Healthcare Plastics Recycling Council

Advanced Recycling of Healthcare Plastics: An Opportunity for Circularity

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EXECUTIVE SUMMARY

Plastics play a critical role in the delivery of safe and cost-effective healthcare services around the world. However, the healthcare industry has recognized that the environmental footprint from the widespread use of plastics, especially packaging, is significant. The **Healthcare Plastics Recycling Council** (HPRC) is a private, technical coalition of industry peers across the healthcare, recycling, and waste management industries seeking to improve recyclability of plastic products and packaging within healthcare, while recognizing that reduction and reuse initiatives have a higher priority on the waste hierarchy and efforts in these areas must continue.

In 2019, we launched the **Flexibles Recyclability Assessment** pilot project through which we demonstrated that mixed-material streams of flexibles from multiple sources can be successfully processed and pelletized into a resin via mechanical recycling for use in a secondary application. While the data gained from the pilot advanced our knowledge on healthcare plastics recycling, we recognized that when taken in the context of the entire healthcare plastics waste steam, there are limitations to traditional mechanical recycling processes. Therefore, in 2020, we initiated a project to explore advanced recycling technologies in an effort to discover if they could address the healthcare plastics waste stream in a meaningful way. Through our research we identified opportunities to expand current healthcare recycling capabilities, as well as challenges posed by the current level of maturity of the various advanced recycling technologies we researched.

Although the advanced recycling industry in the United States is growing rapidly as significant domestic and international investments are being made in recycling technologies and recycling facilities, the application of these technologies to healthcare plastics is still a work in progress. Our research identified the following insights for medical device manufacturer, hospital, and plastics recycler stakeholders:

Medical Device Manufacturer Insights:

- Polyvinyl chloride (PVC) resin is detrimental to most advanced recycling technologies.
- The output from advanced recycling is similar to virgin plastics and can be used to help manufacturers meet recycled content goals for products and packaging.

Hospital Insights:

- Less sorting is required for advanced recycling.
- Logistics challenges are similar for mechanical or advanced recycling.

Recycler Insights:

- Healthcare plastics are well suited and can be a valuable feedstock for advanced recycling.
- Because of the increased environmental impacts associated with advanced recycling compared to mechanical recycling, advanced recycling is a complementary solution to mechanical recycling.

1.0 INTRODUCTION

Plastics, especially plastic packaging, play a key role in the delivery of safe and sterile products to healthcare facilities around the world and in improving global healthcare. In order to meet stringent patient safety expectations and demanding requirements of healthcare use, these plastics must be of the highest quality and purity and engineered to survive the challenging conditions of sterilization and global distribution. Most importantly though, plastic packaging plays the role of keeping medical products free from contaminants, thus ensuring patient safety, while also making it easy for healthcare professionals to access them in a safe and timely manner.

Although plastic packaging is nearly ubiquitous in healthcare settings today, not long-ago glass was the packaging material of choice due to its inert properties and high barrier potential. The packaging transition to flexible plastics from glass bottles was largely driven by cost. While there is not much of a difference in terms of manufacturing costs between a glass bottle and a flexible plastic pouch - about $0.01 more for glass - the real disparity lies in their cost to transport due to the additional weight of glass. For example, a 330 ml plastic bottle contains around 18 grams of plastic, while a comparable glass bottle can weigh anywhere from 190 grams to 250 grams. Transporting these heavier glass containers can require up to 40% more energy, with a corresponding increase in greenhouse gas emissions, and can increase transport costs by up to five times per bottle (Gray 2018).

While plastic packaging has reduced global healthcare costs and increased patient safety, the growth of plastic packaging in healthcare has created challenges around its disposal. Industry analysts estimate that the global market of plastics for healthcare packaging will reach 18.8 billion pounds by 2025 from 14.6 billion pounds in 2020 (BCC Publishing 2020). Polypropylene represents a significant portion of healthcare packaging and is estimated to grow from 4.0 billion pounds in 2020 to 5.2 billion pounds in 2025.

In many healthcare settings, plastic packaging is discarded into the municipal waste stream since it does not pose a biohazard contamination risk and can be collected and transported without restrictions. However, these uncontaminated materials often end up in the landfill. An estimated 2,000 to 3,000 tons of high-quality, non-hazardous, medical plastic is entering our municipal waste stream every day on a global basis and only 14-18% of that plastic waste is recycled (World Economic Forum 2020), while the rest is either incinerated, buried in a landfill, or lost from the waste stream as plastic pollution. HPRC has made it our mission to enable and inspire recyclability and recycling solutions for this healthcare plastic waste stream. Our previous Flexibles Recyclability Assessment pilot demonstrated that mixed-material streams of flexible plastics from multiple sources could be successfully recycled via mechanical processes. The work, while useful as a model, was constrained in its real-world applicability as many waste stream plastics are either too contaminated, degraded, or incompatible for traditional mechanical recycling processes. Therefore, in 2020, we initiated a project to explore the applicability of alternative advanced recycling technologies to the healthcare plastic waste stream in an effort to discover if they could potentially address the healthcare plastics waste stream in a meaningful way.

2.0 HEALTHCARE PLASTICS

2.1 Common Healthcare Plastics

Although plastics are used in many healthcare applications, HPRC targeted a select group of plastics products for this study that fall into five primary applications, all of which have been identified as good candidates for recycling in our previous work. HPRC characterizes the following products or applications as good recycling candidates because there is significant volume, they are easily identified, and collection practices minimize contamination. These plastic products include sterile healthcare packaging, simple accessories (i.e. basins and tubs), and other secondary packaging (i.e. stretch wrap and poly bags).

Apart from simple, hard plastic accessories, the applications that HPRC identified as good recycling candidates are flexible films (often multi-layers), non-woven structures, and complete packages, which often comprise multiple materials and forms. Mixed material packages are not easily classified by single resin identification codes or recycling symbols, as they are not made up of one single resin or polymer type. HPRC recognizes that the lack of simple identification could present challenges for healthcare facilities, as users are not able to easily determine the content used to make the packaging and segregate it appropriately for downstream recycling. As such, this mixed variety of different materials/polymers and package forms (flexible/rigid) creates challenges for traditional mechanical recycling processes when presented as a single stream, making them an undesirable feedstock. Advanced recycling technologies present a new way to potentially recycle these complex streams generated from healthcare systems. Further details on the plastic products that HPRC included in this study are presented below.

Sterilization Wrap

- Commonly referred to as “blue wrap,” sterilization wrap is a sterile material that protects surgical instruments and other items from contamination. If collected before surgery, it is a clean material that can be easily saved. It is made from polypropylene (PP) and may be recycled with other #5 materials or can be collected and baled separately to increase its value.

Irrigation Bottles

- Irrigation bottles, commonly used in operating rooms, can be drained and collected for recycling. They are often made from polypropylene (PP), which can be recycled with other #5 materials. Some saline bottles are made from high density polyethylene (HDPE), which may be recycled with other #2 materials. To identify the type of plastics used, check the bottle for Resin Identification Codes or check with the manufacturer.

Basins, Pitchers, Trays

- Rigid colored and opaque plastic containers (i.e. water pitchers, patient care basins and trays) are typically made from polypropylene (PP) or polystyrene (PS). These materials may be recycled with #5 or #6 materials.

Flexible Primary Packaging

- Flexible sterile barrier packaging is a commonly used design for medical devices. These packages are often constructed from two materials and/or multi-material film laminations or co-extrusions. Tyvek® (high-density polyethylene) and films constructed from polyester, polyethylene (PE), polyamides, polypropylene (PP), and ionomers are common materials used in these packages. These package styles are often referred to as pouches, header bags, vented bags, blister packs, or film bags. Tyvek lids, once removed from rigid trays, may also be segregated into this stream. As noted, Tyvek is HDPE, but it may still be difficult to visually differentiate Tyvek from paper. Both have a similar appearance; however, long intertwined fibers can be seen in Tyvek material when a light source is placed behind the material. In addition, paper tears easily while Tyvek is difficult to tear.

Rigid Primary Packaging

- Rigid sterile barrier packaging serves a similar purpose as flexible sterile barrier packaging; however, the form and type of materials are different. The packages are rigid and hard in nature and may or may not be sealed with a flexible lid made from Tyvek, film, or paper. Rigid healthcare packages are primarily made from polyethylene terephthalate glycol (PETG), high impact polystyrene (PS), and sometimes polycarbonate, polypropylene (PP), and high-density polyethylene (HDPE) trays.

Other Flexible Packaging

- Flexible clear packaging includes shrink wrap, stretch film, and plastic bags. These materials are usually found in large quantities at incoming dock areas as secondary and tertiary packaging. This flexible packaging is typically made from low density polyethylene (LDPE) and may be recycled with #4 materials.

2.2 Today's Challenges in Recycling Healthcare Plastics

Significant untapped value exists in the recycling of healthcare plastics that has not been addressed due to a variety of challenges**.** It is estimated that there is a $120 billion addressable market in the U.S. and Canada for plastics and petrochemicals that could be met, in part, by recovering waste plastics, including those from the healthcare sector (Luu 2020). While recycling of healthcare plastics has challenges in common with other common plastics with limited or no end-of-life solutions, there are some unique industry nuances that HPRC has identified as the primary challenges hindering a higher rate of healthcare plastics recycling:

- **Collecting and Sorting** of healthcare plastics at the point of their generation, or soon after, is key to creating a waste stream of high-purity materials that is sought after by mechanical recycling. However, given the mixed nature of healthcare plastics in both form and materials, end-users (hospitals and surgical centers) may experience challenges generating a volume of high-purity and homogeneous waste streams that would be attractive to traditional mechanical recyclers.

- **Contamination** can happen in different forms to a plastics waste stream. The most common type of contamination is biological, however, contamination by foreign materials (i.e. paper, metallic foils, variations in plastic colors, and unwanted plastic resins and materials) can also occur.

- **Multi-laminate flexible packaging** makes up a large volume of healthcare plastic waste including plastic bags, stretch and shrink film used around pallets, sterilization wrap, and medical device sterile packaging (i.e. pouches, header bags, and vented bags). These plastics contain a variety of resin types, including polyethylene film (i.e. LDPE); non-woven polypropylene (sterilization wrap or blue wrap); non-woven polyethylene (Tyvek, which is often sealed and attached to a multi-layer film or rigid tray); and multi-layer/multi-material film structures (often laminated or co-extruded films constructed from PET, LDPE, PA, and PP). As demonstrated in HPRC's Flexibles Recyclability Assessment pilot project, recycling of these materials through mechanical recycling processes is complicated because of the presence of different polymers/materials due to the multi-material packaging designs.

- **Logistics** processes in support of the healthcare plastics waste stream are not well developed. HPRC recently launched a project to help drive connections between recyclers and healthcare facilities through an online Recycler Vendor Directory. Currently, due to the absence of sorting at the source in a majority of healthcare facilities nationwide, almost all non-hazardous healthcare waste is incorporated into MSW (Municipal Solid Waste), which is collected by local waste haulers, and disposed of in landfills. The complexity of waste sorting due to the presence of mixed material streams, costs of installation and implementation of recycling programs, coupled with competitive landfilling costs in several pockets of the country (~$45/ton in southwest/southcentral regions vs ~$70/ton on the coasts), creates barriers for effective recycling. Furthermore, typical healthcare packaging waste (sterilization wrap and flexible clear packaging, including Tyvek) has low mass per unit area relative to other more commonly recycled materials (i.e. aluminum and polyethylene terephthalate (PET) containers), which decreases mass per load, thereby increasing transportation costs. Separation of mixed stream plastic waste from MSW is largely manual, and any potential contamination to enable sorting post collection is viewed by waste haulers as a high-risk endeavor. Currently, recycling reverse logistics is set up to support single stream waste that is easily separated at the source. Logistics processes associated with plastics waste (i.e. sorting, contamination and accumulation of sufficient volumes of mixed stream waste) are some of the key challenges that need to be addressed in order to enable effective collection.

- **Market volatility** is a major barrier to developing the necessary recycling infrastructure to support a robust healthcare plastics recycling strategy. This concern is nothing new and is currently well understood in the mechanical recycling landscape, wherein the demand for recycled plastics is affected by the price of virgin commodity plastics. The presence of mixed material healthcare plastic waste streams that need sorting based on implementation of recycling programs at the source (or careful sorting of MSW) and lower basis weights that may lead to higher reverse logistics costs per load could amplify the total costs of the output of mechanical or other recycling processes that leverage them as feedstock. Even with thoughtful local coordination of the recycling supply chain to minimize these costs, price comparison with volatile virgin polymer feedstock introduces inherent uncertainty in support for efforts to recycle healthcare plastic waste. For instance, The European Recycling Industries Confederation's (EuRIC) position paper on chemical recycling states that the capital investment required to use heavy chemical recycling plants that process mixed waste streams (i.e. through processes such as pyrolysis) would be competitive with virgin feedstock above a crude oil price of $65-75/barrel (European Recycling Industries' Confederation 2019). However, over the last five years, oil prices have not been above this range. Notably, there is a vast amount of plastic waste available for recycling and momentum building for advanced recycling technologies, which presents an opportunity to integrate these recyclers with the appropriate local reverse logistics networks. This would help ensure costs are minimized and recycled products become cost-competitive with their virgin counterparts.

3.0 AN OVERVIEW OF ADVANCED RECYCLING

3.1 Advanced Recycling Technologies

Advanced recycling is a combination of several different technologies that complement traditional mechanical recycling to address plastic waste that is too degraded, complex, or contaminated to be recycled by mechanical means alone. These advanced recycling technologies increase our ability to keep our plastics in use while simultaneously reducing our reliance on virgin polymers and fossil fuel consumption. In certain instances, these technologies allow plastics to be recycled multiple times without the degradation in quality that comes from mechanical recycling. The advanced recycling technologies are divided into three primary categories. (Timmy Thiounn 2020).

- **Purification** is the process that separates plastic polymers from additives, colorant, odor, and other resins. The purified polymers can then be made into new plastics. This technology generally requires segregated and single streams of particular plastic types. PureCycle Technologies, for example, is taking polypropylene (PP) plastic waste and using this technology to convert it into a recycled polypropylene product.

- **Decomposition/Depolymerization** consists of chemical processes that break the molecular bonds of plastics into monomers and intermediates. Similar to purification, the inputs are generally single plastic types and the end products can be used to make new plastics. There are three methods of decomposition: biological, chemical, and thermal. Eastman Chemical Company, for example, uses a form of decomposition (glycolysis) to take polyester plastic waste derived from polyethylene terephthalate (PET) bottles and textiles and turn it into monomers that can be used to manufacture new plastic products.

- **Thermal Conversion** brings plastics back to their most basic petrochemical building blocks by breaking molecular bonds. The resulting products from these processes are liquid and gaseous hydrocarbons that can be used for fuels and as raw materials for the circular repolymerization of new plastics. Pyrolysis and gasification are two types of thermal conversion processes that are commonly used in advanced recycling technologies. Pyrolysis uses medium temperatures in the absence of oxygen or air to convert plastic waste into liquid and gaseous products as well as a char byproduct. In contrast, gasification uses higher temperatures than pyrolysis with limited air or oxygen and the char byproduct is then further converted to a gaseous product. Syngas is a common output from both of these technologies. Thermal conversion can process more complex mixtures of plastic/polymer types, which is an advantage over the first two technologies listed above. Sierra Technologies, for example, processes mixed plastic waste by gasification into syngas.

3.2 Advanced Recycling Industry Overview

The rapidly evolving global regulatory landscape around plastic waste has facilitated the recent growth of advanced recycling companies. For instance, through 2017 and 2018, China rolled out its intent to ‘phase out imports of solid wastes (recyclables) that can be substituted by domestic resources’ by introducing an extremely low contamination threshold in accepted waste (Alademi 2020). Malaysia is expected to follow suit (Dickinson 2019). In addition, a 2018 EU Circular Economy directive aspires to make all plastic packaging recyclable by 2030 (First Circular Economy Action Plan 2019). Many advanced recycling technologies are positioned to complement mechanical recycling to help address these regulatory changes, taking in mixed material streams that would not be compatible with mechanical recycling and converting them into a broad spectrum of products.

The advanced recycling industry is rapidly expanding with significant investment in new projects. Closed Loop Partners' April 2019 report on the advanced recycling industry provides an overview of more than 40 technology providers that are operating commercial scale plants in the U.S. and Canada today or within the next two years (Closed Loop Partners 2019). Especially encouraging is that investors and strategic partners are engaging with advanced recycling companies, and technology providers are operating profitably with higher margins as they mature and scale. According to the American Chemistry Council, 66 new plastics recycling projects with a value of $5.5 billion have been announced between July 2017 and February 2020, with the potential to divert 4.1 million tons of waste from landfills (American Chemistry Council 2021). And that is just the tip of the iceberg; according to an analysis by Closed Loop Partners, there is an existing $120 billion addressable market in the U.S. and Canada for recovered plastics and petrochemicals that could be met by scaling advanced recycling technologies (Closed Loop Partners 2019).

Advanced recycling of healthcare plastics will not only help reduce the ecological impact of the thousands of tons of healthcare waste anticipated to be sent to landfills, it will also support a circular economy strategy for plastic waste that is essential for reducing our reliance on virgin feedstocks. With that being said, not all advanced recycling technologies are equal in terms of their circularity. Research conducted by the Global Alliance for Incinerator Alternatives identified that the majority of U.S. advanced recycling activities to date focus on converting recovered plastics to fuel rather than back into new plastic products (Crunden 2020). For advanced recycling to be a truly circular solution to the global plastic waste crisis, plastics to plastics recycling must be widely embraced by the industry. While the landscape for the advanced recycling of healthcare plastics is currently in its infancy, work is being done in the healthcare community to support its adoption; hospitals are developing new practices around segregation and logistics (i.e. collection, sorting, and delivery); recyclers are becoming aware of the value of the recovered materials; and manufacturers seeing the value in introducing these materials back into their products and packaging.

3.2 Environmental Aspects

The negative environmental impacts related to plastic production and use are well documented and include the degradation of natural systems as a result of leakage (especially in the ocean), greenhouse gas emissions, and health and environmental impacts from substances of concern. While advanced recycling technologies help to reduce these impacts, they are still energy-intensive in nature. Compared to incineration however, advanced recycling technologies provide not only a usable output in the form of plastic or fuel, but also have a smaller environmental footprint in terms of both emissions and energy input. A recent, well-regarded study by the Dutch firm CE Delft analyzed the greenhouse gas reduction benefits of various advanced recycling technologies. They identified that in general, purification and depolymerization technologies were comparable to mechanical recycling in terms of greenhouse gas emissions per kg of material input. Thermal conversion technologies, while generating greater greenhouse gas emissions than mechanical recycling, still fell below what would be expected from incineration. This conclusion was reinforced by LCA work completed by Sphera, which identified that a thermal conversion technology used by BASF emits approximately half the CO_2 of incineration (BASF n.d.).

In the U.S., advanced recycling facilities are subject to occupational health and safety regulations under U.S. OSHA and environmental regulations (waste generation, water discharges, and air emissions) under U.S. EPA. A study by the American Chemistry Council identified that thermal conversion technologies are expected to have lower air emissions of U.S. EPA Clear Air Act pollutants than traditional incineration processes (Good Company 2021). Most promising is that given the relative immaturity of advanced recycling technologies, it is expected that their environmental footprint will shrink on a per ton basis as technologies scale and processes get more refined.

Recent critiques call into the question the end use of the recycled waste. Some pyrolysis and gasification processes convert plastic waste to fuels, which are then combusted, leading to increased CO2 emissions (Schlegel 2020). That being said, fuels derived from recycled plastic reduce our reliance on virgin fuels and in turn offset some of their impacts related to extraction and transport, which can be significant. Within the pantheon of advanced recycling technologies, purification processes – where molecular bonds are not broken – should result in the lowest carbon footprint; however, a lot depends on whether the solvents used in the process are burned off or reused. While the landfilling of plastics appears to have the lowest impact on greenhouse gas emissions, reducing the life cycle of the emissions to about a third compared to incineration without energy recovery (and also reduced emissions compared to incineration with energy recovery), it is not circular, requires access to land, and can cause toxic products to leach into soil and groundwater (Dr. Ina Vollmer 2020).

A majority of advanced recyclers we surveyed as part of this work indicated that their processes have less environmental impact when compared to virgin plastic production from fossil fuels; however, process specific environmental emission data and data comparative to other competitive technologies was not readily available for a rigorous comparison. Although the environmental footprint of advanced recycling technologies is evolving, the avoided emissions from fossil fuel consumption, elimination of landfill and incineration, flexibility to address mixed waste plastics, and circularity enabled by the conversion of plastics to plastics makes a compelling case to further explore advanced recycling technologies as a solution to reduce the impact of our plastic waste.

4.0 HPRC ADVANCED RECYCLING PROJECT

4.1 Project Intent and Scope

HPRC's project mission was to investigate the current landscape of advanced recycling technologies in the U.S. and gain an understanding of whether they could address the healthcare plastics waste stream in a meaningful way. To accomplish this, we conducted a literature review as well as hands-on outreach to selected organizations. Specifically, the outreach included in-depth interviews with advanced recycling companies, hospitals, and logistics providers to gain an understanding of current industry practices, and a healthcare packaging material survey to understand unique characteristics of the healthcare plastics waste stream.

4.2 Advanced Recycling Company Interviews

To gain more knowledge on industry practices, HPRC conducted interviews with 16 advanced recycling companies from across the U.S., including recyclers with expertise in one or more of the three key technologies: purification, decomposition, and conversion. Among the recyclers that participated in these discussions, conversion technologies were found to be the most commonly employed advanced recycling process, with decomposition technologies being the next most popular in frequency. Similarly, the majority of participating recyclers identified fuel or some form of crude oil to be among the key outputs of their current operations.

The group of advanced recyclers selected for interviews were chosen in a way to provide a proxy of the current state of the advanced recycling industry. More than half of the recyclers interviewed had pilot or demonstration facilities in operation to test new markets, processes, and feedstocks. Although most of the recyclers at the time of our discussions had not previously worked with/processed healthcare plastics within their current facilities or operations, most recyclers expressed an interest in further dialogue to explore additional recycling solutions for several of the common healthcare plastics noted in **Section 2.1**. One notable exception was the recyclability of PETG trays, which were identified by several interview participants to be either low-yield or problematic to machinery, and, consequently, not acceptable or desirable within existing operations. A breakdown of the companies interviewed, categorized by their primary feedstocks and technology type is provided in **Table 1**.

Table 1. Advanced Recycling Companies Interviewed

Company	Primary Feedstocks	Technology		
		Conversion	Decomposition	Purification
EcoFuel Technologies	PE, PP, PS	X		
New Hope Energy	PE, PP	X		
Nexus Fuels	PE, PP, PVC	X		
Rampf	PET, PUR, PP	X		
Fulcrum BioEnergy	Municipal solid waste, raw garbage	X		
Renewlogy	PE, PP, PS, PET	X		
Sierra Energy	PP, PE, PS, mixed plastics	X		
Eastman	PP, PE, PET	X	X	
Agilyx	PP, PE, PS, mixed plastics, autoclaved waste	X	X	X
Ravago	PP, PE, PS, mixed plastics	X		
Brightmark Energy	PP, PE, PS	X		
GreenMantra	PE, PP, PS		X	
Resynergi	PP, PE, PS		X	
Freepoint Commodities	PE, PP, PS		X	
Reclaimed EcoEnergy	Mixed plastics			X
PureCycle Technologies	PP, PE, PS, PVC			X

Feedstock Compatibility

Intuitively, the closer a process gets to restoring polymers to their building blocks by breaking bonds, the more accepting it is of mixed material waste streams, and the less needy it is for rigorous presorting. This explains the popularity of decomposition/depolymerization and conversion processes among the surveyed companies. For instance, companies using gasification (i.e. Sierra energy, Fulcrum Bioenergy) are comfortable utilizing municipal mixed solid waste without much presorting (except for PVC in the case of Fulcrum Bioenergy) and have a healthy tolerance for cellulosics. The majority of these companies are converting mixed plastic waste into syngas, which can be used downstream for generating electricity, hydrogen for fueling applications, or new plastics. In the case of pyrolysis, mixed waste streams are acceptable, however, in order to maintain process efficiencies and deliver their desired end products (syngas and/or pyrolytic oil) with viable yields, the feedstock needs to be more carefully sorted to remove all traces of unwanted plastic (i.e. PET and paper, which can introduce moisture, as well as PVC, which can form corrosive hydrochloric acid). In addition, a majority of the companies surveyed are currently not equipped pre-process to handle any biohazardous waste that may inadvertently be present in healthcare waste.

Purification

As purification is the least intensive advanced recycling process capable of generating a product comparable to virgin resin, it should be a prime focus for recycling healthcare plastics. Drawbacks of this process include requirements for resin purity, removal of contaminants pre-process, and converting the various form factors of plastic waste into a manageable state for the reactor to accept. The logistics of collection, the pre-processing needs, and the yield of the recycling process all feed into its overall cost-effectiveness. For purification, these issues are greater than other technologies due its current limited availability and its sensitivity. However, the purity of the recycled resin makes it easier for manufacturers to incorporate it into their products so long as the cost is not excessively higher than virgin material.

Decomposition

Advanced recycling methods such as decomposition that break down plastics into their respective monomers and intermediates, should be used when the stringent criteria associated with purification can't be met. This process still requires cleanliness and specific form factors (rigid vs. flexible), but overall, this technology is more receptive to a variety of resin types and material conditions. To encourage manufacturers to use the output, some level of assurance of purity is required for integration into existing product lines.

Conversion

Should a healthcare plastic waste stream not meet the requirements of either purification or decomposition technologies, conversion recycling processes should be considered, as these technologies can successfully process a high mix of materials of variable form factor and are not sensitive to most contaminants. Contamination with materials such as metals, paper, and liquids are undesired, as they decrease the yield and increase the amount of leftover waste and transportation costs associated with moving the extra weight of the contaminants. Energy and fuel companies have relied on conversion technologies, as they produce outputs that can be added directly into their existing processes with minimal refinement.

Key Outputs and Circularity

Each advanced recycling technology results in different outputs that vary in their level of flexibility to be used as a raw material for particular end products. For purification, the resin type is preserved throughout the process. For example, polypropylene waste would be converted back into polypropylene polymers that would then be used to generate polypropylene plastic products (PureCycle technology). For decomposition/depolymerization, this preservation of the resin type is also true, but there is a higher degree of molecular breakdown. For example, polystyrene is broken down into styrene monomers that are then converted back into polystyrene plastic (Agilyx technology). In contrast, conversion technology breaks down the molecular bonds, resulting in outputs that have more flexible applications for fuels and a variety of different resin types (New Hope Energy and Nexus Fuels technology).

Some other interesting applications for outputs that we identified through our research include:

- Gas byproducts that were returned for use in the recycling process (EcoFuel Technologies, Nexus Fuels);
- Additives for construction materials such as roofing and asphalt (GreenMantra); and
- Electricity generation (Sierra Energy).

When looking at a circular solution for plastics, the desired outcome is to take plastic waste and create new plastics that could be recycled again, extending their useful life. Many of the surveyed companies were focused on creating the raw materials for new plastics, which is promising for establishing a more circular plastic waste stream in the future. Of particular note is Nexus Fuels' recent agreements with Shell and Chevron to use output from their conversion technology (pyrolysis oil) to create new plastic (Solving the Plastics Problem: Cox Enterprises Invests in Nexus Fuels 2021).

4.3 Hospital and Logistics Provider Interviews

In order to provide further insights into the feasibility of advanced recycling as a solution for healthcare plastics, HPRC carried out interviews with a number of logistics providers and healthcare facility professionals. The goal of these interviews was to understand the challenges associated with the collection of healthcare plastics at the point of generation and the logistics of transporting those materials to an advanced recycling facility capable of processing them. Within healthcare facilities, the interviewed stakeholders noted that a primary focus should be enhancing training to guide the waste segregation process at the point of generation. Additionally, the specific need for training around potential contaminants and biohazards within janitorial teams was also identified, as well as providing ongoing training with healthcare facility staff to emphasize acceptable and unacceptable waste categories, illustrating the appropriate handling and placement of waste receptacles within hospitals, and providing effective communication materials and signage.

Most of the stakeholders interviewed indicated that some form of segregation of wastes and recyclable materials occurs on the hospital/healthcare facility premises. Some of the most difficult challenges raised during the interviews involved the collection and handling of waste by logistics providers. One notable challenge was the risk of contaminants and biohazards which could potentially be present within healthcare facility waste streams. The risk of contaminants is perceived as a major health and safety concern by some recycling logistics providers, particularly in cases where hand-sorting is necessary. The most common challenge that was frequently cited by interviewed stakeholders was associated with the relatively low volumes of segregated healthcare plastics streams identified within the scope of this study. In order to generate the needed volumes to be cost-effective, several healthcare facilities generating similar waste streams would need to be concentrated within a certain distance of one another so the waste could be aggregated.

4.4 Multilaminate Flexible Healthcare Packaging Material Survey

From past HPRC work, multilaminate flexible healthcare packaging has been identified as an exceptionally difficult material to recycle because of the multiple materials present in this waste stream. As another component of this project, HPRC launched a Flexible Packaging Survey to identify and quantify components in multilaminate flexible healthcare packaging materials that may present challenges to advanced recycling technologies. To maintain confidentiality with proprietary information, all surveys were distributed, collected, and analyzed by a third party. At the time of writing this white paper, data collection is still underway.

Once data collection is complete, data will be aggregated by packaging type, top and bottom web materials, multilayer/material films, and expected percentages of different materials that might be present in a mixed healthcare plastics stream from a hospital. Aggregated data will be reviewed with advanced recyclers to assess potential recyclability impacts. The summary of our findings, including insights regarding specific packaging components that are readily recyclable or may be more challenging to recycle, will be available later in 2021.

5.0 CONCLUSIONS

Healthcare plastics represent a valuable, high-quality plastic feedstock that can be circulated back into the production of goods. Up to now, a large percentage of healthcare waste could not be effectively recycled by mechanical means alone and was incinerated, landfilled, or lost to the environment, the primary barrier being mechanical recycling's low tolerance for contamination from both undesired resins and foreign materials. Advanced recycling technologies stand to address this barrier so that a large portion of that healthcare waste previously unable to be processed by mechanical means can now be effectively recycled. Given the growing interest from healthcare providers to direct their plastic waste to beneficial uses, and manufacturers to include recycled content in their products and packaging, advanced recycling technologies can be an important part of the solution to connect all stakeholders.

Many insights into the application of advanced recycling technologies to healthcare plastics were gained from this study. For one, it is expected that mechanical recycling will continue to be an important option when developing a healthcare plastics recycling solution. Advanced recycling should be viewed as a complementary solution to existing mechanical recycling strategies, and the optimum recycling solution for hospitals will depend on available logistics (i.e., sorting, collecting, transporting), material types, and quantity. Although advanced recycling requires less sorting than mechanical recycling, to maintain cost parity, hospitals should still attempt to sort their healthcare plastics to a level of purity commensurate with the chosen technology to avoid added effort on the backend. Additionally, there needs to be a sufficient quantity of material available from hospitals on an ongoing basis, so these logistics concerns will likely need to extend outside of a single hospital so that the quantity necessary can be accumulated. In light of these challenges, hospitals should weigh the additional investment required for better sorting processes and collection systems with an understanding that costs will increase in the short-term until these systems become more efficient.

From the perspective of the medical device manufacturer, advanced recycling technologies are poised to play a key role in enabling their ability to increase the use of recycled content in their products and packaging. This is especially true for complex materials like flexible films, which do not have economically viable avenues for reuse via mechanical recycling alone. As demand for recycled content increases, recyclers should look to collaborate with hospitals and manufacturers to determine how the costs of the system can be shared to ensure all players have an economically viable position and to make sure there is enough material to scale up to meet manufacturer needs. In the longer term, a circular perspective needs to be integrated into the business model, with manufacturers, hospitals, and recyclers treating healthcare plastic waste as a valuable raw material. Only once this mindset is realized will we be able to move beyond the incremental changes that are currently being made to our recycling system to a truly systemic shift that fully embraces advanced recycling technologies.

The advanced recycling industry is growing rapidly, and the applicability of these technologies to healthcare plastics is promising despite the continuing challenges of sorting and logistics. For the next phase of our work, HPRC will be investigating how to best address these logistical challenges through piloting a circular model for healthcare plastics using advanced recycling technologies. Building upon our research with a successful proof-of-concept will demonstrate the important role that the healthcare plastics waste stream can play within a larger circular plastics economy.

ACKNOWLEDGEMENTS

The Healthcare Plastics Recycling Council (HPRC) is a private technical coalition of industry peers across healthcare, recycling and waste management industries seeking to improve recyclability of plastic products within healthcare. For more information, visit www.hprc.org.

Special thanks to the recyclers, hospitals, and logistics providers interviewed for this project.

Recyclers

Agilyx
Brightmark Energy
Eastman
EcoFuel Technologies
Freepoint Commodities
Fulcrum BioEnergy
GreenMantra
New Hope Energy
Nexus Fuels
PureCycle Technologies
Rampf
Ravago
Reclaimed EcoEnergy
Renewlogy
Resynergi
Sierra Energy

Hospitals

Dartmouth Hitchcock Medical Center
Cleveland Clinic
Kaiser Permanente

Logistics Providers

Advanced Disposal
Casella
Lakeshore Recycling
Stryker

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APPENDIX A - INTERVIEW QUESTIONNAIRES

Questionnaire

Advanced Recycling Technology Interviews

Company Name and Website: ____
Contact Person: _____________________________________ Phone No:_________________________
Email Address: _____________________________________
Interviewed by: ____________________________________ Date: _____________________________

Project Overview – HPRC has initiated a project to evaluate the use of advanced recycling technologies for healthcare plastics.

Interview Purpose – Understand the applicability, opportunities, and challenges of using your company's advanced recycling technology for recycling healthcare plastics.

A. INTRODUCTION TO HEALTHCARE PLASTICS

Common healthcare plastics (https://www.hprc.org/common-recyclable-healthcare-plasti)

Sterilization Wrap

Commonly referred to as "blue wrap," sterilization wrap is a sterile material that protects surgical instruments and other items from contamination. If segregated before surgery, it is clean material that can be easily collected. It is made from polypropylene (PP).

Irrigation Bottles

Irrigation bottles are commonly used in operating rooms and contain sterile saline solution. These bottles can be drained and collected for recycling. They are often made from polypropylene (PP). Some saline bottles are made from high density polyethylene (HDPE).

Basins and Pitchers

Rigid colored and opaque plastic containers such as water pitchers and patient care basins and trays are typically made from polypropylene (PP).

Trays

Trays are commonly used to hold instruments for sterilization and distribution. Trays made from polyethylene terephthalate glycol (PETG) or high impact polystyrene (HIPS) are commonly sealed with Tyvek@ Medical Packaging, to form a sterile barrier or placed in a flexible sterile barrier package.

Questionnaire

Advanced Recycling Technology Interviews

Flexible Clear Packaging

Flexible clear packaging includes shrink wrap, stretch film, and plastic bags and is usually found in large quantities at incoming dock areas and as secondary and tertiary packaging for healthcare products. Flexible clear packaging is made from polyethylene (PE).

Tyvek®

Tyvek® is a common material utilized in sterile barrier packaging, typically as part of a chevron peel pouch or a lid on a rigid tray. Tyvek® is made from high-density polyethylene (HDPE). It can be difficult to visually differentiate Tyvek® from paper. Both have a similar appearance; however, long intertwined fibers can be seen in Tyvek® material when a light source is placed behind the material. Also, paper tears easily while Tyvek® is difficult to tear, although some coated paper is also difficult to tear.

Flexible Primary Packaging

Flexible sterile barrier packaging is a common package design used to hold devices for sterilization and distribution. These packages are often constructed from two different types of materials and/or multi-material film laminations or co-extrusions. Tyvek® (high-density polyethylene) and films constructed from Polyester, Polyethylene, Polyamides, Polypropylene, and Ionomers are common materials used in these packages.

These package designs are often referred to as pouches, header bags, vented bags, blister packs or film bags. Tyvek® lids, once removed from rigid trays may also be segregated into this stream. As noted, Tyvek® is HDPE but I may be difficult to visually differentiate Tyvek® from paper. Both have a similar appearance; however, long intertwined fibers can be seen in Tyvek® material when a light source is placed behind the material. Also, paper tears easily while Tyvek® is difficult to tear, although some coated paper is also difficult to tear.

Example specification for sterilization wrap polypropylene:

- 80% Homopolymer Polypropylene with a 20% Impact Modifier
- 40 melt
- 1.3 Izod
- 200.000 + flex
- 4800 + tensile
- Ash .08 or less

Questionnaire

Advanced Recycling Technology Interviews

Example specification of irrigation bottle /cap, provided courtesy of Baxter:

- Resin type or number: Polypropylene Copolymer. FHR 23N1OA
- Manufacturing (such as injection or extrusion grade): extrusion grade
- Melt rate: 9.5
- Density: 0.89 – 0.91 g/ml @ 77°F (25°C)
- Color: colorless
- If it's a homo or co-polymer: random co-polymer
- It has a white silicone (LSR) gasket and a paper label

Example specification of Tyvek® Medical Packaging HDPE, provided courtesy of DuPont:

- Material Composition: over 99.8% Density Polyethylene Homopolymer CAS# 9002-8-4
- Melt Index:
  - With 2.16 kg at 190C 0.6 to 0.82 g/10 min.
  - With 21.6 kg at 190C 24 to 37 g/10 min.
- Density. above 0.955 g/cc
- Ash: below 160 ppm

Quantities and Characteristics

- About 1 million tons per year in the United States of healthcare packaging materials
- 80% flexibles / 20% rigids, almost 50% sterilization wrap
- For more information, please see our Healthcare Plastics Guide for Recyclers at https://www.hprc.org/guidance-for-recyclers

Questionnaire

Advanced Recycling Technology Interviews

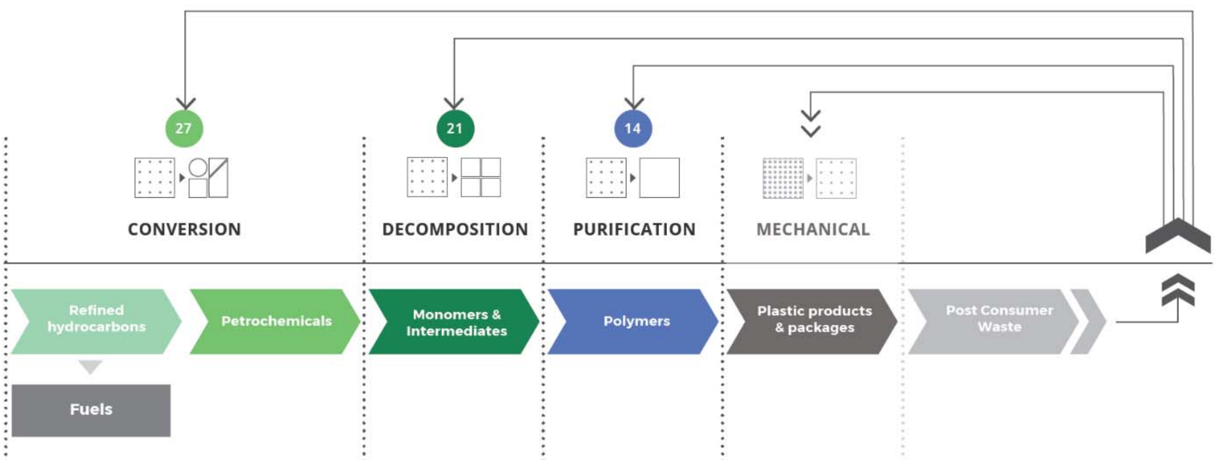
HPRC Healthcare Plastics Recycling Council

B. RECYCLING TECHNOLOGY INFORMATION

1. How would you describe your technology (circle one or more)?

   Conversion   Decomposition   Purification   Other

   If other, please describe ____



2. Do you have pilot or full-scale facilities in operation today or planned in the near future? Can you share location, capacity, and feedstock?____
   ____
   ____

3. If available, please provide a description or published specification of acceptable feedstock for your process. ____
   ____
   ____

4. For the healthcare plastics described above, please comment on their acceptance/tolerance in your process as it relates to chemical compatibility, form factor compatibility and any other criteria of importance to you.
   Comments:____
   ____

5. How would the following materials affect your process (tolerable, unacceptable):

Material	Tolerable /unacceptable	Comments
Paper		
Metal		
PVC		
Non-Hazardous Liquids		
Others?		

6. Can you accept materials that potentially contain or have contacted biological contaminants (Biohazards)? Yes / No
   Comments ____________________

7. What is the preferred form and what is an acceptable form for your feedstock, i.e, loose in bags, gaylords, compactor; bales; flake; regrind; pellets; etc.? ____________________
   ____
   ____
   ____

8. If you accept baled or loose materials (bags, gaylords, compactor), can you provide or help arrange for transport logistics for the hospital? Yes / No
   Comments ____________________

9. Can you accept loads of mixed plastics (mixed resins, mixed forms – rigids and flexibles)? Please provide details of what would be acceptable ____________________
   ____
   ____

10. Do you have on-site or contracted pre-processing operations (shredding, grinding, densifying/agglomeration, pulverizing, etc.)? Can you describe them?____________________
    ____
    ____

11. What do you envision as the end use for your output? Will your output be used to make new plastics (circularity), fuel, or another end use? ____________________
    ____
    ____
    ____

12. Do you have any environmental and/or human health impact information about your technology that you can share at this time?____
____
____
____

C. OTHER THOUGHTS

Additional Comments:
____
____
____
____
____
____
____
____

Thank you for your participation!

Questionnaire

Reverse Logistics/Pre-Processing Interviews

Company Name and Website: ____

Contact Person: ______________________________________ Phone No:_________________________

Email Address: ______________________________________

Interviewed by: _____________________________________ Date: ____________________________

Project Overview – HPRC has initiated a project to evaluate the applicability of advanced recycling technologies for healthcare plastics. Reverse logistics and preprocessing is an important part of understanding the overall process.

Interview Purpose – Understand the reverse logistics and preprocessing capabilities of your company for recycling healthcare plastics.

A. INTRODUCTION TO HEALTHCARE PLASTICS

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Questionnaire

Reverse Logistics/Pre-Processing Interviews

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Flexible Primary Packaging

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Example specification for sterilization wrap polypropylene:

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- 40 melt
- 1.3 Izod
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- For more information, please see our Healthcare Plastics Guide for Recyclers at https://www.hprc.org/guidance-for-recyclers

B. REVERSE LOGISTICS/PRE-PROCESSING INFORMATION

1. Describe waste collection and pre processing practices in operation today or planned in the near future for healthcare plastics? Please share location(s), capacity, and feedstock if possible______
____
____
____

2. If available, please provide a description or published specification of acceptable feedstock for your process. ____
____
____

3. Of the healthcare plastics described above, which are acceptable to your process:

Healthcare Plastic	Preferred	Tolerable up to xx%, but not Preferred *(please indicate xx)*	Unacceptable	Can be mixed with xx *(please indicate xx)*
Sterilization Wrap (PP flexible)				
Irrigation Bottles (PP, HDPE)				
Basins and Pitchers (PP)				
Trays (PETG)				

Trays (HIPS)				
Flexible Clear Packaging (PE, HDPE, multilaminates)				
Tyvek (HDPE)				

Comments:____
____

4. How would the following materials affect your process (tolerable, unacceptable):

Material	Tolerable up to xx% *(please indicate xx)*	Unacceptable
Paper		
Metal		
PVC		
Non-Hazardous Liquids		
Others?		

5. Can you transport/pre process materials that potentially contain or have contacted biological contaminants (Biohazards)? Yes / No
Comments ____

6. What type of training (if any) should be provided to healthcare employees to enable segregation/sorting of healthcare plastics at the hospital? Does your organization provide training to healthcare facility staff about sorting processes within healthcare facilities? Does your organization provide sorting receptacles or other assistance, such as communication templates, to facilitate sorting on site? _______________________________________
____
____
____

7. Please describe typical logistics for transporting healthcare plastics from a hospital to your facility. For example, do you provide transportation as a part of your services or do you typically work with a 3rd party vendor? Do you provide equipment such as bailers, compactors, roll-off bins, etc.? What is the preferred format (i.e. gaylords, bags) for collection? What is the typical frequency of pick-up and delivery?
Comments ____
____
____
____

8. Can you accept loads of mixed plastics (mixed resins, mixed forms – rigids and flexibles)? Please provide details of what would be acceptable ____
____
____

9. Do you have on-site or contracted pre-processing operations such as sorting, separation of parts (remove ports, zippers, paper labels), baling, shredding, grinding, densifying/agglomeration, pulverizing, or others)? Do you provide aggregation and storage? Can you describe the flow of materials, pre-processing operations, 3rd parties involved, etc.?___________________________
____
____

10. What is the form of your output (pellets, bales, etc.)? In what markets do you sell your output?__
____
____
____
____

11. Are you currently recycling healthcare plastics? Can you share best practices for a successful recycling programs? What is the maximum economically viable distance between a hospital and a recycler?

12. Have you had requests from hospitals, either in the past or currently, to recycle healthcare plastics? Are you interested in recycling healthcare plastics?

C. OTHER THOUGHTS

Additional Comments:
____
____
____
____
____
____
____
____

Questionnaire

Reverse Logistics/Pre-Processing Interviews

Thank you for your participation!