polypropylene	Automotive parts, pipes, yogurt containers, bottle caps
PS	Polystyrene	Plastic cutlery, packaging foam
PVC	Polyvinyl Chloride	Plumbing pipes, ducts
Prime	Virgin	Newly extracted plastic or other material, as opposed to recycled, which is sometimes referred to as “secondary”
TPA	Terephthalic Acid	Monomer used in PET

Who makes plastic?

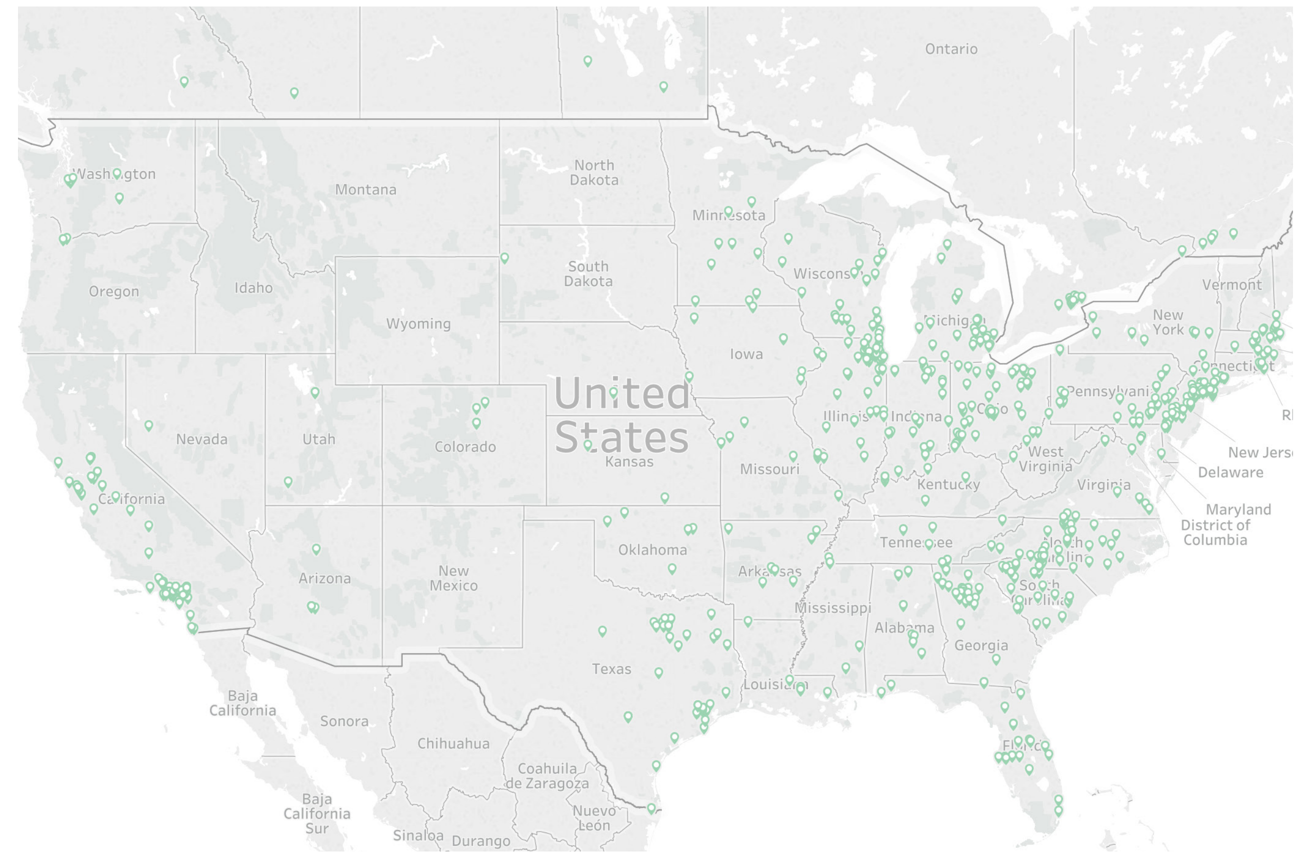
In today's mostly linear economy, chemical and petrochemical (oil and gas) companies are major players in the plastics sector, since they produce crude oil, natural gas liquids and natural gas that is refined into petrochemicals that make plastic polymers. The top 5 plastic producers by market capitalization today are ExxonMobil, INEOS, BASF, ENI, and SABIC. In the U.S. and Canada, infrastructure is very large, highly concentrated in a few key regions.

FIGURE A: OIL AND GAS REFINERIES IN NORTH AMERICA



Prime plastics are produced and sold globally. In the U.S. and Canada, much of the infrastructure where crude oil is extracted and refined exists on the Gulf Coast and in Alberta. Refining yields fractions of raw materials, such as naphtha, ethane, and propane; less than 10% of the material coming out of the refining process can become plastics [28].

FIGURE B: RESIN PRODUCTION FACILITIES IN NORTH AMERICA



Brand owners and manufacturers buy these polymers to use in a wide range of products and packaging - everything from beverage bottles and food containers, textiles, and consumer electronics, to construction materials and automotive parts.

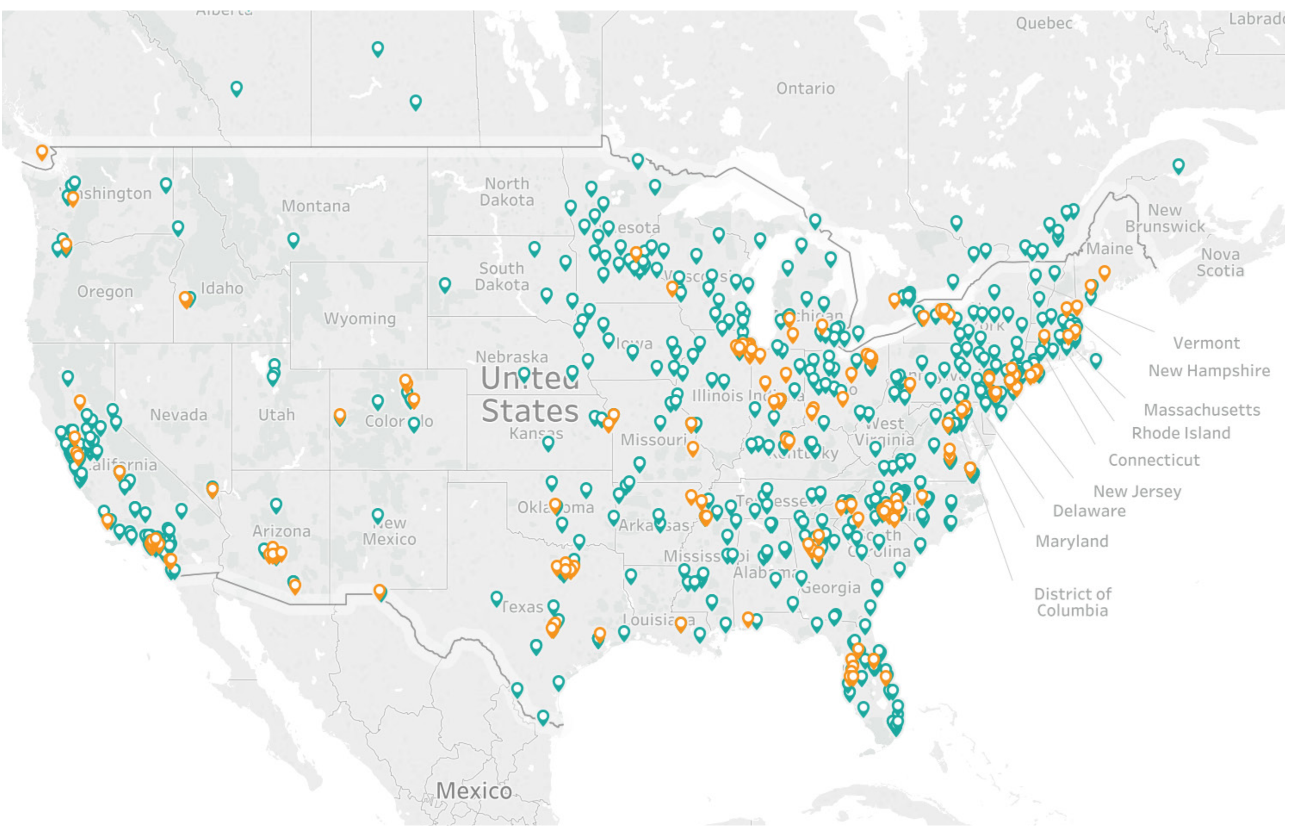
Plastics Production in US & Canada by End-Use [2]

Molded Parts	31%
Films	29%
Pipes	18%
Packaging	4%
Consumer products	4%
Textiles	3%
Coatings	2%
Wire & Cable	1%
Other	8%

Who makes plastic?

There is no shortage of plastics consumed in the United States and Canada. The challenge is that it's highly distributed; we find plastics where people live. After sale and use, post-consumer plastics are collected and either disposed of as waste or, if there is recycling infrastructure, the plastic may make its way to a recycling facility, often called a materials recovery facility (MRF), to be sorted and baled. Then, plastics are mostly recycled mechanically by reclaimers, reprocessors and converters to make new products and packaging from the recycled material.

FIGURE C: POTENTIAL SOURCES OF WASTE PLASTICS



Within the United States, 70% of recycled commodities are processed domestically. According to the [Institute of Scrap Recycling Industries (ISRI)](), 815,000 metric tons of plastic scrap was processed in 2016. In addition, an estimated 5 million+ tons of electronics scrap is processed each year, of which an increasing proportion is plastics. This material flow map shows primary sources of municipal solid waste, coming from residences, commercial businesses, light industrial and construction and demolition sites. Material that is recovered for recycling typically flows through a materials recovery facility (MRF). (Not shown here: Textile mills and other manufacturers that generate significant post-industrial scrap, as well as stadiums, retail malls, airports and other institutional sources of post-commercial material.) Despite the existing infrastructure, 90% of plastics end up in a landfill today (source: US EPA). Recovery is key to keeping plastics in play.

The most significant advantage of utilizing the full spectrum of advanced technologies is the diversity and volume of materials that can be recycled back into useful end products – continuously. Figure C depicts the locations of Material Recovery Facilities (MRFs) and e-waste recyclers. This is a small subset of all of the materials that are potentially available as feedstocks for recycling.

However, the entire Eastern seaboard and Great Lakes regions are ripe for processing mixed plastics from rigid and flexible packaging collected from municipal residential programs. Not pictured, but also important, are post-industrial sources of waste plastics, such as textile mills and packaging manufacturers, which produce scrap material that is more concentrated, more homogenous (i.e., higher quality) and less contaminated than post-consumer sources.

FIGURE D: RECLAIMERS AND REPROCESSORS

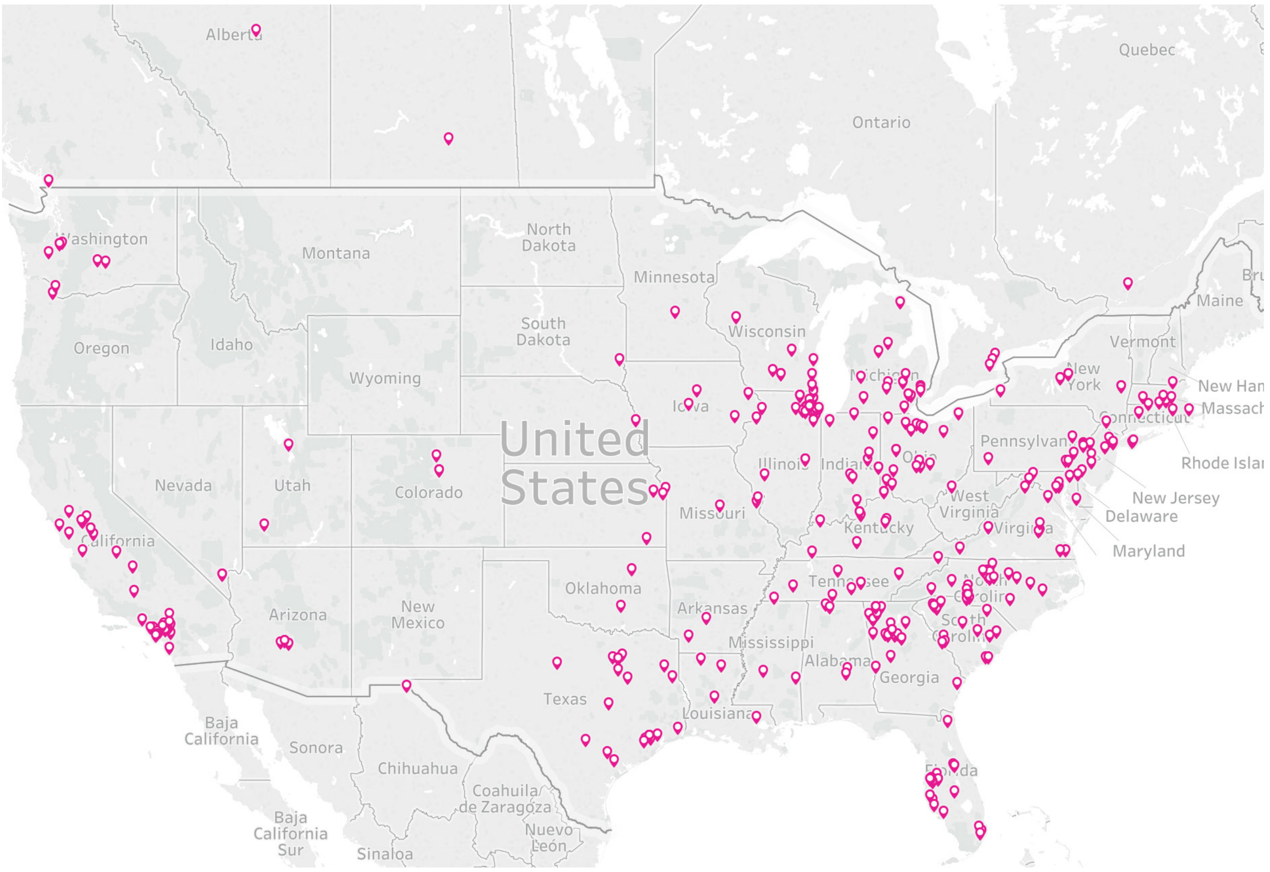
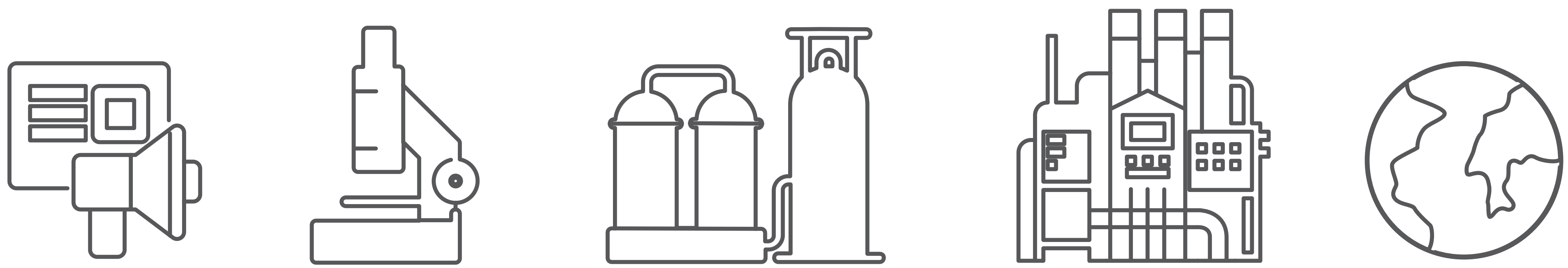


Figure D shows the many reclaimers and reprocessors operating today; nearly all use mechanical processing technologies [28].

Technologies that transform waste plastics into new materials have the potential to create a circular materials economy for all industries, not just the packaging sector.

Defining Stages of Maturity



DESCRIPTION

CONCEPT: 3	LAB: 8	PILOT: 13	EARLY COMMERCIAL: 28	GROWTH: 8
Public announcement made about intended research	Technology is being researched and tested at a lab.	A small pilot demonstrates the technology.	Technology is upscaled to an industrial scale.	Technology is being implemented in various parts of the world.

REFERS TO NUMBER OF PROVIDERS

FULL LIST OF TECHNOLOGY PROVIDERS REVIEWED

	Technology Provider	Profile Available in Appendix (Total: 60)
1	Agile Process Chemicals LLP	Yes
2	Agilyx	Yes
3	AmberCycle (moral fiber)	Yes
4	Anhui Oursun Environmental Technologies	Yes
5	APK	Yes
6	Aquafil	Yes
7	Axens	Yes
8	BASF ChemCycling	No
9	Battery Resourcers	No
10	Biocellection	Yes
11	Bioplasatech	No
12	BioXycle	No
13	Blest	Yes
14	ByFusion	No
15	Cadel Deinking	Yes
16	CarBios	Yes
17	Climax Global Energy	Yes
18	Cogent Energy Systems	No
19	Connora Technologies	No
20	CreaCycle GmbH	Yes
21	Cynar Recycling	No
22	EcoFuel Technologies	Yes
23	Ecopek	Yes
24	Enerkem	Yes
25	Enval	Yes
26	Envion	No
27	Equipolymers	Yes
28	Esun	No
29	Evrnu	No

	Technology Provider	Profile Available in Appendix (Total: 60)
30	Fulcrum BioEnergy	Yes
31	FWD Energy	No
32	Galactic	Yes
33	Garbo	Yes
34	GEEP (Global Electric Electronic Processing)	Yes
35	Generated Materials Recovery	No
36	Genomatica	No
37	Geo-Tech Polymers	Yes
38	Golden Renewable Energy	Yes
39	Gr3n	Yes
40	Green EnviroTech Holdings	No
41	GreenMantra Technologies	Yes
42	IBM VolCat	No
43	Illinois Sustainable Technology Center	Yes
44	Ioniqa	Yes
45	JBI Plastic2Oil	Yes
46	Jeplan	Yes
47	Jet Plastics	No
48	Karlsruhe Institute of Technology	Yes
49	Klean Industries	Yes
50	Kyoto Institute of Technology	No
51	Loop Industries	Yes
52	MBA Polymers	No
53	Modular Genetics, Inc	No
54	Natureworks	Yes
55	New Hope Energy	Yes
56	Next Generation	Yes
57	Nexus Fuels	Yes

	Technology Provider	Profile Available in Appendix (Total: 60)
58	Omnifusion	No
59	Opus12	No
60	Origin Materials	No
61	P4SB	No
62	perPETual	Yes
63	Plastic Energy	Yes
64	Polycycl (previously Ventana Cleantech)	Yes
65	Polystyvert	Yes
66	PureCycle Technologies	Yes
67	Pyrowave	Yes
68	Quality Circular Polymers	No
69	Re:NewCell	No
70	Recenso GmbH	No
71	Reclaimed EcoEnergy	Yes
72	Recycling Technologies	Yes
73	ReNew ELP	Yes
74	Renewlogy	Yes
75	Rensselaer Polytechnic Institute	No
76	RES Polyflow	Yes
77	Resinate Materials Group	Yes
78	Resynergi	Yes
79	RESYNTEX	No
80	SABIC Innovative Plastics	Yes
81	saperatec	No
82	Sep-All	No
83	Sierra Energy	Yes
84	Sustane Technologies Inc.	No
85	Teijin	No

	Technology Provider	Profile Available in Appendix (Total: 60)
86	The Infinited Fiber Company	No
87	The Pennsylvania State University	Yes
88	Total Corbion	No
89	TRASH2CASH	Yes
90	Tyton BioSciences	Yes
91	University of Massachusetts-Lowell	Yes
92	University of Portsmouth	Yes
93	University of Ulsan	Yes
94	Vadxx	Yes
95	Valoren	No
96	VinyLoop	No
97	Worn Again Technologies	Yes

II. Profiles of Technology Providers

We reviewed more than 90 providers, and have completed profiles for 60 technology providers in scope.

apc
Agile Process Chemicals LLP

LOCATION:
Mumbai, Maharashtra, India

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 28, 2019

DESCRIPTION	Agile Process Chemicals (apc) offers an internationally patented pyrolysis technology that converts plastic and tire waste into pyrolysis oil, carbon black, and hydrocarbon gas. For every 12,000 kg of feedstock, the Plastic Pyrolysis Plants and Tire Pyrolysis Plants yield 70-90% and 40-45% pyrolysis oil, respectively.
FEEDSTOCK	apc processes both post-consumer and post-industrial plastics, including laminates, multi-layer plastics, packaging, as well as municipal solid waste (MSW) segregated plastic and tires.
FACILITIES	apc has helped clients establish over 35 pyrolysis plants in United Kingdom, India, Kenya, and United Arab Emirates, among others. Plant capacity ranges from 3 to 12 metric tons/day of plastics.
PARTNERS	Data not available.
BUSINESS MODEL	Currently, apc offers products and services in following steps: 1) Pyrolysis Consultancy, 2) Pilot Plant Trials, 3) Drafting a Business Plan, 4) Signing of Confidentiality Agreement & Plant Visit, 5) Design, Manufacturing, Supply, Installation and Commissioning of Pyrolysis Plant, and 6) Operation and Maintenance of Pyrolysis Plant for the First 2 Years.

*Based on research and validated with Agile Process Chemicals.

agilyx
Reduces. Produces. Creates.

LOCATION:
Tigard, Oregon, USA

TECHNOLOGY TYPE:
1. MPC: Conversion (thermal)
2. PSM: Decomposition (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
1. MPC: Plastics to fuels
2. PSM: Plastics to monomers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 21, 2019

DESCRIPTION	Agilyx creates circular recycling pathways for plastics through the company's two Conversion Facility platforms: The Mixed Plastics-to-Crude (MPC) System which produces lower-carbon crude oil for fuel production, naphtha cracker feed and the single polymer pathway such as the Polystyrene-to-Styrene Monomer (PSM) System which produces styrene oil.
FEEDSTOCK	Agilyx processes both post-consumer and post-industrial mixed plastics. Agilyx performs physical and chemical characterization to understand the feedstock composition before selecting the optimal platform and generates feedstock recipes suitable for the value chain.
FACILITIES	Agilyx owns and operates one facility in Tigard, Oregon, USA with a capacity of 10 tons of PS/day. Agilyx has shipped 800,000+ gallons (processing 8,000,000+ lbs of mixed plastics) of Agilyx Synthetic Crude Oil (ASCO) from prior systems.
PARTNERS	Agilyx works with members in the entire value chain from brand owners and retail to chemical manufacturers, polymer producers, waste industry, and municipal governments. For the MPC Platform, Agilyx is partnered with Delta Airlines and Monroe Energy, a wholly owned subsidiary of Delta Air Lines, to take up to 2,500 bbl/day of ASCO and has an ongoing existing relationship with US Oil. For the PSM Platform, Agilyx has collaborations with Americas Styrenics, INEOS Styrolution, and others to develop 50 ton/day PS recycling facilities.
BUSINESS MODEL	Currently, Agilyx has more than 50 projects in various stages of development that have not been publicly disclosed. In the short term, Agilyx will develop a production facility near Monroe Energy's facility in phases. In the long term, Agilyx plans to continue building multi-stakeholder supply chains through additional partnerships. Agilyx has three business pillars: 1) Conversion Facilities that employ pyrolysis technology to process plastics; 2) Research and Development that generates new circular pathways; and 3) 'Cyclyx' a feedstock logistics division that aggregates and prepares feedstock for the purpose of chemical and circular recycling.

*Based on research and an interview. Validated with Agilyx.

AMBERCYCLE

LOCATION:
Los Angeles, California, USA

TECHNOLOGY TYPE:
Decomposition (biological)

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 22, 2019

DESCRIPTION	Ambercycle (moral fiber) is a materials company that creates virgin-grade materials from textile waste.
FEEDSTOCK	moral fiber targets PET-containing materials (e.g., polyester textiles, PET bottles).
FACILITIES	Data not available.
PARTNERS	moral fiber has a partnership with H&M to create a textile produced entirely from old clothing and has been awarded the Global Change Award from the H&M Conscious Foundation to commercialize their technology. In May 2018, moral fiber was selected for the Fashion for Good Scaling Programme.
BUSINESS MODEL	Currently, moral fiber is scaling with support from their partners. In the long term, moral fiber will aim to build modular recycling units to be co-located with producers of PET waste streams or consumers of PET.

*Based on research and validated with moral fiber.

ANHUI OURSUN RESOURCE TECHNOLOGY

LOCATION:
Hefei, Anhui, China

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 14, 2019

DESCRIPTION	Anhui Oursun Resource Technology Co., Ltd (Oursun Resources) converts plastic waste into diesel oil, gasoline oil, gas, and slag. The company's machine system is continuous and automatic, using computer-controlled equipment. The company has patents on its constant-temperature slagging device, its batch-type mixer, its gas recovery and voltage stabilizing supply device, its plastic cracking catalyst formulation, and its plastic cracking process.
FEEDSTOCK	Oursun Resources targets PE, PP, and PS (Plastics No. 2, 4, 5, 6).
FACILITIES	Oursun Resources' facilities can process between 10 to 500 tons/day of plastic and can yield between 50-90% of oil, depending on the feedstock. The facilities require approximately 280 kWh of electricity for every ton of plastic processed.
PARTNERS	Oursun Resources was established as a joint venture between China, America, and Taiwan.
BUSINESS MODEL	Currently, Oursun Resources is a manufacturer and exporter of pyrolysis technology.

*Based on research only.

APK

newcycling
for infinite resources

LOCATION:
Merseburg, Germany

TECHNOLOGY TYPE:
Purification[1]

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
€18-50 million

LAST UPDATED:
Mar 18, 2019

DESCRIPTION	APK developed a solvent-based, physical recycling technology called Newcycling®. The technology enables separation of different polymer types found in multi-layer films and mixed plastic waste fractions to produce 'virgin-like' polymers. The output is pure, sorted granulates (such as PE and PP).
FEEDSTOCK	APK's technology accepts pre- and post-consumer plastic waste, including multi-layer films and mixed plastic waste fractions. Examples include PE & PA, PET & PE, LDPE, HDPE, and PP.
FACILITIES	A plant has been scaled up in Merseburg, Germany with a capacity of 8,000 metric tons/year. From March 2019, this plant will be focused on recycling PE & PA multi-layer film from post-industrial sources.
PARTNERS	APK is owned by MIG Fonds and AT Newtec. APK is a member of international projects by CEFLEX and the Ellen MacArthur Foundation. APK also has a strategic partnership with MOL Group – an oil & gas company based in Hungary.
BUSINESS MODEL	Currently, APK is commissioning their early commercial plant. In the short term, APK will set up a second Newcycling® plant that will process mixed plastic waste fractions from post-consumer origin. In the long term, APK will aim to set up recycling plants in both Europe and Asia by 2025.

*Based on research and validated with APK.

[1] Solvent-based recycling

AQUAFIL
synthetic fibres and polymers

LOCATION:
Arco, Italy

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 14, 2019

DESCRIPTION	Aquafil's ECONYL® Regeneration System depolymerizes PA6 to its monomer: caprolactam. The monomers are polymerized to produce two kind of yarns: ECONYL® nylon yarns for textile applications and ECONYL® nylon yarns for carpet applications.
FEEDSTOCK	Aquafil processes pre- and post-consumer PA6 products. The three main sources include PA6 fishnets (collected worldwide), PA6 carpets, and oligomers/other plastic waste generated by polymer industries.
FACILITIES	Aquafil has 16 facilities operating in 8 countries over 3 continents. The Group's headquarter is located Arco, Italy, while the ECONYL® Regeneration System is located in Ljubljana, Slovenia. Linked sites are located in Ajdovščina, Slovenia (PA6 waste storage and preparation) and Phoenix, Arizona, USA (Aquafil Carpet Recycling #1 - ACR #1). ACR#1 is able to recycle 16,000 tons/year of used carpet.
PARTNERS	Aquafil has strong relationships with all players along the value chain, from PA6 waste providers to final customers, including clothing brands (e.g., Adidas, Volcom, Stella McCartney) and carpet manufacturers (e.g., Interface, Milliken, Mannington, Tarkett Group).
BUSINESS MODEL	In the short term, Aquafil is planning to open a second plant for carpet recycling (ACR #2) in Spring 2019 in Woodland, California, USA.

*Based on research and validated with Aquafil.

Axens
Powering integrated solutions
An IFP Group company

LOCATION:
Reuil-Malmaison, France (HQ)

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 9, 2019

DESCRIPTION	Axens (a company of the IFP Energies Nouvelles group) and IFPEN developed the GlyPET process which uses glycolysis to depolymerize PET into monomers: bis 2-hydroxyethyl terephthalate (BHET). This is followed by a purification step.
FEEDSTOCK	GlyPET recycles complex polyesters and all types of PET, including opaque PET, colored PET, and trays.
FACILITIES	The GlyPET process has been validated on a lab scale and is currently being optimized on a scale of 1-10 kg/hour.
PARTNERS	The main R&D contributor to the GlyPET technology is IFP Energies Nouvelles, a state-owned industrial and commercial establishment active in the fields of energy, transport and environment. Axens is a worldwide group that provides a complete range of solutions (technologies, equipment, furnaces, modular units, catalysts, adsorbents and related services) for the conversion of oil and biomass to cleaner fuels and major chemical intermediates
BUSINESS MODEL	Currently, Axens & IFPEN are looking for partners to implement a pilot operation (e.g., building an industrial unit). In the long term, Axens is planning to deploy modular units on existing industrial polymerization sites (e.g., sale of equipment and turnkey modules). The business model also includes license sales, service, and sales of monomer products.

*Based on research and validated with Axens.

BioCellection

LOCATION:
Menlo Park, California, USA

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 16, 2019

DESCRIPTION	BioCellection deploys a selective oxidation process to decompose post-consumer plastics into shorter chain molecules, such as oligomers and dibasic acids. The process uses two catalysts, which are both recovered and recycled back into the system.
FEEDSTOCK	BioCellection targets post-consumer plastic feedstocks after industrial sorting, including plastic films (mainly LDPE and HDPE), rigid plastics (PP, PET, PS, PE), and foam plastics (mainly PS).
FACILITIES	BioCellection has a lab in Menlo Park, California, USA, with the ability to process 2 kg/day of plastics.
PARTNERS	BioCellection has a partnership with the City of San José and GreenWaste Recovery.
BUSINESS MODEL	Currently, BioCellection is planning to build a unit which will process 500 kg/day of plastics. In the short term, BioCellection plans to experiment with compost-treated plastics and small format plastic residuals. In the long term, BioCellection will aim to license their technology.

*Based on research only.

Blest

Protect earth from contamination

LOCATION:
Kanagawa, Japan

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 22, 2019

DESCRIPTION	Blest manufactures three different scales of plastic to oil pyrolysis technology, operating between 400-450°C. The technology produces a mixed synthetic light sweet crude composed of diesel, gasoline, kerosene, and heavy oils.
FEEDSTOCK	Blest targets PE, PP, and PS feedstock. Blest machines do not accept PET or PVC.
FACILITIES	Blest offers both batch type machines and continuous system machines. The highest capacity model processes 1,000 kg/day.
PARTNERS	Blest has sold over 100 machines in more than 41 countries. Countries using machines with higher capacities include Japan, Palau, and Canada. Blest's customers include a mix of governments and recycling companies (e.g., Nagatashigyo Co., Ltd. and P&M Recycling Center).
BUSINESS MODEL	Currently, Blest is a manufacturer and distributor of pyrolysis technology.

*Based on research only.

CADEL DEINKING

LOCATION:
Alicante, Spain

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
€1 million to build scaled-up facility and €2 million to build a deinking center and laboratory in USA

LAST UPDATED:
Mar 7, 2019

DESCRIPTION	Cadel Deinking uses water-based purification to remove printed ink from plastic surfaces and does not require solvents. The company is also developing a delamination technology to separate the two layers of laminated products.
FEEDSTOCK	Cadel Deinking targets post-consumer (from commercial/distribution chains and households) and post-industrial plastics. This includes all types of plastics (e.g., HDPE, LDPE, PP, PET) and any inks (e.g., water-based, solvent-based, UV, electron beam).
FACILITIES	Cadel Deinking has a facility in Alicante, Spain, which demonstrated a capacity of 450 kg/hour.
PARTNERS	Cadel Deinking has sold a plant to an Italian converting company. Other existing partners include Repsol and Plastic Bank.
BUSINESS MODEL	Currently, Cadel Deinking owns and operates their facility in Spain and has five new projects in advanced negotiations. In the short term, Cadel Deinking will continue to provide turnkey deinking plants for converters and recycling companies. In the long term, Cadel Deinking will aim to be established in the US market.

*Based on research and an interview. Validated with Cadel Deinking.

CARBIOS

Reinvent Polymers Lifecycle

LOCATION:
Saint-Beauzire, France

TECHNOLOGY TYPE:
Decomposition (biological)

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 6, 2019

DESCRIPTION	Carbios uses enzymatic hydrolysis, a biological process to selectively break down PET materials into two monomers: terephthalic acid (PTA) and ethylene glycol (EG). The enzyme used is optimized and engineered by Carbios and can achieve a 97% yield of monomers in 16 hours.
FEEDSTOCK	Carbios focuses on the recycling of PET, in the form of both rigid plastics (clear, colored, opaque, complex) and textiles.
FACILITIES	Carbios has demonstrated their technology at lab scale and is currently running a pilot project in a 1,000-liter reactor at their headquarter in St-Beauzire, France.
PARTNERS	Carbios completed the final stage of the THANAPLAST™ Program in June 2017. The 5-year R&D program brought together academic and industrial partners, including Toulouse White Biotechnology (TWB) and CNRS. Carbios also has brand partners including L'Oréal, TechnipFMC, Novozymes, and Limagrain Céréales Ingrédients.
BUSINESS MODEL	Currently, Carbios is working to scale up to a demonstration unit and is generating revenue through collaborations. In the long term, Carbios will be aiming to do an industrial roll-out starting in 2023, through international licensing.

*Based on research and validated with Carbios.

CLIMAX GLOBAL ENERGY

LOCATION:
Allendale, South Carolina, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 14, 2019

DESCRIPTION	Climax Global Energy's microwave pyrolysis technology converts waste plastics, used oils, forestry-industry by-products, and biomass into synthetic crude oil, transportation fuels, and industrial petrochemicals. The process does not require a catalyst. Generally, 1 ton of plastic produces approximately 5 barrels of oil.
FEEDSTOCK	Climax Global Energy focuses on non-recyclable plastics such as "mixed" 3-7, but can accept all types of plastics (e.g., PET, HDPE, PVC). The feedstock can be mixed, dirty and wet.
FACILITIES	Climax Global Energy successfully completed a pilot demonstration in Allendale, South Carolina, USA with a capacity to process 3 tons/day.
PARTNERS	Climax Global Energy has relationships with SC Launch and South Carolina Research Authority.
BUSINESS MODEL	Currently, Climax Global Energy is the sole owner-operator of the facility. In the short term, Climax Global Energy will establish direct relationships with refineries for the offtake of their output. In the long term, Climax Global Energy will aim to develop facilities that are modular and replicate their technology on a commercial scale worldwide.

*Based on research only.

CreaCycle GmbH

LOCATION:
Grevenbroich, Germany

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 23, 2019

DESCRIPTION	The CreaSolv® Process is based on selective extraction that regenerates polymers out of plastic. The solvent-based CreaSolv® Process targets plastic waste and can separate different types of polymers and/or imbedded hazardous contaminants or additives. The liquids used run in a closed-circuit and are routinely recycled. The CreaSolv® Process was developed by CreaCycle (solvent formulations with low risk potential for users and the environment) in cooperation with Fraunhofer Institute IVV (process development).
FEEDSTOCK	The CreaSolv® Process targets thermoplastic polymers; specifically, packaging plastic waste (e.g., multi-layer, compounds of different polymers), Waste Electronic and Electrical Equipment (e.g., WEEE containing ABS-HIPS mixtures), and construction insulation foam with banned flame retardants (e.g., EPS with HBCDD).
FACILITIES	A few pilot and demonstration plants are being built globally by different companies and organizations in Indonesia, Holland, and Germany. The smallest commercial plant has a capacity to process 2,000-4,000 tons annually.
PARTNERS	CreaCycle and Fraunhofer IVV work with engineering companies, such as EPC-Group and LOEMI, in order to support licensees interested in building a CreaSolv® Plant.
BUSINESS MODEL	Currently, Fraunhofer IVV adapts the CreaSolv® Process to different waste streams (based on customer needs) and CreaCycle develops tailored proprietary CreaSolv® Formulations. Fraunhofer licenses the CreaSolv® Technology, with CreaCycle supplying specified CreaSolv® Formulations to licensees. CreaSolv® is a registered trademark of CreaCycle.

*Based on research and validated with CreaCycle GmbH.

ecofuel technologies

LOCATION:
Livonia, Michigan, USA

TECHNOLOGY TYPE:
Conversion (chemical)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
$10 million USD

LAST UPDATED:
Mar 13, 2019

DESCRIPTION	EcoFuel Technologies (EFT) converts plastics directly into products that are ready to use in engines (e.g., lubricating fluids, diesel, gasoline, aviation fuel). The technology uses a nano-engineered catalyst and operates at low temperatures (350°C - 450°C).
FEEDSTOCK	EFT targets HDPE, LDPE, PP, and PS feedstocks and can process co-mingled plastics.
FACILITIES	EFT has operated a demonstration unit in Livonia, Michigan, USA. A second unit was sold to a non-profit in Santa Cruz and a third one is operating in India. Once commercial, the modular units can be scaled to handle 200-60,000 lb/day of plastics.
PARTNERS	EFT has partnered with Save Our Oceans Foundation, Ocean Guardian, Ocean Recovery Systems, and SAIC corporation. Teams of engineers from Ireland and India have vetted the technology and want to partner with the rights to build and sell the units in Europe and India.
BUSINESS MODEL	Currently, the team in India is building a 500 lb/day and a 2000 lb/day reactor for sale. In the short term, EFT has active plans to build and sell modular units for the USA and Indonesian markets. In the long term, EFT aims to commercialize the technology globally. EFT plans to enter into partnerships with local entities to build and operate the Plastic-to-Fuel technology worldwide.

*Based on research and validated with EcoFuel Technologies.

ECOPEK

LOCATION:
Pacheco, Buenos Aires, Argentina

TECHNOLOGY TYPE:
Purification[1]

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 28, 2019

DESCRIPTION	Ecopek (formerly CabelmaPET) produces food-grade rPET raw materials from PET bottles. The PET bottles are first mechanically processed into rPET flakes, followed by chemical processes which turn the flakes into rPET pellets.
FEEDSTOCK	Ecopek targets post-consumer PET.
FACILITIES	Ecopek's facility in Pacheco, Buenos Aires, Argentina with a production capacity of 16,000 tons/year of rPET production.
PARTNERS	DAK Americas Argentina S.A. (virgin PET producer) acquired CabelmaPET S.A. in 2014.
BUSINESS MODEL	Currently, a portion of Ecopek's post-consumer rPET is integrated into DAK Americas' virgin PET production at its manufacturing facility in Zarate, Argentina. Ecopek also sells directly to merchants.

*Based on research and validated with DAK Americas.

[1] Mechanical recycling followed by chemical upgrading.

Enerkem

LOCATION:
Montreal, Quebec, Canada

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels & chemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 15, 2019

DESCRIPTION	Enerkem processes municipal solid waste (MSW) into chemicals and biofuels. A thermochemical process (gasification and partial oxidation) converts the material to syngas, which is then washed with water to remove particulates. The syngas is then converted into biofuels using catalytic synthesis.
FEEDSTOCK	Enerkem targets non-recyclable, non-compostable MSW.
FACILITIES	The company operates one facility in Edmonton, Alberta, Canada, which initiated the production of methanol in 2015 and ethanol in 2017. The capacity of this facility is 10 million gallons/year of biofuels.
PARTNERS	Enerkem's partners include Alberta Innovates, BlackRock, Sinobioway, Rho Ventures, Braemar Energy Ventures, Waste Management of Canada, Investissement Quebec, Fonds de solidarite FTQ, Cycle Capital, Fondaction, The Westly Group, and National Bank of Canada.
BUSINESS MODEL	Currently, Enerkem is constructing a facility in Varennes, Quebec, Canada. In the short term, Enerkem will begin project development with their partners in Rotterdam and China. In the long term, Enerkem will aim to license their technology and develop prefabricated modular systems that can be deployed globally.

*Based on research only.

enval

LOCATION:
England, UK

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 16, 2019

DESCRIPTION	Enval utilizes microwave-induced pyrolysis, powered by electricity, to convert pouches and plastic aluminum laminates into low-carbon aluminium and hydrocarbons. The hydrocarbons are separated into high value gas and oil for fuel or specialty chemicals.
FEEDSTOCK	Enval processes multilayer packaging/film, such as pouches and plastic aluminium laminates (e.g., aluminium foil sandwiched between plastic layers).
FACILITIES	Enval's typical plant operates at a nominal capacity of 2,000 metric tons/year. The pyrolysis gas generated by the process is used to produce the electricity required to operate the plant.
PARTNERS	Enval has partnered with Little Freddie, an organic baby food company, for a zero waste to landfill solution for their pouches. Other partners include Kraft Foods and Nestlé.
BUSINESS MODEL	Currently, Enval offers a modular, turnkey solution which includes full training to operate and maintain the equipment, as well as engineering support throughout the lifetime of the plant.

*Based on research only.

equipolymers™

LOCATION:
Schkopau, Germany

TECHNOLOGY TYPE:
Data not available

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 16, 2019

DESCRIPTION	Equipolymers is producing 'Viridis 25': a food-grade PET made with 25% recycled content. In 2009, Equipolymers also launched Viridis 10, a PET containing up to 10% recycled content.
FEEDSTOCK	Equipolymers processes PET feedstocks.
FACILITIES	There is currently a production plant in Schkopau, Germany, operating at a capacity of 350 kiloton/year. At full production, Equipolymers expects to process up to 30,000 metric tons of post-consumer PET per year.
PARTNERS	Equipolymers is owned by MEGlobal, which is a joint venture between Dow Chemical and Kuwait-based Equate Group. Coca-Cola has played a strong role supporting the development of the material and partook in the launch of Viridis 25.
BUSINESS MODEL	Currently, Equipolymers is aiming to start commercial production and claims Viridis 25 will be available for sale in late 2019.

*Based on research only.

LOCATION:
Pleasanton, California, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 16, 2019

DESCRIPTION	Fulcrum BioEnergy (Fulcrum) converts municipal solid waste (MSW) into low-carbon transportation fuels. Fulcrum uses gasification to produce syngas, followed by purification and a Fischer-Tropsch process to convert syngas into syncrude. The syncrude is upgraded to products such as jet fuel and diesel.
FEEDSTOCK	Fulcrum's feedstock is MSW that has been pre-processed to extract commercially recyclable material and inorganic waste.
FACILITIES	The Sierra Biofuels Plant is being constructed in Storey County, Nevada, USA with an expected capacity of 175,000 tons/year of MSW once it is complete. Fulcrum has built the Feedstock Processing Facility at the plant, which has been in operations since 2016.
PARTNERS	Fulcrum's product offtake customers are Cathay Pacific, United Airlines, Andeavor, BP, and World Fuels Services. The gasification system was developed by ThermoChem Recovery International. Other partners include the US Navy and Air Force.
BUSINESS MODEL	Currently, Fulcrum is building the Biorefinery at the Sierra Biofuels Plant, expected to begin operations in 2020. In the short term, Fulcrum will build a facility in Gary, Indiana, USA.

*Based on research only.

LOOPLA by GALACTIC

LOCATION:
Escanaffles, Belgium

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
$10 million USD

LAST UPDATED:
Mar 6, 2019

DESCRIPTION	Galactic is a PLA producer and the company operates its own LOOPLA® PLA feedstock recovery scheme using the technology provided by Futerro.
FEEDSTOCK	Futerro's technology targets PLA.
FACILITIES	Futerro's in-house LOOPLA® feedstock recovery scheme supports Galactic's operation in Escanaffles, Belgium. Another plant is currently under construction in China.
PARTNERS	Galactic has partnerships with other major players in the PLA industry, including NatureWorks.
BUSINESS MODEL	Currently, Galactic is building another plant with Futerro's technology in China. In the long term, Galactic and Futerro plans to be a technology provider and be involved in PLA recycling activities.

*Based on research and validated by Galactic.

GARBO your innovative partner

LOCATION:
Cerano, Italy

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 16, 2019

DESCRIPTION	Garbo developed ChemPET®, a depolymerization process which uses glycolysis to produce a monomer: bis 2-hydroxyethyl terephthalate (BHET). Following the chemical reaction, Garbo purifies the monomers. The entire process takes less than 6 hours.
FEEDSTOCK	Garbo uses PET feedstock, including PET sourced from packaging, fabrics, and fine waste from mechanical recycling processes.
FACILITIES	Garbo has validated the technology at a lab scale of 10 kg/day. The company is currently starting up and validating a pre-industrial production line with a capacity of 3 tons/day.
PARTNERS	Garbo's partners include Indorama, Plastipak, IKEA, and Ester (India) to support the company with recycled PET outlets and quality assessment methods. ChemPET® was developed in collaboration with the University of Modena and Bologna.
BUSINESS MODEL	Currently, Garbo is validating scaled up production. In the short term, Garbo will be building and operating their own recycling line and selling purified BHET. In the long term, Garbo plans to polymerize the BHET and to sell polymers.

*Based on research only.

geep
Global Electric Electronic Processing

LOCATION:
Barrie, Ontario, Canada

TECHNOLOGY TYPE:
Data not available

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 16, 2019

DESCRIPTION	Global Electric Electronic Processing (GEEP) is an established mechanical recycler for mixed e-Waste. For the mixed plastics found in e-Waste that cannot be mechanically recycled, GEEP has developed a technology to produce synthetic diesel fuel. On average, 1 ton of plastic yields about 750 kg of usable product.
FEEDSTOCK	GEEP is using e-Waste containing mixed plastics that cannot be mechanically recycled. This feedstock is sourced from their existing mechanical recycling operations.
FACILITIES	GEEP's pilot for this technology is in Barrie, Ontario, Canada, which has a scale of 500 liters/hour or 6,000 tons/year.
PARTNERS	Data not available.
BUSINESS MODEL	Currently, GEEP is piloting the process at their Barrie facility. In the long term, GEEP will aim to apply this process to their Edmonton Waste Management Centre facility. .

*Based on research only.

Geo-Tech Polymers

LOCATION:
Waverly, Ohio, USA

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 18, 2019

DESCRIPTION	Geo-Tech Polymers (Geo-Tech) de-coats the paints and surface coating from plastics by using eco-friendly chemical processes.
FEEDSTOCK	Geo-Tech targets post-consumer and post-industrial plastics, including thermoplastic olefin (TPO), PC, ABS, PS, PET, HDPE, PP, and LLDPE.
FACILITIES	Geo-Tech has two recycling facilities. The facility in Waverly, Ohio, USA can process 20-30 million lbs/year of plastics and focuses on decorated plastics recycling for the retail packaging industry.
PARTNERS	Geo-Tech is a division of Wastren Advantage Inc.
BUSINESS MODEL	In the long term, Geo-Tech is planning to offer patents for strategic partnerships for global application and commercialization.

*Based on research only.

Golden Renewable Energy

LOCATION:
Yonkers, New York, USA (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Currently finishing B Round

LAST UPDATED:
Mar 11, 2019

DESCRIPTION	Golden Renewable Energy (GRE) uses pyrolysis technology to produce a liquid fuel, with the same characteristics of #2 diesel fuel, from waste plastics.
FEEDSTOCK	GRE processes both post-consumer and post-industrial waste streams. The company does not source its feedstock by polymer type and is flexible to take in different mixes of plastics (No. 1-7).
FACILITIES	GRE currently owns and operates one facility in Zebulon, North Carolina, USA, which has a feedstock capacity of ~8,000 tons/year, producing ~2.0 MM gallons of recycled diesel/year.
PARTNERS	GRE has received plenty of interest and demand for the technology. GRE has contracts/plans in hand to deliver 5 more units in the second half of 2019.
BUSINESS MODEL	Currently, the facility in Yonkers is being converted into an assembly plant to build at least 5 more units. In the short term, GRE will continue to be an owner-operator and generate revenue through both ongoing operations as well as sales and licensing. In the long term, GRE will consider either contract manufacturing or the development of a manufacturing facility with the ability to deliver 50 to 100 units/year.

*Based on research and an interview. Validated with Golden Renewable Energy.

gr3n

LOCATION:
Castagnola, Switzerland

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
€750,000 this year and an additional €3-4 million next year

LAST UPDATED:
Feb 16, 2019

DESCRIPTION	gr3n uses hydrolysis to depolymerize PET plastics to produce two monomers: terephthalic acid (TPA) and ethylene glycol (EG). This technology uses microwaves to catalyze the reaction.
FEEDSTOCK	gr3n can take all types of PET, including bottles, trays (both mono and multi-layer), and textiles (e.g., polyester).
FACILITIES	A small-scale pilot is located in Piacenza, Italy, with a capacity of 10 kg/hour.
PARTNERS	gr3n has partners throughout the entire value chain. Partners include brands and PET users (e.g., H&M, adidas, Nestlé, Unilever, Coca-Cola, IKEA, ALPLA, Logoplaste, Henkel), PET producers (e.g., NEO GROUP), municipalities (e.g., Suez), and equipment producers (e.g., Sorema). The monomer purification process was developed and industrially implemented with Danish Technical University and Processi Innovativi srl.
BUSINESS MODEL	Currently, gr3n is scaling up production. In the short term, gr3n will be selling the monomers. In the long term, gr3n will sell the equipment (e.g., small modular units) and provide maintenance services. gr3n is also planning to license the patented purification process technology.

*Based on research and an interview. Validated with gr3n.

GREENMANTRA TECHNOLOGIES

LOCATION:
Brantford, Ontario, Canada

TECHNOLOGY TYPE:
Conversion (chemical)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers & petrochemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 5, 2019

DESCRIPTION	GreenMantra Technologies (GreenMantra) developed a thermo-catalytic process to transform recycled plastics into CERANOVUS® PE and PP polymer additives, waxes, and styrenic polymers. CERANOVUS® additives are used in asphalt roofing, asphalt roads, polymer processing, and plastic composites. Styrenic polymers are used in coatings, inks, and insulation.
FEEDSTOCK	GreenMantra targets post-consumer and post-industrial HDPE, LDPE, PP, and PS.
FACILITIES	GreenMantra operates one commercial facility in Brantford, Ontario, Canada, containing 3 production lines. A 4th production line will be commissioned in Q4 2019, which upon completion, will double the capacity for CERANOVUS® additives.
PARTNERS	GreenMantra has partnerships with Bioindustrial Innovation Canada, Business Development Bank of Canada, and Sun Chemical.
BUSINESS MODEL	Currently, GreenMantra owns and operates their facility focused on PE and PP. In the short term, GreenMantra will begin operation of their demonstration facility for PS. In the long term, GreenMantra will continue to build capacity at the Brantford facility to meet the growth in market demand, with the intent to establish additional facilities across the globe.

*Based on research and an interview. Validated with GreenMantra Technologies.

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

LOCATION:
Champaign, Illinois, USA

TECHNOLOGY TYPE:
1. Purification
2. Conversion (thermal)

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
1. Plastics to polymers
2. Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 18, 2019

DESCRIPTION	Illinois Sustainable Technology Center (ISTC) is developing two pathways for plastics. One employs a solvent extraction process to produce pure PC. The solvent used is N-methyl-2-pyrrolidone (NMP). The second pathway uses pyrolysis to convert complex mixtures of plastics to fuel.
FEEDSTOCK	ISTC processes plastic feedstocks from e-Waste, including simple mixtures such as PC/PA (via solvent extraction) and complex mixtures such as PC/PA/ABS/PMMA (via pyrolysis).
FACILITIES	ISTC has proven the purification and thermal conversion processes at the lab scale using Plastics No. 7 (Other). ISTC has also conducted pilot scale testing for the thermal conversion of Plastics No. 5 (PP), which is representative of thermal conversion applications to Plastics No. 2, 4, and 6 (HDPE, LDPE, PS).
PARTNERS	Data not available.
BUSINESS MODEL	Data not available.

*Based on research and validated by Illinois Sustainable Technology Center.

Ioniqa Technologies

LOCATION:
Eindhoven, Netherlands

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
€2 million to recycle polyester textiles

LAST UPDATED:
Feb 27, 2019

DESCRIPTION	Ioniqa uses a glycolysis reaction with magnetic metal particles as a catalyst to produce a monomer: bis 2-hydroxyethyl terephthalate (BHET). This process can separate out colorants and other contaminations.
FEEDSTOCK	Ioniqa accepts all types and colors of PET feedstocks.
FACILITIES	Ioniqa has been conducting tests with a 1,000-liter batch reactor and is now building their first continuous unit with a capacity of 10,000 metric tons/year in the Netherlands. The industrial plant is expected to commission in the first half of 2019.
PARTNERS	Ioniqa is a spin-off from the Eindhoven University of Technology. Ioniqa is in a partnership with Unilever and Indorama Ventures. Coca-Cola has extended a loan to Ioniqa to accelerate the development of the technology.
BUSINESS MODEL	Currently, Ioniqa is scaling up with support from their partners. In the short term, Ioniqa will be pursuing the licensing model, potentially to PET producers or plastics recyclers. In the long term, Ioniqa is planning to broaden its technology platform and explore other materials such as polyamides (PA) and polyethylene furanoate (PEF).

*Based on research and an interview. Validated with Ioniqa Technologies.

Plastic2Oil

LOCATION:
Niagara Falls, New York, USA (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 18, 2019

DESCRIPTION	JBI, Inc. developed the Plastic2Oil (P2O) technology which transforms unsorted, unwashed waste plastic into ultra-clean, ultra-low sulphur fuel without the need for refinement. Fuel products include naphtha, fuel no. 2 (such as furnace oil or diesel), and fuel no. 6 (such as heavy fuel for industrial boilers and ships).
FEEDSTOCK	The P2O technology targets HDPE, LDPE, PP, and other plastics (No. 2, 4, 5, 7) and does not accept PET and PVC (No. 1, 3).
FACILITIES	JBI has three operational facilities in the USA.
PARTNERS	JBI has a 20-year master agreement with Veridisyn, who has agreed to license the P2O technology and purchase P2O processors. Other partners include GTI, Indigo Energy, RockTenn, XTR Energy, and Coco Paving.
BUSINESS MODEL	Currently, JBI licenses its P2O technology and is planning to resume fuel production and sales.

*Based on research only.

JEPLAN

LOCATION:
Tokyo, Japan (HQ)

TECHNOLOGY TYPE:
1. Decomposition (chemical)
2. Conversion (thermal)

STAGE OF MATURITY:
1. Pilot
2. Early commercial

SUPPLY CHAIN:
1. Plastics to polymers
2. Plastics to fuels

CAPITAL NEEDS:
$20 million USD for R&D to sort textiles for pure polyester

LAST UPDATED:
Mar 11, 2019

DESCRIPTION	Jeplan is pursing multiple innovation streams in advanced recycling. The first innovation is a chemical depolymerization process for PET using glycolysis to produce a monomer: bis 2-hydroxyethyl terephthalate (BHET). The monomers are used to produce polyester textiles. The second innovation uses pyrolysis to recover oil and metals from e-Waste.
FEEDSTOCK	Jeplan accepts PET (e.g., bottles, polyester textiles) and e-Waste, which are processed through their respective innovation streams.
FACILITIES	Jeplan operates one pilot polyester textiles plant in Kitakyushu, Japan, with a capacity of 2,000 tons/year. Jeplan also acquired a PET facility in Kawasaki, near Tokyo, with a capacity of 20,000 tons/year (currently not operational).
PARTNERS	Jeplan acquired Pet Refine Technology Co., Ltd. (PRT). For the recycling of e-Waste, Jeplan is partnered with DoCoMo.
BUSINESS MODEL	In the short term, Jeplan will supply fabric for uniforms used in the 2020 Olympics using output from the Kitakyushu facility. In the long term, Jeplan will expand capacity to establish factories in China, Indonesia, and USA.

*Based on research and an interview.

Karlsruhe Institute of Technology

LOCATION:
Karlsruhe, Germany

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Concept

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Not actively fundraising

LAST UPDATED:
Feb 18, 2019

DESCRIPTION	Karlsruhe Institute of Technology (KIT) is developing a new catalyst that can be used to depolymerize plastic feedstocks into monomers such as ethylene and propylene. The technology is being explored by a number of companies and involves using a chemical catalyst to heat the material to approximately 932°F.
FEEDSTOCK	KIT targets post-consumer plastics.
FACILITIES	Data not available.
PARTNERS	KIT has signed an agreement with LyondellBasell to advance plastics recycling.
BUSINESS MODEL	Data not available.

*Based on research only.

KleanIndustries
Renewable energy, resource recovery & recycling

LOCATION:
Vancouver, British Columbia, Canada (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 26, 2019

DESCRIPTION	Klean Industries (Klean) uses pyrolysis, liquefaction, and gasification systems to produce refined fuels, recovered carbon black, and nano carbon filler compounds from various petroleum-based feedstocks.
FEEDSTOCK	Klean targets all types of post-consumer and post-industrial plastics (e.g., agricultural plastics, films, automotive shredder residues, e-Waste) and can handle high volumes of undesirable plastics such as PVC and PET alongside the ideal feedstock of HDPE, LDPE, PP, PS, and "mixed" 3-7.
FACILITIES	Klean currently has 17 operational plastics recycling facilities around the globe. The Sapporo Plastic Recycling (SPR) plant in Hokkaido, Japan, was built to process 15,000 metric tons/year and was installed in 1999. The facility was designed as a commercial scale flagship facility and has led to Klean's commercial success for the last 2 decades.
PARTNERS	Klean provides their technology and know-how to the Sapporo Plastic Recycling facility and to Greenfuels AG. Organizations involved with Klean's projects include Dow Chemical, Bayer, BASF, Toshiba Corporation, Sapporo City Government, Mitsui & Co. Ltd., Sacre-Davey, BDC, EDC, and Newalta.
BUSINESS MODEL	Currently, Klean has 15+ active projects for new plastics recycling facilities. Examples include: KleanFuels in Vancouver, Canada which will process 5,000 metric tons/year, GreenFuels in Germany which will process over 35,000 metric tons/year, and a 20,000 tons/year facility in Malta which will also incorporate the new KleanLoop blockchain technology that will bring in additional operational transparency. In the short term, Klean will roll out more facilities in North America and Europe that incorporate new advancements to the SPR technology that is used in Japan.

*Based on research and an interview. Validated with Klean Industries.

loop INDUSTRIES

LOCATION:
Terrebonne, Quebec, Canada

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 19, 2019

DESCRIPTION	Loop Industries (Loop) depolymerizes no and low value waste PET plastic and polyester fiber, to its base building blocks (monomers). In collaboration with their partners, the monomers are filtered, purified and repolymerized to create virgin-quality Loop™ branded PET plastic resin and polyester fiber suitable for use in food-grade packaging.
FEEDSTOCK	Loop targets pre- and post-consumer PET and polyester fibre of any color, transparency or condition, including ocean plastics that have been degraded by the sun and salt.
FACILITIES	Loop currently operates an industrial pilot plant in Terrebonne, Quebec, Canada.
PARTNERS	Loop has entered into a 50/50 joint venture with Indorama Ventures to retrofit existing Indorama facilities and has a Global Alliance Agreement with thyssenkrupp Industrial Solutions that will advance the integration of their respective technologies. Loop has also entered into multi-year supply agreements with PepsiCo, Coca-Cola's Cross Enterprise Procurement Group, Danone and L'Occitance. Other notable customer partners include L'Oréal, Drinkworks by Keurig® and Gatorade Gx.
BUSINESS MODEL	Currently, Loop is developing a full-scale commercial facility in Southeastern USA with Indorama Ventures Limited. Loop is also siting new facilities in other markets around the world. In the short term, Loop has four strategic pillars: 1) expand production capacity; 2) secure feedstock; 3) sell to customers and; 4) grow the brand. Loop intends to develop production capacity through retrofit and license of its technology to manufacturers around the world.

*Based on research and an interview. Validated with Loop Industries.

NatureWorks

LOCATION:
Minnetonka, Minnesota, USA

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 5, 2019

DESCRIPTION	NatureWorks depolymerizes PLA via a hydrolysis reaction to recover lactic acid monomers. PLA is heated at 120-160°C and the process takes ~1-8 hours. The monomers are used to manufacture the company's Ingeo brand PLA and lactides which are used to make plastics and fibers.
FEEDSTOCK	NatureWorks utilizes internally generated pre-consumer PLA waste streams.
FACILITIES	NatureWorks operates a commercial Ingeo polylactide facility in Nebraska, USA, with a capacity of 150,000 metric tons/year.
PARTNERS	NatureWorks is jointly owned by PTT Global Chemical and Cargill. The company has business in North America, Europe, Japan, and Asia Pacific. Partners include EMF, Etimex, Taghleef Industries, Sidaplax, Constantia Flexibles, See Box Corporation, and Synerlink. Envirogreen has tolled converted PLA to lactic acid for NatureWorks.
BUSINESS MODEL	Currently, NatureWorks owns and operates their Nebraska facility and sells Ingeo brand PLA and lactides.

*Based on research and an interview. Validated with NatureWorks.

New Hope Energy

LOCATION:
Tyler, Texas, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Capital required to expand capacity through additional fabrication

LAST UPDATED:
Mar 22, 2019

DESCRIPTION	New Hope Energy (NHE) uses a pyrolysis process to convert plastics into high-quality petroleum products (e.g., bunker 2 and 4, marine gasoil, home heating oil, fuel oil 2 and 4, naphtha, paraffin, asphalt). NHE completes all fabrication in-house, which includes building their patented heat exchange vessels.
FEEDSTOCK	NHE accepts all post-consumer and post-industrial waste plastics, including plastics of mixed colors. NHE prefers HDPE, LDPE, PP, and PS.
FACILITIES	In 2018, NHE commissioned the Trinity Oaks facility in Tyler, Texas, which holds the first of several plastic conversion facilities (PCFs).
PARTNERS	NHE is a member of the American Chemistry Council's Plastics-to-Fuel & Petrochemistry Alliance. NHE has previously sold their renewable oil product to a refinery in Texas and has relationships with several other buyers.
BUSINESS MODEL	Currently, NHE is expanding the Trinity Oaks facility through in-house fabrication. NHE is in the initial stages of production and continues to conduct additional R&D related to technology, product development, renewable alternatives, and recovery. In the long term, NHE plans to issue licenses to plants where NHE is the operating company of record.

*Based on research and an interview.

NGR PLASTIC RECYCLING TECHNOLOGIES

LOCATION:
Feldkirchen, Austria (HQ)

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 18, 2019

DESCRIPTION	Next Generation Group is an established mechanical PET recycling equipment provider. Since 2015, Next Generation Group has also been developing a PET-recycling technology called Liquid State Polycondensation (LSP) to produce food-grade rPET. With LSP, decontamination and rebuilding of the molecular chain takes place in the liquid phase.
FEEDSTOCK	The LSP technology targets PET. Established initially for fibers only, LSP can now allow mixed PET feedstock, including bottles, flakes, sheets, strapping, and thermoforms. LSP can also process co-polymers of PET such as PETG and streams with polyolefin content (e.g., PE, PP).
FACILITIES	Next Generation Group demonstrated the LSP technology at its facility in Feldkirchen, Austria in Nov 2018.
PARTNERS	Next Generation Group is partnered with Ingka Group (parent company of IKEA) in this venture.
BUSINESS MODEL	Currently, Next Generation Group is working with their partner to scale up the technology.

*Based on research and validated with Next Generation Group.

nexus FUELS

LOCATION:
Atlanta, Georgia, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Closing next round for capacity additions

LAST UPDATED:
Mar 14, 2019

DESCRIPTION	Nexus Fuels was founded in 2008 and uses modern pyrolysis technology to process waste plastics into high-grade fuels and waxes composed of a "clean crude" consisting of gasoline, kerosene, diesel, and wax.
FEEDSTOCK	Nexus Fuels processes both post-consumer/commercial/industrial plastics waste streams with preference to feedstock from upstream retail, commercial, agricultural, and industrial sources. System is optimized to accept HDPE, LDPE, PP, and PS and tolerates contaminants. The company performs pre-cycling® to eliminate PVC and PET.
FACILITIES	Nexus Fuels currently operates a commercial 50 ton/day plant scaled from a successful pilot in Atlanta, Georgia, USA. Nexus Fuels welcomes appropriate visitors.
PARTNERS	Nexus Fuels has contracts with plastic waste providers and off-takers around the USA and are signing strategic partnerships as part of their commercialization strategy.
BUSINESS MODEL	In the short term, Nexus Fuels is focusing on strategic operating partnerships to scale. The company will not be pursuing licensing; instead, joint partnerships.

*Based on research and an interview. Validated with Nexus Fuels.

PERPETUAL
making a material difference

LOCATION:
Nashik, India

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Raising capital for expansion

LAST UPDATED:
Mar 8, 2019

DESCRIPTION	perPETual has commercialized its own proprietary low temperature glycolysis process, paired with color removal and depth filtration, to depolymerize plastics into an ester chemical compound. The ester is used to produce polyester yarns for textiles.
FEEDSTOCK	perPETual uses post-consumer PET water bottles, and can also process polyester textiles, PET packaging, and PET film.
FACILITIES	perPETual has a facility in Nashik, India which currently converts ~2 million plastic bottles per day.
PARTNERS	perPETual's recycled yarns are supplied on a repeat basis to over forty customers worldwide, such as adidas, H&M, Zara, Puma, Vero Moda, and Decathlon. perPETual has also partnered with textile mills in several countries.
BUSINESS MODEL	Currently, perPETual owns and operates their facility in India and sells their recycled polyester yarns. In the short term, perPETual aims to increase the capacity of the existing plant and are on track to recycle over 50 million plastic bottles per day by the end of 2021.

*Based on research and validated with perPETual.

PLASTIC ENERGY®

LOCATION:
London, UK (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 13, 2019

DESCRIPTION	Plastic Energy™ uses patented thermal anaerobic conversion (TAC) technology to convert waste plastics into TACOIL, a mixture of naphtha and diesel. TACOIL can be used as feedstock to create new plastics or used as alternative low-carbon fuels.
FEEDSTOCK	Plastic Energy™ targets mixed, contaminated, multi-layered, as well as plastics that can no longer be mechanically recycled. This includes LDPE, HDPE, PS, and PP.
FACILITIES	Plastic Energy™ owns and operates two benchmark facilities: one in Seville, Spain, and one in Almeria, Spain.
PARTNERS	Plastic Energy™ signed a memorandum of understanding for the supply of feedstock to support SABIC's petrochemical operations in Europe. The company has also made commitments to divert plastics with organizations such as WWF Indonesia and the Ellen MacArthur Foundation.
BUSINESS MODEL	Currently, Plastic Energy™ owns and operates their two facilities and sells their TACOIL product. In the short term, Plastic Energy™ will focus on expanding in Europe and Asia and intends to expand Its activities globally in the next 3 years.

*Based on research and validated with Plastic Energy.

POLYCYCL

LOCATION:
Kalka, Haryana, India (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 12, 2019

DESCRIPTION	PolyCycl offers Contiflow Cracker™ - a patented technology that converts waste plastics to high value petrochemical feedstock and industrial fuels using a next-generation ***continuous*** process.
FEEDSTOCK	PolyCycl processes post-consumer and post-industrial plastics, including HDPE, LDPE, PP, PS, and multilayer packaging/film.
FACILITIES	In 2016-2017, PolyCycl setup India's first continuous process demonstration plant for conversion of municipal waste plastics to industrial middle distillate fuels.
PARTNERS	PolyCycl has a joint venture with Ramky Environment - India's largest waste management company. The company's demonstration plant has been audited by Mott MacDonald for product yield and fuel quality. PolyCycl has also established product market offtake acceptance and retails fuel generated from the plant to its industrial clients. PolyCycl was previously Ventana Cleantech.
BUSINESS MODEL	Currently, PolyCycl sells fuel generated from its demonstration plant to several industrial customers. In the short term, PolyCycl will be setting up its first plant in Hyderabad, India with Ramky Group. In the long term, PolyCycl will license its technology to waste management companies globally. PolyCycl also plans to form joint ventures with selective Tier-1 waste management companies to build and operate plastic-to-fuel facilities globally.

*Based on research and validated with PolyCycl.

Polystyvert

LOCATION:
Montreal, Quebec, Canada

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 18, 2019

DESCRIPTION	Polystvert uses a mix of filtration, dissolution, and purification to recycle PS back into PS (in the form of pellets). A coarse filtration process removes large contaminants (e.g., paper, other plastics, cardboard, metals, etc.). The dissolution and purification occur in an essential oil, which acts as the solvent and is recovered.
FEEDSTOCK	Polystvert processes all forms of PS, including expanded PS, extruded PS, and high-impact PS.
FACILITIES	Polystvert has a continuous industrial pilot operating at 125 kg/hr. The estimated output is 600 metric tons/year.
PARTNERS	Polystvert has many investors and financing partners, including capital from grants, equity from seed shareholders, and loans. Polystvert also has an industrial partnership with TOTAL Group.
BUSINESS MODEL	In the short term, Polystvert will begin commercial deployment through a licensing system in Europe and North America. In the long term, Polystvert will continue commercialization through licenses on a worldwide scale.

*Based on research only.

PureCycle Technologies

LOCATION:
Lawrence County, Ohio, USA

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 11, 2019

DESCRIPTION	PureCycle is a solvent-based physical separation process that removes colorants, odors, and other contaminants from PP. It is a 2-stage process.
FEEDSTOCK	PureCycle uses waste PP.
FACILITIES	PureCycle is beginning commissioning of their Feedstock Evaluation Unit (FEU), which is a smaller scale of the commercial scale line, in Hanging Rock, Ohio, USA.
PARTNERS	The technology was developed by Procter & Gamble (P&G). PureCycle has a strategic partnership with P&G as well as relationships with other businesses that are not public at this time.
BUSINESS MODEL	Currently, PureCycle is focusing on start-up and commissioning of Phase I of the plant (the Feedstock Evaluation Unit). In the short term, PureCycle will begin construction on Phase II which will produce 50 kiloton/year, which has already been designed. In the long term, PureCycle will sell their ultra-pure recycled polypropylene (UPRP) at a slight premium to virgin PP.

*Based on research and validated with PureCycle Technologies.

PYROWAVE

LOCATION:
Oakville, Ontario, Canada

TECHNOLOGY TYPE:
Decomposition (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to monomers & chemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 7, 2019

DESCRIPTION	Pyrowave uses Catalytic Microwave Depolymerization (CMD), which uses microwaves to depolymerize plastics to monomers (primarily), waxes, and oil. This CMD technology is modular.
FEEDSTOCK	Pyrowave targets both post-consumer and post-industrial PS, including full range of expanded, rigid, and high impact polystyrene.
FACILITIES	Pyrowave has a small-scale unit near Montreal, Quebec, Canada, capable of treating 400-1,200 tons/year.
PARTNERS	Pyrowave has a partnership with ReVital Polymers Inc. (a plastic recycling operator) and INEOS (as a buyer of the output styrene monomer). Pyrowave's Board of Directors includes former CEO of Total E&P, a partner from Sofinnova Partners, and a partner from Ecofuel. Pyrowave also has relationships with Transition Énergétique Québec and Canadian start-up incubators (e.g., MaRS, RIC Centre).
BUSINESS MODEL	Currently, Pyrowave is developing a PS closed loop model that includes adding multiple units to its current facility in Salaberry-de-Valleyfield, Quebec, Canada. In the short term, Pyrowave will continue to improve the CMD technology. In the long term, Pyrowave plans to join clusters to recycle mixed plastics in strategic locations.

*Based on research and an interview. Validated with Pyrowave.

Reclaimed EcoEnergy

LOCATION:
Newport Beach, California, USA

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to chemicals

CAPITAL NEEDS:
$5-10 million USD to bring 2-3 commercial units to market

LAST UPDATED:
Feb 19, 2019

DESCRIPTION	Reclaimed EcoEnergy (REE) processes feedstocks into lubricants via EcoCavitation™, a physical process that requires no added heat. The process can be described as millions of tiny micro-bubbles that attach to the surface and act as very tiny 'hammers', destroying the weak carbon bonds. The output is pure carbon, which is combined with hydrogen to form pure organic lubricants.
FEEDSTOCK	REE's technology accepts any organic material source, including plastics PET, HDPE, PVC, LDPE, PP, PS, "Mixed" 3-7 and multilayer packaging/film.
FACILITIES	Data not available.
PARTNERS	REE was offered a Purchase and Sale Agreement for five units and a territorial license from an investment group out of Southern California with a background in the O&G sector.
BUSINESS MODEL	Currently, REE is building out their first commercial project and looking to bring to market small-scale integration with MRF facilities.

*Based on research only.

Recycling Technologies

LOCATION:
Swindon, England (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels & chemicals

CAPITAL NEEDS:
£10 million in mixture of equity and debt

LAST UPDATED:
Mar 12, 2019

DESCRIPTION	Recycling Technologies has engineered a modular and scalable technology to chemically convert residual plastic wastes into Plaxx®. Plaxx® is oil cut into fractions. Target applications for Plaxx® fractions are steam cracker feedstock for plastic production (~70%) and wax (~30%).
FEEDSTOCK	Recycling Technologies targets post-consumer and post-industrial PET, HDPE, LDPE, PP, PS, Mixed 3-7, and multilayer packaging/film.
FACILITIES	Recycling Technologies has a demonstration machine (the Beta Plant) with a processing capacity of 100 kg/hour, built and operating at Swindon Borough Council's Recycling Centre.
PARTNERS	Recycling Technologies has offtake partners with InterChem for liquid fractions and Kerax for the wax fraction. Other partners include Ecosurety and Swindon Borough Council. The company is a member of the New Plastic Economy.
BUSINESS MODEL	Currently, Recycling Technologies is building the first commercial scale plant, the RT7000, to be Installed in Scotland. In the long term, Recycling Technologies aims to mass produce and sell RT7000 machines to waste management companies, recycling centers or third parties, with ~1,350 machines sold by 2027.

*Based on research and an interview. Validated with Recycling Technologies.

ReNew ELP

LOCATION:
Redcar, UK

TECHNOLOGY TYPE:
Conversion (chemical)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 5, 2019

DESCRIPTION	ReNew ELP (ReNew) uses a patented hydrothermal upgrading platform (Cat-HTR™) to convert end-of-life waste plastics into hydrocarbon feedstocks (e.g., naphtha, diesel, vacuum gas oil, and heavy waxes).
FEEDSTOCK	ReNew recycles post-consumer plastics, including PET, HDPE, LDPE, PP, PS, and "mixed" 3-7 plastics.
FACILITIES	ReNew is building their first commercial-scale facility in Teesside, UK, which will process 20,000 metric tons/year of plastic.
PARTNERS	ReNew's Cat-HTR™ technology was developed by Licella and the University of Sydney. The commercial facility is being built through a joint venture with Licella and Armstrong Chemicals. ReNew has also partnered with Neste.
BUSINESS MODEL	Currently, ReNew is negotiating feedstock supply agreements and completing construction of its Teesside facility for Q4 2019. In the short term, ReNew will scale up the Teesside facility to 80,000 metric tons/year through 3 additional modular units. In the long term, ReNew will aim to globally roll-out and license the technology to waste producers and waste processing companies.

*Based on research and validated with ReNew ELP.

RENEWLOGY

LOCATION:
Salt Lake City, Utah, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 12, 2019

DESCRIPTION	Renewlogy uses a continuous, automated thermal conversion process to convert waste plastics into liquid fuels (e.g., naphtha, diesel, kerosene, and light fuels).
FEEDSTOCK	Renewlogy targets all post-consumer waste plastics, including "mixed" 3-7.
FACILITIES	Renewlogy currently has two facilities: a demonstration facility in Salt Lake City, Utah, USA, and a large-scale facility in Chester, Nova Scotia, Canada. The Chester facility is capable of processing 6 million lbs/year of plastics.
PARTNERS	Renewlogy partnered with Sustane Technologies and Canada SDTC to set up their Nova Scotia facility. Renewlogy is also working with Western Recycling and Firstar Fiber on the Hefty® EnergyBag® program.
BUSINESS MODEL	Currently, Renewlogy is working with the City of Phoenix on developing a second large-scale facility in Phoenix, Arizona, USA. In the short term, Renewlogy has a pipeline of commitments in other cities across North America, as well as projects in Asia which have support from National Geographic and the Alliance to End Plastic Waste.

*Based on research and an interview. Validated with Renewlogy.

RES POLYFLOW™
RENEWABLE ENERGY SOLUTIONS

LOCATION:
Chagrin Falls, Ohio, USA (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Not actively fundraising

LAST UPDATED:
Mar 9, 2019

DESCRIPTION	RES Polyflow converts mixed contaminated plastics to naphtha, distillate, and paraffin wax. The technology is process dependant, rather than feedstock dependant; therefore, RES Polyflow can obtain consistent outputs despite inconsistent feedstocks.
FEEDSTOCK	RES Polyflow accepts post-consumer and post-industrial plastics (e.g., PET, HDPE, "Mixed" 3-7) which the company pre-treats before feeding into its process.
FACILITIES	RES Polyflow has one demonstration unit that operated in Perry, Ohio, USA and is building a commercial plant incorporating four commercial units in Ashley, Indiana, USA with each conversion vessel running at 6,000 lbs/hr.
PARTNERS	RES Polyflow is partnered with BP and AM WAX in offtake agreements to take products in finished form. RES Polyflow is working with an aggregator in Chicago for its feedstock.
BUSINESS MODEL	Currently, the Ashley, Indiana facility is being retrofitted for scale-up to produce 1,600 bbl/day of ultra-low sulfur diesel fuel and naphtha blend stocks. In the short term, RES Polyflow will own and operate their facility. In the long term, RES Polyflow will license the technology to waste processors, petrochemical companies and other strategic partners, and take the output liquids to refine and sell.

*Based on research and an interview. Validated with RES Polyflow.

Resinate MATERIALS GROUP

LOCATION:
Plymouth, Michigan, USA

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Open to equity stake

LAST UPDATED:
Mar 22, 2019

DESCRIPTION	Resinate Materials Group (Resinate) developed Recycolysis™, a glycolysis process to convert PET into polyester polyols. The polyols can be used to manufacture coatings, adhesives, sealants, elastomers, lubricants, and foams for various applications, such as flooring, furniture, building materials, packaging, and building insulation.
FEEDSTOCK	Resinate targets post-consumer and post-industrial PET plastics, including water bottles, carpet, automotive components, and medical packaging.
FACILITIES	Resinate has an 8,200 sq ft R&D facility in Plymouth, Michigan, USA.
PARTNERS	Resinate collaborated with the Ford Motor Company to test the performance of the output polyols in automotive foam applications.
BUSINESS MODEL	Currently, Resinate has access to 200 metric ton of pilot-scale and 4,500 metric ton of production-scale capacity annually with existing contract manufacturing partners. In the long term, Resinate plans to scale the Resinate brand in North America with technology licensing options for other global regions - all within a Circular Economy model.

*Based on research and validated by Resinate Materials Group.

Resynergi
evolutionary energy recovery systems

LOCATION:
Santa Rosa, California, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to fuels & petrochemicals

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 14, 2019

DESCRIPTION	Resynergi provides pyrolysis and gasification systems for converting plastics to low-carbon and low-sulfur fuels. The system's outputs are 80% ASTM-grade diesel (which is generally sulfur-free) and 20% petrochemicals, comprising of naphtha mixed with heavier oil.
FEEDSTOCK	Resynergi processes HDPE, LDPE, PP, and PS.
FACILITIES	Resynergi is currently operating out of Washington and California in the USA. The company's Evolucient Continuous Microwave Assisted Pyrolysis (CMAP) system is modular, compact, and portable, with a per-unit capacity to process 1-5 metric ton/day of feedstock.
PARTNERS	Resynergi has partnered with the University of Minnesota to develop this microwave-based technology.
BUSINESS MODEL	In the long term, Resynergi aims to sell its modular microwave system to a range of buyers, such as big box stores and manufacturers.

*Based on research only.

SABIC

LOCATION:
Houston, Texas, USA

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Growth

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 18, 2019

DESCRIPTION	SABIC Innovative Plastics (SABIC) uses chemical de-polymerization to process recycled PET plastics into a polymer: polybutylene terephthalate (PBT). PBT is used to produce SABIC's ELCRIN™ iQ compounded resin which contains up to 60% recycled content. The ELCRIN™ iQ compounded resin can be used in consumer electronics, automotive, healthcare, fabrics, building and construction, and more.
FEEDSTOCK	SABIC targets PET, specifically from soda and water bottles.
FACILITIES	SABIC has manufacturing, technology centers and joint-venture sites on a global scale, in the Americas, Europe, Middle East and Asia-Pacific.
PARTNERS	Data not available.
BUSINESS MODEL	Currently, SABIC is increasing capacity and evaluating adjacent solutions. The company operates on a commercial scale and sells ELCRIN™ iQ compounded resin to its customers.

*Based on research and validated with SABIC.

SIERRA ENERGY

LOCATION:
Monterey, California, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
$30 million USD

LAST UPDATED:
Feb 12, 2019

DESCRIPTION	Sierra Energy's FastOx® gasification system converts waste to clean syngas that can subsequently be upgraded to hydrogen, diesel, and electricity end-products. It is a blast furnace technology operating at 4,000°F. Using computer-controlled injection nozzles, Sierra Energy can obtain consistent outputs despite inconsistent feedstocks.
FEEDSTOCK	Sierra Energy can recycle 100% of the entire waste stream, including post-consumer and post-industrial plastics.
FACILITIES	Sierra Energy is currently operating one facility out of Monterey, California, USA. The system has the capacity to process 20 metric tons/day.
PARTNERS	FastOx® was developed in partnership with UC Davis, the California Energy Commission, and the US Army. Sierra Energy has received grants from both the State of California and the US Army, who are also taking their output products.
BUSINESS MODEL	Currently, Sierra Energy is running as an owner-operator. In the short term, Sierra Energy is planning to license their technology, after development of the 50 metric tons/day design. In the long term, Sierra Energy will aim to become a software company for the technology.

*Based on research and an interview. Validated with Sierra Energy.

PennState

LOCATION:
Pennsylvania, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 15, 2019

DESCRIPTION	The Pennsylvania State University developed a process to densify waste plastic into fuel nuggets called Plastofuel™. The technology works by forcing film or rigid plastics through a heated extrusion die.
FEEDSTOCK	Plastofuel can process all plastics but targets non-recyclable plastics, with a focus on agricultural and household waste.
FACILITIES	The scaled-up prototype at the Pennsylvania State University produces 500 lbs/hr of Plastofuel™.
PARTNERS	The technology was developed in the Department of Agricultural and Biological Engineering.
BUSINESS MODEL	Data not available.

*Based on research and validated with The Pennsylvania State University.

TRASH 2 CASH

LOCATION:
Europe

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Concept

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 21, 2019

DESCRIPTION	Trash-2-Cash is developing various chemical depolymerization technologies. One is for the de-repolymerization to obtain recycled polyester (r-PET) fibers. The other is a melt mixing process to obtain mixed-PET pellets. The output products will be converted into polyester that is the same quality as new materials and PET pellets for injection moulding.
FEEDSTOCK	Trash-2-Cash targets PET textile waste.
FACILITIES	Data not available.
PARTNERS	Trash-2-Cash is an EU funded project, with 18 partners from 10 countries. The company is part of the EU Horizon 2020 research and innovation programme. Some partners working on this project include VTT, Aalto University, Fundacion CIDETEC, The University of the Arts London, Material ConneXion Italia, VanBerlo, and RISE, Research Institutes of Sweden.
BUSINESS MODEL	Data not available.

*Based on research and validated with RISE Research Institutes of Sweden.

TYTON BioSciences

LOCATION:
Danville, Virginia, USA

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 19, 2019

DESCRIPTION	Tyton BioSciences (Tyton) uses subcritical water technology to make building blocks for PET and virgin-grade polyester. These building blocks are the PET monomers: terephthalic acid and ethylene glycol.
FEEDSTOCK	Tyton's technology accepts a broad spectrum of starting materials, including cotton. For the plastics supply chain, Tyton can accept PET plastics and polyester.
FACILITIES	Data not available.
PARTNERS	Tyton has joined the Scaling Programme by Fashion for Good in 2018.
BUSINESS MODEL	Data not available.

*Based on research only.

UMASS University of Massachusetts Lowell

LOCATION:
Massachusetts, USA

TECHNOLOGY TYPE:
Decomposition (chemical)

STAGE OF MATURITY:
Concept

SUPPLY CHAIN:
Plastics to monomers & polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 19, 2019

DESCRIPTION	University of Massachusetts-Lowell (UML) will be researching recycling and recovery of plastics, specifically, scalable high shear catalyzed depolymerization of multilayer plastic packaging. The process is intended to recover monomers and/or polymers.
FEEDSTOCK	UML will target multilayer packaging/film. This includes layers of various polymer materials (e.g., PET, PP, PE, PP, PA) that are sometimes combined with paper and aluminum foil.
FACILITIES	Data not available.
PARTNERS	This research project is part of The REMADE Institute's Project Call 1.0. Partners include the Michigan State, Unilever, American Chemistry Council, and National Renewable Energy Laboratory.
BUSINESS MODEL	Data not available.

*Based on research only.

UNIVERSITY OF PORTSMOUTH

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

LOCATION:
Portsmouth, England & Golden, Colorado, USA

TECHNOLOGY TYPE:
Decomposition (biological)

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
Plastics to monomers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 8, 2019

DESCRIPTION	The University of Portsmouth (UoP) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) are co-developing a technology that uses a natural enzyme with amino acid modification to depolymerize primarily PET plastics into monomers: bis 2-hydroxyethyl terephthalate (BHET), terephthalic acid (TPA), and ethylene glycol (EG).
FEEDSTOCK	UoP and NREL targets PET plastics.
FACILITIES	Data not available.
PARTNERS	The research was funded by the University of Portsmouth, the U.S. Department of Energy's National Renewable Energy Laboratory, and the Biotechnology and Biological Sciences Research Council (BBSRC). UoP and NREL worked with Diamond Light Source to study the 3D atomic structure of PETase.
BUSINESS MODEL	Currently, UoP and NREL is developing a techno-economic analysis for their technology. In the short term, UoP and NREL will work on a broad portfolio of upcycling technologies beyond this first study. In the long term, UoP and NREL will also expand its research to include other plastic polymers or plastic alternatives such as polyethylene furandicarboxylate (PEF), polylactic acid (PLA), and polybutylene succinate (PBS).

*Based on research only.

울산대학교 UNIVERSITY OF ULSAN

LOCATION:
Ulsan, South Korea

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Lab

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 18, 2019

DESCRIPTION	University of Ulsan deploys purification to process styrene-based plastics from e-Waste and separate them into ABS and HIPS polymers. After coating with Zinc Oxide (ZnO), a 2-minute microwave treatment rearranges the molecular surfaces of the plastics blend, which eases the selective separation of ABS and HIPS.
FEEDSTOCK	University of Ulsan targets styrene-based e-Waste plastics, commonly known as WEEE (Waste Electrical and Electronic Equipment).
FACILITIES	Data not available.
PARTNERS	The research was funded by the Korea Environmental Industry and Technology Institute. ZnO coating and the floating agent were obtained from Samchun Pure Chemical Co., Ltd. and Daejung Chemicals and Metals Co., Ltd., respectively.
BUSINESS MODEL	Data not available.

*Based on research only.

VADXX — Plastic To EcoFuel

LOCATION:
Cleveland, Ohio, USA

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 14, 2019

DESCRIPTION	Vadxx uses its proprietary continuous feed thermal process to convert plastic waste into diesel fuel, naphtha, waxes/lubes, syngas, and solid carbon products (collectively known as EcoFuels™).
FEEDSTOCK	Vadxx sources mixed waste plastics feedstock from both post-consumer and post-industrial partners via contracts. Their optimal feedstock by weight includes 70% HDPE, LDPE, and PP and 30% of other plastics (e.g. PS and other).
FACILITIES	Vadxx commissioned its first commercial facility in Akron, Ohio, USA in 2016. The plant has the capacity to process 25,000 tons/year of plastic waste.
PARTNERS	Vadxx is an active member of the American Chemistry Council (ACC) and the Plastics-to-Fuels and Petrochemistry Alliance (PFPA). The company's partners include large oil and gas companies and experienced post-consumer waste handlers. Vadxx has a close relationship with an international EPC for future construction and operation of plants around the world.
BUSINESS MODEL	Currently, Vadxx is siting facilities on multiple continents that are 10-15 times the size of the current Akron, Ohio facility. In the long term, Vadxx will own and operate plants individually or through partnerships. Vadxx will also sell their technology.

*Based on research and an interview.

worn again technologies

LOCATION:
London, UK

TECHNOLOGY TYPE:
Purification

STAGE OF MATURITY:
Pilot

SUPPLY CHAIN:
Plastics to polymers

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Mar 12, 2019

DESCRIPTION	Worn Again Technologies uses a patented solvent-based polymer recycling technology to separate and decontaminate PET and cellulose from cotton using dye removal, dissolution, purification, and restoration to produce PET pellets and cellulosic pulp.
FEEDSTOCK	Worn Again Technologies processes pure and blended non-reusable polyester and cotton textiles, post-consumer PET bottles, and packaging.
FACILITIES	Worn Again Technologies is planning their first industrial demonstration plant to be built in 2020.
PARTNERS	Worn Again Technologies has partnerships with H&M, Kering, Sulzer Chemtech, Himes Corporation, Directex, Miroslava Duma's Future Tech Lab, and Qvartz.
BUSINESS MODEL	In the short term, Worn Again Technologies aims to establish their first industrial demonstration plant to be operational by 2021. In the long term, Worn Again Technologies will offer licenses to commercial plant operators.

*Based on research and validated with Worn Again Technologies.

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