Feedstock Quality Guidelines for Pyrolysis of Plastic Waste

Report for the Alliance to End Plastic Waste

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Contents

Report for

ALLIANCE TO END PLASTIC WASTE

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About the Alliance to End Plastic Waste
The Alliance to End Plastic Waste (Alliance) is a global non-profit organisation with the mission to end plastic waste in the environment. Its focus is implementing projects and investing in innovative solutions to develop or enhance waste management systems. As of June 2022, its portfolio comprises over 50 projects across 30 countries worldwide.

Tackling plastic waste is a complex challenge that requires collective action. Since 2019, the Alliance has convened a global network of industry leaders across the plastics value chain, together with government, civil society, entrepreneurs, and communities to work towards advancing a circular economy for plastic waste.
For more information, visit: **www.endplasticwaste.org**

Executive Summary

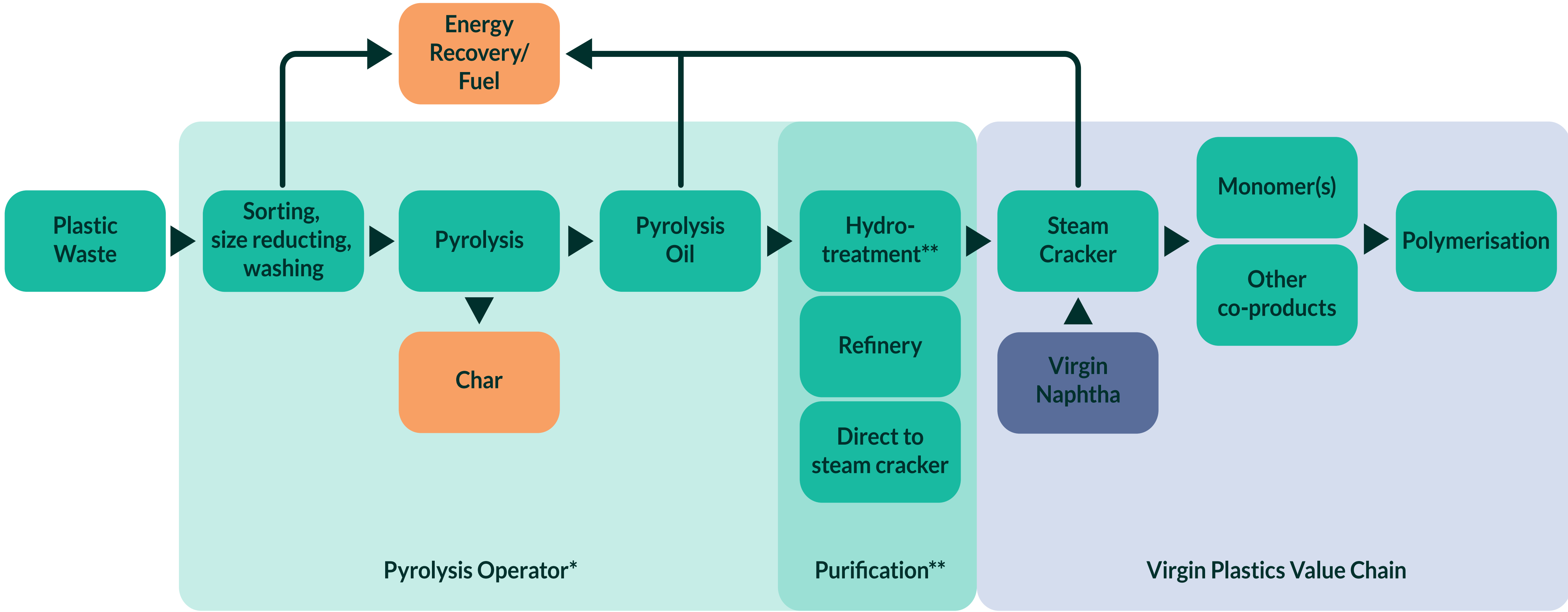
Introduction

Stakeholder groups ranging from packaging manufacturers to government agencies are interested in the potential of advanced recycling to add new dimensions to plastic waste recycling, particularly with expectations that the technologies will complement mechanical recycling by:

- providing a recycling solution for plastics that are currently challenging to recycle with mechanical recycling technologies,
- generating streams or products that can be used to produce recycled plastics with virgin-like properties, particularly regarding aesthetic properties, food safety or human contact considerations.

The study focuses on feedstock considerations for pyrolysis. Pyrolysis is classed as thermal depolymerisation technology that creates new feedstocks for use as building blocks for new plastics or fuels. The model specification has been produced based on discussions with pyrolysis operators in Europe and the US. Figure 1 shows a generalized depiction of the placement of pyrolysis within its value chain, showing the full system that must align in order for pyrolysis to contribute to plastics-to-plastics recycling at scale.

Figure 1: Pyrolysis within the Advanced Recycling Value Chain



In defining a model feedstock specification, this study aims to understand and communicate the feedstock quality requirement. While this study does not aim to prescriptively define the feedstock that must be supplied to all pyrolysis operators, the model feedstock specification should serve as a starting point for an inclusive conversation on the types of systems that need to be developed to supply pyrolysis operators and the nuances surrounding pyrolysis operators' feedstock considerations.

Deepening the understanding of feedstock requirements for pyrolysis can also assist in progressing the understanding of advanced recycling's role alongside mechanical recycling.

In addition to providing a model pyrolysis specification, this report also highlights some of the potential feedstock limitations of pyrolysis, which can help inform the packaging design decisions and circular economy strategies of brand owners and their supply chain partners.

* The pyrolysis operator may have front end sorting or contract this out. It may also include an in-house purification step or sell directly to a third party.

** There are several possible ways to purify including hydrotreatment or feeding into a refinery. This step is often optional as the low volumes can be diluted straight into the cracker as these two technologies have yet to be refined.

> "This study aims to serve as a starting point for an inclusive conversation on the types of systems that need to be developed."

Feedstock Requirements

Pyrolysis

Pyrolysis is the process of breaking down plastic waste at high temperatures with minimal oxygen to produce pyrolysis oil, which can be used in the production of new plastics as a replacement for fossil feedstocks. To create quality outputs that are suitable for direct integration into the plastics production value chain, pyrolysis operators require well-sorted, clean, and largely homogenous feedstock – in the vicinity of 85% polyethylene (PE) and polypropylene (PP) – and suffer from contamination similarly to mechanical recyclers. The proposed model feedstock specification is intended to serve as a baseline characterisation. Operators may have tolerances that fall outside of thresholds provided, in terms of overall level of contamination as well as specific contaminants. These thresholds vary due to individual operators' specific practices in pre-sorting and posttreatment, the specifications of their offtaker, differing pyrolysis technologies, and/or the pyrolysis operator's overall value equation. This is similar to the established landscape of feedstock specifications for mechanical recyclers where each recycler has its own process considerations and overarching value equation that forms its particular needs and tolerances for feedstock materials. It should also be noted that many pyrolysis operators are in the early stages of refining and optimizing their processes, and their feedstock requirements are likely to evolve over time.

Model Feedstock Specification for Pyrolysis

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

Minimum **85% polyethylene or polypropylene**

Maximum moisture content: 7%

Maximum total contamination: 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%:

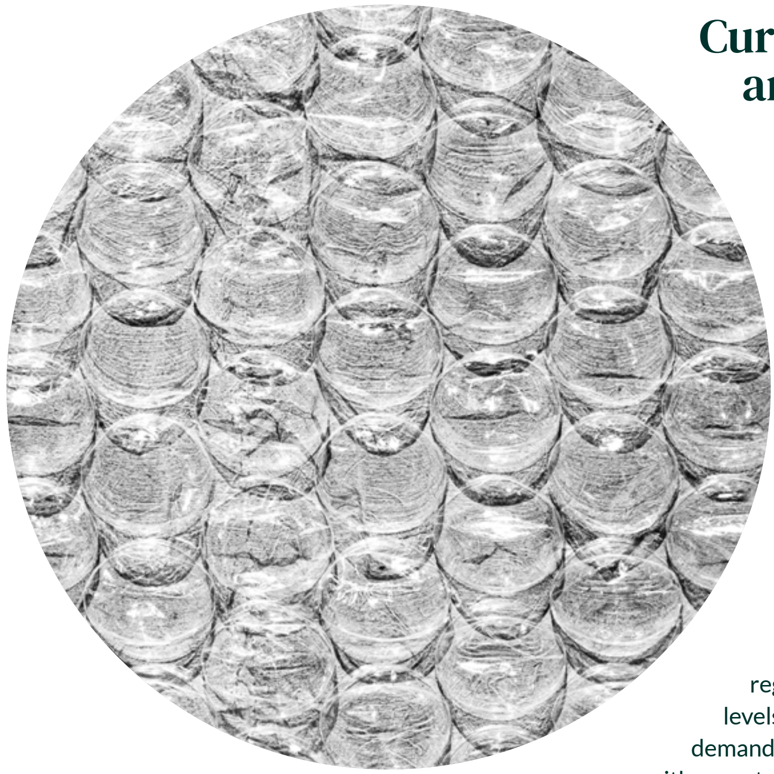
PVC/PVDC: 1%

PET/EVOH/Nylon: 5%

PS: 7%

Rigid metal/glass/dirt/fines: 7%

Paper/organics: 10%



Current Market – Opportunities and Challenges

There is robust demand by mechanical recyclers for rigid PE and PP, but challenges for mechanical recycling remain due to the presence of non-targeted polymer grades, colours, odours, and the use of varying additives. **Most sorted rigid PE and PP streams will find a reasonable uptake by the mechanical recycling industry, with the remainder providing a possible feedstock opportunity for pyrolysis operators.**

Flexible PE and PP plastic packaging, in particular from household waste, does not have the same uptake from mechanical recyclers. The majority of mechanical recyclers target PE film from post-commercial and post-industrial sources, as this tends to be clean, homogenous and in large formats. Acceptance levels of post-consumer PE film from households vary depending on country and region but are generally markedly lower than acceptance levels of other sources of PE. PP film does not have significant demand from mechanical recyclers regardless of its origination in either post-consumer or post-industrial sources. Although pyrolysis operators generally accept both rigid and flexible PE and PP formats, **many pyrolysis operators are currently targeting flexible PE and PP over rigids, which may provide an opportunity for pyrolysis to complement mechanical recycling in demand for feedstock.**

> **"Changes to collection and sortation systems will generally be required to address film collection which is anticipated to be a main feedstock for pyrolysis operators.**

Multi-material films consist of a variety of different polymers and other materials, laminated or extruded together to form a single packaging unit. Common materials used for layers alongside PE or PP include PET (as a barrier against moisture and chemicals), aluminium (as a barrier also against light and UV), EVOH (as an oxygen barrier) and nylon (polyamide, for strength and barrier properties). A composition analysis of waste multi-material film in Belgium shows that the ratio of PE and PP to other materials found in this waste stream would not meet the feedstock requirements for the range of pyrolysis technologies investigated in this study, so while there is broad interest in the potential for pyrolysis to provide a recycling outlet for multi-material films, it would likely need to be mixed with other PO rich streams to be recycled via pyrolysis. However, actions are being taken to simplifying multi-material film structures to eliminate or reduce many of the non-PE and non-PP materials, and this trend should improve the prospects of multi-material films as a feedstock for pyrolysis.

Regardless of the film composition, there is an overarching challenge surrounding the collection of post-consumer films with historical sortation technology. Films of any material type have tended to be problematic in material recovery facilities (MRFs), where they can wrap around sorting equipment and cause costly disruptions, so they are often prohibited from the commingled collection systems that provide the vast majority of the post-consumer material supply to recyclers. Dedicated drop-off receptacles can be an alternative collection system, but consumer participation in these collection programmes is generally low and the established programmes are designed only to collect PE films for mechanical recycling outlets.

Market Outlook

The future of the market is shaped by changes in policy, demand and design.

Policy can drive up recycling targets leading to increased collection and investment throughout the recycling value chain. Mandated recycling targets for plastics, specifically for flexibles, along with extended producer responsibility (EPR) schemes may be important influencers to support the viability of advanced recycling. These policy frameworks can drive and finance the collection and sorting of plastics that are currently not recycled at scale due to a history of unfavourable free market economics in mechanical recycling systems.

Changes in the design of packaging are being pursued by brand owners and their packaging suppliers. A move towards mono-material packaging could see a greater percentage of flexible packaging become compatible with technologies like pyrolysis, however not all packaging can be designed as mono-material as some products require the barrier properties associated with multi-material packaging applications. It is also possible that pyrolysis technology will evolve to be able to process more laminate films.

The key advantage that pyrolysis has over mechanical recycling from a feedstock perspective is that pyrolysis feedstock can contain both PE and PP at varying levels, and pyrolysis can readily accept films.

Both mechanical and advanced recyclers require consistent streams of feedstock with minimal contamination and while advanced recycling should be viewed as a recycling outlet for a different range of materials, it should not be viewed as a recycling outlet for contaminated materials or unsorted materials.

Conclusions

The key advantage that pyrolysis has over mechanical recycling from a feedstock perspective is that pyrolysis feedstock can contain both PE and PP at varying levels, and pyrolysis can readily accept films.

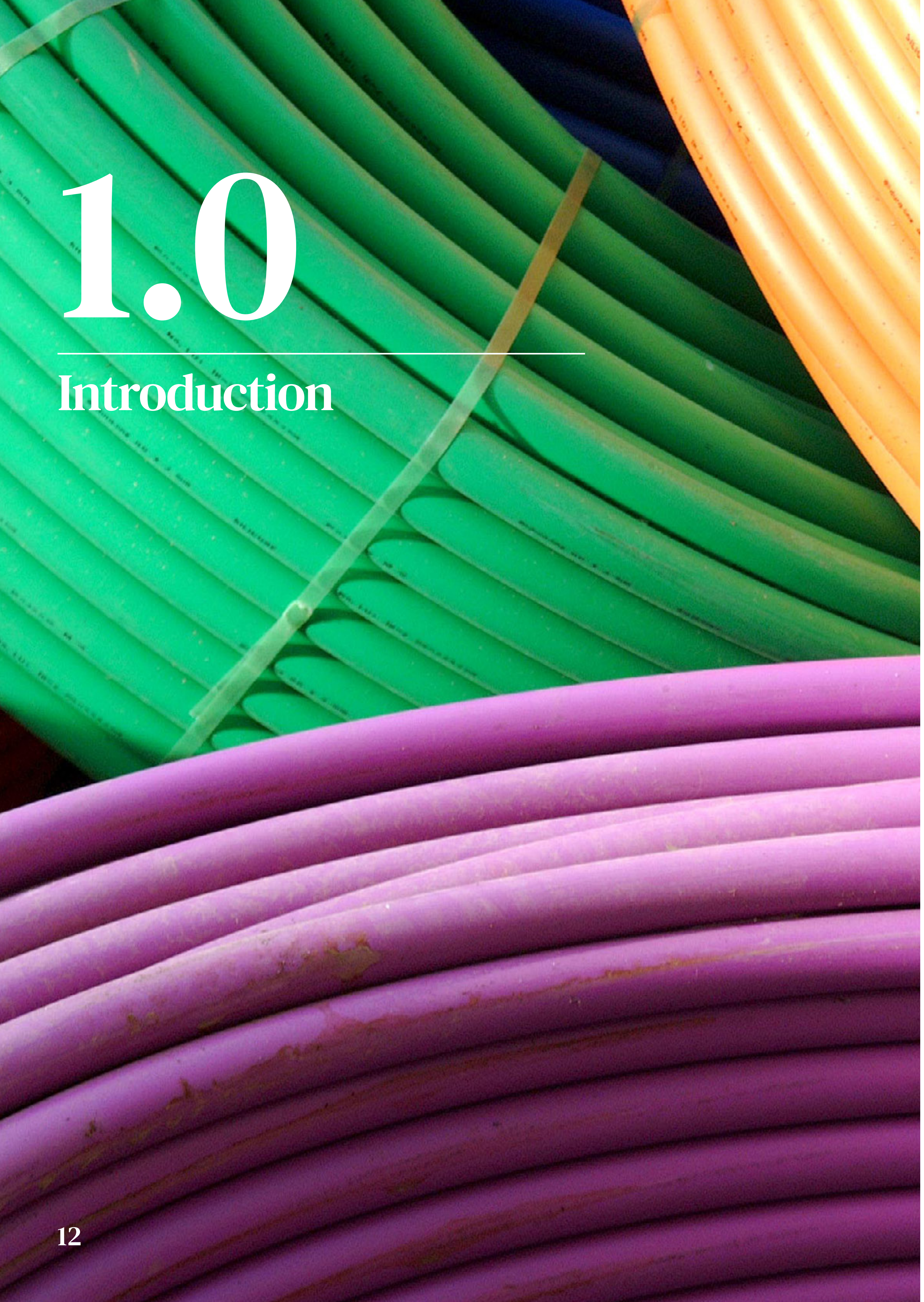
While a broad spectrum of multi-material films cannot be accepted as pyrolysis feedstock in high concentrations, certain types of multi-material films such as those that are mixtures of PE and PP can be accepted and it is possible to combine multi-material feedstocks with mono-materials to meet feedstock specifications.

Both mechanical and advanced recyclers require consistent streams of feedstock with minimal contamination and while advanced recycling should be viewed as a recycling outlet for a different range of materials, it should not be viewed as a recycling outlet for contaminated materials or unsorted materials.

Like any feedstock specification, the specification set out in this study provides guidance as to what can typically be accepted by a pyrolysis operator. What individual operators purchase and the arrangement that they may have with suppliers will be depend on many factors including pre-sorting and post-processing steps, feedstock cost, offtaker specifications and revenue streams. This study provides an indicative pyrolysis feedstock specification based on responses from current operators.

Glossary

Advanced Recycling	Any reprocessing technology using chemical agents or processes that directly affect either the formulation of the plastic or the polymer itself
EVOH	Ethylene vinyl alcohol
Gasification	A type of thermal depolymerisation that uses low volumes of oxygen to aid the degradation process
Heteroatom	Atoms of any element besides carbon or hydrogen
Mono-material	Packaging material, such as film, made from one polymer
MRF	Material recovery facility
Multi-material	Packaging material, such as film, made with a variety of materials (e.g., polymers and/or metals) either laminated or extruded together
Offtaker	The organisation which purchases the end-product from advanced recycling
PA	Polyamide (nylon)
PE	Polyethylene
PET	Polyethylene terephthalate
Polyolefin	A family of polyethylene and polypropylene thermoplastics
Post-commercial	Material, at the end of its life, generated by commercial facilities in their role as end-users of the product
Post-consumer	Includes post-consumer from households and post-commercial materials
Post-industrial	Material, at the end of its life, generated by industrial facilities in their role as end-users of the product
Post-consumer from households	Material, at the end of its life, generated by households in their role as end-users of the product
PP	Polypropylene
PRF	Plastic recovery facility
PS	Polystyrene
PVC	Polyvinyl chloride
PVDC	Polyvinylidene chloride
Pyrolysis	A type of thermal depolymerisation that high temperatures in the absence of oxygen to aid the degradation process
Sorting systems	Describes the whole of currently used sorting technologies and processes
Thermal Depolymerisation	Also known as thermal cracking and thermolysis, is the process by which a polymer is broken down into smaller molecules using heat treatment



1.0 Introduction

Advanced recycling, also referred to as chemical recycling or molecular recycling, is the broad term for a suite of technologies that convert the chemical structure of the polymer into chemical building blocks including monomers that can then be used again as a raw material in chemical processes[1].

Stakeholder groups ranging from packaging manufacturers to government agencies are interested in the potential of advanced recycling to add new dimensions to plastic waste recycling, particularly with expectations that the technologies will complement mechanical recycling by:

- providing a recycling solution for plastics that are currently challenging to recycle with mechanical recycling technologies,
- generating streams or products that can be used to produce recycled plastics with virgin-like properties, particularly regarding aesthetic properties, food safety or human contact considerations.

There is the potential for pyrolysis to deliver these expected benefits and contribute to the circularity of plastics. To enable this to happen the feedstock requirements and the factors influencing those requirements must be understood.

Study Aims

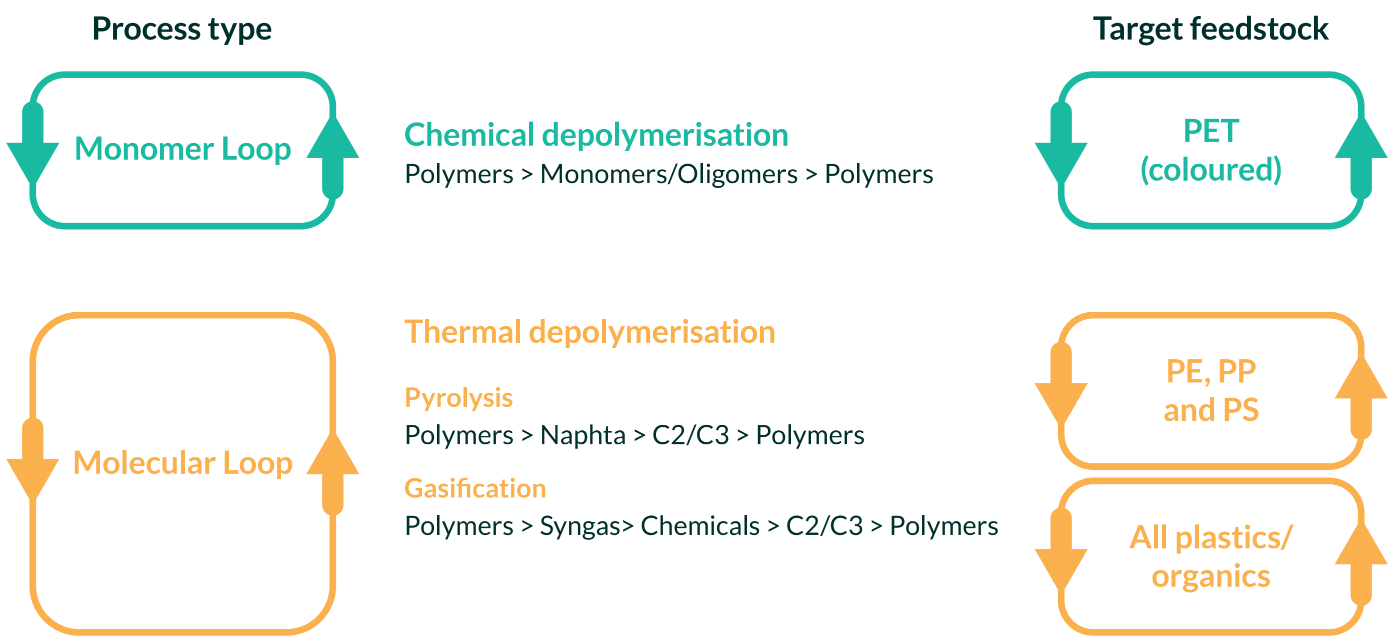
The purpose of this study is to help to provide clarity around the input feedstock requirements for pyrolysis and to propose a model feedstock specification that can be used as a starting point for discussions between pyrolysis operators and material suppliers. Model feedstock specifications for secondary materials (e.g., EN 643 for wastepaper grades) have been shown to facilitate both the supply of material of a quality appropriate for reprocessing and the demand for that material from new facilities. Many feedstock specifications for mechanical plastic recycling have been developed, and these specifications have proven instrumental in harmonizing plastic waste collection and sorting practices to feed mechanical recyclers at scale. However, the existing feedstock specifications are insufficient for pyrolysis.

Improving the understanding of feedstock requirements for pyrolysis should also assist in progressing our understanding of pyrolysis's role alongside mechanical recycling. By identifying the feedstock characteristics for pyrolysis, the differences between the value propositions for mechanical recycling and pyrolysis can be better understood.

Equally, it is also important to understand some of the potential limitations of pyrolysis that can help brand owners and their supply chain partners focus on solutions that are more technically attuned to these.

"Improving the understanding of feedstock requirements for pyrolysis should also assist in progressing our understanding of pyrolysis's role alongside mechanical recycling."

Figure 1.1: Chemical Recycling Processes



Study Scope

Advanced recycling technologies cover a broad range of technologies that fall under chemical or thermal depolymerisation process types (Figure 1.1), with additional categories in each sub-family of technologies.

This study intended to focus on developing a model feedstock specification for pyrolysis and gasification technologies with a specific emphasis on operators and marketing in Europe, Canada and the United States (US).

Study Focus

Despite reaching out to multiple gasification technology suppliers and operators, insufficient data was made available to the technical team to enable the development of a credible specification for gasification. As such this report focuses on a model specification for pyrolysis only. In addition, it needs to be noted that data availability and quality was greater from operators in the European market than in North America.

Study Approach

This model feedstock specification for pyrolysis was developed using information shared by several operators regarding their feedstock requirements via a questionnaire and a series of interviews (see Appendix A.1.0 for full details on the methodology used). Information provided by operators was contextualised according to considerations such as the extent of pre-sorting and post-treatment operations.

The information provided by pyrolysis operators is mostly grounded in the context of actual marketplace transactions that have been and are occurring, and therefore their thresholds, which are incorporated into this model feedstock specification, are based on a pragmatic balance of operational requirements and market availability. It needs to be noted that the input feedstock may require additional pre-processing (e.g., sorting) or post-processing (e.g., purification) steps which in return influences the cost effectiveness of the process.

It is important to note that many pyrolysis operators are in early stages of maturation, and feedstock specification may evolve as processes improve and scale.

Report Content

Section 2.0 of this report discusses the feedstock requirements and explains the key challenges of particular contaminants within the process. Section 3.0 provides an overview of the current recycling market for polyolefins and identifies opportunities in line with the feedstock requirements of pyrolysis operators.

Section 4.0 provides the key conclusions that can be drawn from this study as well as recommendations on the next steps that need to be taken to ensure that the model specification can remain relevant in an evolving market. The Appendix includes the study methodology, details on study participation, sample specifications currently found in Europe and North America, as well as an overview of the waste management landscapes in each region.

2.0

Pyrolysis Feedstock Specification

- Many pyrolysis operators are in early stages of maturation and their feedstock considerations are likely to evolve
- Pyrolysis recycling operators require well-sorted, clean and largely homogenous PP and PE missed feedstock
- Contaminants impact product yield, quality and facility operating efficiencies and costs

Pyrolysis is the process of breaking down plastic waste at high temperatures with minimal oxygen[2] to produce gas, char and pyrolysis oil.[3] Depending on the composition, pyrolysis oil can be used in the production of new plastics replacing fossil feedstocks. Pyrolysis is a relatively simple and flexible technology that typically targets difficult-to-recycle polyolefins which can include multi-material packaging. While it can target heterogenous polyolefins, other materials are generally viewed as contaminants that cause undesirable effects including lowered process yield, reduced output quality, and wear on equipment, which all add cost burdens. Recognizing that supplies of pure, uncontaminated waste polyolefin feedstocks are difficult to obtain, operators are accustomed to accepting certain levels of contamination. Tolerances for contaminants vary according to:

- the type of contaminant;
- the operator's specific process operating parameters;
- output purification processes; and
- the quality requirements of the offtaker.

In addition to having contaminate tolerances, there is often a requirement to upgrade the pyrolysis oil quality before it can be used in new plastic production.[4] The study did not consider refinement processes.

Like other recycling processes, pyrolysis serves to connect the circular economy value chain by linking waste management operations with new manufacturing operations. Directly upstream from pyrolysis are waste collection, aggregation, and sorting operations, which create streams of feedstocks that pyrolysis operators can utilise. Directly downstream from pyrolysis are offtakers who produce new plastics or specialty chemicals or use pyrolysis outputs as fuel. This value chain is shown in Figure 2.1, though the boundaries delineating pyrolysis operations from upstream and downstream stakeholders can vary. Preparation of waste as pyrolysis feedstock occurs predominantly within upstream stages, such as sorting operations at material recovery facilities (MRFs) or plastic recovery facilities (PRFs), but some preparation can occur at the pyrolysis operator. The extent to which each party engages in feedstock preparation varies from value chain to value chain. There is similar variability surrounding the extent to which post-treatment of pyrolysis outputs occurs between pyrolysis operators and offtakers. This flexibility between the roles of pyrolysis operators and their adjacent partners is similar to the flexibility in more established mechanical recycling value chains and should be expected to remain when pyrolysis matures and scales. This underscores the need for a specification for pyrolysis feedstock that can serve as a standard reference point for supply transactions, while allowing flexibility to suit specific pyrolysis operators' needs.

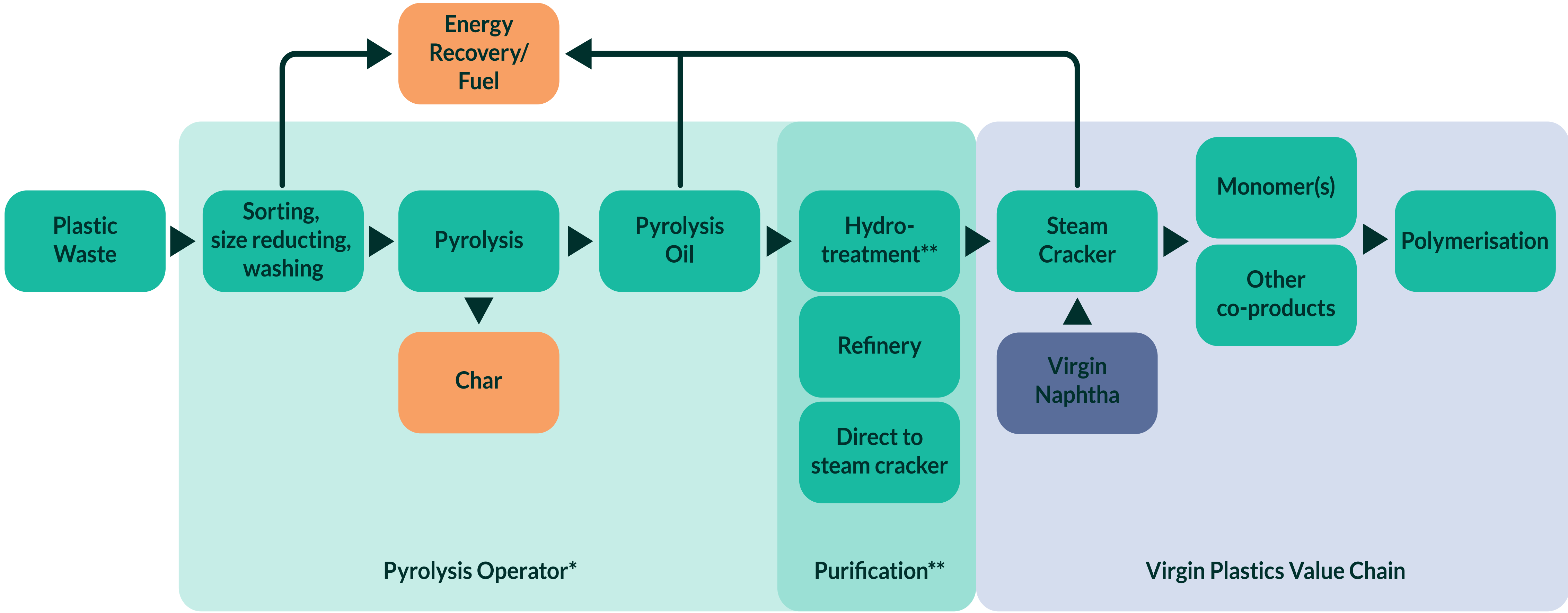
Advantages of pyrolysis include that it is a relatively simple and flexible technology and that it typically targets difficult-to-recycle and highly heterogenous plastic waste, such as mixed polyolefin plastic waste or multi-material packaging. Its disadvantages are its sensitivity to contamination in feedstock and the common requirement to upgrade pyrolysis oil quality before it can be used in new plastic production.

This model feedstock specification was developed using information shared by several pyrolysis operators regarding their feedstock requirements via a questionnaire and a series of interviews (see Appendix A.1.0 for full details on the methodology used). Information provided by operators was contextualised according to considerations including the extent of pre-sorting and post-treatment operations.

The information provided by pyrolysis operators is mostly grounded in the context of actual marketplace transactions that have been and are occurring, and therefore their thresholds, which are incorporated into this model feedstock specification, are based on a pragmatic balance of operational requirements and market availability. It needs to be noted that the input feedstock may require additional pre-processing (e.g., sorting) or post-processing (e.g., purification) steps which in return influences the cost effectiveness of the process.

Lastly, it is important to note that many pyrolysis operators are in early stages of maturation, and their feedstock considerations are likely to evolve. As operations scale, it is reasonable to assume that pyrolysis operators will adjust their operational parameters, value equations, and pre-sorting and/or post-treatment capabilities, and they may also receive adjusted specifications from their offtake partners. It is therefore recommended that feedstock providers openly engage with chemical recycling operators to define specific feedstock requirements and allowed tolerances that meet specific operators' needs.

Figure 2.1: Pyrolysis within the Advanced Recycling Value Chain



* The pyrolysis operator may have front end sorting or contract this out. It may also include an in-house purification step or sell directly to a third party.

** There are several possible ways to purify including hydrotreatment or feeding into a refinery. This step is often optional as the low volumes can be diluted straight into the cracker as these two technologies have yet to be refined.

2.1 PE and PP Content

Identified model minimum threshold: 85%

Polyethylene (PE) and polypropylene (PP) are the principal desired feedstock of pyrolysis operators, and the proposed model feedstock specification reflects the optimum level of PE and PP believed to be attainable in practice. Items made of pure PE or PP are generally accepted with little to no restrictions on their characteristics, and pyrolysis operators did not express any meaningful distinction between PE and PP. Attitudes on preferences between rigid or flexible packaging formats as feedstock vary between process operators with the majority taking an agnostic approach. High potential was seen in the flexible film segment due to the challenges it currently poses for mechanical recycling, which is further discussed in Section 3.0.

Lower portions of combined PE and PP content in feedstock generally mean higher presence of heteroatoms[5] such as oxygen and nitrogen, which are problematic for many pyrolysis operators. A high heteroatom content might lead to lower yield and/or the need for post-process hydrotreating to meet the offtake specifications which has economic implications on the process.

2.2 PVC / PVDC Content

Identified model contamination limit: 1%

Polyvinyl chloride (PVC) and polyvinylidene chloride (PVDC) films introduce chlorine atoms into the pyrolysis process, which can cause corrosion to equipment and persist into the finished hydrocarbon product as heteroatoms. Pyrolysis operators have limited cost-effective means of removing PVC/PVDC or circumventing the challenges it poses. It is plausible that pyrolysis operators could conduct a pre-sort by employing optical sorters tuned to PVC/PVDC, but in practice, none indicated that they are doing or plan to do so. Many operators employ some form of hand-sorting to remove contaminants that are obvious to visually identify, but PVC/PVDC film tends to be challenging for manual sorters due to its similarities to polyolefin films. Some pyrolysis operators indicated that their feedstock suppliers actively sort out PVC/PVDC before transactions. However, PVC/PVDC can be expected to be a very small portion of most post-consumer recycling streams and it is expected that this is unlikely to change in the future.

Since the primary concern from pyrolysis operators is the presence of chlorine, it is recommended that PVC and PVDC be considered collectively. The threshold of 1% for the combined presence of these materials is intentionally strict, as pyrolysis operators indicated that chlorine is one of the most problematic contaminants. In practice, pyrolysis operators' specific thresholds for PVC/PVDC will vary. Several operators expressed a near-zero tolerance for PVC/PVDC, while others indicated a threshold that was meaningfully higher than 1%.

2.3 PET/EVOH/Nylon Content

Identified model contamination limit: 5%

Polyethylene terephthalate (PET), ethylene vinyl alcohol (EVOH), and nylon represent a family of contaminants that are problematic because they contain molecules that include oxygen and more complex hydrogen-carbon structures. The presence of oxygen atoms in the feedstock results in oxygenated products, which reduces yield and negatively impact the quality of pyrolysis oil. Some more complex hydrogen-carbon structures, such as nylon and PET do not break down as easily as those of PE and PP, and some by-products of their decomposition will act as impurities in the finished product.

Offtakers can accommodate these impurities by diluting the product with larger volumes of virgin hydrocarbons, using the product for lower-grade applications such as fuel, or conducting hydrotreatment, in which hydrogen atoms are reacted with the product to chemically combine with impurities, facilitating their removal. Hydrotreatment can also be done by the pyrolysis operator prior to the offtaker, but this is rare and generally viewed by pyrolysis operators as being cost-prohibitive.

Within this family of contaminants, operators indicated more specific, tighter limits on EVOH and nylon. Operators did not provide specific information regarding related polymers such as ethylene-vinyl acetate (EVA), ethylene-methyl acrylate (EVM), ethylene-acrylic acid (EAA), or polyurethane (PU), but it is expected that these polymers will cause similar challenges due to their chemistries including nitrogen and/or oxygen. It is important to note, however, that these polymers are not expected to be present in significant amounts within the waste streams targeted by pyrolysis operators. Individual tolerances for PET are markedly higher, however it can also be expected that PET will occur in relatively greater amounts than EVOH or nylon.

2.4 Polystyrene Content

Identified model contamination limit: 7%

Considerations surrounding polystyrene (PS) vary between pyrolysis operators. Polystyrene is generally not viewed as a prohibitive contaminant, and one operator even expressed a preference for using measured amounts of polystyrene as a process aid. Nonetheless, it is common for pyrolysis operators to set limits on the amount of polystyrene in their feedstock.

Individual operator tolerances for PS may vary significantly, perhaps more than any other contaminant. Some operators expressed very loose thresholds for maximum PS content, while others indicated tighter thresholds that still may be within the expected range for PS occurrence in mixed plastic feedstock streams.

2.5 Metal/Glass/Dirt/Fines Content

Identified model contamination limit: 7%

This family of contaminants is problematic because these materials tend to be abrasive and can significantly damage equipment, and because they represent a significant cost burden to pyrolysis operators as they are relatively heavy, which increases costs as input feedstock is typically purchased on a per-unit-weight basis. Pyrolysis operators are generally able to remove these materials either in pre-sort operations or during reactor maintenance and cleaning operations, but both represent additional cost burdens. These materials are generally nonreactive in pyrolysis operations and therefore do not present challenges to the chemistry of the product.

Aluminium is often used in multi-material packaging such as snack bags or candy wrappers, albeit in small quantities. Pyrolysis operators did not express any concern of receiving these packaging formats as such; however, the overall limits specified above should not be exceeded.

Individual operators' tolerances for these materials can be expected to vary. Some operators indicated a preferred tolerance of 1% or less for each of the sub-categories of metals, glass, and dirt/fines, while others indicated much more forgiving thresholds. This may stem from the range of pre-sorting technologies in use, and it is possible that tolerance thresholds will unify as operations mature, and the use of pre-sorting technology becomes more robust and consistent.

2.6 Paper/Organics Content

Identified model contamination limit: 10%

Similar to non-polyolefin plastics, paper and other organic materials containing oxygen and more complex molecule structures which may reduce the quality of the end product. Hydrotreatment can be employed to remove the impurities introduced by these materials, but as discussed above it is a costly process step.

Operators indicated a fairly broad range of thresholds for these materials, with some operators expressing a relatively relaxed limit. As with other families of contaminants, these thresholds may be correlated with pre-sorting technologies.

2.7 Other Feedstock Considerations

Size and moisture are other considerations for pyrolysis operators.

Most pyrolysis operators did not express a minimum size or density requirement for incoming feedstock. They recognize that while they could require suppliers to meet size requirements, most shred the incoming material to a uniform size to ensure improved performance during the reprocessing.

Moisture is another concern. Regardless of whether moisture is present as a residual liquid or entrained in paper or organic materials it can be removed by employing a pre-process drying step. Some pyrolysis operators employ this step, but this was not common among the interviewed operators and may pose an additional investment burden. For this reason, the model specification has a moisture limit.

2.8 Model Pyrolysis Feedstock Specification

The below model specification is intended to be applicable to feedstock as it is received by a pyrolysis operator. All percentages are given on an "as received" weight basis.

The proposed model feedstock specification is intended to inform typical feedstock requirements. It is expected that some operators will have tolerances that are significantly greater or smaller than the thresholds expressed in the model feedstock specification, both in terms of overall level of contamination and specific contaminants. This is similar to the established landscape of feedstock specifications for mechanical recyclers where each recycler has its own process considerations and overarching value equation that forms its particular needs and tolerances for feedstock materials. It should also be noted that many pyrolysis operators are in early stages of refining and optimizing their processes, and their feedstock requirements are likely to evolve over time.

The feedstock requirements of individual pyrolysis operators will vary from this model feedstock specification, with some pyrolysis operators having stricter requirements tolerances than others, for both the percentage polyolefin as well as for different contaminants. While precise ranges cannot be specified due to confidentially, pyrolysis operators generally expressed the most similar tolerance thresholds for PVC and PVDC and the most variable tolerance thresholds for PET, EVOH, and nylon.

Factors that may differ a pyrolysis operator's feedstock specification and how prescriptive the tolerance levels may be are summarized in Figure 2.2.

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 85% PE or PP

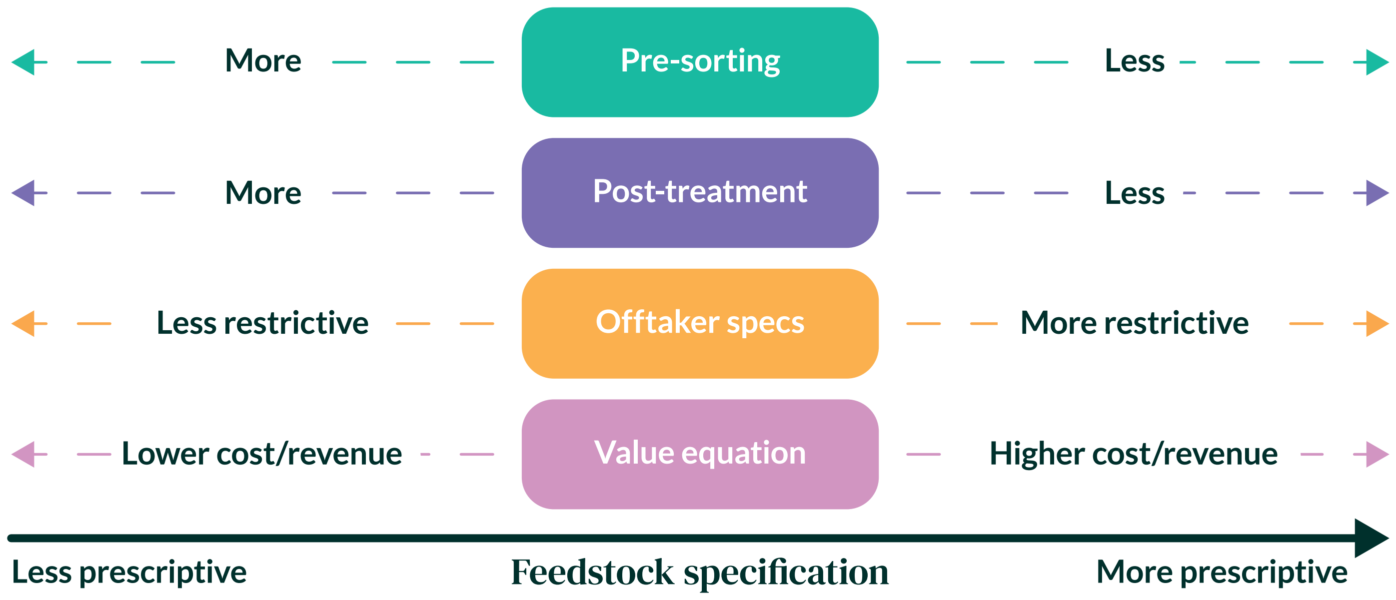
Maximum moisture content: 7%

Maximum total contamination: 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: 1%
PET/EVOH/Nylon: 5%
PS: 7%
Rigid metal/glass/dirt/fines: 7%
Paper/organics: 10%

Figure 2.2: Drivers that Determine the Feedstock Specification



3.0

Current Market: Opportunities and Challenges

- Existing plastic waste sorting systems have been developed to supply the requirements of mechanical recyclers
- One primary difference between mechanical recycling and advanced recycling technologies, such as pyrolysis, is the ability to accept mixed material feedstocks i.e., both PE and PP
- A multi-material film feedstock stream will have to demonstrate that the contents consist of at least 85% PP/PE
- The pyrolysis specification presented does provide additionality and complement existing specifications developed for mechanical recyclers
- The average composition of a mixed multi-material bale from an assessment in Europe would not satisfy the requirements of the pyrolysis specification without additional pre-sortation or mixing with other rich PO feedstock streams

3.1 The Mechanical Recycling Market

Existing waste plastic sorting systems have been developed to suit the requirements of mechanical recyclers, and it is important to understand how the introduction of a feedstock specification for advanced recyclers may interact with the existing system.

Rigid polyolefins have a wide acceptance in post-consumer collection programmes from households and have a valuable offtake market by mechanical recyclers. Flexible film plastic packaging, in particular from household waste, is not generally collected because difficulties existing mechanical recycling systems have with this feedstock and therefore typically utilise PE film from post-commercial and post-industrial sources.

Accessing supply is likely to be a challenge for pyrolysis operators as collection systems are not in place. If there is a push for films to be collected in mixed recycling collections such as in France, it is likely that there will be feedstock available for pyrolysis operators as limited amounts of this material will be targeted by mechanical recyclers for application in lower grade applications such as trash bags. Films collected within mixed recycling will require additional sorting to meet the specification set out in this report.

3.1.1 Available Feedstock in Europe

Total flexible film consumption in Europe, across all polymers, is estimated by market experts to be in the region of 13-15 Mt (metric) per year, with quantities of PE consumption estimated by at about. 8.5 Mt (metric) per year with the remainder evenly split between PP and multi-material flexible packaging, respectively.[6] These film types have grown significantly and are expected to continue growing.

The lack of demand from mechanical recyclers for film and flexibles is also reflected in the low collection quantities in Europe. It is estimated that only one third of the flexible packaging material available for collection is collected for recycling. This weight estimate is inclusive of contamination such as dirt and product residue, and so the actual volume collected for recycling is likely much lower. Of the collected volumes, approximately 4Mt per year is PE film with only around 1.2Mt per year of recycled output.[7]

Of the total flexible packaging placed on the market, only approximately 23% is food grade.[8] Flexible food packaging has the highest ratio of non-PE materials such as PP mono-materials (35%) and multi-materials (20%). Very little to none of the post-consumer recyclate is used in new food packaging applications.[9]

Table 3.1: Comparison of Model Pyrolysis Specification against Existing Sorting Specifications in Europe

	Pyrolysis Specification	310 Plastic Films	323 Mixed PO	323-2 Flexible PO	350 Mixed Plastics
Main composition	PP / PE	All polymers; sheet size >A4	Rigid and flexible PE and PP	Flexible PE and PP	PE, PP, PS, PET packaging
Min PE+PP content (min)	85%	Unknown	85%	90%	Unknown
Contamination (max)	15%	8%	15%	10%	10%
PVC/PVDC (max)	1%	Not stated	0.5%	Not stated	0.5%
PET/EVOH/nylon (max)	5%	Not stated	7.5%	5%	4% (clear bottles)
PS (max)	7%	Not stated		0.8% (EPS)	Not stated
Rigid metal/glass/dirt/fines (max)	7%	0.5% metal 4% others	3%	1% metal 3% others	2% metal 3% others
Paper/organics (max)	10%		5%	3%	5%
Others (max)		Max. 4% rigid plastics	Undersize <20mm: max 2%		
Moisture (max)	7%	Not stated	Not stated	Not stated	Not stated

Table 3.2: Comparison of Model Pyrolysis Specification against Existing Sorting Specifications in North America

	Pyrolysis Specification	1-7 Bottles and All Rigid Plastic[10]	PE Retail Bags and Film[11]	LDPE Coloured Film[12]	MRF Curbside Film[13]
Main composition	PO / PE	Rigid plastics	PE film	LDPE film	PE film
Min PE+PP content (min)	85%	unknown	95%	98%	95%
Contamination (max)	15%	5%	5%	2%	5%
PVC/PVDC (max)	1%		0%	0%	0%
PET/EVOH/nylon (max)	5%	Not stated	Not stated	Not stated	Not stated
PS (max)	7%	Not stated	Not stated	Not stated	Not stated
Rigid metal/glass/dirt/fines (max)	7%	1% metal	0%	0%	0%
Paper/organics (max)	10%	2%	5% 0% food waste	Not stated	Not stated
Others (max)		1% plastic bags, sheets, film	Other polymers, twine and tape included in paper tolerance; 0% metallised films and multi-layer pouches	Max. 2% other polymers, labels and moisture; 0% metallised films and multi-layer pouches	Max 2% non-polyethylene other plastics, or labels
Moisture (max)	7%	1%	2%	Included in others	1%

Existing Sorting Specifications in Europe

In Europe, the German producer responsibility organization Der Grüne Punkt has defined a set of model mechanical recycling feedstock specifications that have been widely adopted throughout Europe. From these model feedstock specifications and knowledge of materials targeted by mechanical recyclers, the following sorting fractions can be identified as a potential source of feedstock for pyrolysis operators in Europe. Four of these existing model feedstock specifications are included in Appendix A.2.0:

- 310 – Plastic Films
- 323 – Mixed Polyolefin Items
- 323-2 – Flexible Polyolefin Items
- 350 – Mixed Plastics

Table 3.1 compares these existing sorting specifications against the model pyrolysis specification developed in section 2.8. The model pyrolysis specification presented in this report is more detailed in respect to the level of specific contaminant types that existing specification however the tolerance levels for some contaminants such as PS and metals/glass/fines is less restrictive which would be a benefit to feedstock suppliers and sorters. The level of purity in respect to the target material e.g. PP/PE in the pyrolysis specification is comparable to other specifications.

While these specifications are in place, it should be noted that not all collection systems will deliver against these specifications in the same way and some may deviate significantly from these, similarly to the model specification discussed in Section 2.8.

Existing Sorting Specifications in North America

For North America, the Institute of Scrap Recycling Industries (ISRI) publishes their *Scrap Specification Circular* which is considered the de facto standard collection of model feedstock specifications in North America targeting mechanical recycling. Three of these existing model feedstock specifications are included in Appendix A.2.0:

- 1-7 Bottles and All Rigid Plastic
- PE Retail Mix Film
- LDPE Coloured Film

These feedstock streams have limited demand from mechanical recyclers, and the supply of these streams is limited. The higher-grade PE film streams have specifications that are closest to those desired by pyrolysis operators and may be suitable feedstocks but as stated previously the ability for pyrolysis operators to take a PP/PE blend provides additionality.

Table 3.2 compares these existing sorting specifications against the model pyrolysis specification developed in section 2.1.8. The purity levels of existing specifications are significantly higher than that required for the pyrolysis specification presented in this report and existing specifications also have a much lower tolerance level which should be well received by the market.

3.2 Opportunities and Challenges for Pyrolysis

Rigid polyolefins have a valuable offtake market by mechanical recyclers and while the presence of non-targeted polymer grades, colours, odours, and the use of varying additives remain as challenges, most sorted rigid polyolefin streams will find a reasonable uptake by the mechanical recycling industry. Pyrolysis operators could target the remainder, but volumes are likely to be low.

In interviews, many pyrolysis operators indicated that they are currently targeting flexible polyolefins, and the following overview summarises the recyclability opportunities and limitations for each material by technology type. Recyclability has not been assessed in a pure technological sense, as most materials could be recyclable. Instead, a view is taken on whether the recycling of the material in the current state of the market is taking place or may take place without significant change and investment. Further details on this assessment are provided in the sections below. Where limitations to mechanical recycling are identified, opportunities and possible challenges for pyrolysis are explored based on the model specification developed in section 2.8.

Table 3.3: Mechanical Recycling vs Pyrolysis

	Mechanical Recycling	Pyrolysis
Mono-PE Film	+	+
Mono-PP Film	-	+
Multi-layer PE/PP	X	+
Multi-material Film	X	-

Mono-PE Films

Demand for PE in mechanical recycling is mostly limited to post-industrial and high-quality post-consumer material and predominately in larger uncoloured formats. The majority of post-consumer PE collected flows through to low grade applications such as lumber and outdoor furniture. Demand exists for recycled PE with properties suitable for use in new products with rigorous performance requirements like packaging, but mechanical recyclers are often only able to create a limited supply using the highest-grade PE film waste streams.

Mono-PP Film

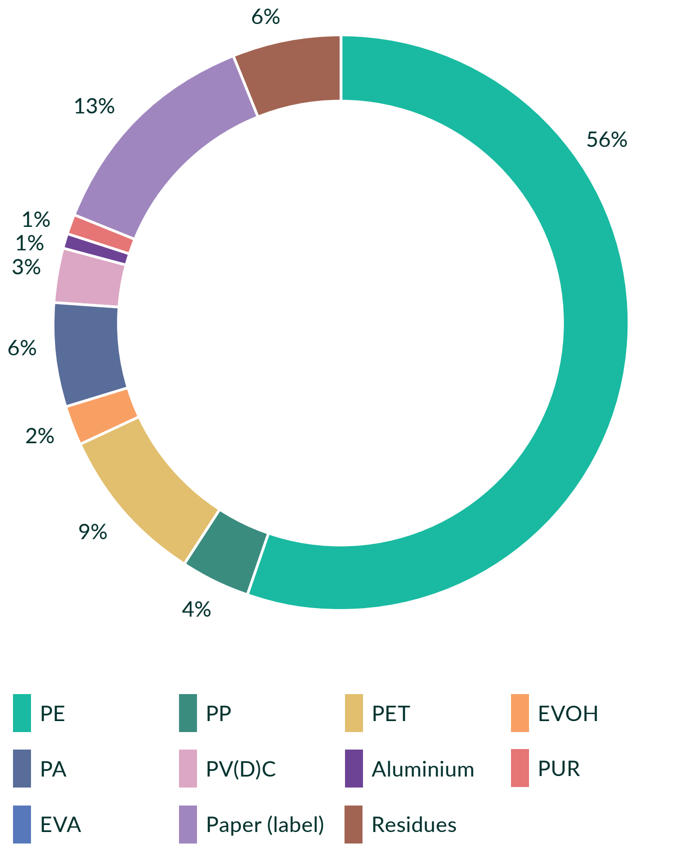
While PP is a highly recyclable material, post-consumer PP film is rarely separated into a distinct stream. In Europe, it is usually grouped into a mixed plastics or mixed polyolefin output or sorted as a contaminant into a reject stream destined for energy recovery or landfill. In the US and Canada, the Association of Plastics Recyclers does not publish a bale specification for PP films and the MRF curbside film bale specifications focuses on polyethylene. There are often challenges with the recycling of PP film, particularly as it is often found in small formats with high levels of ink e.g., snack food wrappers. Very small quantities of PP film may be recycled into lower quality applications from mixed polyolefin sources.[14] While the mechanical recycling industry is working on solutions for post-consumer PP film recycling, it has not yet been demonstrated at scale.

Multi-material Films

Multi-material films can consist of a variety of different polymers and other materials, laminated or extruded together to form a single packaging unit. Common materials used for layers alongside PE or PP include PET (as a barrier against moisture and chemicals), aluminium (as a barrier also against light and UV), EVOH (as an oxygen barrier) and nylon (polyamide, for strength and barrier properties). Multi-material film packaging is a broad family of packaging including formats such as wrappers, pouches and bags with compositions that can have up to nine layers. The lack of a standard composition adds to the recycling challenges of multi-material film through conventional recycling routes.[15] Advanced recycling processes, including to some extent pyrolysis, do have the ability to manage multilayer films. However, with efforts by packaging producers to make their materials 100% recyclable, compostable or biodegradable there is an expectation there will be less multi-layer packaging. The design changes will increase the volume available for both mechanical recyclers and pyrolysis operators.

The suitability of multi-material packaging for pyrolysis processes depends on its overall composition. One example of the composition of a multi-material multi-layer film is a PET/PE laminate at a ratio of 12 to 58, which means 17% of the structure is PET.[16] The PET content of a bale of this composition would likely be too high for a pyrolysis operator. In reality, the composition varies greatly. A study by Roosen et al. (2020) analysed the composition of selected plastic waste products.[17] While a pure PE film stream shows a purity of 91% PE vs 9% residues, the multi-material film waste category shows a significant amount of non-polyolefin materials, as shown in Figure 3.1. To illustrate the issue with multi-material films, the average composition of a multi-material bale from Belgium would not meet the pyrolysis specification. A bale of this composition would be a need to mixed with one that had a higher percentage of PE or PP. This could be done prior to arriving at the pyrolysis operator or on the pyrolysis operators' site.

Figure 3.1: Average Composition of Multi-Material Film Waste, Belgium

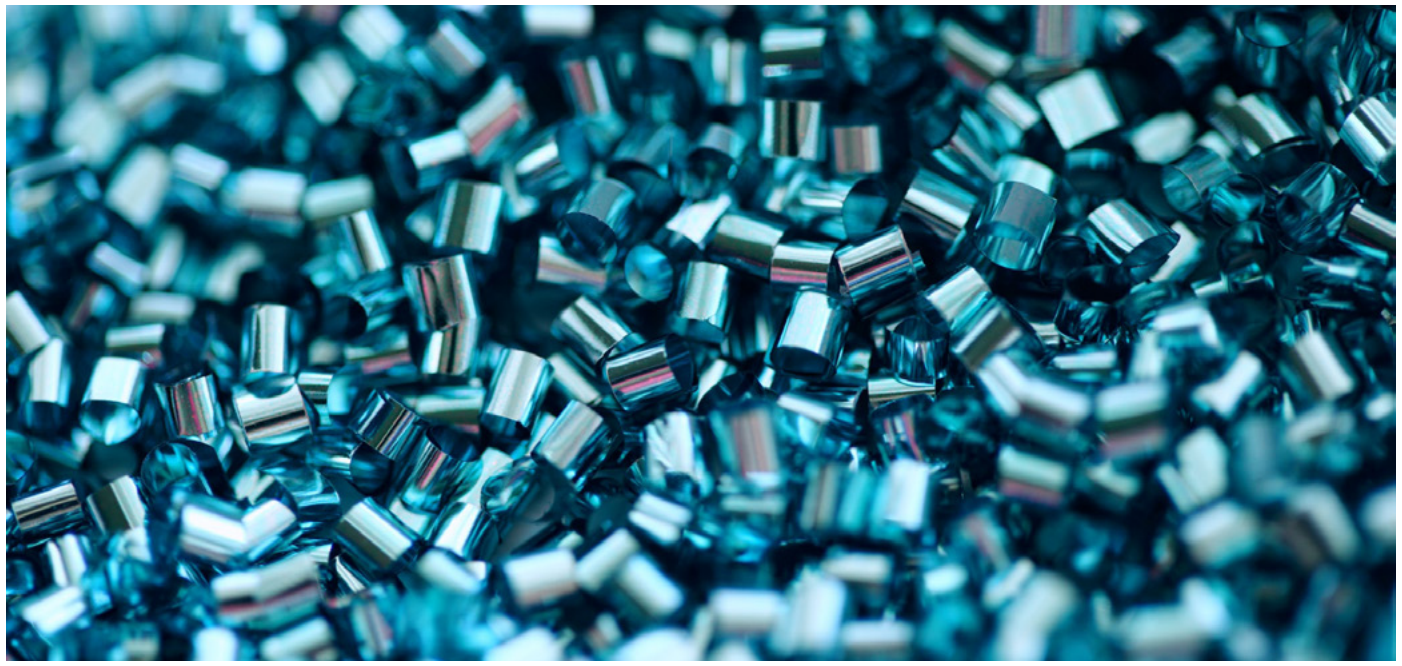


Source: derived from Martijn Roosen, Nicolas Mys, Marvin Kusenberg, et al. (2020) Detailed Analysis of the Composition of Selected Plastic Packaging Waste Products and Its Implications for Mechanical and Thermochemical Recycling, Environmental Science & Technology, Vol.2020, No.54, pp.13282–13293.

4.0

Conclusions and Next Steps

- **Mechanical recycling and pyrolysis routes require and will target consistent streams of feedstock with minimal contamination.**
- **Pyrolysis operators can take a mix of polyolefins and colours and have a different set of considerations surrounding contaminant threshold limits than mechanical recyclers.**
- **Both mechanical recyclers and pyrolysis operators would benefit from packaging design changes that reduce the number of different material layers specifically in flexible films.**



This study shows that feedstock requirements of pyrolysis operators have a common centre and can vary considerably from that centre.

> **Pyrolysis recycling operators require well-sorted, clean and largely homogenous feedstock, and they suffer from contamination similarly to mechanical recyclers.**

A difference is that while mechanical recyclers must distinguish between the different polyolefins (e.g., PP vs PE) and focus on single-colour streams, pyrolysis operators can take a mix of polyolefins and colours and have a different set of considerations surrounding contaminant threshold limits.

The key contaminants that must be avoided are materials that produce a chlorine by-product in the process (such as PVC or PVDC) and materials that could be abrasive, such as glass and rigid metals. For many operators, the oxygenates introduced by PET are also important and may be the most difficult to deal with in terms of sortation changes to meet the specifications. As the market matures and further trials are conducted, some changes to the model specification presented in section should be expected.

Current sorting specifications in the European and Northern American markets have been established around the requirements of mechanical recyclers. Some specifications provide material that also closely matches the requirements of pyrolysis operators.

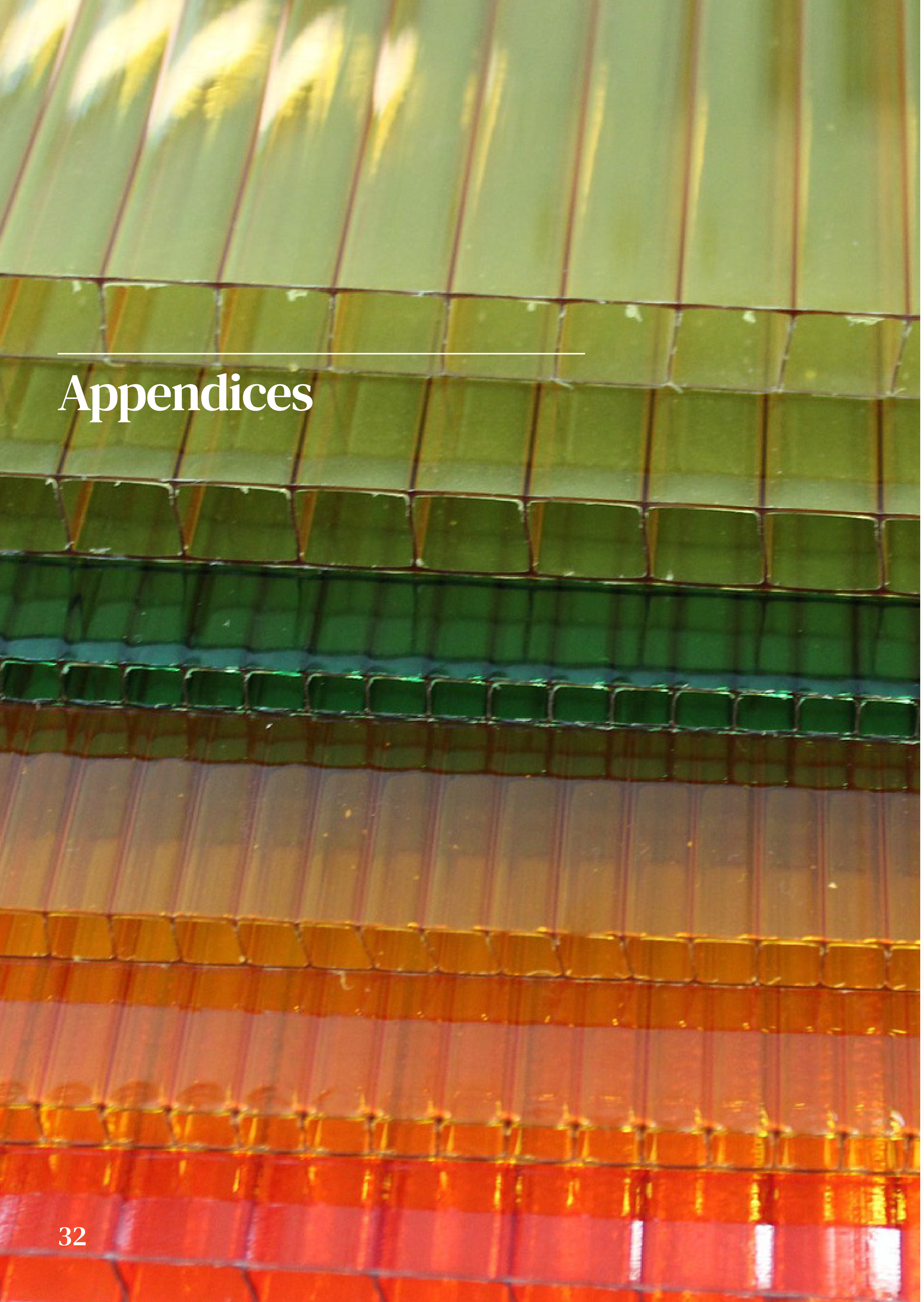
Both mechanical recyclers and pyrolysis operators would benefit from packaging design changes that reduce the number of different material layers.

The largest opportunity for pyrolysis recycling of polyolefins lies within the flexible film segments for which collection remains low – this will be a barrier to these technologies scaling.

Changes in the wider recycling market are inevitable. Policymakers, brand owners and the general public are shaping future targets and aspirations. This will stimulate innovation and investment into new technologies and designs.

While the development of a model feedstock specification is an important start, several subsequent activities should be undertaken to stimulate progress. The model feedstock specification inherently describes a recycling stream that does not exist at scale today. It is important to understand what barriers exist to creating that stream, to identify the optimal pathways for overcoming those barriers, and to evaluate the cause-and-effect relationship between this new feedstock stream and the existing feedstock streams that largely feed the mechanical recycling community.

This study focusses only on providing a draft feedstock specification for pyrolysis, there are other advanced recycling technologies that are emerging but for which there is less data to enable a specification to be developed. The study does assess in detail feedstock availability and how the existing recycling supply chain, from collection through to the recycler will need to evolve to enable this specification to be met. It does not consider where investment will be needed to most cost effectively enable the material to be captured and sorted to the defined specifications.



Appendices

A.1.0 Methodology

Foundational information was established through secondary research methods, including a review of data from Eunomia's previous relevant projects as well as desk-based research on existing standards and guidelines. This information was consolidated to provide the following for both Europe and North America:

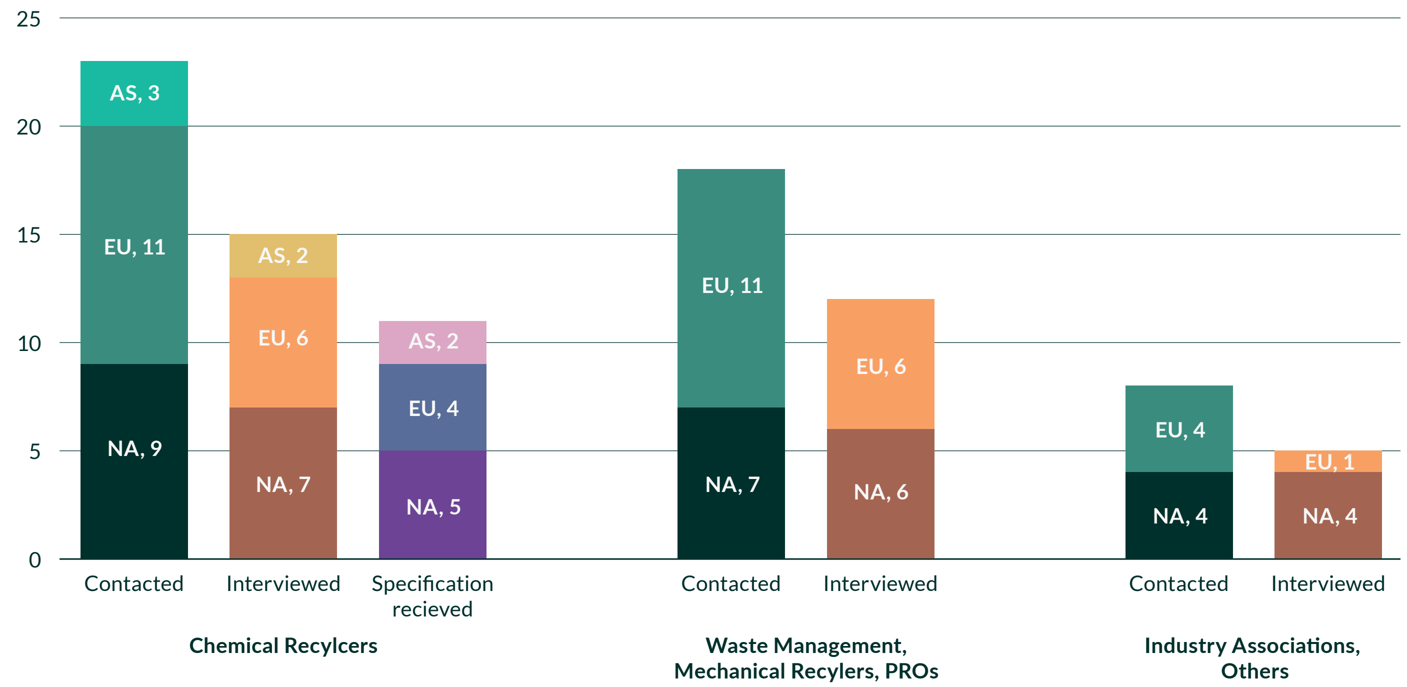
- A summary of the overall market;
- Details of collection and sorting arrangements;
- Key players in collection and sorting; and
- Details of existing sorting requirement and guidelines.

A broad collection of stakeholders was identified, with each classified by the type of organisation and, in the case of advanced recyclers, their technology. The scope of technologies and materials to be considered in the study was finalised, allowing for the short listing of the relevant organisations for interview. The study focused on advanced recyclers who were past the experimental phase, and whose technology was in scope – polyolefin inputs, with the outputs also going back into polymer production. Stakeholders were approached with details of the background to the study and an invitation to an introductory call to determine whether they would be willing to participate. Introductory interviews were held, followed by the distribution of the questionnaire and any requested confidentiality agreements.

The questionnaire covered a range of topics, from plant capacities to offtaker relationships, as well as requesting specific details of the required level of target materials and tolerances of contaminants, e.g.:

Target materials	Min	Max	Comment
e.g., LDPE, HDPE, LLDPE			

The responses from completed questionnaires were inputted into a knowledge matrix that allowed for comparisons to be drawn between organisations. After responses were reviewed, interview guides were developed where further follow up was needed.



A.2.0 Selected Existing Model Feedstock Specifications

A.2.1 Europe[18]

Product Specification 04/2009
Fraction-No. 310

Sorting Fraction	PLASTIC FILMS

A Specification/Description

Used, residue-drained, system-compatible items made of plastic film, surface > DIN A4, e.g. bags, carrier bags and shrink-wrapping film, including secondary components such as labels etc.

The supplement is part of this specification!

B Purity

At least 92% by mass in accordance with the specification/description.

C Impurities

Max. total amount of impurities	8% by mass
Metallic and mineral impurities with a unit weight of >100g are not permitted!	
Other metal items	<0.5% by mass
Other plastic items	<4% by mass
Other residue items	<4% by mass

Examples of impurities
- Glass
- Paper, cardboard
- Composite paper/cardboard materials (e.g. beverage cartons)
- Aluminised plastics
- Other materials (e.g. rubber, stones, wood, textiles, nappies)
- Compostable waste (e.g. food, garden waste)

Product Specification 03/2018
Fraction-No. 323

Sorting Fraction	MIXED POLYOLEFIN ITEMS (MPO)

A Specification/Description

Used, residue-drained, system-compatible items made of polypropylene (PP) and polyethylene (PE) such as bottles, cups, trays, films as well as substantially identical household and plastic items including secondary components such as labels etc.

The supplement is part of this specification!

B Purity

At least 85% by mass in accordance with the specification/description.

C Impurities

Max. total amount of impurities	15% by mass
Metallic and mineral impurities with a unit weight of >100g and cartridges for sealants are not permitted!	
Paper, cardboard	<5% by mass
Other non PE/PP plastic items (PET, PS, etc.)	<7.5% by mass
PVC items	<0.5% by mass
Other residues	<3% by mass
Max. undersize fraction (item <20mm)	<2% by mass

Examples of impurities
- Glass
- Paper, board, cardboard and composite paper/cardboard materials (e.g. liquid packaging boards)
- Other materials (e.g. rubber, stones, wood, textiles, nappies)
- Compostable waste (e.g. food, garden waste)

Product Specification 03/2018
Fraction-No. 323-2

Sorting Fraction	FLEXIBLE POLYOLEFIN ITEMS

A Specification/Description

Used, residue-drained, system-compatible, flexible items made of polyolefin (PE, PP) that are typical for packaging such as films, carrier bags (including aluminised films) and plastics made of Polyolefins that are dimensionally stable such as trays, covers including secondary components such as lids, labels etc.

The supplement is part of this specification!

B Purity

At least 90% by mass in accordance with the specification/description.

C Impurities

Max. total amount of impurities	10% by mass
Metallic and mineral impurities with a unit weight of >100g are not permitted!	
PET items	<5% by mass
EPS items	<0.8% by mass
Paper, cardboard, carton, liquid packaging boards	<3% by mass
Other residues	<3% by mass
Other metal items	<1% by mass

Examples of impurities

- Glass
- Other plastic items
- Other materials (e.g. rubber, stones, wood, textiles, nappies)
- Compostable waste (e.g. food, garden waste)

Product Specification 03/2018
Fraction-No. 350

Sorting Fraction	MIXED PLASTIC

A Specification/Description

Used, residue-drained, system-compatible items made of plastics that are typical for packaging (PE, PP, PS, PET) including secondary components such as lids, labels etc.

The supplement is part of this specification!

B Purity

At least 90% by mass in accordance with the specification/description.

C Impurities

Max. total amount of impurities	10% by mass
Metallic and mineral impurities with a unit weight of >100g are not permitted!	
Paper, cardboard	<5% by mass
Other metal items	<2% by mass
PET bottles, transparent	<4% by mass
PVC items other than packaging	<0.5% by mass
Other residues	<3% by mass

Examples of impurities

- Glass
- Composite paper/cardboard materials (e.g. liquid packaging boards)
- Other materials (e.g. rubber, stones, wood, textiles, nappies)
- Compostable waste (e.g. food, garden waste)

A.2.2 North America[19]

1-7 Bottles and ALL Rigid Plastic

Description

Rigid plastic generated in a positive sort from a curbside, drop-off, or other public or private recycling programme that does not separately sort any plastic bottles. Bales consist of all plastic bottles - no bottles should be removed from the mix prior to baling - and household containers (including thermoform packaging, cup, trays, clamshells, food tubs and pots, and bulky rigid plastic (e.g. drums, crates, buckets, baskets, toys, totes and lawn furniture.

Product

Bottle and non bottle containers

Source

Post-consumer material

Contamination

Total contaminants should not exceed 5% by weight

2% maximum acceptable

- Paper/cardboard

1% maximum acceptable

- Metal
- Plastic bags, sheets, film
- Liquid of other residues

The following contaminants are not allowed at any level (zero percent allowed):

- Wood, glass, electronics scrap
- Oils, grease, rocks, mud, dirt
- Containers which held flammable, corrosive or reactive products, pesticides or herbicides
- Medical and hazardous waste
- Productions with degradable additives

PE Retail Mix Film

Description

Any polyethylene bag and overwrap accepted by retailers from their customers or polyethylene stretch wrap or other film generated back of house may be included. Bags may be mixed colour or printed and primarily High-Density Polyethylene (HDPE, #2) but are expected to include other polyethylene bags and LDPE/LLDPE overwrap. Films may be coded with ASTM D7611 resin identification code "#2, HDPE" and #4, LDPE". All bag bundles should be free of free-flowing liquids.

Product

Mixed film

Source

Post-consumer material

Contamination

Total contaminants should not exceed 5% by weight

- Non-polyethylene other plastics
- Loose paper
- Strapping, twine or tape
- Liquid residue (2% maximum)

The following contaminants are not allowed at any level (zero percent allowed):

- Medical and hazardous waste
- Food waste
- Wood
- Glass
- Oils and grease
- Rocks, stones, mud, dirt
- Metallized labels or films
- Multi-material pouches
- Silicone coated film
- Film with oxo or bio-degradable additives
- PVDC layers
- Acrylic coatings

LDPE Coloured Film

Description

Any mixture of natural translucent Low Density Polyethylene (LDPE, #4) film and mixed colour translucent Low Density Polyethylene (LDPE, #4) film with limited label contamination is acceptable. Films may be coded with ASTM D7611 resin identification code #4) LDPE. All film bundles should be free of free-flowing liquids.

Product

LDPE Coloured Film

Source

Post-consumer material

Contamination

Total contaminants should not exceed 2% by weight. No more than 2% by weight of any of the following individual contaminants with be allowed

- Non-polyethylene other plastics
- Labels
- Water

The following contaminants are not allowed at any level (zero percent allowed):

- Medical and hazardous waste
- Wood
- Glass
- Oils and grease
- Rocks, stones, mud, dirt
- Metallized labels or films
- Multi-material pouches
- Silicone coated film
- Film with oxo or bio-degradable additives
- PVDC layers

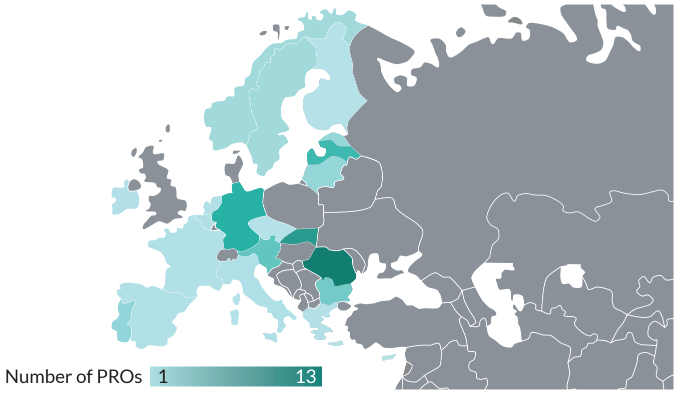
A.3.0 Waste Management

A.3.1 Waste Management in Europe

The European waste management infrastructure is heavily shaped by Extended Producer Responsibility (EPR) schemes, a policy tool designed to extend a producer's financial and operational responsibilities for a product to the management at the end of a product's lifecycle. A producer responsibility organisation (PRO) is an entity acting to deliver compliance for a number of obligated organisations ('producers') and has responsibility for discharging their legal obligations in respect of recycling. In doing so, it is required to pay for a defined element of the cost of services being relied upon for the recycling required to deliver the obligation. These costs are met through fees payable by the producers within the scheme. For this report, the PROs operate in the field of recycling of post-consumer packaging.

While EPR schemes are not a pre-defined tool required in the Packaging and Packaging Waste Directive, it has become a policy tool to fulfil the obligations and meet recycling targets. This has resulted in countries taking different approaches. Figure 5.1: Number of PROs in European countries. Figure 5.1 demonstrates that the number of PROs in European countries vary from countries with many competing PROs, such as Romania, to countries, that only have one single PRO managing the member state's post-consumer packaging waste.

Figure 5.1: Number of PROs in European countries



Five countries have taken a different approach altogether and do not use a PRO run model. These are Croatia, Denmark, Hungary, Poland and the United Kingdom.

Under their respective EPR regulations in different countries, PROs have varying levels of influence on the operational and financial side of the management of packaging. There are differences in responsibilities for collections and sorting operations, as well as variances in post-consumer packaging material targeted in collections for recycling.

Collections

In many countries the responsibility for collection still rests with the municipalities, which enables the optimised coordination between collection of packaging waste, and the collection of other fractions (residual waste, food waste, non-packaging recyclables, etc.). Where packaging waste is collected in bring systems as opposed to kerbside collections, the coordination of collections is easier, however bring systems are often less successful than kerbside collections. Where multiple PROs are in place, the collected material may be split in accordance with the PRO's respective market shares to which the responsibility is then passed over to the particular PRO.

Sorting

In cases where municipalities have responsibility for collection, they are also likely to be in control of operating / procuring sorting facilities. However, in some cases, PROs play a role in effectively requiring municipally collected materials to be directed to sorting centres operating under contract to PROs. There is increasing recognition that large numbers of smaller, less technically sophisticated sorting facilities may not be up to the task that will be required of the infrastructure in future. Hence, we may expect some evolution in this area.

Recycling

In most PRO led systems the arranging for the recycling of sorted packaging is in the control of PROs. However, this is not always the case: in Finland, Greece, Ireland, Latvia, Luxembourg and Portugal, and sometimes in France and Germany, the matter is largely in the hands of either municipalities or sorting plant operators.

A.3.2 Waste Management in North America

Canada

Five of Canada's provinces have an EPR system for packaging. Maine and Oregon are the only states in the US which have passed an EPR bill for packaging, and neither is operational currently. British Columbia is the only territory in North America with a packaging EPR system which is fully producer funded and operated. Ontario and Quebec will become fully producer funder and operated in the next five years.

Under the EPR programmes in British Columbia, Saskatchewan, Ontario, Manitoba and Quebec, fees are paid on plastic films sold into the market. However, film is not universally collected in each of the provinces.

In Ontario, 60% of households have kerbside services which target plastic films.[20] In British Columbia, plastic film is only allowed to be collected at drop-off centres. The two largest cities in Saskatchewan do not collect plastic film in their kerbside programmes.

Table 1.1 below lists the reported recovery rates for British Columbia, Saskatchewan, Ontario and Manitoba, taken from each of the EPR programmes annual reports for 2019 and 2020.

Table 1.1: Reported Film Recovery Rates in EPR Provinces

	British Columbia (2020)	Saskatchewan (2020)	Ontario (2020)	Manitoba (2019)
Plastic film Recovery Rate	24%[21]	Not Reported	9.7%	14%
All Non-Beverage Plastic Packaging	52%	11%	30%	51%

In Canada, 23% of recycled plastic film was collected through kerbside programmes in 2018.[22]

United States

Of the plastic film recycled in the United States, the vast majority originates in post-commercial streams – most importantly, the back-of-house collection of stretch wrap at retailers – while less than 1% is collected from residential consumers through kerbside programmes.[23] Collection receptacles for post-consumer film from households are commonly placed at grocery stores and other retail locations, but while a large percentage of the US population has access to those collection receptacles, the overall amount of material gathered through that system is small.

Mono-material PE film is the only type of film collected in US recycling streams. The US has a film packaging recycling rate of 10%.[24] Additionally, 18% of plastic film packaging is combusted, this relates to 740,000 tons of combusted plastic film.

Endnotes

1 cefic (2020) *Introducing chemical recycling: Plastic waste becoming a resource*, https://cefic.org/app/uploads/2022/04/Cefic-position-paper-on-Chemical-Recycling.pdf

2 While pyrolysis operators are striving for a no-oxygen environment, this is technically not entirely achievable.

3 Martyna Solis and Semida Silveira (2020) Technologies for chemical recycling of household plastics – A technical review and TRL assessment, *Waste Management*, Vol.105, No.2020, pp.128–138

4 Martyna Solis and Semida Silveira (2020) Technologies for chemical recycling of household plastics – A technical review and TRL assessment, *Waste Management*, Vol.105, No.2020, pp.128–138

5 Heteroatom - Atoms of any element besides carbon or hydrogen. Only carbon and hydrogen are required as the building blocks of polyolefins, and therefore other atoms are considered to be contaminants.

6 Plastic Recyclers Europe (2020) *Flexible Films Market in Europe: State of Play*, 2020, https://743c8380-22c6-4457-9895-11872f2a708a.filesusr.com/ugd/dda42a_ff8049bc82bd408faee0d2ba4a148693.pdf

7 Ibid.

8 Ibid.

9 Ibid.

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