How to Scale the Recycling of Flexible Film Packaging: Modeling Pyrolysis' Role in Collection, Quantity and Costs of a Comprehensive Solution

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APR ASSOCIATION OF PLASTIC RECYCLERS

eunomia

Report For

Association of Plastic Recyclers

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Foreword

Film and flexible packaging (FFP) is a significant and growing packaging segment. It's important that its collection and recovery for recycling is scaled successfully to reduce plastic waste and build a cleaner, more circular economy. While the challenges and potential opportunities for recycling film and flexible packaging have been discussed for nearly a decade, we are now at an inflection point for these materials. Several countries and U.S. states are setting recycling goals for FFP, and numerous brand companies have publicly committed to producing only reusable, recyclable, or compostable packaging by 2030. Yet there is limited recovery of FFP to date and substantial questions remain about how to scale FFP recycling. In recent years, increased attention has been focused on pyrolysis, a form of chemical recycling, as a potential pathway for recycling FFP into food-grade quality post-consumer recycled content. This report provides the first-ever analyses and modeling of scaled FFP collection and recycling, examining the potential design changes, policy drivers, collection methods, and sortation needs for FFP. It estimates the potential collection volumes that could be achieved and the approximate costs to get recovered FFP to re-processors, whether pyrolysis facilities or mechanical reclaimers.

This report uses best available data and relies on well-considered assumptions around collection methods, rates and policy in a future scaled scenario for FFP that does not currently exist, modeling the volumes that could potentially be recovered. In building out all the necessary steps of a potential system for FFP, it is our hope that the modeling and analysis will help guide future design, policy, infrastructure, and technology investments to spur the changes needed to successfully recycle these plastics back into new plastics. As the data shows, this will likely be a complex and expensive process, and will require substantial coordination, investments, and system changes to scale effectively.

The APR chose to focus this report on FFP used by consumers in the home, knowing it to be one of the most challenging packaging streams to collect, sort and recycle due to its light weight and diversity of materials, sizes, and formats, as well as the challenges with collecting relatively small quantities of material from households across the country. Post-commercial FFP material streams are not the focus of this report's analyses, nor are post-industrial. Post-commercial FFP is generally clean and high-quality (e.g., stretch and pallet wrap and similar polyethylene films) and can be readily processed today by mechanical recyclers. With that in mind, this report focuses on the logistics and costs for how pyrolysis might complement mechanical recycling for the complex, diverse packaging formats of consumer facing FFP streams. It is worth noting, though, that given the costs and complexities of residential FFP recovery, as detailed on the following pages, priority might instead be given to the collection and recycling of post-commercial feedstocks from the business sector in the near term to increase the overall recovery of FFP more quickly and relatively cost-effectively.

This report represents an important next step in the conversation because it links together the changes needed to create a scalable recovery system for residential FFP. To date, much of the information promoting chemical recycling technologies overlooks the necessary design, collection, sortation, and end markets that need to be in place for any type of recycling to scale. Chemical recycling technologies, including pyrolysis technologies, are only one step within a larger recycling system; like mechanical recycling, chemical recycling will not scale without concurrent changes in package design and collection and sortation infrastructure, as well as stronger consumer participation, and improved economic levers for manufacturers to encourage more use of recycled content. An assessment of the true costs of delivering usable materials to re-processors is an important part of driving investment to scale effective FFP recycling. This analysis takes a first look at those systemic changes to project how future scenarios might unfold to drive higher FFP recycling rates.

The APR supports responsible chemical recycling technologies that complement mechanical recycling by converting post-consumer plastics back into recycled resins for new plastic products. This report did not model the production of fuel, energy, or other byproducts as those are not considered recycling. Also not included in the scope of this report are comparisons between mechanical recycling and pyrolysis pertaining to costs to produce post-consumer material or related environmental impacts.

Recycling is an essential solution in the broader strategy to reduce plastic waste and pollution. The APR is committed to working with partners to find solutions for all plastic packaging, including FFP, through packaging design innovations, policy interventions, and more. Thanks to our report partner, Eunomia Research & Consulting, for their thorough analyses around our scope of work. The APR also recognizes the Flexible Packaging Association (FPA) and Stina Inc. for their comprehensive data on U.S. film and flexible package generation and film recovery for recycling, as cited in this report. Finally, a special thanks to the APR Chemical Recycling Research Working Group members for their guidance and input on the scope and detail of this project.

Steve Alexander, APR President & CEO

Executive Summary

Film and flexible packaging (FFP) is a complex and growing material stream. The range of packaging formats within the stream includes everything from polyethylene shrink wrap used as tertiary packaging to metalized multi-material pouches used in primary packaging to contain and protect food. The complexity of the material stream, combined with who is generating the waste at the end of life, impact the ability to find viable and cost effective recycling solutions that have sustainable end markets.

While there are technically proven collection and mechanical recycling solutions for commercial polyethylene films, there are limited examples for how to effectively and efficiently collect, sort, and find markets for mixed FFP generated from households, a waste stream that includes packaging such as bread bags, snack packaging and a wide array of pouches. The small amount of this material that is collected is being mechanically recycled into products such as plastic lumber for which there are limited end markets and which do not provide a circular solution. Recycling solutions for FFP generated from households is of particular importance to consumer goods companies that have publicly stated goals as well legislative requirements set out in emerging Extended Producer Responsibility (EPR) that will not only require packaging placed on the market to be recyclable but which will also set high recycling targets. The inability to comply with this legislation could prevent the packaging from being used. In addition, companies have voluntary commitments and emerging legislative requirements to use more recycled content in their packaging to replace virgin plastic use. Increased recycling of FFP can increase the amount of PCR for companies and potentially expand the options to use food-grade quality materials.

This report focuses on pyrolysis, a thermal depolymerization technology that is scaling relatively quickly relative to other chemical processing technologies. Pyrolysis has the potential to process a FFP stream that consists of 85% plus polyolefin waste.[a]

The purpose of this study is to provide first-ever analysis that considers the potential role pyrolysis could play in processing polyolefin FFP generated primarily from households. Included in the study are estimates of the cost of collecting, sorting and secondary sorting a mixed FFP waste steam suitable for a pyrolysis facility that could then turn the FFP plastics back into recycled resin suitable for use in new products. Calculations include a consideration for loss rates that occur at each stage in the process. This study does not consider the costs or material losses at the pyrolysis facility or the subsequent steam cracker, both of which will impact on the total cost of the system and the quantity of recycled output that would be available to displace virgin plastics in new FFP.

The following sections cover the key findings from each of the steps of the system needed to effectively scale recycling of residential FFP through pyrolysis:

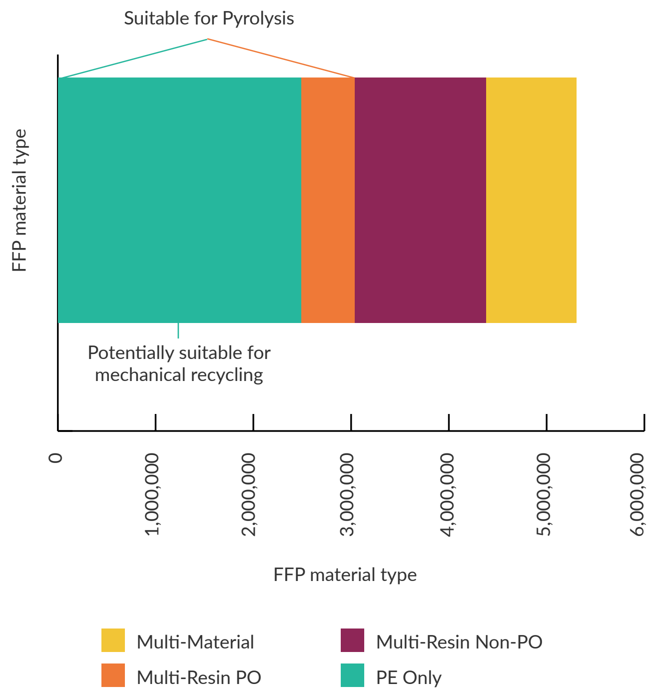
- Available tons of ready to process materials from households;
- Collection methods and processing to prepare for pyrolysis;
- Capture rates and yield losses; and
- Overall system costs.

[a] Eunomia Research & Consulting. “Feedstock Quality Guidelines for Pyrolysis of Plastic Waste.” Alliance to End Plastic Waste, August 2022. https://www.eunomia.co.uk/reports-tools/feedstock-quality-guidelines-for-pyrolysis-of-plastic-waste/

Residential FFP Currently Suitable for Pyrolysis

Of the ~12 million tons of FFP generated in 2019 in the US only 4% was recovered for recycling, all of which was PE film. Approximately 6.5 million of the 12 million tons was generated by households compared to the commercial sector. Currently only an estimated 3 million tons (shown as the teal and orange sections of the bar chart in Figure E-1) meet pyrolysis feedstock specifications and could be processed through a pyrolysis facility if successfully collected and sorted. Other FFP formats are multi-material or multi-resin containing metals, PET, or EVOH, the presence of which is restricted in pyrolysis facilities. Of this 3 million tons, approximately 2.5 million tons could also potentially be mechanically recycled as it is PE. This estimated tonnage is for the whole of the US and equates to ~15 lbs per capita.

Figure E-1: Composition of Residential FFP (2019)



Source: Calculated by Eunomia based on data from Flexible Packaging U.S. Market Profile & Segmentation Report by PTIS, LLC. Prepared for the Flexible Packaging Association, August 2021.

Residential FFP Available for Pyrolysis in 2030

By 2030 the residential FFP stream is expected to grow to an estimated 7.1 million tons, inclusive of all package resins and materials. In order to consider how much FFP from residential could be available for collection and sorting to enable processing through a pyrolysis facility, Eunomia made the assumption, based on commitments being made by brands and the likely impact of recyclability policy, that 50% of multi-material and multi-resin non-PO FFP formats will have switched to mono- or multi-resin designs that meet a recyclability standard of >90% PE, PP, or PO (PE/PP blends). We recognize that these are bold assumptions that likely reflect a best case or optimistic future state.

Under this future scenario 5.6 million tons of material could be available for pyrolysis, with 2.2 million tons (~40%) of this 5.6 million the result of design changes. Fifty nine percent (3.3 million tons) of the 5.6 million tons could also potentially be mechanical recycled since model anticipates that it will mono-PE or mono-PP.

Collecting and Sorting Residential FFP for Pyrolysis Processing

Globally there are limited at scale collection systems for FFP generated from residential households however there are some examples, such as Belgium's curbside collection of FFP funded through Extended Producer Responsibility, or the UK's store takeback program. It is difficult to know exactly how changes in policy and voluntary action will evolve but for the purpose of estimating what volumes could be available for mechanical recycling and processing through pyrolysis the following assumptions have been made:

- **EPR impacts:** The model assumes EPR is fully implemented in all states that currently have, or are currently considering, EPR policies and that these systems collect FFP that has been designed for recycling through curbside collections. This equates to ~ 43% of the U.S. population.
- **Voluntary action impacts:** The model assumes that producers fund programs to capture material in non-EPR states primarily through retailer takeback and municipal drop-off programs.

Again both of these assumptions are optimistic and will require a significant step change from both a policy and voluntary action perspective. What has not been considered in a future state is the capture of FFP through mixed waste sorting. For this to be an option in the future, states would also have to have policy that mandates organic waste collections to remove the wet fraction of the waste.

Capture Rates

Not all material that is placed on the market and suitable for processing through a pyrolysis facility will be captured. There is very little data on how much residential FFP can be captured through curbside programs however limited information from Ontario's annual municipal Datacall suggests that it is 1.5 times that captured through municipal drop off programs. The analysis assumes a 30% capture rate from households that have curbside programs and a 15% capture rate from households that are required to use retail takeback programs. Clearly to achieve these capture rates there would need to be extensive education and consumer engagement.

Sorting Requirements

For the purposes of assessing the cost of collection, sorting and secondary sorting of residential material to enable it to be processed through a pyrolysis facility, it has been assumed that FFP collected via:

- Retail takeback programs will be taken directly to a pyrolysis processor without the need for any sorting.
- Municipal drop-off programs will be source separated and can be shipped directly to a pyrolysis facility.
- Curbside material collected through single-stream will be sorted to FFP stream which will then be shipped to a Plastic Recovery Facility (PRF) for secondary sorting into specifications desired for mechanical recyclers and pyrolysis facility operators.

Loss Rate Assumptions

In addition to not all FFP being captured through collection programs, target material will also be lost at each stage along the recycling value chain. Based on research carried out for this study the assumed loss rates used for the analysis are:

- MRF yield losses: 35% of FFP collected is lost at the MRF, this could be a result of material flowing through to the disposal stream or material that ends up in other material bales, impacting the quality and potential value of that bale.
- PRF yield losses: 9.5% of material that enters the PRF is disposed.

Assuming these capture rates and loss rates:

1.2 million tons
of PO, PE, and PP residential FFP would be collected.

54% through curbside

~6% through municipal drop off

40% through retail takeback

77%
Estimate of the proportion of the total volume collected that would be suitable for a pyrolysis facility, with a subset of that proportion also suitable for mechanical recycling

35%
of the total material captured through curbside will be secondary sorted through a PRF.

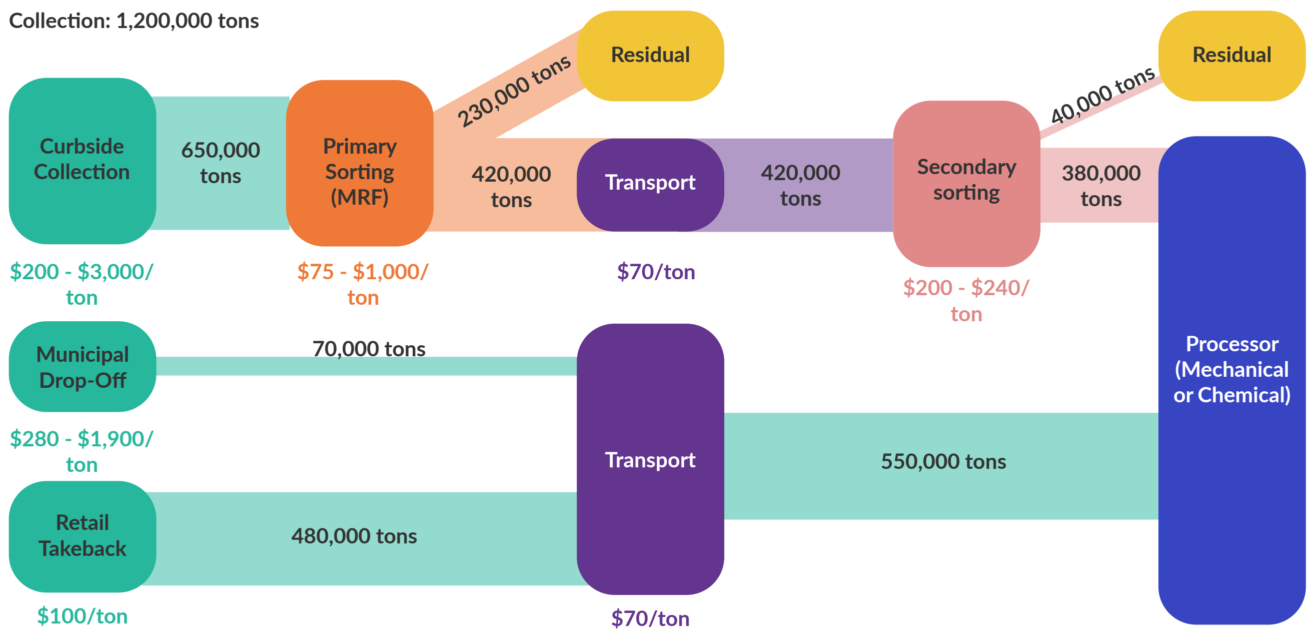
This projected recovery volume of 930,000 total tons —380,000 tons from curbside plus 550,000 from drop off — represents just 13% of the targetable residential FFP stream.

Assessment of Cost

In addition to considering how much residential FFP could be available for processing through a pyrolysis facility it is important to consider what the cost of collecting, sorting and secondary sorting this material would be, as this cost will need to be covered by one or many actors in the recycling value chain. Where collections are taking place in Europe, this cost is being picked predominately by producers through EPR fees or voluntary investments.

Figure E-2 summarizes both the volume of material collected, sorted, and secondary sorted as well the cost per ton range at each point in the value chain.

Figure E-2: Projects 2030 Tonnage and Cost by Activity



Due to the limited number of residential FFP collection and sorting systems operational the estimated costs have been calculated using data derived from:

- Programs in Canada (British Columbia) and Europe (Belgium);
- Interviews with operators of sorting facilities; and
- Application of volume to weight or bulk density estimated to apportion a percentage of collection costs to FFP.

As part of the cost calculation process we also consider how costs may change out to 2030 when for example there is new infrastructure that has been designed to sort FFP.

Limitations

The analysis within this report only seeks to estimate the amount of residential FFP material that could be collected and sorted for processing through a pyrolysis facility and to give estimated costs for doing so. It does not consider commercial FFP nor rigid PO material that could be processed through a pyrolysis facility. It also does not consider the cost and yield losses at the two further steps in the recycling value chain required to produce recycled content that can replace virgin material in new products. Both of these stages at the pyrolysis facility and steam cracker will add costs and result in yield losses reducing the quantity of recycled material from the value chain. Yield losses at pyrolysis facilities can be between 15 and 50% depending on the feedstock quality and, when the pyrolysis oil goes into the cracker, further losses of ~40% could be incurred.

Key Conclusions

Based on the available data and the projected investments in FFP packaging design changes, expansion of collection programs, and both voluntary and regulatory actions, a 2030 scenario for recycling residential FFP could:

Supply:

FFP collected for pyrolysis:

~1.2 million tons

FFP available for pyrolysis after sorting:

~ 930,000 tons

of which 35% would be suitable for mechanical recycling

Cost:

Total cost: approximately

$827 million

Cost per ton collected:

$689

Cost per ton sorted:

$889

These cost estimates can be used to drive the comprehensive design, policy, infrastructure, and technology investments to reach these outcomes. Each step of this scenario is a dynamic space and these estimates will be further refined as better data and more programs emerge. This first analysis helps to provide the foundation for that work and the substantial collaboration and investment needed to scale effectively recycling of FFP into use in new plastic products.

Contents

Glossary & Acronyms

Term/Acronym	Description
A4	Rectangular size, similar to letter-size paper, that is 210 x 297 mm or 8.3 x 11.7 inches.
Capture rate	The weight of recyclable material collected for recycling (not including contaminants) divided by the weight of all recyclables in the waste stream. Capture rates can be calculated for individual materials or for the overall recycling stream. This term is also used in the context of material sorting. For example, a Material Recovery Facility might report that it can capture an average of 80% of a particular material entering the facility. In other words, 80% of that material is successfully sorted and baled while the remaining 20% is unable to be separated from other materials.
Commercial Generation	The total amount of waste, including recyclable material, produced by commercial entities. The basic formula is disposal plus diversion equals generation.
EPR	Extended Producer Responsibility
EVOH	Ethylene Vinyl Alcohol
Films & Flexible Packaging (FFP)	Film and Flexible Packaging: All packaging made of any flexible materials to be used for the containment, protection, handling, delivery, and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer. Note, some other sources use a similar acronym: FPP, flexible plastic packaging.
FFS	Form/Fill/Seal packaging
HDPE	High Density Polyethylene; A strong, durable, lightweight, and chemically resistant plastic material popular for a variety of applications, including rigid plastics. Coded as plastic resin #2.
LDPE	Low Density Polyethylene; A soft, flexible, lightweight plastic material. It is often used for sandwich bags and cling wrap. Coded as plastic resin #4.
Materials Recovery Facility (MRF)	An establishment primarily engaged in sorting mixed recyclable materials into distinct categories and preparing them for shipment.

Term/Acronym	Description
Multi-Material	Multi-material films and flexible packaging often consist of plastic along with other non-plastic materials such foil, paper, etc. These materials are laminated together. Examples include paper/plastic chip bags, lidding for apple sauce or yogurt cups, and multi-wall bags (paper and plastic).
Multi-Resin	Multi-resin, or multi-plastic, films and flexible packaging consist of multiple types of plastics coextruded or laminated together for a structure. Examples in this category include most stand-up pouches and lay flat bags used in confectionery products.
Naphtha	A hydrocarbon fraction than can be refined from oil, which can be processed in a steam cracker to produce a variety of other hydrocarbons including ethylene and propylene.
Olefins	Olefins are a class of chemicals made up of hydrogen and carbon with one or more pairs of carbon atoms linked by a double bond. They are used as building block materials for products such as plastics, detergents, and adhesives. Ethylene and propylene are examples of olefins.
PA	Polyamide
PE	Polyethylene. Types of PE include LDPE, LLDPE and HDPE, which are all compatible in the PE film recycling stream.
PET	Polyethylene Terephthalate
PLA	Polylactic Acid
PMMA	Polymethyl Methacrylate
Polyolefins (PO)	A family of thermoplastics that includes polyethylene (PE) and polypropylene (PP). They are produced by polymerizing the olefin monomers ethylene and propylene, respectively, which are commonly derived from oil and natural gas but can also be derived from renewable resources.
Post-Consumer	ISO 14021:2016 defines post-consumer material as material generated by households or by commercial, industrial, and institutional facilities in their role as end users of the product which can no longer be used for its intended purpose. This includes returns of material from the distribution chain. It excludes post-industrial (pre-consumer) material (e.g., production scrap).
Post-Commercial	A subset of Post-Consumer material generated by commercial, industrial or institutional faciltieis, as described above.

Term/Acronym	Description
Post-Industrial	Also referred to as Pre-Consumer, ISO 14021:2016 defines as materials diverted from the waste stream during a manufacturing process.
PP	Polypropylene
Primary Sorting	Collected material is first sorted at a material recovery facility (MRF). This is often the first sorting location for material collected curbside or via municipal drop-off systems.
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl Chloride or Vinyl
PVDC	Polyvinylidene Chloride
Pyrolysis	The thermal breakdown of plastic waste at in the absence of oxygen to produce pyrolysis oil, which can be used as a substitute for naphtha in steam crackers to produce olefins and other virgin quality intermediates.
Residential Generation	The total amount of waste, including recyclable material, produced by residents and households. The basic formula is disposal plus diversion equals generation.
Secondary Sorting	After being sorted at a MRF (primary sorting), material is further sorted to produce bales to meet recyclers specifications. This is often the first sorting location for less-contaminated material streams, such as that from retail takeback systems.
Small format (<A4)	FFP that is smaller than 210 x 297 mm or 8.3 x 11.7 inches. Commonly used by the Ellen MacArthur Foundation and the U.S. Plastics Pact. Important here because the Materials Recovery for the Future (MRFF) study revealed an approximately 20 percentage point difference in sorting capture of materials <A4 compared to those >A4. For example, cereal bags, bread bags, and retail bags had an average of 20% greater capture rate at the MRF compared to pouches, small chip bags, and small storage bags.
Ton(s)	This study uses US (short) tons. 1 US ton is equivalent to 0.91 metric ton.

1.0

Introduction

1.1 Introduction and Content Summary

There is increasing focus on recycling options for films and flexible packaging (FFP) because the category accounts for a significant proportion of plastics produced, is expected to continue growing, and has a relatively low recycling rate. An estimated 12 million U.S. (short) tons of FFP was placed on the U.S. market in 2019.[1] FFP material includes everything from bags, wrappers, stand-up pouches, retort pouches (for sterile applications), lidding, shrink sleeves and labels, shrink wrap, stretch films, retail carry bags, storage and trash bags, and medical packaging. Table 4 in the appendix provides additional detail on the various FFP material subcategories. The FFP category as a whole is expected to grow an average of 2.8% across most formats, taking the total expected quantity of FFP in 2030 to 15.8 million tons.

While there is established collection and mechanical recycling infrastructure for rigid plastics, a lack of collection and sorting logistics currently limit options for FFP, particularly FFP used in residential settings. Few people (~1% of U.S. households) have access to curbside collection programs that accept bags and film.[2] Rural communities or, in the near future, states with Extended Producer Responsibility (EPR) programs may offer depot drop-off facilities that include collection of FFP material, but there are currently a negligible number and none of them collect material other than plastic bags and film.

In contrast to municipal curbside and drop-off programs, many households theoretically have access to retail takeback programs for plastics bags and film. A recent Bloomberg article reported that 12,000 retail locations (e.g., Target, Home Depot, and Kroger) offer such programs.[3] A 2022 Resource Recycling Systems (RRS) study conducted for GreenBlue analyzed access to retail takeback programs in California using three measures: radial distance; driving distance; and driving time. The results were that 87.6% of the population is within a three miles radial distance of a retail takeback location, 78.1% are within three miles driving distance, and 92.9% are within a 15-minute drive.[4]

Even if the results from California can be generalized to the entire country, access to such programs does not equate to participation. According to a 2017 ACC report, only 32% of Americans say they have ever returned plastic shopping bags to stores for recycling.[5] And while this study is becoming dated, the percentage of people regularly returning plastic bags and film to retail locations has likely not increased significantly given total post-consumer film recovered for recycling from all sources only increased from 510,000 tons in 2012 to 553,000 tons in 2021.[6]

Overall, material collected through these two drop-off scenarios is potentially cleaner than material that has traveled through a material recovery facility (MRF), but participation and volumes are expected to be far lower than for materials collected at curbside due to the relative inconvenience of drop-off programs.

The FFP category as a whole is expected to grow an average of 2.8% across most formats, taking the total expected quantity of FFP in 2030 to 15.8 million tons.

Looking at potential capture of FFP in curbside programs, the material is lightweight and travels poorly through MRFs that were designed to sort mainly rigid containers and paper. This sortation obstacle does not apply to post-commercial material, which is generated at back-of-house retail establishments and in other commercial or institutional settings and remains relatively uncontaminated, so can be aggregated and shipped directly to a processor. An estimated 2 million tons of post-commercial polyethylene (PE) material generated in 2019 would have theoretically been available for recycling through post-commercial channels (shown in Figure 4).

While we acknowledge that post-commercial FFP material is a potential target stream for both mechanical and chemical recyclers, the focus of this report is on the complex challenge of potentially capturing and processing a larger quantity of residentially generated FFP through curbside collection, municipal drop-off, and retail takeback programs.

Even if recovered at higher rates from residential and commercial settings, recycling options for FFP are limited at present because about half of FFP is multi-plastic or multi-material formats, as will be further parsed below. For the purposes of this report, we are using the definitions of multi-plastic based films and multi-material films from the Flexible Packaging Association report, which are further defined in the Glossary. Multi-plastic FFP consists of multiple resins coextruded or laminated together. Multi-material FFP include a plastic as well as other materials such as foil, paper, etc.. Recycling sorting facilities do not currently have the technology to easily detect and sort material formats with multiple layers, recycling processors cannot readily separate the layers, and there is no market demand for recycled content with mixed or unknown content. Additionally, all FFP formats, whether mono-material, multi-plastic, or multi-material, may also include attachments, additives or barrier coatings that should be avoided, or that may impact recyclability.[a]

There is already a push to phase out multi-material FFP containing a mix of plastics and other materials thanks to the implementation of various design-for-recycling guidelines. And, when implemented, EPR laws will provide additional incentive for producers to improve the recyclability of their packaging. In the meantime, though, major brands have already committed to follow design recommendations such as the APR Design® Guide, which is focused exclusively on polyethylene design guidance (LDPE, LLDPE and HDPE) since this is the only stream with measurable post-consumer collection (for recycling) at this time.[7] Providing high-level packaging design principles, the Consumer Goods Forum Golden Design Rules promote the use of at least 90% of either polyethylene or polypropylene, anticipating the development of processing for mono-PP post-consumer FFP. In response to this shift in demand from their clients, packaging producers, such as PepsiCo and Mars, are developing 90% PE or PP film structures that can still provide the functionality of multi-material packaging.[8] The adoption rate and application suitability of these emerging options has not been assessed as part of this study, and references throughout this report to mono-PE or PO FFP are assumed to also include any shift to mono-PP formats.

Designing for recycling compatibility is key for future collection and processing, whether mechanical or chemical, and it's important to understand the likely material flows as part of this discussion. Currently, consumer-facing post-consumer collection (e.g., retail takeback collection of consumer bags and wraps) relies on a polyethylene stream, as mentioned above. If post-commercial collection is either polyethylene or polypropylene – not a polyolefin mix – this stream is also suitable for mechanical recycling. There are several technologies that are commonly grouped

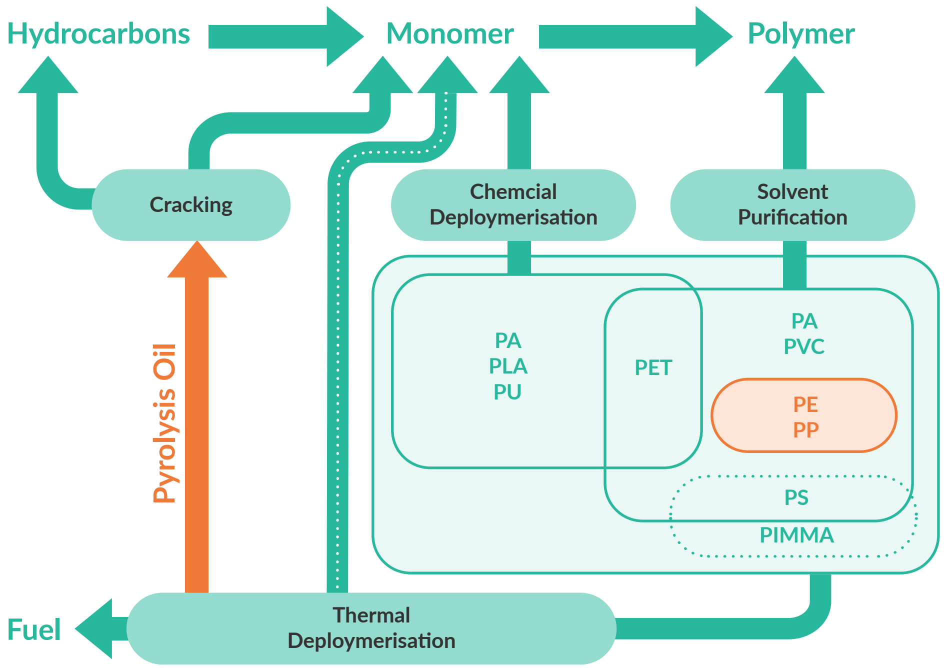
[a] See APR Design Guide for PE for more detail.

within chemical recycling (Figure 1). This report focuses on pyrolysis because a polyolefin mix is within pyrolysis feedstock specifications (see section 2.0), whereas a mix of plastics and other materials is not suitable for any processing technology. It is important to note that pyrolysis can tolerate small amounts of non-PO plastic and other materials, although this may impact yields (see Figure 3). Eunomia's modelling, which is based on numerous sources including the Flexible Packaging Association, U.S. Plastics Pact, and waste characterization studies, suggests that the residential flexible packaging market is currently made up of approximately 35% multi-resin and multi-material packaging. We expect this to shift over the next 10 years as a result of design for recyclability commitments. The challenge for producers is whether to invest in design changes and hope that the recycling system evolves to be able to recycle the material or wait for investment in the system and then make the changes.

Compared to other materials, including rigid plastics, capture and recycling rates are low for PE Only FFP (e.g., bags and PE film) and negligible for PO FFP (e.g., blends of PE and PP). Given the expected growth of these materials within our waste stream, it is critical to consider how to feasibly collect, sort, and recycle them. Key questions include which technologies will be the most economic and environmentally efficient to enable circularity and how to support diversified end markets for the recycled resins produced.

As mentioned above, a polyolefin mix can be processed via pyrolysis. Chemical recycling includes a range of different technologies. For each technology, the main deployment pathways that are currently or may potentially be employed for different polymers to achieve different outputs along the plastics value chain are summarized in Figure 1.

Figure 1: Overview of Recycling Technologies excluding Mechanical Recycling



Acronyms Key	
PA	Polyamide
PE	Polyethylene
PLA	Polylactic acid
PMMA	Polymethyl methacrylate
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl chloride

Source: Eunomia Research and Consulting and CHEM Trust

This report focuses on pyrolysis, a thermal decomposition process that can process polyolefin material and that is scaling faster than any of the other chemical processing technologies. The pyrolysis process does not result in a product that can directly replace virgin PE or PP in new products. The resulting pyrolysis oil must first be further processed in a steam cracker, where it can potentially partially replace naphtha. The cracking process uses the pyrolysis oil to produce a variety of chemical intermediates which includes olefins (for polymerization or other), other chemical products, and fuels. The outputs have the same qualities as their fossil derived equivalents and as such can be used in a wide range of applications, including food contact packaging.

This report:

- Considers what is required to collect, sort, and prepare post-consumer polyolefin packaging to enable it to be processed in a pyrolysis facility.
- Estimates the current amount of polyolefin material that could be available for treatment through pyrolysis in a future scenario where there is increased collection as a result of policy such as Extended Producer Responsibility (EPR) plus voluntary investment by producers in states that are unlikely to have EPR.
- Estimates what it might cost, in the future, to collect, sort and secondary sort post-consumer polyolefin waste from the residential sector such that it can be accepted by a pyrolysis facility.

It should be noted that this report focuses on consumer packaging that is potentially collected through curbside programs, retail grocery drop-off, or other drop-off depot programs.

The report does not include:

- The cost of processing the material through the pyrolysis facility (which is likely to include a feedstock preparation stage).
- The mass balance calculation necessary to determine the amount of pyrolysis oil that would be available to send to a steam cracker.
- The mass balance calculation necessary to determine the amount of product from a steam cracker that could be available to replace virgin material in the production of new plastics.

The report consists of the following sections:

- Section 2.0: Provides an overview of the pyrolysis technology.
- Section 3.0: Sets out how much flexible film and flexible plastics is currently generated in the U.S. and how this might change in a future scenario. The future scenario includes packaging design changes to maximize the amount of recyclable FFP captured and both legislated and voluntary action needed to enable the current recycling system to capture the target FFP material.
- Section 4.0: Estimates the cost of collecting and sorting PO FFP.
- Section 5.0: Summarizes the findings.

The purpose of carrying out this work is to provide an objective assessment of consumer-facing FFP material volumes suitable for recovery, potential collection pathways, and costs to deliver to reprocessing markets. It's anticipated that this data will help facilitate industry stakeholder conversations about what it will take to move toward a circular economy for post-consumer polyolefin packaging, potentially through a recycling value chain that includes pyrolysis as complementary to mechanical recycling.

2.0

Pyrolysis and the Recycled Content Supply Chain

Pyrolysis is a thermal decomposition process that can process polyolefin materials into pyrolysis oil that can then be used as a naphtha substitute in a steam cracker to produce olefins and other virgin quality intermediates.

The quality of the pyrolysis oil is dependent on the specification of the feedstock. On average these facilities need a feedstock that is at least 85% polyolefin content by weight.

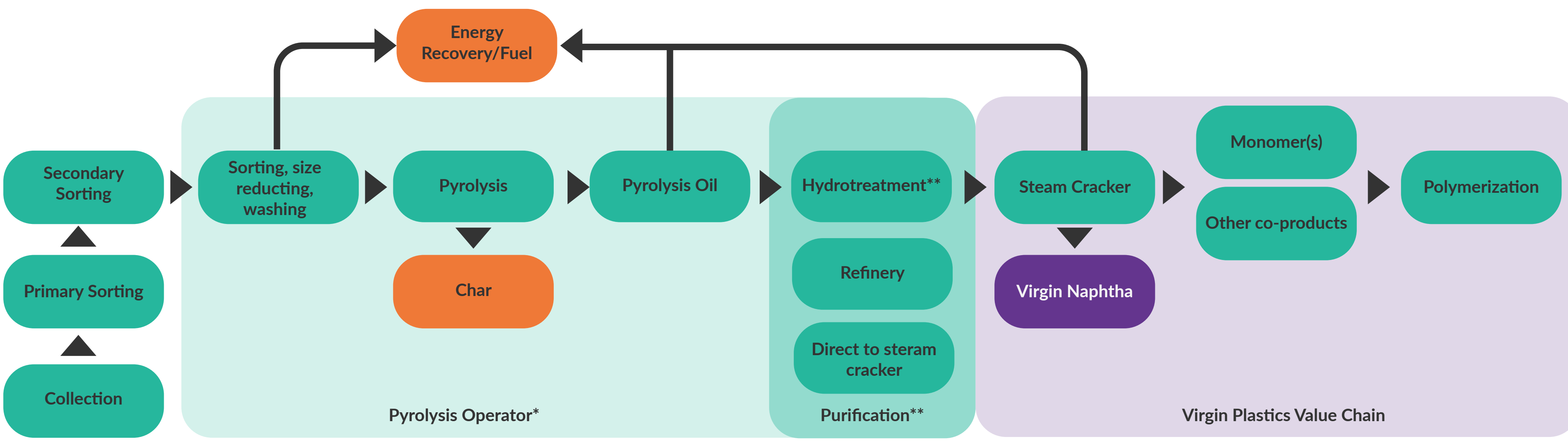
Yield losses occur at both pyrolysis and cracker stages. A mass balance approach is required to calculate the fraction of plastics input to pyrolysis that is available as a recycled material output from the cracker.

2.1 Pyrolysis as a Chemical Recycling Process

Chemical recycling technologies are in the early stages of development and commercialization. Pyrolysis is the most established of the technologies[9,10] and of interest to the packaging sector due to its ability to process mixed polyolefin materials into olefins and other virgin quality intermediates. Pyrolysis is a thermal decomposition technology that breaks down polymer chains using high temperatures in the absence of oxygen. The resulting pyrolysis oil, depending on the quality of the inputs and the process, may require further refining before it can be used as a partial replacement for naphtha in a steam cracker to produce olefins and other virgin quality intermediate materials. A case study described in a recent journal recent article used a 20% pyoil substitution rate (80% naptha) and required purification to remove impurities and contaminants that could affect the operation in the cracker.[11]

Figure 2 provides a detailed recycling value chain that includes pyrolysis. Depending on how polyolefin materials are collected, they may have to be sorted at a MRF and then further sorted, size-reduced, and potentially washed and dried before meeting the specification of a pyrolysis facility. The pyrolysis process can produce a number of outputs including energy recovery and fuel, the former of which can be used for internal facility consumption. As previously noted, the remaining pyrolysis oil output may need to go through a purification step before it can replace naphtha in a steam cracker. The purification step at the end of the pyrolysis process is itself dependent on the quality of the input to the pyrolysis facility. The steam cracker which takes in pyrolysis oil as naphtha substitute will produce fuel, olefins that can be polymerized to make new plastics and products, and other intermediate materials.

Figure 2: Pyrolysis in the Plastics Value Chain[12]



Source: Eunomia Research & Consulting.

2.2 Pyrolysis Feedstock

Pyrolysis facilities can process a range of polyolefin rigid or flexible plastic packaging, including High Density Polyethylene (HDPE), Polypropylene (PP), Low Density Polyethylene (LDPE) and PP films. Pyrolysis facilities target feedstock of slightly different specifications depending on facility design and pyrolysis oil customer specifications. In 2022 Eunomia developed, through consultation with pyrolysis facility developers and operators, a model pyrolysis feedstock specification details of which are contained in Figure 3.[13]

For comparison, mechanical recycling model bale specifications can be found on the Association of Plastic Recyclers' website.[b]

The specification demonstrates that like most recycling technologies pyrolysis has a relatively defined feedstock requirement, it can take a mixed polyolefin blend, but it cannot take a broad mix of plastic polymers. The quantity and quality of polyolefins within the feedstock will impact on the amount of naphtha, or "light fraction", in the pyrolysis oil, which can impact on the subsequent step of creating monomers from the steam cracker. It is these monomers from steam cracking which can then be made into new plastics. Essentially, the higher the percentage of polyolefins in the feedstock the greater the pyrolysis oil yield at the pyrolysis facility.

The conversion of polyolefin feedstock to pyrolysis oil is not one to one, meaning that there is yield loss through the process. The typical yield within the process is between 50-85% depending on the quality of the feedstock.[14,15,16,17,18,19] The pyrolysis oil then goes to a cracker where there are further losses, which could be from 40%, as it is turned into monomers. It is important to recognize that, like many mechanical recycling processes, there will be yield loss and it is crucial to control the quality of the feedstock. The yield from incoming materials through to recycled flake or pellet for mechanical recycling is also dependent on feedstock. Average yields from mechanical recycling will vary from over 90% to the mid-50's. However, the loss is primarily due to feedstock variation and non-usable incoming weight (e.g., liquids, fiber, dirt, non-plastics); only a small percentage of loss comes from the process itself with relatively minimal production of co-products (e.g., caps and closures stream) as compared to pyrolysis.

Figure 3: Model Feedstock Specification for Pyrolysis

Items made of PE (LDPE, LLDPE, or HDPE) and PP such as containers, trays, cups, films, and bags. All items should be free of contents or free flowing liquids and rinsed.

Minimum	Maximum moisture content:	Maximum total contamination:
85% PE, PP, or any combination of PE and PP	**7%**	**15%**

The following individual contaminants must not be present in amounts exceeding their specified thresholds, and the combined presence of all contaminants should not exceed 15%:

PVC/PVDC	PET/EVOH/Nylon	PS	Metal, glass, dirt/fines	Paper/organics (including food residues):
1%	**5%**	**7%**	**7%**	**10%**

Source: Eunomia Research & Consulting and Alliance to End Plastic Waste

b APR's website on "Model Bale Specifications" contains more information: https://plasticsrecycling.org/model-bale-specifications

3.0

Polyolefin Film and Flexible Plastics Supply – Current and Future

Assumptions on FFP Supply

According to the FPA, twelve million tons of FFP was generated in 2019. In 2020, 493,000 tons of post-consumer plastic film was recovered for recycling, increasing to 553,000 tons in 2021.[20, 21] Recovered film volumes include PE films only. It's important to caveat in the context of film volumes reported as recovered for recycling that no measurable non-film residential post-consumer FFP has been recovered for recycling to date, nor has it been targeted for collection. Nearly all of the captured residential FFP (124,000 tons) was PE film collected through grocery retail takeback programs. (Remaining 2020 capture volumes are post-consumer, but are from post-commercial sources and not the focus of this study.)

Of the 12 million tons, 9 million tons could potentially be a target for mechanical recycling and pyrolysis with package design changes. The remaining 3 million tons are categories not suitable for capture, such as trash bags. Currently, only an estimated 5.3 million of the total 9 million tons would be available for these technologies because of the PE make-up of these volumes: 3 million tons from the residential sector and 2.3 million tons from the commercial sector. The remaining 3.7 million tons are multi-resin and multi-material products incompatible with either mechanical recycling or pyrolysis at this time (Figure 4).

The amount of FFP sold in the U.S. is expected to grow on average at an average of 2.8% per year across formats, which means there will potentially be 15.8 million tons on the market in 2030 (a 31% increase over 2019). For the potential future swcenario explored in this study, the amount of FFP available for both mechanical recycling and pyrolysis is anticipated to be impacted by design changes reducing the amount of multi-material FFP, the passage of packaging EPR in additional states, and potential voluntary action in states where there is unlikely to be EPR.

In this future 2030 scenario, of the estimated 5.6 million tons of PE Only and PO FFP available from the residential sector based on the assumptions listed above and further detailed in this section, a total of 1.2 million tons of material would be collected for recycling. There would be a total of 930,000 tons of material available to recycling processors in the 2030 scenario, compared to 118,000 tons in 2020. The 930,000 tons would be comprised of 340,000 tons of PE only material and 590,000 tons of PO material (e.g., blend of PE and PP).

3.1 Current Supply

3.1.1 FFP Generation 2019

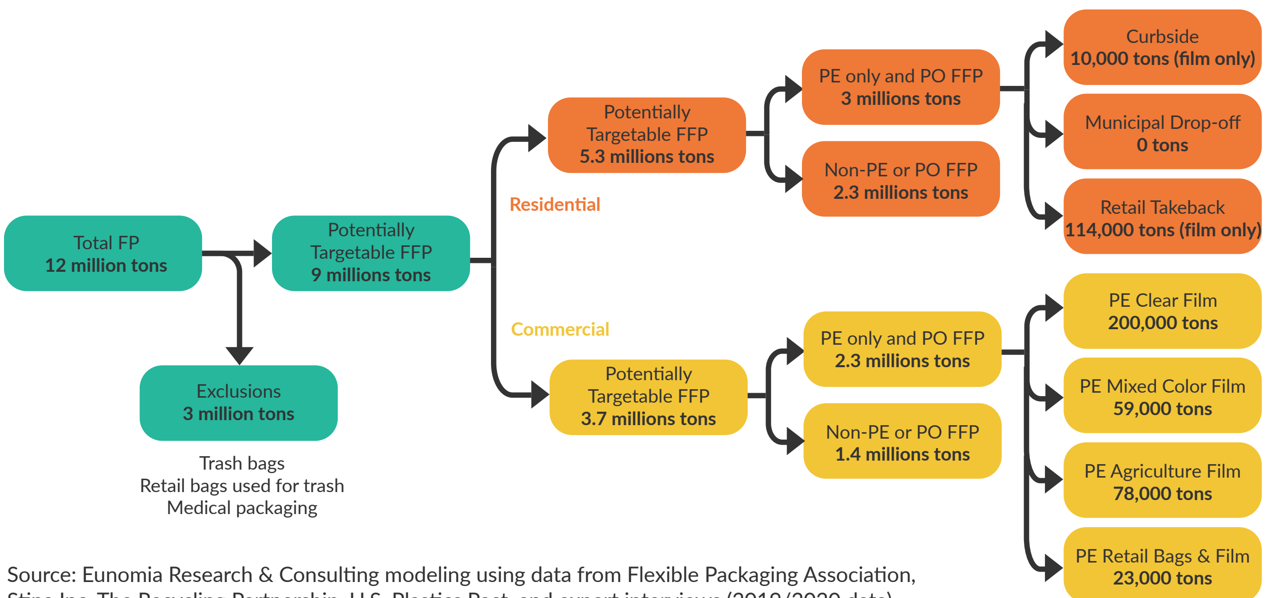
FFP is a complex material stream due to the variety of formats, sizes, uses, and material compositions. For example, FFP includes bags, wrappers, stand-up pouches, retort pouches, lidding, shrink sleeves and labels, shrink wrap, stretch films, retail carry bags, storage and trash bags, and medical packaging. A list of categories, sub-categories, and descriptions from the Flexible Packaging Association (FPA) appears in the Appendix.

The FPA estimates that 12 million tons of FFP was sold in the United States in 2019, as shown in Figure 4.[22,c]

About half (53%) of total FFP material is estimated to be comprised of PE only material, about a third (31%) of multiple resins, and the remainder (16%) of multi-materials formats (see Figure 5). Three million of the 12 million tons are trash bags, retail bags used for trash, and medical packaging, which would not be targeted under residential and commercial programs. Medical or pre-patient medical packaging could be targeted for recycling but it has unique considerations.

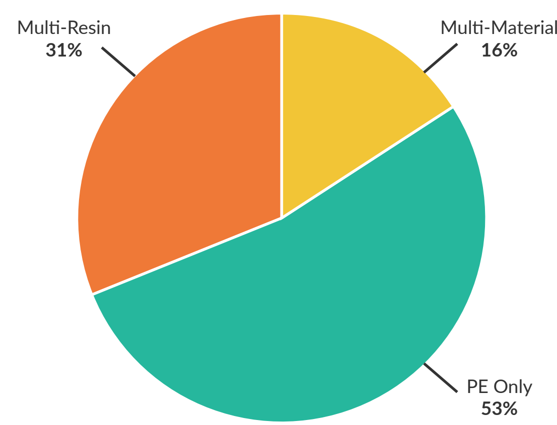
Therefore, an estimated 9 million of the total 12 million tons could potentially be recycled mechanically or through pyrolysis if it was both captured for recycling and comprised of only PO resins (e.g., either PE only or a blend of PE and PP). Of those 9 million tons, it is estimated that 5.3 million are made of PE only (4.5 million tons) or a blend of PE and PP (0.8 million tons). The remaining 3.7 million tons would require design changes to be suitable for either mechanical or pyrolysis recycling.

Figure 4: Current Estimated Material Flows



Source: Eunomia Research & Consulting modeling using data from Flexible Packaging Association, Stina Inc, The Recycling Partnership, U.S. Plastics Pact, and expert interviews (2019/2020 data).

Figure 5: Film and Flexible Packaging Sold in the U.S. in 2019 (Includes Residential & Commercial Volumes)



Source: Based on data from Flexible Packaging U.S. Market Profile & Segmentation Report prepared by PTIS, LLC for the Flexible Packaging Association, August 2021

[c] The FPA reports 12.6 million tons of FFP sold in the U.S. in 2020, but this includes retail paper bags. We removed paper bags for this study.

Table 1 reveals that Form/Fill/Seal (FFS) packaging is largest category of FFP placed on the market in 2019, accounting for more than a quarter (27%) of all FFP by weight. This type of packaging is typically used for snacks, cookies, crackers, cereals, bread, salad mixes, flour, sugar, dry mixes, frozen foods, coffee, pet food, etc. Bags accounted for a third (34%) of FFP. This includes trash bags (13%), retail bags (10%), and bags typically used for newspapers, bread, produce, dry cleaning, and frozen vegetables (11%). Stretch film, primarily sold business-to-business, and used to wrap pallets for transport, makes up nearly one tenth.

Table 1: Categories of FFP Placed on the Market in 2019[23]

Format Category	Total % of FFP	PE Only (% of Total FFP)	Multi-Resin (% of Total FFP)	Multi-Material (% of Total FFP)
Form/Fill/Seal (FFS)	27%	1%	18%	8%
Trash Bags	13%	13%	0%	0%
Bags	11%	9%	0%	2%
Retail Bags	10%	10%	0%	0%
Stretch	10%	10%	0%	0%
Pouches	9%	0%	5%	3%
Medical Packaging	5%	1%	3%	1%
Protective Packaging	5%	5%	0%	0%
Wraps	4%	3%	1%	1%
Labels	4%	0%	3%	1%
Lidding	1%	0%	0%	1%
Liners	1%	1%	0%	0%
Bundling	1%	1%	0%	0%
Thin Films	1%	1%	0%	0%
Food Forming Films	<1%	0%	0%	0%

Source: Calculated by Eunomia using data from Flexible Packaging U.S. Market Profile & Segmentation Report prepared by PTIS, LLC for the Flexible Packaging Association, August 2021

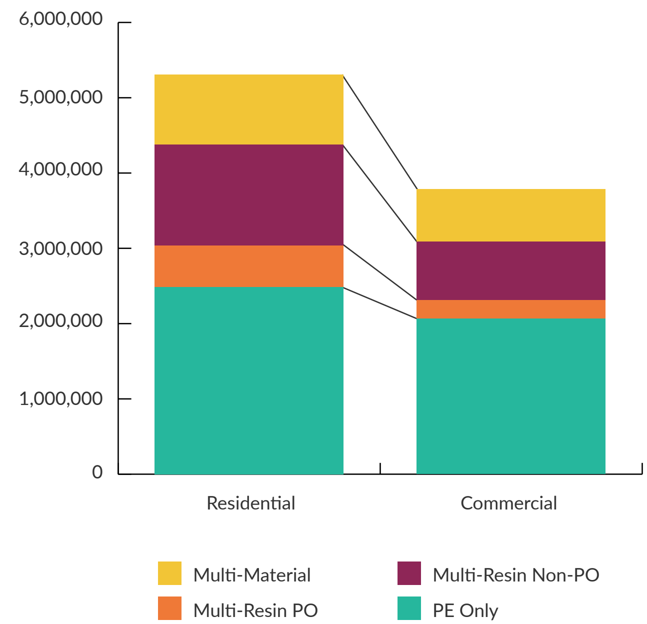
Eunomia estimates that 55% (6.5 million tons) of the 12 million tons of total FFP sold in the U.S. in 2019 was for residential use and the other 45% (5.5 million tons) was for commercial use, inclusive of "non-target" materials (e.g., trash bags) identified in Table 4. The starting point for this split was data from waste characterization studies (e.g., California, Washington). In other words, most FFP is not captured for recycling and a large amount ends up in landfills. Therefore, waste characterization studies measuring FFP separately for residential and commercial sources provide reasonable estimates for what percentage of each format is generated from the residential or commercial sector.

The format categories used in waste characterization studies do not align perfectly with FPA data, though, so additional refinements and assumptions are necessary. Eunomia relied on additional sources such as "Addressing the Challenge of Film and Flexible Packaging Data for The Recycling Partnership's Film and Flexibles Coalition" (February 2021) and data from the U.S. Plastics Pact, for example, to fine tune the results.

The FPA data also does not quantify the percentage of multi-resin materials comprised of only PO resins (e.g., PE and PP) as opposed to other resins (e.g., PET) that would be considered contamination as a pyrolysis feedstock. Eunomia relied on various data sources and conversations with packaging experts to develop these estimates. The results suggest that approximately 800,000 tons (27%) of the 2.9 million tons of potentially targetable multi-resin FFP is comprised of only PO resins (e.g., PE and PP). Of the 800,000 tons, 550,000 tons are estimated to be generated by the residential sector and 250,000 tons by the commercial sector.

Figure 6 combines the residential and commercial estimates with Eunomia's estimates of multi-resin formats comprised of PO only material to show the composition of 9 million tons of FFP material that could have potentially been targeted for recycling in 2019 if it had been captured. Of the 5.3 million tons of potentially targetable FFP generated by residential sources, an estimated 2.5 million tons (47%) was comprised of PE only material, 550,000 tons was comprised of PO only multi-resin material, 1.3 million tons of multi-resin materials including non-PO resins, and 900,000 tons of multi-material formats. Of the 3.8 million tons of potentially targetable FFP generated by the commercial sector, 2 million tons was comprised of PE only material, 250,000 tons of PO only multi-resin material, 800,000 tons of multi-resin materials including non-PO resins, and 700,000 tons of multi-material formats.

Figure 6: Estimated Composition of 9 Million Tons of Targetable Residential and Commercial FFP Generation (2019)



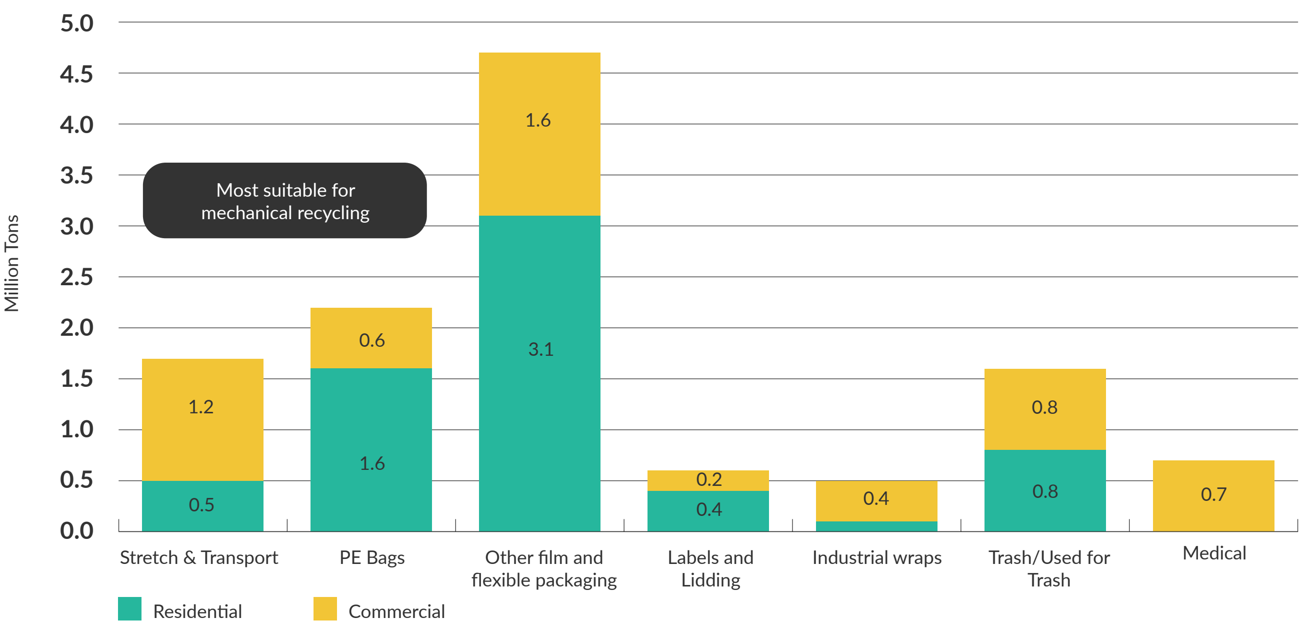
Source: Calculated by Eunomia based on data from Flexible Packaging U.S. Market Profile & Segmentation Report by PTIS, LLC. Prepared for the Flexible Packaging Association, August 2021.

Figure 7 shows the results of residential versus commercial generation modeling. This illustrates that, for example, stretch and transport films are most likely to arise from commercial sources, while PE bags are most likely to arise from residential sources. Eunomia also recategorized bags to distinguish between bags that are made only with PE ("PE Bags"), bags that are not PE (included in the "Other film and flexible packaging" category), and an estimate of retail PE bags used for trash ("Trash/Used for Trash").

Importantly, this recategorization highlights that two formats, "Stretch & Transport" film and "PE Bags" add up to approximately 3.9 million tons (1.7 million tons of stretch and transport film and 2.2 million tons of PE bags) of clean, valuable material that would have been available to mechanical recyclers or pyrolysis operators in 2019 if the materials had been captured. Based on Eunomia's estimates of residential versus commercial generation, that is 2.1 million tons of stretch and transport film and PE bags from residential sources and 1.8 million tons from commercial.

A large portion of residential material in the "Other film and flexible packaging" in Figure 7 is FFS and pouches (see Table 1), which are almost entirely multi-resin or multi-material products that are not currently designed for either mechanical or pyrolysis recycling.

Figure 7: Residential and Commercial FFP Generation (2019)



Source: Calculated by Eunomia based on data from Flexible Packaging U.S. Market Profile & Segmentation Report by PTIS, LLC. Prepared for the Flexible Packaging Association, August 2021

3.1.2 Captured for Recycling 2020

In 2020, 493,000 tons of plastic film were collected for recycling.[24] Flexible packaging was not collected and recycled in any measurable quantity. Nearly 70% of collected film was from commercial (PE Clear Film and PE Mixed Color Film) and Agricultural (PE Agricultural Film) sources while more than a quarter (28%) was specifically from retail takeback programs (PE Retail Bags & Film).

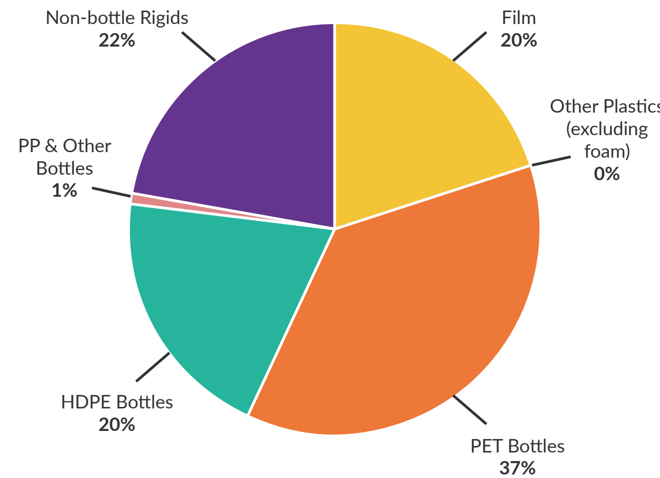
To provide context, plastic film accounted for approximately one-fifth (20.5%) of the 2.4 millon tons of post-consumer plastic recovered for recycling in 2020.[25] That same year, 3.3 million tons of PET resin was generated for use in U.S. PET bottles and 884,000 tons of PET bottles were recovered for recycling, which accounted for 37% of post-consumer plastic recovered for recycling.[26] While nearly twice the amount of PET bottles was recovered by weight, it should be noted that FFP recycling has not been the focus of recycling investment unlike PET for many reasons including ease of collection, sorting challenges, and end markets.

Table 2: U.S Sourced Post-consumer Film Recovered for Recycling by Category

Film Category	Total Recovered for Recycling in 2020 (Tons)	Percent of Total Recovered
PE Clear Film	201,450	41%
PE Mixed Color Film	58,650	12%
PE Agricultural Film	78,150	16%
PE Retail Bags & Film	136,850	28%
Other Film	17,750	4%
Total	492,800	100%

* Includes MRF Curbside Film since total pounds recovered were negligible.
Source: Stina. "2020 U.S. Post-consumer Plastic Recycling Data Report." April 2022.

Figure 8: U.S. Sourced Post-consumer Plastic Recovered for Recycling by Category (2020)



Source: 2020 U.S. Post-consumer Plastic Recycling Data Report, Stina (April 2022). The 2021 U.S. Post-consumer Plastic Recycling Data Report is available, but 2020 data was used for better comparison to 2019 FPA FFP generation data.

Residential Focus

There are many challenges to accessing quality FFP from residential generators including:

Available Collection Pathways

According to The Recycling Partnership, only one percent of U.S. households have access to curbside collection programs accepting FFP. In contrast to municipal curbside and drop-off programs, many households theoretically have access to retail takeback programs for plastics bags and film. A recent Bloomberg article reported that 12,000 retail locations (e.g., Target, Home Depot, and Kroger) offer such programs.[27] A 2022 Resource Recycling Systems (RRS) study conducted for GreenBlue analyzed access to retail takeback programs in California using three measures: radial distance; driving distance; and driving time. The results were that 87.6% of the population is within a three miles radial distance of a retail takeback location, 78.1% are within three miles driving distance, and 92.9% are within a 15-minute drive.[28]

These results from California cannot be generalized across the entire country, but even if they could, access to such programs does not equate to participation. According to a 2017 ACC report, only 32% of Americans say they have ever returned plastic shopping bags to stores for recycling.[29] And while this study is becoming dated, the percentage of people regularly returning plastic bags and film to retail locations has likely not increased significantly given total post-consumer film recovered for recycling from all sources only increased from 510,000 tons in 2012 to 553,000 tons in 2021.[30] Eunomia estimates that an average of only two pounds of FFP was captured in 2020 from households with access to such programs, out of approximately 75 pounds per year of FFP generated per household (excluding trash bags).[31]

MRF Challenges

While new technology is coming, there are significant collective challenges for the more than 350 MRFs in the United States that process consumer-facing materials. These include everything from upgrade costs and ROIs, space to expand, and retrofit downtime to contamination, potential impacts to other commodity streams (e.g., paper), and end market consistency.

Size

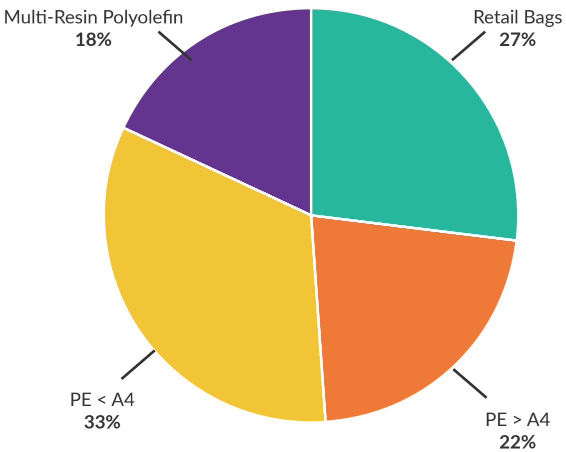
We estimate that there are nearly one million tons of small format (<A4) PE Only materials in the residential waste stream, which is one-third of residential FFP material that could theoretically have value to recyclers today if designed to be compatible with the recycling stream (most of this is snack packaging). Eunomia's analysis of the results of The Material Recovery for the Future (MRFF) pilot suggests that a third (32%) of this stream could be captured by curbside programs.[32] Small sizes are a challenge for sorting systems, though, even those with the upgrades described in the MRFF pilot. In the MRFF pilot, recovery rates of small chip bags and storage bags were lower than their larger equivalents by 15-20 percentage points.

Sorting Yield

Sorting FFP remains a challenge for sorting facilities in general. In large, single stream MRFs, FFP generally flows with paper due to its two-dimensional shape. The MRFF pilot was able to achieve a 70% average sorting efficiency (capture into film bale), though, via upgrades to optical sorters, air flow controls, collection hoods, and other peripherals on fiber lines in a large, modern MRF with anti-wrap screens. There was considerable variation by format, with around 85% efficiency for retail bags and other PE bag formats, and lower efficiencies for other packaging formats.

The cost to overcome these challenges is one of the causes for the low recycling rates of residential FFP. Figure 9 shows a breakdown of the 3 million tons of residential PE and PO only material generated in 2019, of which 2.1 million tons were estimated to be comprised of PE material potentially suitable for both mechanical recycling and pyrolysis operators if it could be identified and sorted from mixed and multi-materials. Approximately 550,000 tons was multi-resin PO material that would be of interest to pyrolysis operators but not targeted by mechanical recyclers (see Section 3.1.1).

Figure 9: Composition of 3 Million Tons of Targetable Residential Generated PE and PO FFP in U.S. (2019)



Source: Calculated by Eunomia based on data from Flexible Packaging U.S. Market Profile & Segmentation Report by PTIS, LLC. Prepared for the Flexible Packaging Association, August 2021

In total, 124,000 tons of the three million tons of potentially targetable residential PE and PO material were collected in 2020 (film only). Ninety percent (114,000 tons) of the material collected was captured though retail takeback programs. The remaining 10,000 tons were collected through the few curbside recycling programs accepting FFP and by the few MRFs sorting FFP received as contamination.[d]

Retail takeback programs have a relatively higher proportion of retail bags (and, presumably, other larger PE bag formats) than other materials, and capture potentially 10% of retail bags available for recycling, compared to 2-4% for other PE FFP formats.[e] Collecting FFP at the curbside appears to result in a better capture rate for a wider range of formats, though is still highest for PE film and bags (>A4), and lower for smaller PE film (<A4), multi-resin and multi-material packaging.[f]

Because current collections are dominated by retail takeback programs, retail bags account for 58% of residential FFP captured and have the highest capture rate of targetable residential material at 9% of generation. Other PE Only film, small (<A4) and large (>A4), accounts for 38% of captured FFP (19% each). Though curbside collection data is mimimal, what is available suggests that a small amount of multi-resin and multi-material FFP is captured through curbside programs, of which only a fraction is PO material suitable for pyrolysis.

In summary, an estimated 123,000 tons of residential PE only FFP (film only) was captured in 2020, which was mechanically recycled. Only about 1,300 tons of residential PO FFP material (e.g., multi-resin PE and PP material) is estimated to have been collected that would have been suitable only for pyrolysis (see Section 3.1.1).

[d] From non-residential sources, PE clear film (e.g., stretch wrap) was the largest category of film collected in 2020 (201,000 tons), followed by PE agricultural film (78,000 tons) and PE mixed color film (59,000 tons) (Stina, 2021).

[e] Comparing FPA data with retail take-back film compositions from Stina.

[f] Comparing FPA data with collected FFP input compositions from MRF for the Future.

3.2 Future Supply - 2030

When considering the role that pyrolysis can play in the recycling of FFP in the future we have to not only consider what FFP the technology can accept as set out in Section 2, but also where facilities will source material from. While the overall FFP recycling rate is low, a large proportion of the commercial stream, which consists of stretch and transport films, PE films and industrial wrap, could be mechanically recycled if collected. As previously mentioned, this shaped the rationale for the scope of this report in terms of the target FFP streams. In order to focus on the additionality pyrolysis could deliver, the analyses of future volumes and costs (Section 4) focus on material largely from the residential sector that could be collected through curbside, municipal drop-off, and retail takeback programs.

3.2.1 Factors Impacting Future Supply and Recycling Potential

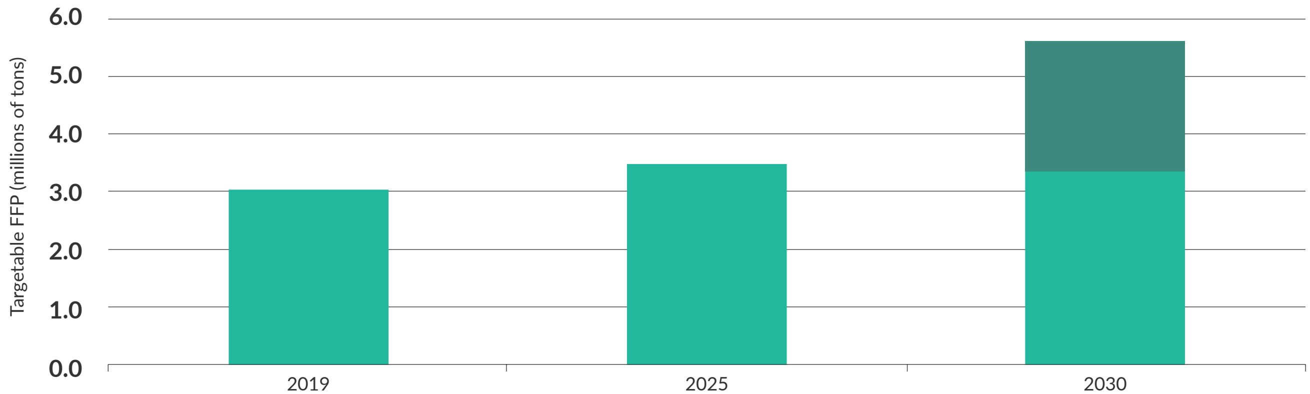
The amount of FFP sold in the U.S. is expected to grow on average at an average of 2.8% per year across formats, which means there will potentially be 15.8 million tons on the market in 2030 (a 31% increase over 2019).[33] While volumes will increase out to 2030 and beyond, the next sections seek to model a "what if" scenario and assumes a number of changes Eunomia believes would be needed to significantly increase recovery of material FFP for both mechanical recycling and pyrolysis. The changes may be considered optimistic and, therefore, the scenario presented is informative as to just how much policy, design change, and investment is needed to capture the amount of FFP estimated by our modeled scenario. The modeled scenario includes:

- **Design Changes:** Multi-material FFP is gradually phased out. Packaging producers are shifting to PE or PP only formats, developing 90% PO blends which provide the functionality of multi-material packaging but are designed for recycling. We may also see some packaging shifting to paper.
- **Extended Producer Responsibility (EPR) for Packaging Policy:** We expect EPR for packaging schemes to increase the quantity captured for recycling. Four states have already passed EPR legislation that should be implemented within the next few years (California, Colorado, Maine, and Oregon). Another 15 states are considering legislation that that could reasonably be implemented by 2030.
- **Voluntary Action:** In states where there is unlikely to be legislation, it is unclear if and how much voluntary action will take place, especially regarding retail takeback programs. Moore Recycling Associates found that bin placement, standardized signage, and educational campaigns can increase participation in retail return programs by 125%, but any step change in the amount of material collected through voluntary action will require the producers of flexible packaging to collaboratively invest in the necessary systems.[34] An example of this model is the Flexible Plastic Fund in the United Kingdom, which is funded by Mars, Mondelēz International, Nestlé, PepsiCo, and Unilever.[35]
- **Technology.** Sortation at MRFs, and ability to secondary sort to meet mechanical or chemical specs.

3.2.2 FFP Generation 2030

Of the 15.8 million tons of FFP estimated to be generated by 2030, 5.6 million tons of PE only and PO material could be generated from the residential sector. This volume has been calculated assuming 50% of multi-resin and multi-material formats shift to a design that meets a recyclability standard of >90% PO content by weight with similar residential and commercial proportional splits as used in Figure 4 and Figure 6. This is the highest percentage of material we would expect to undergo such a transformation based on conversations with flexible packaging experts, meaning that this scenario illustrates "what is possible" rather than "what is likely." Assuming collection of all FFP, either through MRFs or drop-off, this would leave significant volumes of unmarketable waste material for either MRFs or Plastic Recovery Facilities (PRFs) or other secondary sorters, a cost not accounted for in Section 4.. Figure 10 compares the volume of residential PE and PO now compared to what could be available based on growth and design changes out to 2030.

Figure 10: Million Tons of Residential PE and PO FFP for Potential Target: With Growth Only (2025) and with Growth and Design Changes (2030)



Source: Calculated by Eunomia based on data from Flexible Packaging U.S. Market Profile & Segmentation Report by PTIS, LLC. Prepared for the Flexible Packaging Association, August 2021

3.2.3 Material Collected and Sorted for Recycling

It is difficult to know exactly how changes in policy and voluntary action will evolve but for the purpose of estimating what volumes could be available for mechanical recycling and processing through pyrolysis we have made the following assumptions:

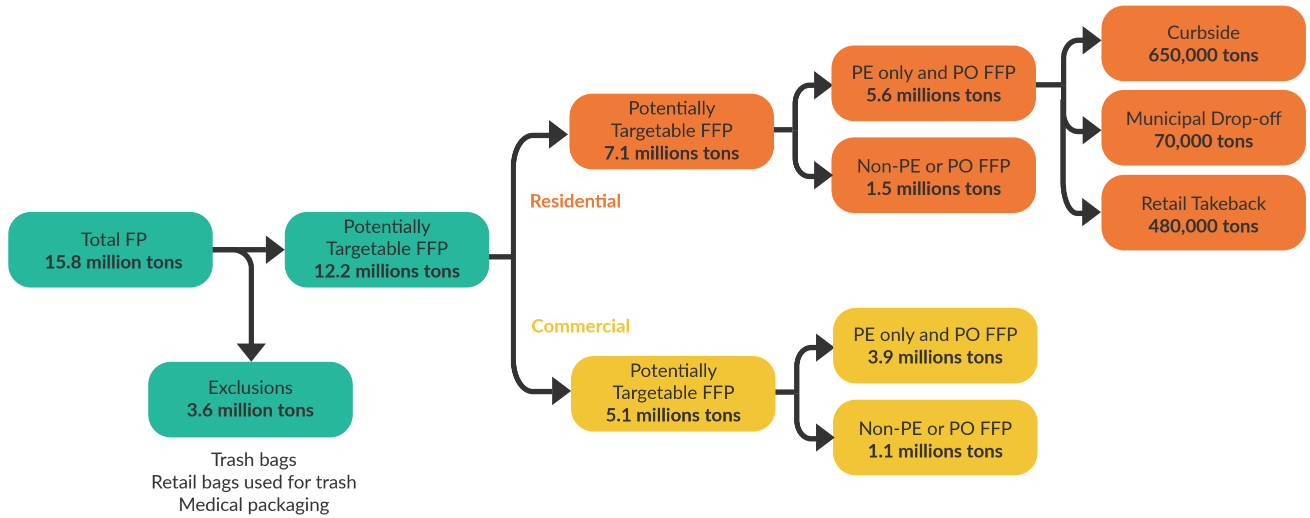
- **EPR impacts:** The model assumes EPR is fully implemented in all states that currently have, or are currently considering, EPR policies and that these systems collect FFP that has been designed for recycling. This would equate to 19 states accounting for 43% of the U.S. population. This is an optimistic view of what could be realized through current political ambition and, therefore, is likely to result in an overstatement of the amount of material collected.
- **Voluntary action impacts:** Assumption that producers fund programs to capture material in non-EPR states primarily through retailer takeback and municipal drop-off programs.

In scoping what the future might look like for the supply of PE only and PO FFP supply, we have excluded the option of capturing FFP material through mixed waste sorting. Unlike in Europe, where this method is being actively investigated, most of the U.S. does not have comprehensive organics and food scrap collection systems. Any FFP material in mixed waste is therefore likely to be too contaminated to be considered a quality source of PE and PO material for recyclers. Capturing PE and PO FFP from mixed waste will be feasible only when organics waste is removed from the residential waste stream.

Figure 11 shows the material flow under a 2030 future system which included design changes and investment in collection through EPR and voluntary producer action. Of the 5.6 million tons of PE only and PO FFP available from the residential sector, a total of 1.2 million tons of PE only and PO material would be collected for recycling. Approximately 650,000 tons are assumed to be collected by curbside programs, 70,000 tons at municipal drop-off facilities, and 480,000 through retail takeback programs based on an approximate 30% capture rate at curbside and depot locations in EPR states and nationwide improvement to 15% capture rate at retail takeback and municipal drop-off locations.

The diagram does not represent commercial collection as that was not modeled. Nor does it represent the amount of non-PE or PO FFP that is collected as contamination. Also note that numbers may not add up to expected totals due to rounding.

Figure 11: High-level material flow in modeled 2030 scenario



Source: Eunomia Research & Consulting.

In the scenario modeled, FFP material collected via retail takeback programs will be taken directly to a processor as that is a common scenario today. However, it's important to note that as the level of non-PE film, mixed FFP material increases, additional sorting would be required to separate and sort the mixed FFP from the polyolefin film portions of these bales. This is not a model commonly in practice at this time and is not costed out in Section 4, but is noted as a potential additional cost in Figure 13. For FFP collected through municipal drop-off facilities, the model assumes it will be source-separated and, therefore, can be shipped directly to a processor (based on British Columbia's methods).

In contrast, curbside collection is modeled as single-stream or commingled collection. Therefore, that material will need to be sorted at an MRF. The model relies on the costs and results achieved in the Materials Recovery for the Future (MRFF) pilot as that is one of the few sources of U.S. data available based on actual operations. The following is a brief description of the process and technologies used for that pilot:

"As established during the MRFF research program's previous research, the geometry of FPP [flexible plastic packaging] dictates its flow with other two-dimensional materials in the MRF. Thus, the equipment modifications to sort rFlex at the pilot facility were installed after the screens that separate two- and three-dimensional materials. The system, illustrated in Figure 2, consists of three Tomra Autosort 4 optical sorters that eject FPP from the fiber lines, followed by a fourth Autosort 4 that ejects fiber from the resulting FPP stream. The ejected stream from the fourth optical sort is manually quality controlled for any collaterally ejected FPP. The final component of the system is a Lubo Paper Magnet flex/rigid separator used to remove 3-D materials from the cleaned FPP stream. The resulting materials are conveyed via a suction system to a dedicated rFlex bunker." [36]

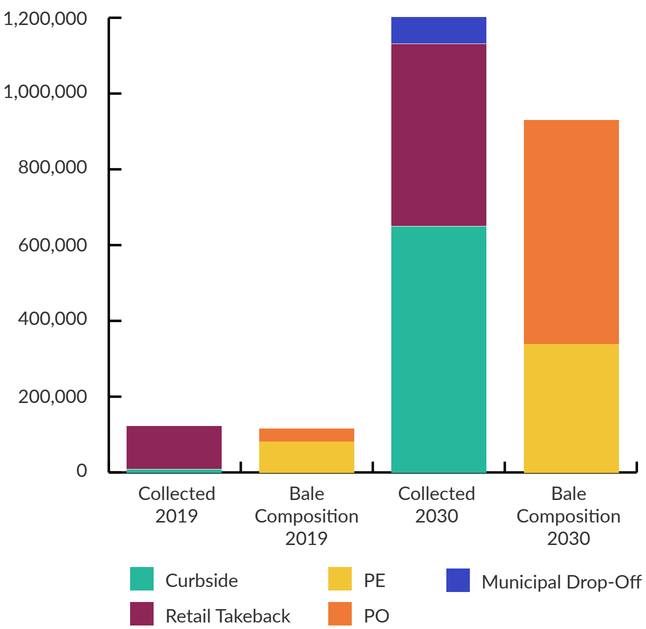
Because the FFP collected will be a mix of PE, PO and multi-material resins not suitable for reprocessing, the model then assumes the resulting bales are sorted again at a secondary sorter (PRF) to achieve bale specifications desired for mechanical recycling or pyrolysis. It should be noted that, once baled, FFP is challenging to sort by resin due to material compaction. Trials are needed to assess the sortation efficacy and end market suitability of this material. In this scenario, the secondary sortation facility would bear the costs of the non-PO FFP residuals as well as non-plastic materials, such as paper, which can comprise up to 30% of MRF film bales in trials to date. End markets or EPR fees would need to compensate the secondary sorting facility for these costs.

Eunomia recognizes that there are alternative methods for sorting FFP. For example, MRFs in the United States typically sort plastics commodities using optical sortation to detect and sort plastics by resin type rather than by form. The subsequent sorting of a resin stream by form is typically done by hand or through robotics (e.g., PET bottles vs. PET thermoforms). If MRFs use near-infrared (NIR) sortation to positively sort PE only and PO FFP, this stream could theoretically go directly to pyrolysis markets and eliminate the costs associated with secondary sorting if nuanced sortation systems are able to differentiate FFP at typical MRF processing rates . This sortation model was not modeled and would require increased MRF investment and bunker capacity for the additional FFP resin streams, in addition to the line space and down time that are challenging for all MRF upgrades. As previously mentioned, the cost burden of non-marketable residue material for the MRF or PRF would need to be considered, as well as the potential impacts on other commodities.

Figure 12 compares the tons of material captured from the residential sector and sorted for recycling in 2030 against 2020. There will be a total of 930,000 tons of material available to recycling processors in the 2030 scenario, compared to 118,000 in 2020. The 930,000 tons will be comprised of 340,000 tons of PE only material and 590,000 tons of PO material (e.g., blend of PE and PP).

The 480,000 tons of FFP collected through retail takeback programs and 70,000 tons collected at municipal drop-off facilities are both assumed to be shipped directly to processors. The 650,000 tons collected through single-stream curbside recycling programs in 2030 is sorted at both primary and secondary sorting facilities, resulting in 380,000 tons of high-quality material (approximately 170,000 tons of PE and 210,000 tons of PO material).

Figure 12: Tons of Material Collected in 2030 Scenario



Source: Eunomia Research & Consulting.

3.2.4 Summary

The future scenario represents an ambitious and successful roll out of curbside and municipal drop-off-based FFP collections that achieves high capture rates of all film packaging formats, and provides improved participation in retail takeback film collections. Not addressed in detail in this report is post-commercial material generated in non-grocery retail and manufacturing contexts, which continues to be an important source of post-consumer films and is an obvious target for expansion of recycling capture.

The future scenario involves policy and as well as voluntary action by producers to support programs in states that are unlikely to pass policy. If these changes can be realized, there is the potential for a dramatic increase, perhaps more than 10x in a decade, in the quantity of sorted material for which pyrolysis operators will not be in direct competition with mechanical recyclers for, namely curbside mixed polyolefins.

Design changes are expected to increase that even further, as small format FFP shifts from unrecyclable multi-resins and multi-materials to recyclable PO blends (>85% PO). However, a countervailing switch of a portion of some FFP formats to paper packaging, as well as possibly reuse and refill formats, could reduce the net impact of those recyclability shifts. It is also clear design-based improvements in recyclability will mean very little without substantial increases in film collection, improvements in MRF sorting capabilities, and the development of a functioning market for post-consumer PO FFP.

In the future scenario, a portion of the tonnage of material available for pyrolysis could also be captured for mechanical recycling. Thus, mechanical and pyrolysis operators may be competing for this portion of the available material, but ideally these technologies are complementary.

4.0

Cost to Produce Recycled Material via a Recycling Supply Chain that includes Pyrolysis

This study considers the costs to the system for the following activities:

1. **Collecting PE, PP and mixed PO material through curbside, municipal drop-off, and retail takeback programs;**
2. **Sorting curbside material at a MRF; and**
3. **Secondary sorting to produce bales that meet mechanical recycling and pyrolysis specifications.[g]**

FFP collection is not happening at scale in the United States and there is extremely limited data available, a problem highlighted in The Recycling Partnership's 2021 report, "Addressing the Challenge of Film and Flexible Packaging Data."[37] The costs reported here have been estimated using the limited data that is available, interviews with industry representatives, Eunomia analyses conducted for other projects, and bottom-up calculations (e.g., using bulk densities to derive the cost of curbside FFP collection from the cost of curbside mixed plastic recyclables collection). Though we must choose individual cost figures to use in our models, we recognize costs can vary dramatically depending on specific circumstances.

The Eunomia team used data from previous work and in conjunction with APR to develop cost ranges for the value chain steps from collection through sorting. The costs are reported using a system approach. In other words, costs are treated as costs to the system, not as costs borne by any individual system stakeholder. For example, curbside collection may be paid by taxpayers or by individual subscribers. Both are costs to the system that a producer would theoretically be responsible for under a producer responsibility scheme, at least to some degree. Looking at the total system cost is a common first step in developing EPR fees or incentives because it accounts for all costs to the system before allocating them.

As a reminder, we are not considering the collection costs of post-commercial FFP material as part of this study. The costs to collect, sort, and process that material is assumed to be lower than they would be for FFP from residential origins because post-commercial material tends to arise in larger volumes per location and to be a more homogenous material stream.

Section 4.1 details the system costs by activity and Section 4.2 considers the cost to process the 1.2 million tons of material theoretically collected in the 2030 scenario.

[g] The costs of mechanical recycling, pyrolysis, and steam cracking are not included here but will be considered in future studies.

4.1 System Costs by Activity

Curbside FFP Collection

Range:
$200 to $3,000 per ton collected

Estimate Used for Analysis:
$750 per ton collected

Given the limited availability of actual cost data for curbside collection of FFP, estimates must be developed indirectly. One approach is to begin with the cost per ton of collecting all plastic material, for which there are at least several data points, and then to use volume to weight or bulk density estimates to derive the cost per ton for a specific material type. The reason behind using a volume-based calculation is that recycling collection vehicles usually fill up before they reach their maximum payload by weight, which means they are more constrained by volume than by weight. In other words, transporting one ton of a low-density material will cost more per ton than transporting a higher density material. As a starting point, Eunomia identified costs between $200 and $350 per ton for curbside collection of commingled recyclables.[38,39,40,41] We would expect this to reflect the low-end of the range of film collection costs. Eunomia found calculations used by EPR schemes that use the bulk density of individual materials in uncompacted states (e.g., Ontario). Using that approach, EPR costs (inclusive of collection and sorting) were found to be around the range of $1,800 to $2,600 per ton.

However, uncompacted bulk densities do not reflect the actual density of the material in collection vehicles. Plastic films are low density and do not compact much under their own weight. They also have low mechanical strength, so they compact easily under the weight of other materials that are heavier, like glass and rigid plastics, in a commingled collection vehicle. Therefore, the bulk density of FFP will be higher in practice. When the bulk densities are adjusted through reference to other data sources (e.g., WRAP) and some internal estimations, the costs drop to approximately $750 per ton.[42] This is consistent with Ontario's EPR fee for films and laminates, which is $800 per ton.

Eunomia's internal modeling of a variety of voluntary collection system types resulted in a figure of approximately $3,000 per ton for curbside film collection. Voluntary collection is considerably more expensive per ton than integrating into existing curbside services, due to the low level of participation in relation to the cost of setting up additional collection infrastructure.

In summary, estimates range from $200 to $3,000 per ton. The low figure is based on all plastic material and is therefore too low to represent the contribution of films and flexible packaging to collection cost. The high value is for a voluntary system, where all aspects of the system would require investment. We use $750 as our current best estimate but recognize there will be variation depending on specific circumstances. At the same time, the estimates align with how costs would be apportioned to FFP in an EPR system.

Municipal Drop-off Collection

Range:
$287 to $1,882 per ton collected (transportation to processor not included)

Estimate used for analysis:
$839 per ton collected

British Columbia's packaging and paper product (PPP) extended producer responsibility plan offers one of the few real-life examples of depot collection costs. Recycle BC reported that 2019 depot collections costs ranged from $108 per ton to $1,882, including all recyclable materials collected by municipal and privately owned facilities. The weighted average was $287, and the report noted that this increased from $202 per ton in 2017 due to increased volume of light-weight material.

Costs were not calculated for each recyclable material stream but the proposed depot incentive of $839 per ton for plastic bags and overwrap may be used as an approximation.[43] An additional $443 incentive is offered if depots bale the PPP. It is important to note, however, that we did not have access to the incentive calculation methods and cannot assume that the incentives represent actual PPP collection and baling costs. For example, producers are not required to pay the complete costs of the system under British Columbia's program so these incentives could be set lower than expected costs.
Overall, Recycle BC's cost study provides us with a valuable range as FFP collection costs are certainly expected to be greater than the weighted average $287 per ton to collect all recyclable materials but could be as high as $1,882 per ton.

Retail Takeback Collection

$100 per ton collected (transportation to processor not included)

There is no data available for the cost of collecting film through retailer takeback programs. An estimate of $100 has been used, which was the five-year average price per ton for Grade B plastic film. At this time, PE bags and film collected through the front of house retail takeback programs is in many instances mixed with the high value back-of-house film, such as pallet wrap, which subsidizes the costs for front-of-house collection. Costs may vary considerably depending on whether or not the retailer bales the film, quantity and quality of film collected, and the amount of investments the retailer makes in marketing and community the program to increase participation.

Primary FFP Sorting (e.g., MRF)

Range:
$75 to $1,000 per ton input

Estimate Used for Analysis:
$125 per ton of input (transportation not included)

While estimates for manual FFP sorting are as high as $1,000 per ton,[44] several data sources estimate film and flexible packaging sorting costs through mechanical processes in the range of $75 to $100 per ton.[45,46,47] The mechanical sorting estimates include capital investments in optical sorters and air conveyance, which are annualized over the lifetime of the equipment and allocated according to proportion of FFP material handled. The overall facility capital and operating expenditures are also included in proportion to the amount of FFP processed. The costs per ton would be substantially higher if the total equipment investments were instead treated as marginal investments required to begin sorting FFP in addition to the other materials.

For the purposes of this study, Eunomia assumes MRFs would increase mechanical processing capabilities with investment from producer responsibility programs. Therefore, we lean toward the $75 to $100 estimates but use $125 per ton to account for the additional cost of sorting small format FFP.

These costs do not account for any residual cost (e.g., if MRF sorts FFP stream to mono-material and PO mix only to meet processor specifications), nor do they take into account any degradation to fiber streams or costs to sort film from these streams.

Transport from Primary Film Sorting to Secondary Film Sorting (baled)

$70 per ton transported

Industry sources tell us that the cost to transport C grade / pick line FFP (e.g., MRF) bales from a primary to secondary facility is approximately $70 per ton. This assumes nationwide van and inter-modal transport to a central facility.

Secondary Film Sorting

Range:
$200 to $240 per ton output

Estimate Used for Analysis:
$220 per ton of output

Data on secondary sorting is sparse, especially regarding cost. According to industry experts interviewed, the cost to produce an 85%+ PO bale (meeting pyrolysis feedstock spec) from an incoming stream of C grade / pick line FFP is between $200 to $240 per ton. This excludes the cost of the incoming material but includes all capital and operating expenses. This estimate is based on a facility with the capacity to produce 50,000 tons per year. Smaller facilities would have higher costs per ton.

4.2 System Costs: 2030 System

Total Cost for Collection and Sorting

In the 2030 scenario, an estimated 1.2 million tons of material could be collected through curbside, municipal drop-off, and retail takeback programs. Table 3 details the volume of material managed at each stage of this potential future scenario, along with the costs. This is also visualized in Figure 13.

The assumption is that single-stream material collected through curbside haulers is sorted at a MRF into mixed FFP bales. The outputs of the MRF are hauled to the secondary sorter for further sorting. For municipal drop-off locations, the assumption is that materials are source separated and transported directly to a processor as is the case in British Columbia. FFP collected through retail takeback programs is also transported directly to either a mechanical or pyrolysis in this scenario.

As previously noted, as the level of mixed FFP material in retail takeback increases, additional sorting will likely be required to separate and sort the mixed FFP from the polyolefin film portions. How this model might evolve has not been studied and potential costs required for additional sorting, baling and shipping are not included in Figure 13 or Table 3.

Figure 13: Projected 2030 Tonnage and Costs by Activity

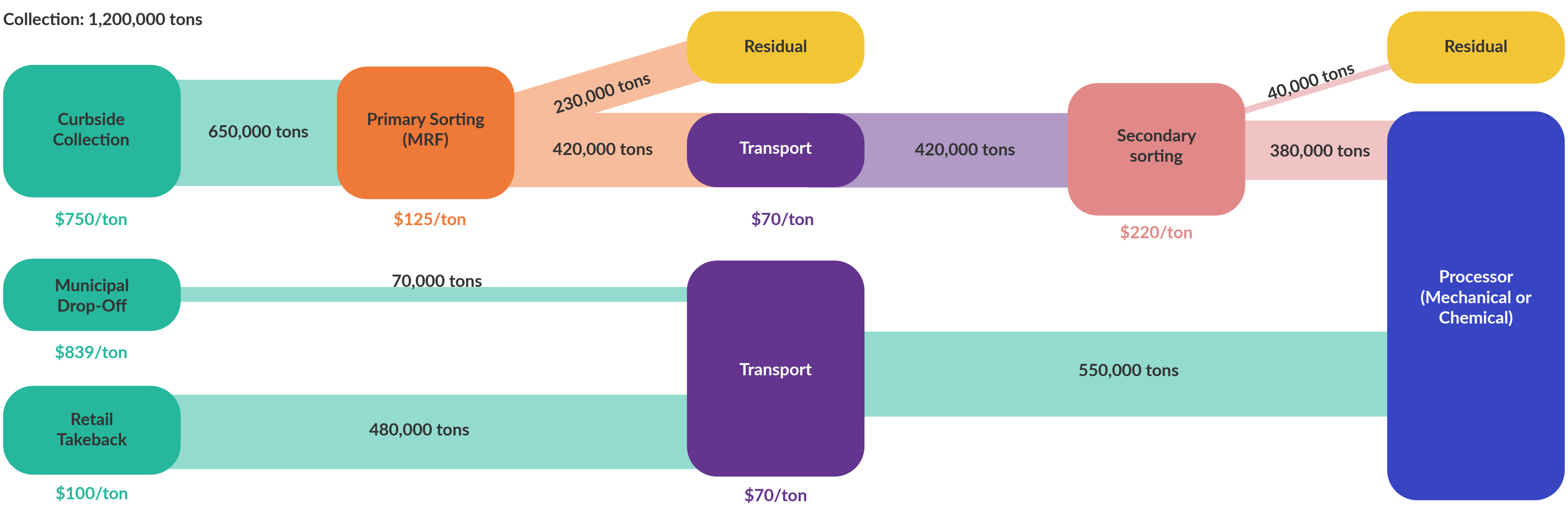


Table 3: Tonnage and Associated Costs by Activity

Stage	Tons	Per Ton ($)	Total ($ million)
Collecting (Curbside, Municipal Drop-Off, and Retail Take-back) – cost is weighted average	1,200,000	495	594
MRF Sorting Input	650,000	125	81
Transport	970,000	70	68
Secondary Sorting Input	420,000	200*	84
Total Tons Available to Processors / Total System Cost	930,000	889	827

* The secondary sorting cost is $220 per ton of output, which is equivalent to $200 per ton of input

The total system cost of collecting and sorting 930,000 tons of FFP is estimated to be $827 million. This is equivalent to $889 per ton of sorted material or $689 per ton of total FFP collected through curbside collection, municipal drop-off, and retail takeback programs. As a point of comparison, a Reclay StewardEdge study reported approximately $898 per marketed ton.[48] Currently, taxpayers and curbside collection subscribers are absorbing much of the cost of collection and sorting. In the future, EPR producer fees could ease the burden on taxpayers and consumers. Recycled content policy would result in greater demand for recycled material, which would also offset system costs by increasing the prices sorting facilities and processors can charge. These policies would not necessarily have to be specifically for packaging but could also be for durables and textiles. There are currently no such requirements in the U.S.

5.0

Conclusion

Approximately 12 million tons of FFP were placed on the market in 2019. This is nearly four times the amount of PET bottle resin placed on the market (3.2 million tons) demonstrating the size of this material stream and the importance of looking for solutions to recycle the stream. An estimated 6.5 million tons of this FFP is generated through the residential sector and 5.5 million tons from the commercial sector.

While post-commercial FFP material is a potential target stream for recyclers, this study focused on the complex challenge of potentially capturing and processing a larger quantity of residentially generated FFP through curbside collection, municipal drop-off, and retail takeback programs. An estimated 3 million tons of residential sector PE and PO FFP could be targeted now through these collection routes for recycling, yet only 123,000 tons of this material were collected for recycling in 2020. Ninety percent of the collected material was PE bags and film collected through retail takeback programs.

The challenges to recycling FFP currently include insufficient collection due to minimal takeback infrastructure and limited curbside collection. Both are linked to the fact that MRFs do not have the equipment necessary to sort this complex material stream. The lack of investment in such equipment is partly due to unpredictable and inadequate markets for the varied material stream.

The amount of FFP sold in the U.S. is expected to grow on average at 2.8% per year across formats, which means there will potentially be 15.8 million tons on the market in 2030 (a 31% increase over 2020).[49] To consider the role that pyrolysis may play in the recycling of this material in the future, it is necessary to explore a future system design. This study considers a future scenario in which producers implement design changes shifting to mono-PE and mono-PP formats or 90% polyolefin blends; EPR supports the collection of FFP in 19 states representing 49% of the population; and brands voluntarily support FFP collection and sorting in those states unlikely to implement EPR.

As a result of the modeled design changes, by 2030 there could be 5.6 million tons of residential FFP that is mono-PE, mono-PP, or 90% PO blend. Modeling the expansion of FFP collection in EPR states and the aforementioned voluntary efforts (see Section 3.2) results in estimated 21% (1.2 million tons) of this material collected for recycling. The estimated gross system cost per ton for collecting FFP through curbside programs, municipal drop-off facilities, and retail takeback programs is estimated to be $889.

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Appendix

The below table outlines the categories, definitions and examples used in this study.

Table 4: Materials and Product Categories

Material	Category	Sub Segment	Definition	Examples
PE Only	Bags	Single Film Bags (PE)	"Single film bags" are made from PE and include bread bags, diaper bags, produce bags, textile bags, frozen vegetable bags, dry cleaning bags, and other non-food bags used to collate and merchandise multiple items.	Newspaper bags, bread bags, produce bags, dry cleaner bags, frozen vegetable bags.
PE Only	Bags	Coex Film Bags	Coextruded film consisting of coextruded HDPE, LLDPE, or LDPE.	Cereal film liner, multi-layer but all PE-based pouches.
PE Only	Retail Bags	Bags Retail Carry – Light Gauge	Range of item containers sold business to business and given—or sold—to retail customers for transporting goods at the time of sale – LDPE/HDPE based.	Plastic HDPE/LDPE bags – grocery store/ carry out.
PE Only	Bags	Storage Bags	Business to consumer for improvised storage of household goods.	Ziploc® type bags, "baggies," etc.
PE Only	Trash Bags	Trash Bags	Serve to contain various wastes and discards destined for disposal. Some are designed to mask or absorb odors from the wastes to some degree.	Trash bags or other bags used for trash disposal.
PE Only	Bags	Heavy Duty Shipping Sacks	Single-layer and coextruded films consisting of HDPE, LLDPE, or LDPE.	FIBC liner, bag mulch, potting soil bags.
PE Only	Thin Films	Thin Gauge Films (typically of LLDPE, easily heat sealable)	Sold business to consumer as well as business to business for temporary containment and protection of food products. Both Institutional and household products are included in the category.	Cucumbers, cheese, meat with or without a tray that has a wrap around it. Stretch film around a tray. Pre-cut fruit (watermelon).

Material	Category	Sub Segment	Definition	Examples
PE Only	Form/Fill/Seal (FFS)	Horizontal and Vertical Form/ Fill/Seal (FFS) Packages	The segment includes conventional 3- and 4- side "pillow-style" sealed pouches made from single-ply or laminated PE-only films, formed with neither side nor bottom gussets. As estimated here, the pouches are formed/filled/sealed from rollstock in integrated operations. “Pillow pouches” in this category represent bags made from one web, formed into a tube-shape; sealed edge to edge (i.e., machine direction) to preserve the tube form; and then sealed in the cross-web direction for top and bottom seals.	Snacks/cookies/crackers, cereals, bread, salad mixes, confectionary, flour/sugar/dry mixes, frozen foods, coffee, pet food/treats, etc.
PE Only	Pouches	Stand-up Pouches	“Stand-up pouches” incorporate gussets in either the bottom, bottom and top, or sides to provide a stand-up feature. These include both premade and form/fill/seal pouches made of all-PE single ply and laminated films.	Snacks/cookies/ crackers, cereals, confectionary, condiments, dry mix pouches, frozen foods, coffee, etc.
PE Only	Pouches	Stand-up Pouch with Fitment	No significant volumes of PE are used in this category.	Sauces, frosting, Method refill pouches.
PE Only	Labels	Stretch/ Shrink Sleeve Labels	These are labels requiring a compressive force or heat to affix them to their containers. The force is accomplished in one approach by stretching the circumference of the sleeve as it is placed over a container. With the force removed, the sleeve snaps back to hold snugly around the container. Alternately, heat is used to relieve residual stresses heat- set in the film after the sleeve is placed over the container.	Stretch and shrink sleeves and labels for bottles, cups, tubes, etc. made from PE.
PE Only	Wraps	Printed and Unprinted – Light Gauge	Wrap-around labels and product wrappers sold business to business. The common feature of this segment involves cutting a length of material from a roll and then automatically wrapping the cut piece around another object.	Paper towel, napkins toilet tissue. Bundle wrap/shrink.

Material	Category	Sub Segment	Definition	Examples
PE Only	Bundling	Shrink Bundling – Heavy Gauge	Wrap-around labels and product wrappers sold business to business. The common feature of this segment involves cutting a length of material from a roll and then automatically wrapping the cut piece around another object.	Shrink bundle around beverage multipacks (printed or clear), can in trays.
PE Only	Stretch	Stretch Film	Used as pallet-load unitizers, sold business to business.	Stretch film around pallets. Stretch film around a tray.
PE Only	Protective Packaging	Air Pillow/ Cushioning	This is roll film often sold as flat tubing that is converted into air pillows at distribution centers. The pillows are filled with air to take up excess space in a box and provides cushioning for the product. This is supplied B2B as roll film that is formed into bubble wrap or as preformed bubble wrap. This is used as protective packaging for shipping small to large items.	Air cushion pillows, bubble wrap, LDPE component bags. Air pillows are typically MDPE or HDPE Coex. Includes film rollstock formed into bubble wrap.
PE Only	Protective Packaging	PE-based Mailers	Plastic-based mailers are usually made from PE-based material. Can be either poly sheet or interior lined with "bubble wrap" for product protection.	LLDPE based mailers, bubble mailers, HDPE poly mailers.
PE Only	Wraps	Industrial Wraps	A peelable film that has release characteristics from the surface to which it is applied. Leaves no residue.	Industrial wraps, cling wraps, protective wraps – micro-perf, cling, UV-blocking films.
PE Only	Liners	Box Liners	Liner to keep dust out – premade liners.	PE box liners – Gaylord/drum liner. Large box liner, bulk packs.
PE Only	Medical Packaging	Bottom Forming Webs	Rollstock that runs on FFS machines such as Multivac, Ossid, or other similar equipment.	Coex LLDPE and Polyolefin Copolymers or Surlyn Coex. Tubing sets, antiseptic swabs, sterile solutions, surgical supplies.
PE Only	Medical Packaging	Bags	Rollstock bags, liner bags, wicketed bags. Often hand loaded or bulk bags. LDPE and LLDPE.	Bulk liner bags for sterilization, case liners, hand loaded bags for non-sterile packaging.

Material	Category	Sub Segment	Definition	Examples
Multi-Resin	Form/Fill/Seal (FFS)	Horizontal and Vertical FFS Packages	The segment includes conventional 3- and 4- side "pillow-style" sealed pouches made from multiple plastic laminated films, formed with neither side nor bottom gussets. As estimated here, the pouches are formed/filled/ sealed from rollstock in integrated operations. “Pillow pouches” in this category represent bags made from one web, formed into a tube-shape; sealed edge to edge (i.e., machine direction) to preserve the tube form; and then sealed in the cross-web direction for top and bottom seals. These packages are most often fabricated in a form-fill-seal process. “Stand-up bags,” both pre-made and vertical form/fill/seal, represent a hybrid format.	Snacks/cookies/ crackers, cereals, bread, salad mixes, confectionary, flour/sugar/dry mixes, frozen foods, coffee, pet food/treats, etc.
Multi-Resin	Pouches	Stand-up Pouches – Food	“Stand-up pouches” incorporate gussets in either the bottom, bottom and top, or sides to provide a stand-up feature. These include both premade and form/fill/seal pouches made of multiple plastic laminated films.	Snacks/cookies/ crackers, cereals, confectionary, condiments, baby food/applesauce, drink pouches, frozen foods, coffee, etc.
Multi-Resin	Pouches	Stand-up Pouches – Nonfood	“Stand-up pouches” incorporate gussets in either the bottom, bottom and top, or sides to provide a stand-up feature. These include both premade and form/fill/seal pouches made of multiple plastic laminated films.	Dry and liquid soaps, personal care, laundry/household products, cleaning chemicals, automotive fluids, etc.
Multi-Resin	Pouches	Retort stand- up Pouch	Multi-layer laminated films, formed into flat pouches typically filled on horizontal fill/seal equipment. Primarily stand-up and some lay-flat pouches filled with products for which thermal sterilization (retorting) is necessary to stop pathogen growth in vulnerable products.	MREs and MRE equivalents, tuna, chicken, stews, sauces, desserts, other low acid foods.
Multi-Resin	Pouches	Stand-up Pouch with Fitment	Multi-layer laminated films, formed into flat pouches, typically filled on horizontal fill/seal equipment. Filled with products for which a fitment provides functionality.	Baby food, applesauce, sour cream/yogurt, condiments, drinks, powders, confectionary, personal care, household products, etc.

Material	Category	Sub Segment	Definition	Examples
Multi-Resin	Food Forming Films	Bottom Forming Webs	Generally, coextruded films (PE, PP, nylon, EVOH, etc.) that provide formability, toughness, and barrier properties, sealed to a non-forming top web.	Meat and cheese bricks/foodservice/ retail, fruits/nuts, snacks, condiments.
Multi-Resin	Labels	Stretch/ Shrink Seeve Labels	These are labels requiring a compressive force or heat to affix them to their containers. The force is accomplished in one approach by stretching the circumference of the sleeve as it is placed over a container. With the force removed, the sleeve snaps back to hold snugly around the container. Alternately, heat is used to relieve residual stresses heat- set in the film after the sleeve is placed over the container.	Stretch and shrink sleeves and labels for bottles, cups, tubes, etc. – PP, PETG, OPS, PVC are typical materials.
Multi-Resin	Labels	Pressure-sensitive, Transfer, and In-mold Labels	PP, PET/PETG, OPS, PP.	Bottle, can, cup, lidding, cartons, stickers, etc.
Multi-Resin	Labels	Glued Labels	Glued labels, wrap-around label.	Bottled and canned beverage labels, wrap around (canned foods), carton/case labels.
Multi-Resin	Lidding	Cup Lidding	All plastic structures (coex and/or laminations, plus coatings) layer capable of sealing to a plastic, metal, or glass container.	Apple sauce and fruit cups, yogurt cups, chip dip, cottage cheese.
Multi-Resin	Wraps	Industrial wraps	Peelable release films, house and construction material wraps, industrial wraps.	Industrial wraps, cling films, protective wrap – PVC, PE, CPP.
Multi-Resin	Medical Packaging	Rollstock and forming films	PE, Nylon, and PP resins, either coex or laminates that need to be highly puncture resistant and strong.	Forming films, Pouch films.
Multi-Resin	Medical Packaging	Medical bags	High performance PE resins that need high puncture and tensile properties.	Biohazard, general hospital waste, box liners, sterilization liners.
Multi-Material	Bags	Multiwall Bags	Paper/poly/paper, paper/poly/foil/poly, Film/poly/paper/poly, film/poly/foil/poly, etc.	Pet food bag, cement, ag chemicals, resins, dry ingredients.

Material	Category	Sub Segment	Definition	Examples
Multi-Material	Form/Fill/Seal (FFS)	Horizontal and Vertical FFS Packages	The segment includes conventional 3- and 4- side "pillow-style" sealed pouches made from a combination of plastic, foil, and paper laminated films, formed with neither side nor bottom gussets. As estimated here, the pouches are formed/filled/sealed from rollstock in integrated operations. “Pillow pouches” in this category represent bags made from one web, formed into a tube-shape; sealed edge to edge (i.e., machine direction) to preserve the tube form; and then sealed in the cross-web direction for top and bottom seals. These packages are most often fabricated in a form/fill/seal process.	Snacks/cookies/crackers, cereals, bread, confectionary, flour/sugar/dry mixes, frozen foods, coffee, pet food/treats, gum, mac and cheese mix, etc.
Multi-Material	Pouches	Stand-up Pouches – Food	“Stand-up pouches” incorporate gussets in either the bottom, bottom and top, or sides to provide a stand-up feature. These include both premade and form/fill/seal pouches made of a combination of plastic, foil, and paper laminated structures.	Snacks/cookies/crackers, cereals, confectionary, condiments, baby food/applesauce, drink pouches, frozen foods, coffee, etc.
Multi-Material	Pouches	Stand-up Pouches – Nonfood	“Stand-up pouches” incorporate gussets in either the bottom, bottom and top, or sides to provide a stand-up feature. These include both premade and form/fill/seal pouches made of a combination of plastic, foil, and paper laminated structures.	Dry and liquid soaps, personal care, laundry/household products, cleaning chemicals, automotive fluids, etc.
Multi-Material	Pouches	Retort stand-up Pouch	Multi-layer plastic film, foil, and/or paper laminated structures, formed into flat pouches typically filled on horizontal fill/seal equipment. Primarily stand-up and some lay-flat pouches filled with products for which thermal sterilization (retorting) is necessary to stop pathogen growth in vulnerable products.	MREs and MRE equivalents, tuna, chicken, stews, sauces, desserts, other low acid foods.
Multi-Material	Labels	Pressure-sensitive and Transfer Labels	Generally, web-fed labels not requiring secondary gluing operation. Packaging-related uses only.	Bottle, can, cup, lidding, cartons, stickers, etc.
Multi-Material	Labels	Glued Labels	Glued labels, wrap around labels. Packaging-related uses only.	Bottled and canned beverage labels, wrap around (canned foods), carton/case labels.

Material	Category	Sub Segment	Definition	Examples
Multi-Material	Lidding	Cup Lidding	Multi-layer structures made from plastic, paper, and foil, some with heat sealable coatings – capable of sealing to a plastic, metal, or glass container.	Apple sauce cups, yogurt cups, chip dip, cottage cheese.
Multi-Material	Wraps	Industrial Wraps	House and commercial construction material wraps, industrial wraps.	Industrial wraps, protective wraps - paper and foil laminations, Tyvek®.
Multi-Material	Medical Packaging	Medical Pouches	Typically, this is a flat "bag" with a Tyvek® side and a film side. Almost all are peelable so that they can be opened for sterile presentation in a medical setting.	Syringes, fitments, tubing sets, blood management, sutures, gauze medical instruments.
Multi-Material	Medical Packaging	Bottom Forming Webs	These films are heated and formed to create a pocket that is loaded with anything from syringes, medical fitments, or sterile solutions up to full medical kits used in surgery.	Medical instruments, syringes, gowns, surgical tools, sutures, full medical procedure kits.
Multi-Material	Medical Packaging	Laminated Films	Laminated products for high barrier applications. These include PP, foil, PET, LLDPE, and various combinations of these.	Pills, tablets, medications and other pharma products requiring barrier properties.

Source: Flexible Packaging Association. "Flexible Packaging U.S. Market Profile & Segmentation Report" PTIS, LLC., August 2021.

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