



STANDARDS RESEARCH

A Roadmap to Support the Circularity and Recycling of Plastics in Canada – Technical Standards, Regulations and Research

The Current Landscape and the Need for Change

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Abbreviations

ABS	Acrylonitrile Butadiene Styrene	LCPS	Low Carbon Plastics Standard
ACC	American Chemistry Council	LDPE	Low-Density Polyethylene
AI	Artificial Intelligence	MFI	Melt Flow Index
APR	Association of Plastic Recyclers	MFR	Melt Flow Rate
ASTM	American Society for Testing and Materials	MRF	Material Recovery Facility
CCME	Canadian Council of Ministers of the Environment	MVR	Melt Volume-Flow Rate
CRD	Construction, Renovation, and Demolition	NIR	Near-Infrared
CRF	Container Recovery Facility	PCR	Post-Consumer Recyclable
CHP	Combined Heat and Power Recovery Plant	PHA	Polyhydroxyalkanoates
ECCC	Environment and Climate Change Canada	PLA	Polylactic Acid
ELV	End-of-Life Vehicle	PE	Polyethylene
EPR	Extended Producer Responsibility	PET	Polyethylene Terephthalate
EPS	Expanded Polystyrene	PP	Polypropylene
HDPE	High-Density Polyethylene	PPP	Packaging and Printed Paper
ICI	Industrial, Commercial, and Institutional	PRRC	Plastic Recycling Corp. of California
IEC	International Electrotechnical Commission	PRE	Plastics Recyclers Europe
IR	Infrared	PRF	Plastics Recovery Facility
ISO	International Organization for Standardization	PS	Polystyrene
		PVC	Polyvinyl Chloride
		SDG	Sustainable Development Goals
		UV	Ultraviolet
		WEEE	Waste of Electrical and Electronic Equipment

Executive Summary

The current quantity of unrecycled plastics creates an ever-growing problem, especially given the continued large growth forecasts for the plastics manufacturing industry. Plastic's versatility, low cost, and ease of manufacturing have spurred rapid growth since production began in the 1950s; today, plastic is ubiquitous throughout society. The sheer volume of plastics produced creates environmental and waste management challenges of growing concern. To address this, national, provincial, and local governments are introducing a diverse range of policies and mandates to regulate plastics, especially single-use plastics and plastic packaging.

Under Canada's G7 presidency in 2018, the government championed the development of the Ocean Plastics Charter to move towards a more sustainable approach to producing, using, and managing plastics. Through the Canadian Council of Ministers of the Environment (CCME), the federal, provincial, and territorial governments approved in principle the Canada-wide "Strategy on Zero Plastic Waste." Building on the Ocean Plastics Charter, the strategy takes a circular economy approach to plastics and provides a framework for action in Canada. The strategy outlines areas where changes are needed across the plastic life cycle, from design to collection, to clean-up and value recovery, and underscores the economic and business opportunities resulting from long-lasting and durable plastics. The strategy is expected to be a driver for innovation and to create opportunities that will increase competitiveness in new business models, product design solutions, and waste prevention and recovery technologies. In 2019, the CCME approved the first phase of the action plan, which identifies the government activities that will support the implementation of the strategy. A second phase will follow in 2020 to address the last five key areas of the strategy.

This report intends to explore the current landscape and potential for standards to help achieve a circular economy for plastics. Currently, in Canada, only 9% of plastics are recycled at their end-of-life [1]. Approximately 90% of Canadian plastics originate from the oil and gas industry. Nearly all sectors of society currently use plastic and create plastic waste, ranging from residential and work environments, to construction and agriculture. While governments, corporations, and organizations have been making commitments to address the low recycling rates, there are still major challenges and barriers that affect the recyclability of plastics.

The research for this report focused on soliciting input from industry stakeholders and experts, environmental organizations, recycling advocates, governments, and academics on the topics of barriers, challenges, opportunities, and standards-based solutions to Canada's low plastics recycling rate. All aspects of the plastics value chain were reviewed through a series of interviews, meetings, and research that focused both on the current and future system for recycling plastics in Canada and leading jurisdictions around the world.

This report explores the management of post-consumer and post-industrial plastics that must be managed at the end-of-product use. The multiple step/multiple stakeholder processes of collection, sorting, and recycling plastics are all interconnected and influenced by the first use of the plastic materials. Several major brand owners have committed to increasing their use of recycled plastics and many are making changes to their products to increase recyclability at their end-of-life through voluntary programs such as the Ellen MacArthur Foundation's New Plastic Economy Global Commitment. Many jurisdictions also have policies, regulations, and standards in place to support increased recycled content in manufactured products.

The use of post-consumer plastics in new products is hindered by four important factors: (1) cost, (2) quality, (3) supply, and (4) market demand. Because of its high cost, variable quality, and limited supply, the upstream supply chain lacks incentive to use post-consumer plastics. This behaviour is equivalent to a general contractor or developer preferring to use new building materials because virgin materials are more economical, easier to work with, the quality is more consistent, there is ample supply if more is required, and there is no economic incentive to use a material that takes more time and effort to use.

An interesting development across all industry participants was an awareness of an increasing market demand for plastic products that contain recycled/post-consumer plastics. It has become evident that retailers and institutional purchasers are enquiring about or requiring a certain level of post-consumer plastics in the products they procure. Promoting this evolving market demand for post-consumer plastics is a crucial step in increasing the recycling rate of plastics entering the Canadian marketplace. The development of several key standards and guidelines is recommended to support this marketplace as summarized in Table E1. The terms “standards” and “guidelines” as outlined within the solutions section of this report (Table E1 and Table 8) are used interchangeably, and refer to an accredited standards-based development process.

Table E1: High-Priority Solutions

	Challenge and Opportunity	Recommendations
Terminology	Terminology promotes clear communication along the entire value chain and reduces time spent on negotiating and developing agreed-upon definitions in business transactions. Terminology standards exist for recycling terminology; however, these definitions are often inconsistent.	Review existing standards (ISO, APR, PRE) for suitability or develop a new Canadian standard with definitions to support national recycling terminology.
Terminology	Numerous methods of recycling exist due to the wide array of plastics and their various uses today. Comparing the main recycling methods when making recycling decisions can lead to better decision-making and can support a circular economy. Research exists classifying over 60 non-mechanical methods, but this classification is not in common use today.	Develop definitions and related processes to classify methods of non-mechanical recycling, including purification, depolymerization, and conversion technologies to support a national accepted definition of recycling.
Demand	Extended producer responsibility (EPR) programs for many but not all plastic waste categories in Canada. Implementation of required EPR programs in Canada would require organizations that produce or use plastic products to have their plastics collected and recycled at the end of their intended use.	Develop national EPR programs to mandate the extended responsibility of the plastic product at its end-of-use, which in turn will incentivize the design for product recyclability.
Recycling	Certain resins and products have historically been recycled in low numbers. For these resins and products, defining appropriate producer responsibility or stewardship initiatives can improve recycling rates for these respective products.	Set a threshold, product by product, to counteract low demand for certain resins by setting a level of conformity for producer responsibility/stewardship.
Recycling	Design guidelines for recyclability have been developed by various organizations. However, guidelines across organizations are not harmonized, nor are their specific guidelines for each product category. Improved product design can support increased recycling rates.	Develop “design for recyclability” guidelines and standards that address all product categories to ensure that best practices for recyclability are considered in product design. The product design should be detailed to a level that manufacturers require to make design choices for a circular economy.
Manufacturing	The performance of plastic is important when designing products as needs vary greatly across uses. Standards exist to measure various properties and the properties of virgin plastics are very well known. Common properties need to be better understood for recycled plastics in relation to virgin materials which use the same standard performance measures.	Develop standards to address minimum performance requirements and testing methods to describe and quantify a small, core set of properties to define “near-virgin quality” in recycled resin.
Innovation	A low carbon plastics standard (LCPS) would incentivize the use of both renewable chemistries to make plastic as well as recycled content as a low carbon feedstock.	Establish an LCPS to incentive a plastic circular economy which is powered by renewable energy and zero waste [2].

A comprehensive roadmap of prioritized standards is included in Section 9 of the report.



“There is a notion in society that plastics are very recyclable; however, that is challenged when it is reported that only a small proportion of plastics are repurposed as new products at their end-of-life.”

1.0 Introduction

1.1 Research Objectives

This research report explores the drivers behind the low 9% recycling rate of plastics that are recycled at their end-of-life. It investigates why plastic producers and manufacturers are not using more post-consumer recycled plastic materials in their products. It also intends to identify what elements need to change in order for plastics manufacturers to incorporate higher levels of recycled content into their products. Overall, this report aims to outline a shift from our current linear model to a more sustainable model that takes into consideration circular economy principles.

Plastic is a versatile, low-cost, easy-to-manufacture material that makes it ubiquitous today in a wide-range of products. The rapid growth of plastics production began in the 1950s and there are no signs that this industry is slowing down. Unfortunately, the sheer volume of plastics produced creates environmental and waste management challenges when it comes to end-of-life management. In Canada, it is reported that only 9% of plastics that end up in the waste stream are recycled for use in newly manufactured products. The remaining 91% of unrecycled plastic waste in Canada is disposed of in managed landfills (86%), incinerators (4%), and unmanaged domestic dumps and the receiving environment (1%) [1].

There is a notion in society that plastics are very recyclable; however, that is challenged when it is reported that only a small proportion of plastics are repurposed as new products at their end-of-life. To understand where that idea is failing, stakeholders were interviewed to acknowledge their roles in recycling success, methods for increasing recycling rates, barriers to using recycled content, and incentives to utilize secondary plastic resins in new products. Recommendations to make recycled plastics more appealing to manufacturers were identified with recommendations that discuss standards to support greater recycling rates.

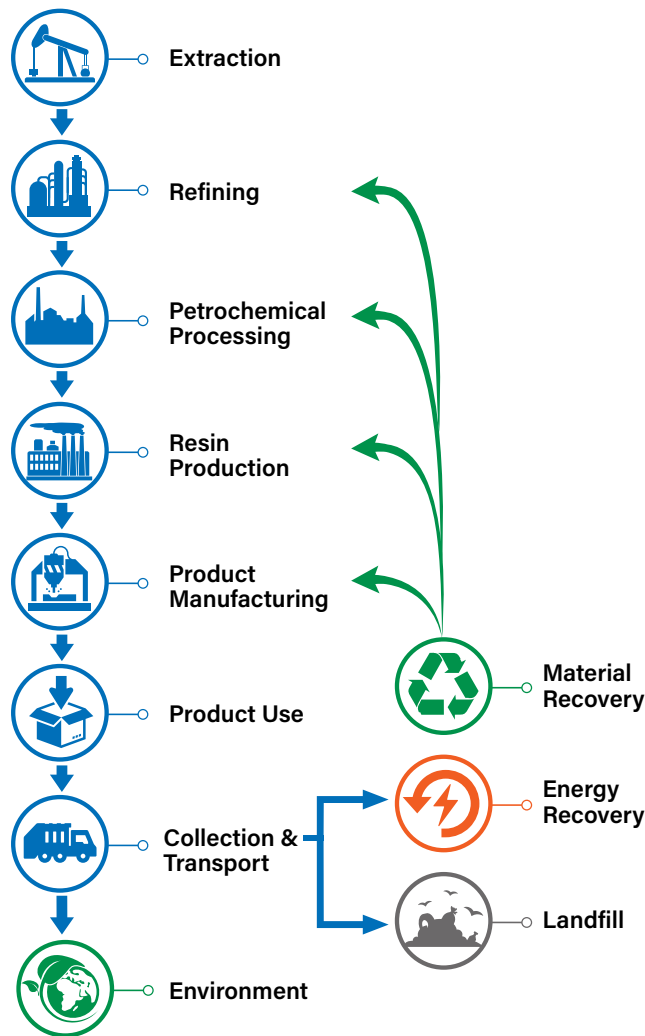
Future opportunities to increase recycled plastics using voluntary standards were developed by speaking with a wide variety of industry stakeholders. Stakeholders were asked to categorize standards by their feasibility of implementation in the Canadian market. The result is a roadmap intended to increase the use of post-consumer plastic in new products.

1.2 The Plastics Industry

Approximately 90% of plastics in Canada originate from the oil and gas industry [3]. Plastics from oil and gas feedstocks are technically able to be recycled for use in newly manufactured products. The life cycle of plastics from the oil and gas industry is illustrated in Figure 1. This diagram shows the various stages of the plastics life cycle from the point of extraction to the final endpoint where that material stops being used.

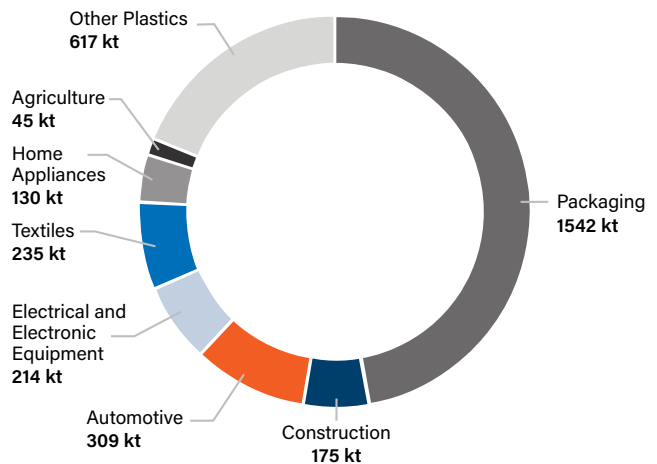
As plastic products reach the end of their useful life, these materials are discarded and become part of the solid waste management system. Whether they are discarded from single-family homes; multi-family homes; industrial, commercial, and institutional (IC) sources; construction, renovation, and demolition (CRD) sources; or agricultural sources, the waste stream contains these plastic materials. Waste materials are collected and transported to the various end points (energy recovery, landfill disposal, or released into the environment) or captured in the material recovery stage where there is an opportunity to recycle those materials back into the plastic development stages.

Figure 1: Life cycle of plastics that are produced from the oil and gas industry



The plastics in the waste stream come from several sources as illustrated in Figure 2. The largest amount of waste plastics is from the packaging industry.

Figure 2: Sources of waste plastics in 2016. Source: House of Commons Canada [3]



Collecting plastic waste is the first step in ensuring more plastic can be recycled. Collection is completed using either pick-up or drop-off systems and details of those systems vary by location throughout Canada.

After collection, the materials containing plastics are transferred to sorting facilities such as material recovery facilities (MRFs) where the various types of plastics are sorted by polymer or resin type. Depending on market requirements, polymers will also be sorted by application (PET bottles vs. thermoforms), colour (HDPE natural vs. colour), or other characteristics. Recent advances in sorting technologies involve automated sorting processes that are fast and use artificial intelligence (AI) to reduce the amount of hand-sorting, thereby potentially reducing plastic-sorting and processing costs.

An ever-growing array of recycling technologies exist in the plastics industry throughout Canada. There are domestic resources to recycle the most common resins, as well as several engineered resins such as acrylonitrile butadiene styrene (ABS), polycarbonate-ABS, and polycarbonate. The traditional method of recycling is called mechanical recycling and it involves separating, melting, and creating recycled resin that can then be reused in manufacturing.

Another method of recycling that tends to involve more resources is known as chemical recycling, which is a developing area, with a few commercial operations in Canada. The two primary categories of chemical recycling are **purification recycling** and **molecular recycling**. In purification recycling, polymers are dissolved in a suitable solvent, filtered, and then precipitated out of a solution to produce a near-virgin polymer. In **molecular recycling**, the polymer chains are broken down into their original monomer building blocks and then repolymerized to produce virgin-equivalent polymers.

Conversion technologies, such as pyrolysis and gasification, utilize difficult-to-recycle plastic waste to create fuels or other specialty chemicals. These same technologies can be used to chemically recycle plastics, such as pyrolyzing polystyrene to produce styrene monomer, followed by purification and repolymerization.

The method of recycling affects the properties of recycled plastic. One method of plastics “recycling”, conversion, is debated among industry members as to whether or not it can be called “recycling.” Since the original plastic material is converted to another material, often syngas or fuel, the output of conversion technologies does not always return the product to the plastics supply chain. In some conversion methods, the output is used to make new plastics.

The end goal of plastics recycling is to improve the quality of the recycled material and to find markets where this material can be used and not discarded. For recycled resins, reuse can take the shape of the original plastic product recycled, a different plastic product, or use in a product not typically containing plastics. For example, plastic water bottles being recycled into new plastic water bottles is an example of returning to the original product, which is called “closed-loop recycling.” Coloured HDPE bottles or pesticide containers being recycled into corrugated drainpipe is an example of returning spent plastic materials to a different plastic product and is called “open-loop recycling.” Incorporating polyethylene (PE) film plastic as polymer additives in asphalt binders for roads, parking lots, or pathways is an example of using recycled plastic in a product not typically containing plastics to provide a useful property to the product. This

form of open-loop recycling, which has been referred to as “downcycling” by some professionals, is when the recycled content from a product does not return to the same product [4]. This can include using recycled plastic for constructing roads as well as making synthetic wood for outdoor furniture.

1.3 Definitions

1.3.1 Plastic Resin Classification

With the wide variety of plastics available today, it is important to have knowledge of the different plastic resins in order to understand the barriers that make it difficult to increase the recycled content in plastic products. There are two broad types of plastics: “thermoplastics,” which can be remelted for reuse, and “thermosets,” which due to cross-linking in the creation of the initial object cannot be remelted for reuse.

The six common thermoplastics are as follows: polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS). These are identified on products with resin identification codes (RIC) #1 to #6, as standardized initially in 1988 and defined within the current ASTM D7611/D7611M *Standard Practice for Coding Plastic Manufactured Articles for Resin Identification*. When using mechanical recycling, each resin type is almost always separated before it can be recycled. RIC #7, “Other,” is a catch-all category that represents all other plastics that are not within the spectrum types from #1 to #6, as detailed in Table 1.

Note: When recycled, these RICs are denoted as rPET, rHDPE, rPVC, rLDPE, rPP, and rPS.

2.0 Project Methodology

This research was conducted in several stages. Consultation with plastics industry experts occurred throughout the process and informed results are shared throughout the report. The stakeholders consulted were connected to all areas of the plastics life cycle and included industry associations, resin manufacturers, converters, brand owners, recycling companies, material

Table 1: Plastic Resin Identification Codes (RICs) and Common Products

#1 PET	#2 HDPE	#3 PVC	#4 LDPE	#5 PP	#6 PS	#7 Other
Polyethylene terephthalate	High-density polyethylene	Polyvinyl chloride	Low-density polyethylene	Polypropylene	Polystyrene	Other
<ul style="list-style-type: none"> ▪ Carpets ▪ Cups ▪ Jars ▪ Textiles ▪ Thermoforms ▪ Water bottles 	<ul style="list-style-type: none"> ▪ Detergent bottles ▪ Drainpipes ▪ Grocery bags ▪ Milk jugs ▪ Outdoor furniture 	<ul style="list-style-type: none"> ▪ Pipes ▪ Pool liners ▪ Security packaging ▪ Sheeting ▪ Siding 	<ul style="list-style-type: none"> ▪ Bread bags ▪ Plastic wrap ▪ Trash bags 	<ul style="list-style-type: none"> ▪ Automotive parts ▪ Cups ▪ Hangers ▪ Juice bottles ▪ Straws ▪ Twine 	<ul style="list-style-type: none"> ▪ Cups ▪ Keyboards ▪ Refrigerator liners ▪ To-go containers ▪ Transportation packaging 	<ul style="list-style-type: none"> ▪ PLA ▪ Acrylic ▪ Polycarbonate

recovery facilities, governments, and academics. These experts provided input on the barriers, challenges, and potential standard-related solutions to increase the use of recycled plastics and secondary resins in product development through the improved recycling and recyclability of plastics.

Research was structured to answer the following key questions:

- What standards and regulations govern the use of secondary resins in manufacturing?
- What are the major barriers for manufacturers incorporating increased recycled plastics (secondary resins) into plastic products?
- What are the emerging and innovative processes and technologies that are helping to increase recycled content in plastic products?
- Where can barriers be addressed through technical standards? What standards are needed to address technical barriers?

Research was coordinated in four stages to create multiple engagement opportunities with industry stakeholders and leaders. Each research stage is summarized below.

Stage 1: Current Industry Landscape Review

Stage 1 focused on reviewing the Canadian plastics manufacturing industry, with a focus on the flow of plastics in Canada, existing regulations and standards, challenges in recycling, and ongoing technology and

process development. Research began by reviewing the research reports and programs developed in recent years, including:

- Canadian Council of Ministers of the Environment, “2018: Strategy on Zero Plastic Waste” [60];
- Environment and Climate Change Canada, “Economic Study of the Canadian Plastic Industry, Markets and Waste” [1]; and
- House of Commons of Canada, “The Last Straw: Turning the Tide of Plastic Pollution in Canada” [3].

Stage 1 research was compiled to identify promising technological developments and stakeholders to be engaged through supply chain interviews.

Stage 2: Supply Chain (Stakeholder) Interviews

Interviews were conducted with industry stakeholders throughout the plastics manufacturing supply chain to identify barriers to recycling, barriers to including post-consumer plastics in new products, differences between using recycled versus virgin plastic, and innovations that are available in the industry. Fifteen stakeholders were engaged through 30-minute interviews during Stage 2 using a standardized questionnaire. Stakeholders were categorized based on their role within the supply chain. All responses were transcribed for analysis with responses anonymized within each category.

Following Stage 2, a select group of industry experts were consulted to review and assess research to date and comment on plans for Stage 3 and Stage 4.

Stakeholders identified industry innovators and leaders to be interviewed during subsequent research stages.

Stage 3: Industry Innovator Interviews

Stage 3 research focused on engaging industry innovators and those organizations leading the development of technologies and processes that have the potential to increase plastic recycling in Canada and elsewhere in the world. Thirteen industry innovators were engaged and included brand managers, technology developers, recyclers, and manufacturers from multiple industries. A modified questionnaire was used to conduct interviews that focused on the potential for standards to further promote and support use of recycled plastics in manufacturing. Responses to interview questions were transcribed and anonymized within categories of industry innovators for analysis.

Stage 4: Research Gap Analysis

Stage 4 research focused on filling in gaps in the information that was collected during Stages 1 to 3. Several research methods were used to collect additional information, including confirming responses with previously interviewed stakeholders, searching for relevant technology patents, and reviewing existing standards and regulations that influence the use of recycled plastics and other recycled materials in leading jurisdictions around the world.

Potential standards-related solutions were developed following Stage 4. Select industry experts were consulted to offer comment on these potential standards and provide further input on key considerations for the approach to using standards. The resulting research and recommendations are summarized in the following sections.

2.1 Research Limitations

This research was intentionally limited in scope in order to maintain the focus on increasing the use of recycled materials in manufacturing. Standards mentioned in interviews that were outside this scope included standards to limit the leakage of plastics into the environment, such as in-service shed maximums for clothing to reduce micro plastic shedding, filters

on washing machines/storm drains to trap plastic particles, and in-service standards to reduce tire dust. Bioplastics research was limited due to the study's focus on secondary resins and on increasing recycled content in manufacturing.

3.0 Current Flow of Recycled Plastics

3.1 The Many Uses and Recycling of Plastics

Plastic is everywhere, as is plastic waste. Segments of the Canadian economy generating these waste products during 2016 were examined by Deloitte in 2019 [1].

The popularity of plastic stems from its performance and wide applicability of uses across many sectors. From the lightweight advantages of plastics in cars for fuel efficiency to the food waste prevention benefits of plastics in food packaging, plastic is the material of choice for many uses. Given the wide and growing use of plastic, end-of-life management concerns are mounting.

Currently, 91% of plastics move in a linear fashion of “make-use-dispose” [1]. When considering post-consumer recycling, under 1% of all plastic ever made has been recycled more than once [5]. This reality is markedly different from the Ellen MacArthur Foundation's New Plastic Economy goal, which envisions “a circular economy for plastic in which it never becomes waste” [6].

3.2 Case Study: How the EU is Increasing Plastics Recycling

Plastic waste is not unique to Canada. Growing amounts of plastic waste and the resulting environmental impacts are a global concern. To increase the percentage of products recycled, the European Union has enacted waste regulations that cite specific targets [7]. These targets are percentages of recycling required out of all waste produced and are tailored by waste stream. For all municipal waste, a long-term target of 65% recycling is set for 2035. For packaging, a higher target of 70% recycling is set for five years earlier in 2030. For plastic specifically, a lower recycling target of 55% is set for 2030. Prior to reaching the long-term targets, intermediate targets are defined in 5% increases over five-year intervals. This requires all municipal solid



“Products containing plastic are discarded widely throughout Canada when they reach their end-of-life. To be recycled, this plastic waste must be diverted from landfills, incineration, and the environment.”

waste to reach 55% recycling by 2025, 60% recycling by 2030, and finally 65% by 2035; packaging to reach 65% recycling by 2025 and 70% by 2030; and plastic to reach 50% by 2025 and 55% by 2030.

“A European Strategy for Plastics in a Circular Economy” under the Circular Economy Action Plan (revised in 2020) outlines the future of a “smart, innovative, and sustainable plastics industry where design and production fully respects the needs of reuse, repair, and recyclability” [8]. Specifics of the plan include ambitious targets for 2030, including recycling more than half of all European plastic waste and the following goals:

- Ensuring all plastic packaging in the EU is reusable or recyclable in a cost-effective manner;
- Recycling more than half of all European plastic waste;
- Sorting and recycling capacity will have increased fourfold as compared to 2015;
- Phasing out of plastics manufacturing substances that hamper recycling; and
- Increasing demand in the market for recycled plastics fourfold.

Planning for a circular economy in Europe starts early in the value chain by ensuring plastics are designed for recyclability. However, metrics that measure only the recycling rate only consider the end of the value chain and may miss the impacts of waste reduction programs

and policies. Alternatively, introducing metrics at points along the value chain could provide further insight into progress towards the larger goal of decreasing plastic waste. For example, measuring a decrease in the amount of plastic products produced would provide insight into the efficacy of banning plastic, and measuring the percentage of plastic bottles recycled into plastic bottles more than once would provide insight into true circularity gains but would require manufacturers and brand owners to report on materials produced and imported.

3.3 Recycling Process Overview

3.3.1 The Challenge of Collecting Plastics for Recycling

Products containing plastic are discarded widely throughout Canada when they reach their end-of-life. To be recycled, this plastic waste must be diverted from landfills, incineration, and the environment. Depending on the source, plastic waste to be recycled is classified as post-consumer or post-industrial (also called pre-consumer).

As illustrated in Figure 3, plastic products enter the waste stream through a collection process and are then transferred to a sorting facility or directly to a reprocessing facility. Collection is conducted through a mixture of methods, including public and private collection systems and drop-off locations that include recycling

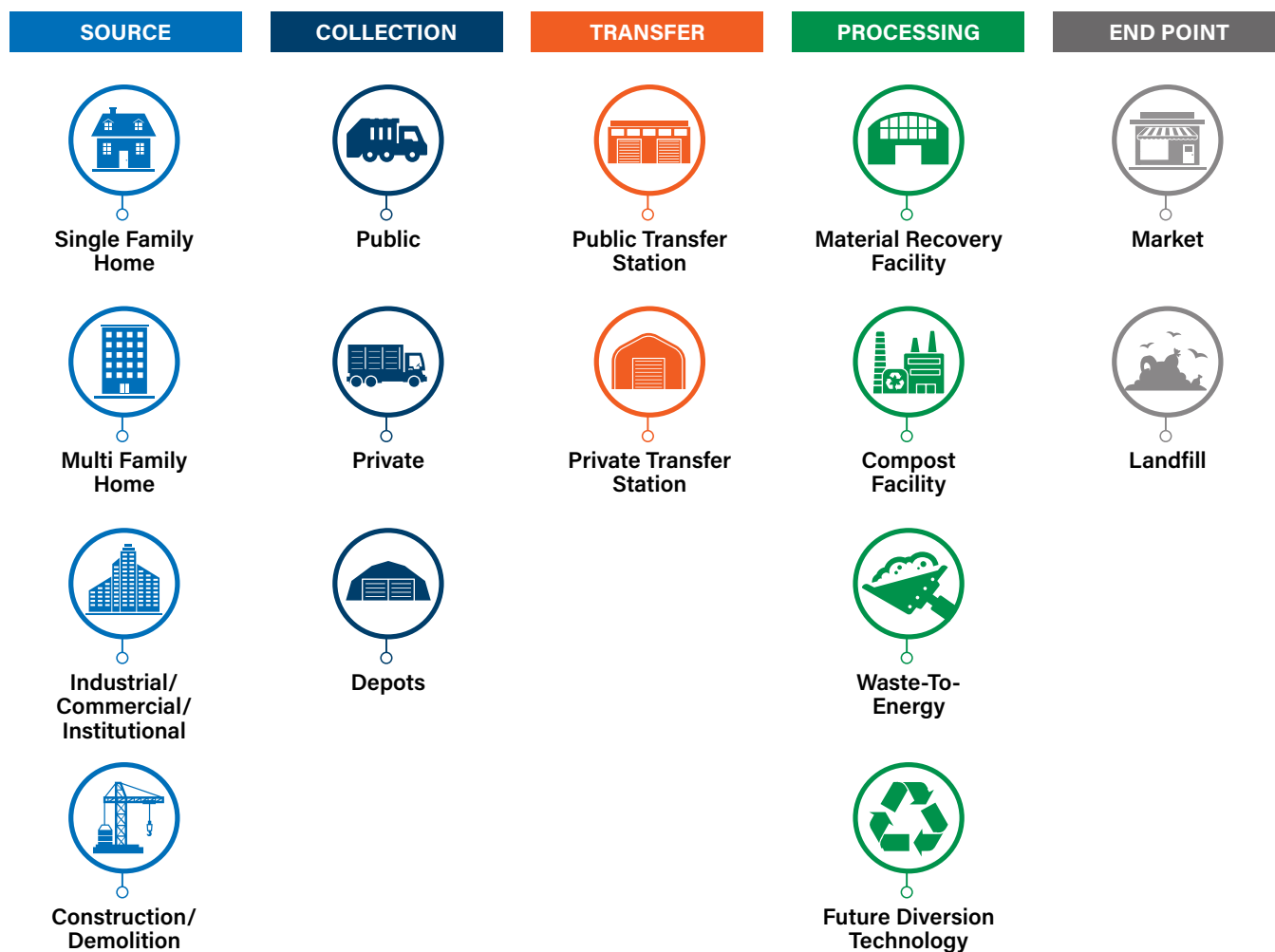
depots, eco-centres, and retail locations. It is during this collection process that many different materials are mixed together for efficiency in transportation. Material recovery facilities then sort materials into commodities that they can sell into material markets.

From the transfer station, the plastic waste goes to its processing location. Depending on the collection point and method of processing, the routes that plastic waste take can vary.

— 3.3.1.1 Material Recovery Facility (MRF)

At material recovery facilities (MRFs) throughout Canada, waste plastic is sorted by type and then baled for transport to its respective domestic or international commodity markets. Each MRF receives a different mix of plastic waste and uses a combination of human labour and sorting technologies. Smaller local MRFs with limited supply often complete a limited sorting to remove non-valuable materials then transfer recyclables to larger regional MRFs that have the size and technology needed to produce higher value materials. In recent

Figure 3: Solid Waste Management – Flow Diagram



years, a few container recovery facilities (CRFs) and plastics recovery facilities (PRFs) have been established that focus on high grading the mixed plastics that come from MRFs. This has enhanced the market value of post-consumer plastics by reducing contamination and improving colour separation.

— 3.3.1.2 Compost Facility

Biodegradable plastics, such as PLA, can be composted given the correct industrial composting conditions and are considered to have a role in many specific applications, including food packaging. However, these materials can also become easily mixed in, or confused, with non-compostable plastics and become a contaminant to recycling. If discarded into the environment, PLA will not necessarily break down in the absence of conditions found at an industrial composting facility.

— 3.3.1.3 Waste to Energy

Plastics are also processed by capturing their energy content through combustion processes. Depending on the combustion process, plastic and mixed waste are typically not sorted and can be burned together.

— 3.3.1.4 Other Diversion Technology

Mobile thermal conversion facilities exist and can travel to locations where the plastic waste can be recycled into another product and diverted from disposal.

The supply chain for recycled plastics requires a connection between all the above-noted processes. For a plastic to be recycled, it must first be considered an accepted material in the collection program. Once collected, the specific material must reach the processing facility either directly or after being consolidated at a transfer station. At the MRF, the plastic must be targeted for sorting and sale to markets.

3.3.2 Sources of Plastic Waste

Different sources generate distinct waste streams. The waste plastic materials from each source can be separated for recycling. Major waste streams for plastics recycling feedstock include residential waste; durable goods waste, ICI waste, CRD waste, and agricultural

waste. Within each waste stream there is a different mix of plastic products:

- Lightweight and small-size packaging are found in residential waste;
- Automotive waste in the form of end-of-life vehicles are collected in their own stream;
- Electric and electronic equipment are mostly collected and processed separately from other waste streams, but a limited number of items can be found in residential, ICI, and CRD waste;
- Textiles post-use are found in residential streams, pre-use in ICI streams, and in donation centre waste after items collected cannot be sold;
- Plastic building materials both pre- and post-use are found in construction waste from CRD sources; and
- Post-use white goods, including home appliances, are collected in their own stream as are agricultural plastics.

Each waste stream has different pathways to material recovery and recycling, resulting in different mixtures and qualities of recycling feedstock.

— 3.3.2.1 Post-Consumer Waste

Residential, durable goods, CRD waste, and agricultural plastic waste streams contain plastic products that can be recycled into post-consumer resin (PCR). These are varied, and often contaminated, sources of plastic feedstock requiring additional layers of sorting prior to recycling. There are emerging processes that take mixed recycling from residential waste and recycle it into products with a limited amount of sorting, as well as conversion processes that take the plastic feedstock back to fuel or utilize it as a fuel substitute.

Durable goods containing plastics that have reached their end-of-life after residential use are collected as separate waste streams. These products include waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELV), and white goods (appliances). When recovered, these products can be shredded and the plastic is separated from other metals. Prior to recovery, hazardous components must be removed, which may include mercury, asbestos, and refrigerants.

— 3.3.2.2 *Post-Industrial/Pre-Consumer Waste*

One of the sources of plastic coming from this stream are the scrap cuts of plastic created by plastic manufacturers. This is a clean and often uniform source of plastic feedstock used to make recycled post-industrial plastics, also called pre-consumer resin.

In addition to pre-consumer scrap cuts of plastic, ICI waste also includes varied post-use sources of plastic feedstock that can potentially be highly contaminated. Some plastics in use at ICI locations are contaminated to a level prohibiting recycling and have no, or minimal, diversion opportunities. Medical waste, for example, falls into this category.

3.4 Plastic Stewardship and EPR Programs

Plastics recycling is done via stewardship programs and extended producer responsibility (EPR) programs for many of the plastic waste categories throughout Canada. Overall, both stewardship and EPR programs promote environmentally conscious waste management. In the European Union, widespread EPR directives since the early 2000s have positively impacted global supply chains, ensuring that manufacturers, importers, and distributors take responsibility for the waste their products generate [9].

Stewardship is defined by the Canadian Council of Ministers of the Environment (CCME) as programs where manufacturers and brand owners are not directly responsible for recycling program funding or operations, but are funded by consumers or operated by public agencies or administrative organizations [10]. Stewardship can be voluntary or required by legislation; in some version of stewardship programs, costs are directly passed on to the consumer such as bottle deposits. EPR programs are defined as policy approaches that require a producer to be responsible for its products’ entire life cycle and that are usually mandatory. Introducing an EPR can result in harmonized collection systems, since the systems are typically based on product categories such as packaging, electronics, and large appliances, which all contain plastics as well as other divertible materials. The recycling of plastics resulting from stewardship and EPR programs is varied across and within provinces. As a policy tool, an EPR program is implemented through product takebacks, collection schemes, recycling targets, or deposit-refunds. In all cases of EPR programs, the costs associated with disposal are placed back on the consumer or the producer [11], which has proven to incentivize recyclability.

Table 2: Packaging and Printed Paper Recycling Programs in Canada

Province	Year Est.	Summary of Producer Responsibility	Additional Details
British Columbia	2014	100% producer responsibility for cost of collecting and processing recyclable materials	Municipality responsible for collection of some items, program collection for other items. Program responsible for processing and marketing recyclables.
Manitoba	2010	80/20 industry/municipality cost share	Municipalities responsible for collection, processing, and marketing recyclables.
Ontario	2004	50/50 industry/municipality cost share * transitioning to 100% EPR by 2025	
Québec	2006	100% producer responsibility for cost	
Saskatchewan	2015	75/25 industry/municipality cost share	

3.4.1 Packaging

Packaging to protect and transport items is often designed for a single use. The consumer discards the packaging as soon as the product reaches its destination. This results in plastic packaging having a useful lifetime of approximately six months [5]. Several provinces in Canada have EPR programs that focus on collecting packaging and printed paper (PPP) for recycling from consumers. Plastic packaging is collected for recycling as well as paper, glass, steel, and aluminum packaging. The history of provincial programs is listed in Table 2 [12].

The objective of these programs is to collect consumer waste packaging, often through programs operated by municipalities. Plastic packaging waste also exists within other segments, including construction, vehicle, and agriculture; the packaging used in these segments is not covered by programs focused on consumers.

3.5 Industry Recycling Practices

The secondary use of recycled plastics can be influenced by their initial use in part due to material properties created in their first use and due to the systems in place to collect and process the material. Table 3 summarizes industry best practices for recycled plastics based on their first use.

Table 3: Examples of Plastic Use and Industry Best Practices

Plastic Use by Industry	Industry Best Practices for Recycled Content Plastic Use
Automotive	
<p>End-of-life vehicles (ELVs) are now covered under an Ontario EPR program. In 2016, Ontario enacted Ontario Regulation 85/16 requiring environmentally responsible waste management for vehicles [13]. The regulation mentions metal but does not mention plastic waste. When using plastic in automobiles, the plastic is in use for approximately 10 to 16 years most of the time [5].</p> <p>In the United Kingdom, regulations were introduced to recover materials in ELVs requiring 85% of weight to be recycled. Simply recovering metals did not meet the regulatory requirements. This led to a joint venture between European Metal Recycling Ltd. (EMR) and MBA Polymers where automotive shredder residue recovers the plastic shredded.</p>	<p>Volvo unveiled specially made recycled plastics in its XC60 T8 plug-in hybrid SUV to demonstrate its commitment to use at least 25% recycled plastic in every newly launched Volvo starting in 2025. Volvo also adheres to the European Union’s End-of-Life Vehicle Directive 2000/53/EC requiring that 85% of the vehicle (by overall weight) is recycled [14].</p> <p>Recycled content in new car bumpers from old car bumpers is an example of closed-loop recycling by Toyota. Recycled content in new mud guards from old car bumpers is an example of open-loop recycling by Honda [15].</p>
Electric & Electronic Equipment	
<p>Most plastic used in electric and electronic equipment is in use for 6 to 10 years [5]. In Canada, 10 provinces and one territory have WEEE product stewardship and/or EPR programs. In Alberta and the Northwest Territories, televisions and printers, scanners, and copiers are collected for recycling. In Manitoba, New Brunswick, Newfoundland and Labrador, Ontario, Nova Scotia, Prince Edward Island, Québec, and Saskatchewan, programs also collect cellular phones, audio equipment, cameras, and video equipment. The most extensive program exists in British Columbia where additional electric and electronic items are collected.</p> <p>The European Union leads in electric and electronic recycling due to legislation in 2003 directing Member States to enact EPR programs for electronics. This WEEE directive also requires that electronics being sold in all European Union nations to include the WEEE logo, indicating that the electronic is not to be put into the landfill waste stream.</p>	<p>Electronic manufacturers use recycled plastic both for their products and their packaging. Apple releases environmental reports for its products and aims to use only recycled or renewable products. In the 13-inch MacBook Air environmental report from 2018, Apple used 35% recycled plastic in the speaker, 45% recycled plastic in the vent, and 87% less plastic packaging than for the 2017 MacBook.</p> <p>Manufacturers also increasingly collect their products. For example, Hewlett Packard has offered free collection for ink cartridges which it has been turning into new cartridges since 2002. In 2018, Apple expanded its collection and recycling of iPhones by introducing a return to retail program. iPhones can be dropped off for free at stores for recycling and customers can receive a discount on a new phone purchase. Phones to be recycled are reported to be dismantled by a recycling robot named Daisy which can dismantle 15 different iPhone models at the rate of 200 per hour [16]. When manufacturers collect more plastic than they can use themselves, they are able to offer this to the recycled plastic market. For example, Dell Canada both buys recycled plastic to use in manufacturing and sells the plastic from products returned to Dell. Dell uses an average of 30 to 35% recycled content in new products.</p>

Plastic Use by Industry	Industry Best Practices for Recycled Content Plastic Use
Textiles	
<p>The textiles industry is emerging as both a user and provider of recycled plastics. In addition to long-established used clothing collectors, major label clothing producers, including H&M Group, now have textile return bins in their stores accepting clothing from any brand. This is an example of a voluntary return-to-retail stewardship program operating in every H&M store.</p> <p>Two Canadian municipalities have banned textiles from their landfills to encourage textile recycling. In Markham, ON, and Brandon, MB, clothing is collected for recycling. As part of a national study with 160 municipalities in Canada, Diabetes Canada and York University are currently focusing on how textile diversion impacts municipalities [17].</p>	<p>Patagonia has been an industry leader in recycled content since 1993 when it started making fleece from soda bottles recycled into polyester. Patagonia continues today as an industry leader: it began using 69% recycled content in its fabrics in the fall of 2019 with a goal of using 100% recycled or renewable materials by 2025. Patagonia uses its own recycled fleece to make its new fleece, with some fibres coming from Unifi, a leader in recycled textiles supplying nearly 100 brands.</p> <p>Unifi’s three recycled polyester yarns are made from recycled plastic bottles, a hybrid of recycled bottles and pre-consumer fibres, and a hybrid of plastic bottles and post-consumer fibres.</p>
Construction	
<p>The construction industry, for both residential and commercial development, relies on the functionality of plastic for constructing, remodelling, and demolishing structures. Plastics used include permanent building materials, plastics used during work phases, and single-use plastic packaging. When plastics are used in permanent building materials, the plastics will remain in the buildings for decades. The average length of time in use is 35 years [5].</p> <p>The plastic products used in construction are growing as plastic alternatives are approved for traditional construction materials, including wood. One example of voluntary building producer responsibility is the Vinyl Council of Australia’s member Armstrong Australia that is collecting manufacturing offcuts and end-of-life flooring material containing polyvinyl chloride [18].</p>	<p>Advanced Drainage Systems provides pipes, fittings, and chambers that are made from up to 60% recycled plastics. Through its subsidiary, Green Line Polymers, Advanced Drainage Systems has become the largest consumer of recycled #2 HDPE products in the United States [19]. The installed recycled pipes are reported to have a lifespan of over 30 years.</p>
White Goods	
<p>White goods include large kitchen appliances and heating, ventilation, and air conditioning items, which are collected for recycling in a variety of ways across Canada. In some areas, refrigerators, dishwashers, stoves, washers and dryers, furnaces, and hot water heaters can be dropped off or picked up for free either by municipalities or by producers.</p>	<p>In 2008, Electrolux’s Green Collection launched a vacuum cleaner made from 55% recycled plastic.</p>
Agriculture	
<p>Agricultural uses of plastic are wide and varied, including weed suppression, row coverage, silage wrap, pesticide and fertilizer containers, large containers up to 23 litres, plastic bags, twine, and more. In Canada, Clean Farms is a stewardship organization operating in six provinces to recycle agricultural waste, including plastics [20].</p>	<p>Plastic agricultural film can be turned into moulded products made of 100% recycled plastic such as landscape timbers, fencing, planking for farm pens, roadside posts, benches, and picnic tables. Envorinex is an Australian manufacturer of recycled plastics, taking agricultural plastics from farms and turning them into fence posts for farms [21].</p> <p>Agricultural waste has been known to have its own unique issues since 1995 when the Ontario Ministry of Agriculture, Food and Rural Affairs released a fact sheet discussing the challenges of recycling agriculture plastic waste and packaging. These challenges include dirt, sand, stones, grease, vegetation, water, other types of plastic, glue, tape and ultraviolet (UV) light degradation. All these contaminants require large amounts of water to clean products prior to recycling. Ak Inovex in Mexico applied for a water-free patent in 2015 [22]; and Plastic Forests in Australia cleans agricultural plastics using no water [23].</p> <p>In Canada, Merlin Plastics will accept agricultural plastics with less than 10% contamination [24]. All agricultural plastics accepted must be segregated.</p>

Plastic Use by Industry	Industry Best Practices for Recycled Content Plastic Use
Other Sectors	
Plastics in this category range widely across all other products containing plastics that do not fit into the above categories. This includes plastics used in toys, sporting goods, personal care, household furniture, mattresses, medical and dental areas, industrial machinery, and chemical products [3].	Sources of plastic waste are not always immediately obvious. For example, toys are one category of product producing other plastic waste. The world’s largest toymaker, Lego, has pledged to replace all its oil-based plastics by 2030 [25]. Furniture is also a source of plastic waste. Ikea has initiated a national Buy-Back Program to provide store credit for used items that can then be refurbished and resold or recycled [26].

3.6 Recycling Methods

Pathways to recycled content can be through mechanical recycling, purification recycling, molecular decomposition, and conversion technologies. The most frequently used and economically viable pathway for recycled content in Canada is through mechanical recycling with 97% of recycled content being mechanically recycled. Mechanical recycling uses many methods of washing waste plastics. Purification recycling and molecular decomposition are collectively referred to as “chemical recycling.” In purification, contaminants such as additives and colourants are removed from waste plastic using solvents. Purification recycling keeps the plastic molecules intact, not breaking the molecular bonds in polymer chains. Molecular decomposition, also commonly called chemical recycling, does break apart the molecular bonds of the plastic polymer chains.

Chemicals, thermal processes, and biological processes can be used to depolymerize plastic that result in monomer building blocks from which new plastic can be made. Conversion also depolymerizes plastic and can produce a petrochemical product that can be reused to make recycled resin or to make a liquid or gas fuel then used for other purposes.

The terminology associated with plastics recycling and recovery is not standardized across the industry. For example, the practice commonly known as “closed-loop recycling,” where a product is reprocessed into a product with equivalent properties, is interpreted by some industry members as reprocessing into any product. Table 4 illustrates existing standards and definitions referring to the same process by different names [27], [28], [29].

Table 4: Terminology of Plastics Recycling and Recovery Across the Industry

Plastics Industry Terms	ASTM Definitions	ISO Definitions
Mechanical Recycling: Closed-loop recycling	Primary recycling	Mechanical recycling
Mechanical Recycling: Open-loop recycling Downgrading Downcycling	Secondary recycling	Mechanical recycling
Purification Recycling (Dissolution) & Molecular Decomposition (Depolymerization)	Tertiary recycling	Chemical recycling
Conversion: Valorization Pyrolysis Gasification	Quaternary recycling	Energy recovery



“Mechanical sorting technology is constantly advancing to improve speed and accuracy. The industrial-scale optical sorting technology in use at MRFs today holds the promise of even more precise and faster sorting in the future.”

Recycling definitions often do not recognize conversion technologies as a form of recycling as plastics are turned into fuel or synthetic gas (syn gas) rather than becoming inputs to newly manufactured products. Technical, economic, or commercial challenges can limit the feasibility of each of these methods.

3.7 Innovative Approaches to Recycling

New technologies currently in development have the potential to transform aspects of existing recycling systems, including additives, digital watermarks, and robotic sorting. For example, additives including opalescent markers could be added to plastics with specific built-in messages enabling infrared sorters in MRFs to more precisely sort recyclables. Additives to identify and track plastic could be used to more precisely follow a plastic product through its life cycle and connect it to blockchain technology for tracking through multiple recycling iterations. Invisible watermark barcodes printed or embossed on plastic packaging could also track plastics in databases across multiple recycling iterations. Robots with AI are now able to sort recycling by identifying packaging details such as logos and images, allowing for more precise automated sorting. Robots in development promise to be faster and more accurate than human sorters who are limited to picking 30-40 items per minute from a conveyor belt.

Mechanical sorting technology is constantly advancing to improve speed and accuracy. The industrial-scale

optical sorting technology in use at MRFs today holds the promise of even more precise and faster sorting in the future. Vision technology can identify colours and shapes, near-infrared (NIR) technology can identify resins based on infrared (IR) absorption levels to separate look-alike plastics such as PET and PVC, and X-ray technology can identify additives in plastics. Using technology such as the National Recycling Technologies’ Multisort IR/ES Combo polymer sorting system will enable plastic sorting by colour. A major limitation with NIR technologies is the challenge in sorting black plastics due to light not bouncing back from black plastic; however, there are black plastic additives available to enable NIR sorting and technologies for sorting by colour.

There are two chemical recycling methods that can be employed to increase the purity of the materials produced. In purification recycling, chemical solvents decontaminate and purify polymers to a level not achieved through mechanical recycling methods. In molecular recycling, thermochemical processes break plastic polymers down into their building blocks (monomers) which can then be further refined and repolymerized to produce virgin-equivalent resin. Separation of polymers may not always be exact and cross-contamination of polymers can still exist in the final product.

There are new and innovative chemical methods still being developed today. New recycling methods are initially tested in labs, and after testing is successful,

methods move onto piloting and commercial-scale applications once economic viability has been proven.

The ability to clearly calculate material inputs and outputs used in different recycling pathways would serve as a basis for comparison and traceability. Along with the energy required for recycling, this would create a way to compare new, promising technologies and confirm that recycled content has truly been achieved.

3.8 Current Use of Recycled Materials in Plastics Manufacturing

Over the past 50 years, virgin plastic has become increasingly a product of choice over recycled plastic due to the purity and price of virgin resin. Using recycled plastic in packaging and products which have always used virgin plastic in the past requires additional product research and development. Numerous colours, grades, and form-factors of recycled plastics exist for each of the resin types (as described in Section 2.3.1). Manufacturers must consider the products in which the recycled content is going to be used in order to determine appropriate substitutions of recycled resins. Research has uncovered specific concerns with recycled product differences such as yellowing for white plastic bottles, lack of durability for outdoor products, lack of softness for textiles, and many generic concerns related to product properties. In all cases, continued research and development was cited as the solution to overcoming barriers to using recycled content.

There is great importance placed on maintaining high levels of health and safety when incorporating recycled

content into products previously made with virgin content. The largest concern is with food applications and obtaining a No Objection Letter from Health Canada which states there are no deficiencies within clinical or quality aspects of the product. There are also concerns expressed that plastics containing hazardous substances need to be sorted out during material recovery without fail as recycling this content into new products might have inherent risks such as further exposure to harmful substances. Therefore, there is a need to reliably remove these products from the recycling stream or to have a process to decontaminate recycled plastic before it is reused.

At the end-of-life stage, as the level of complexity of the plastic product increases (colourants, additives, different material types, and multi-layer materials), recycling becomes more challenging. One challenge is the difficulty in efficiently separating material streams. Another challenge is that a product containing plastics may be incompatible for recycling due to its design.

In all cases, the exact properties of a recycled resin will determine the range of secondary plastics able to be manufactured from the recycled resin. See Appendix B for a sample of products incorporating recycled content.

3.8.1 Leaders in Adoption of Recycled Content

Several brand owners have voluntarily committed to adopting recycled content in their newly manufactured products over the coming years. Table 5 summarizes commitments from companies that have pledged to

Table 5: Examples of Brand Owners Designing for the Environment

Company	ISO Definitions
The Coca-Cola Company [30]	<ul style="list-style-type: none"> Global plastic packaging will be 100% reusable, recyclable, or compostable by 2025
L'Oréal [31]	<ul style="list-style-type: none"> 50% of plastics used in packaging will be recycled content or biosourced
Marks & Spencer [32]	<ul style="list-style-type: none"> Simplified plastic resins used in private label packaging Removed microbeads in products
Patagonia [33]	<ul style="list-style-type: none"> Use of recycled polyester made from soda bottles to create fibres for clothing Polybags for packaging will be made of 100% recycled content in 2020
PepsiCo [34]	<ul style="list-style-type: none"> Design 100% of packaging to be recyclable, compostable, or biodegradable by 2025 Use 25% of recycled content in plastic packaging by 2025

design more sustainable products as signatories of the Ellen MacArthur Foundation's New Plastic Economy Global Commitment. Over 450 signatories, including packaged goods companies, plastics producers, recyclers, and governments, have committed to the following three-pronged vision:

- Eliminating problematic and unnecessary plastic items;
- Ensuring plastics are reusable, recyclable, or compostable; and
- Circulating plastic items to keep them out of the environment.

Many of the world's largest consumer goods companies have made commitments to reducing packaging waste and making their production of plastic transparent to the public, including their use of recycled content [35]. On average, these companies have committed to using 25% recycled content in their packaging by 2025. Taken together, this will result in an unprecedented demand of 5.4 million tonnes of recycled plastic by 2025.

Berry Global, the world's third largest plastic packaging producer (by revenue), reports that the limited supply of recycled plastic has limited its commitment to 10% recycled content by 2025. The rates of recycled content possible in plastic packaging are illustrated by its new line of personal care packaging, where 25 to 100% of the packaging uses recycled content. This product line includes PET bottles, HDPE bottles, PE tubes, PP jars, and PP caps and closures.

Commitment to plastics recycling is supported by many environmental non-profit groups which bring members together to collaborate, share best practices, and commit to change. The Ellen MacArthur Foundation, Sustainable Packaging Coalition, Surfrider Foundation, American Chemistry Council (ACC), Textile Exchange, and Alliance to End Plastic Waste are some of the many organizations working for the more sustainable use of plastics.

Countries have also made commitments to reduce packaging waste. For example, Norway has a positive reputation for its plastic bottle recycling rate. Tax regulations are placed on producers of plastic bottles to

incentivize recycling, where the more bottles recycled, the lower the tax. At 95% recycling, the tax reduces to zero. Norway has had a collective recycling rate of over 95% since 2011 with 92% of plastic bottles being recycled back into plastic bottles. Over the past number of years, it is reported that closed-loop recycling of bottles has been achieved more than 50 times [36]. However, the cost of this method of recycling limits the application to under 15% of material collected.

3.8.2 New Markets for Secondary Uses

Designing plastic products is a growing area for recyclers who aim to earn better margins than are available from selling plastic pellets. These manufacturers are not replacing the plastic products they previously manufactured using virgin plastics. They are designing new products that can be created using recycled plastics. This innovation takes the recycler beyond manufacturing pellets and makes them a plastics product manufacturer. For example, widely used recycled plastic products, including single-use plastic carry bags, have been piloted in programs using recycled plastic in construction materials, roads, and more. Oftentimes, a recycler of products used in a certain industry will design closed-loop recycling solutions for its industry.

— 3.8.2.1 Finding and Growing a Demand Niche for Bioplastics

One emerging trend in plastics today is the use of biodegradable polymers, which can be composted, and plant-based bioplastics, which cannot be composted. Biodegradable bioplastics, which are compostable, are emerging as promising materials in specific food packaging areas. Two compostable bioplastics are polyhydroxyalkanoates (PHA) and polylactic acid (PLA). PHA is compostable while PLA is both compostable and recyclable. Other non-biodegradable bioplastics exist. Biodegradable bioplastics are promising for use in multi-layer packaging where food residue remains on the packaging. For example, compostable stand-up food pouches were designed by the VTT Technical Research Centre of Finland where all but one layer was designed to be compostable [37]. This design enables the biodegradable bioplastic layers and food residue to compost, after which the recyclable layers are recycled.

4.0 Supply Chain Perspectives

Challenges of including recycled content in newly manufactured products fall into four main categories: (1) supply, (2) demand, (3) cost, and (4) quality. The supply and market demand of recycled plastics are impacted by the cost and quality of these products. Cost is often cited as one of the largest barriers to choosing recycled content. The increased demand for recycled plastic is a relatively new factor that has a strong capability to drive development of plastic recycling systems. Sections 6 and 7 that follow discuss the factors affected by demand and supply: cost and quality.

4.1 Refiners and Petrochemical Processors

Refiners and petrochemical processors are predominantly supportive of new additives and chemical recycling methods that would make recycling easier. Processors cite the recent advances in these technologies and the need for commercializing at scale as key factors in successfully increasing recycling in the future. Refiners and petrochemical processors acknowledge the low cost of oil and gas that can create inexpensive virgin resins to dominate the manufacturing industry.

4.2 Resin Producers

Resin producers have recycled resin product lines; however, these lines are currently a small part of their businesses. Supply of recycled resin is a key concern for those looking to increase recycled product lines. Resin producers find that most brand owners are focused on price, unless a brand owner specifically requests recycled content. Resin producers prefer the use of virgin resins which they have found outperform recycled content in all key performance measures. Resin producers are required to create plastic with specific features requested by their customers. Producers are confident that these specifications can be reliably met using virgin resin, but they perceive limitations to recycled resin material properties.

4.3 Product Manufacturers

Product manufacturers are supportive of including more recycled content in their products yet face barriers to doing so. One emergent theme is research and

development. Where the research and development for using virgin plastic has already been done, the research and development for using recycled content is expected to be an ongoing effort. To avoid the need for ongoing research and development, product manufacturers prefer recycled resins to have near-virgin material qualities where possible.

The changing landscape of plastic usage, regulations, and bans creates uncertainty for product manufacturers. As new bans come into place, manufacturers worry about the available supply for new product manufacturing. Product manufacturers are primarily concerned with replicating their current products to the same high-quality standards when using recycled materials. For example, recycled resins were found to be rougher than virgin resins in clothing manufacturing; recycled resins were more brittle and less durable; and recycled resins did not produce completely clear plastic that is often demanded for drinking bottles.

4.4 Recyclers

Recyclers recognize the potential to increase the recycling of plastic if more products were designed for recycling.

Mechanical recyclers are seeking practical approaches to open-loop recycling, approaches which take the plastic provided and process it into something new. Not all recyclers agree that recycled plastic can replace virgin plastic, suggesting that such perceived barriers need to be further investigated to determine what technical barriers exist in practice. Receiving approval for use of food contact was one example of a real barrier. Examples of open-loop recycling are provided in Section B.2 of Appendix B.

In many cases, recyclers are becoming recycled product manufacturers in addition to recycled pellet producers because higher margins are available in product manufacturing. When manufacturing a product out of recycled plastic that has never been manufactured before, there are barriers to obtaining accepted use for the product.

Purification and molecular decomposition (chemical) recyclers benefit from the near-virgin quality of their output, and they are challenged with ramping up



“Some environmental economists endorse the use of virgin material taxes to encourage the use of recycled materials. These taxes can narrow and/or equalize the relative cost of virgin materials versus recycled materials, making recycled materials more economically attractive.”

their businesses to be commercially viable. These organizations recycle plastic waste material that mechanical recyclers cannot, as they are taking the plastic back to a near-virgin state.

Conversion recyclers have cited their ability to take any plastic as input. For example, California's regulations exclude conversion from the definition of recycling thereby limiting the state's ability to increase plastic recycling as defined by the legislation.

5.0 Cost of Recycled Resin vs. Virgin Resin

Cost is considered a key challenge in the move from virgin plastics to recycled plastics. Recycled plastics cost relatively more in part due to low oil and gas prices. Recycled resins require collection and processing before the plastics can be made into a resin.

5.1 Collection and Processing Costs

Discarded plastics collected from single-family and multi-family sources are typically transported to a local MRF for sorting and baling. Most MRF sorting capabilities are limited, and this affects both the types and amount of material that can be collected and the unit processing costs, which are highly influenced by economies of scale.

In areas with single-stream recycling programs, the amount of sorting required by MRFs is more extensive

than in areas where recycling programs require a certain level of material source separation. Areas with source-separated collection require residents to provide an initial level of separation, which results in less processing at the MRF and less contamination in the product. Both programs produce variable mixes of plastics, along with items not intended for plastic bales, including food particles, paper, glass, metal, and other plastic resins. Plastics separation at the MRF can be manual, automated, or a mix of both.

5.2 Taxation of Virgin Material

Taxes were introduced in Sweden and the UK to discourage the use of virgin natural resources. In Sweden, the tax was introduced to reach a policy target of 30% gravel and 70% substitute in road construction and exceeded its goal with gravel dropping to 19%; however, the UK tax policy was considered inefficient. A motive for taxing virgin natural resources in these countries was to encourage the use of recycled materials. This is based on the fact that using virgin materials generally results in more negative externalities than using recycled materials [38].

Continued use of virgin materials will result in the continued growth of plastic waste. Some environmental economists endorse the use of virgin material taxes to encourage the use of recycled materials. These taxes can narrow and/or equalize the relative cost of virgin materials versus recycled materials, making recycled materials more economically attractive. By taxing the

front-end of production, as opposed to an end-of-life tax on waste, the taxation logistics can be less complicated to manage. Taxing the production of plastic could result in fewer parties needing to be taxed, would not introduce additional incentive for illegal disposal to avoid end-of-use taxes, and could be used in conjunction with waste-disposal taxes. However, any tax placed on Canadian producers should consider the economic and competitive impacts on an industry with a high level of export and international trade.

6.0 Quality of Recycled Material

In addition to cost, another reason why virgin resin is chosen over recycled resin is due to quality. Recycled resin is described as having the potential for issues with quality and inconsistency.

6.1 Sorting Technology and Baling Gaps

Sorting technology itself can introduce challenges in recycling plastics. For example, in some areas in Canada, including Toronto, black plastics are not able to be sorted by optical sorters because carbon black plastics absorb light instead of reflecting it back to the sensor [39]. Due to this technological limitation, black plastic is not accepted in Toronto's blue box recycling program. As part of the New Plastics Economy Global Commitment, brands are staying away from using black plastic. For example, Nestlé has committed to eliminating carbon black coffee capsules in the first financial quarter of 2020.

The new resin PLA also presents waste management challenges when discarded. PLA was developed to be either composted or recycled. A compost facility may not have the required industrial composting technology to biodegrade the plastic. A sorting facility using human labour for manual sorting may not be able to identify and remove the plastic due to its visual similarity to conventional plastics. Compostable plastics could therefore add a source of contamination to recycled plastics. The similarity in look of compostable plastic, including PLA and PET, could affect the sorting's effectiveness. An automated technology, such as optical sorting, would be required to differentiate these two materials in water bottles. Failing to remove

PLA from mechanical recycling processes could damage machinery since PLA has a lower melting temperature than PET, causing it to melt too early when moving through the recycling process. The amount of biodegradable plastics in waste streams today is very low; however, the use of compostable bioplastics and bioplastics is expected to increase in coming years and this will have impacts on recycling systems.

Once materials are sufficiently sorted, plastics are condensed into marketable bales to be sold into plastic commodity markets. Variable degrees of sorting technology and user-introduced contaminants result in a range of qualities available for baled plastic. Due to the large degree of variability in bales produced by different MRFs, marketing materials often require discussions and photos sent between buyers and sellers. A bale of low-quality plastics may result in the need to further sort already baled plastics before they are recycled.

6.2 Contamination from Prior Usage

Recycled plastics contain levels of contamination not present in virgin plastics, even with MRFs and recyclers following best practices in sorting and baling. One source of contamination is related to the recycled products' prior use. Depending upon the source, post-consumer plastics contain different residuals, which can include spoiled food, perfumes, paints, and soil. Post-industrial scraps of plastics have not been used by consumers and do not have any contamination introduced from usage and therefore are often considered to be of higher quality for recycling.

6.3 Contamination from Additives

The way a product is designed can have a large impact on the quality of the resulting recycled plastic when that product reaches its end-of-life. Many additives are mixed into plastic to improve specific performance properties. Each filler changes the plastics' properties, and recycled plastics with these additives will not perform the same as virgin plastics. Examples include calcium carbonate, talc, glass fibre, UV stabilizers, DEHP phthalate plasticizers, and metals [40]. Another example is additives that limit the flammability of plastics since plastics are naturally flammable.

In some cases, the resulting contamination is so significant that regulations prevent the recycling of plastics containing certain additives.

6.4 Contamination from Colourants

Another contaminant that negatively impacts quality comes from colourants added to plastic, which are used to adjust a plastic's colour and appearance. Unless sorted by colour, recycling plastics from mixed colours results in a grey-coloured recycled product. Due to the mixing of colourants, plastic products requiring specific aesthetic and branding needs are more easily manufactured from virgin resins. Before adding colourants, virgin plastics come in different colours that include naturally white opaque for PVC, white waxy semi-transparent for PP, and dark transparent for PET. As part of the New Plastics Economy Global Commitment, brands are moving away from colours. For example, Sprite bottles are changing from green to clear to make it easier to recycle the bottles into new bottles and increase the rPET to 50% in 2020.

6.5 Contamination from Multi-Materials

Plastics of a heterogeneous nature are another source of contamination. Different types of polymers are mixed or layered together to create a plastic product with a blend of strength, flexibility, and weight. These mixed products then enter the recycling stream with polymeric contamination. When creating secondary resins, these first-use desired blends of plastic polymers create uncertainties in the quality of the secondary plastics. Increasingly, mono-material laminate is being chosen under the New Plastics Economy Global Commitment. For example, chocolate maker Ferrero is moving to mono-material plastic films that will increase the quality of the recycled plastic coming from its chocolate packaging.

7.0 Designing Products for Recyclability

Design choices of plastic products matter, especially when these products reach their end-of-life and enter the waste management stream. The initial design of a plastic product can either enhance or reduce its end-

of-life recyclability. Thermoset plastics are only able to be shaped once, so this type of plastic is not recyclable through mechanical recycling. Thermoplastics, on the other hand, are theoretically recyclable, however design choices such as those mentioned above may hinder their recyclability.

A sustainable, circular future is one in which the design of a product does not limit the material's subsequent uses. However, in today's linear economy, brand owners are designing plastic products that are regarded as unrecyclable due to the difficulty or cost involved in recycling. When brand owners provide detailed specifications to manufacturers without calling for end-of-use recyclability, the manufacturers produce products containing certain additives, colourants, and plastic types that can be difficult to recycle at end-of-life. Focusing on the design stage and explicitly considering how the choice of polymers, colourants, and additives influence the product's end-of-life is widely termed "designing for the environment." This is also known, more narrowly, as "designing for recyclability." Ensuring brand owners are responsible for the overall manufacture, use, and end-of-life management provides an opportunity to improve design to minimize these impacts and lead to more sustainable plastics.

Common practices in the design stage can be considered as contamination during recycling. For example, mixing resins during the manufacturing process is a source of contamination at the recycling stage. Combined with the addition of plasticizers, colourants, flame retardants, stabilizers, and metals, these product design choices at the very start introduce recycling challenges at the product's end-of-life.

Several plastic product design guides already exist and include those from the Association of Plastics Recyclers (APR), British Plastics Federation (BPF), European PET Bottle Platform (EPBP), Plastics Recyclers Europe (EuPR), RECYcling of Used Plastics Limited (RECOUP), the Consumer Goods Forum, and Wrap Recycling Action Program (WRAP). Common themes to improve recyclability and the supply of recycled plastic include using mono-polymers without additional additives [27]. A single polymer, such as a PET water or soda bottle,



“Several brand owners are currently designing for the environment, with voluntary commitments to produce more sustainable products made under the New Plastics Economy Global Commitment.”

can be melted and reformed an infinite number of times in theory. However, once colourants are added, it is a challenge to remove the colourant and this limits the markets for the recycled product.

Several brand owners are currently designing for the environment, with voluntary commitments to produce more sustainable products made under the New Plastics Economy Global Commitment. Especially in the use of packaging, it is becoming common for multi-national corporations to pledge to make their plastic packaging more sustainable. These pledges support a circular economy.

8.0 Existing Standards and Tools

8.1 Overview

Existing plastics-related standards come from a variety of sources and are influenced by activities that were occurring at the time the standards were developed. Due to the varying perspectives and priorities, standards from different sources may have inconsistent or opposing environment requirements, guidelines, and solutions.

National and international standards development organizations have developed standards that support recycling terminologies, classifications, and performance specifications. These organizations have general standards that can be considered for the Canadian plastics recycling industry.

The International Organization for Standardization's technical committee on the circular economy is focused on developing frameworks, guidance, supporting tools, and requirements for the implementation of activities of all involved organizations, and to maximize the contribution to sustainable development. ISO/TC 323, *Circular economy* focuses on public procurement, production and distribution, end-of-life, as well as wider areas such as behavioural change in society and assessment.

8.2 Characterization and Product Performance

Plastic properties and their performance vary widely. Manufacturers select plastics based on the application and desired performance. Important considerations for plastic properties include tensile strength, flexural modulus of elasticity/stiffness, Izod impact/toughness, heat deflection temperature, and water absorption [41].

Plastic properties fall into different categories such as physical, mechanical, thermal, electrical, and optical. Measurement of these properties allow for characterization of the plastics and comparison with other materials.

Performance standards test products by simulating their performance under service conditions. Prescriptive standards identify product characteristics that can be tested, such as material thickness, type, and dimension. In Canada, recycled plastics undergo the same testing and product standards as virgin plastics.

In Japan, specific recycled plastic standards have been developed and address recycled content considerations in targeted applications, including plastic wood, plastic pallets, median roadblocks, rainwater covers, and surveying stakes. The Japanese standards focus on the recycled plastic product replacing different materials such as wood or metal. Having similar standards in Canada would support manufacturers embarking on new markets for recycled plastic.

New markets for recycled plastics, such as in concrete blocks, are currently being developed in a limited scale in Canada. Working together with early stage innovators to standardize the performance required for recycled plastic blocks could encourage more recycled plastic manufacturing, other new recycled plastic products, and acceptance of recycled plastic blocks as an alternative material.

8.3 Terminology

There is a need to clarify and define terminology as it relates to plastics. Terms are different because they depend on an organization's perspective. For instance, the plastic recycling industry has terminology that focuses on packaging because plastic packaging accounts for nearly 50% of all plastic waste, whereas ISO 21067 – *Packaging – Vocabulary: Part 1 – General Terms* has terminology that is used differently because the perspective is from the packaging industry. Additional examples of standards are listed in Appendix B. A list of standard references with appropriate language should be developed for future regulations that are focused on recycled plastic packaging.

There are international standards such as ISO 14021 that guides the use of environmental terms. Industry and public sector organizations may need to develop their own definitions and glossaries in addition to referencing terminology standards defined by other organizations. For example, the Ellen MacArthur Foundation has been both endorsing the definitions of others and creating its own definitions in its work of promoting the circular economy. In 2013 the Foundation adopted the EU's definition of material recycling from Article 3(7) of Directive 94/62/ EC and the UK's Centre for Remanufacturing and Reuse definitions for all other recycling terminology used in the Foundation's report on the circular terminology [42].

The Association of Plastics Recyclers (APR) in the United States and Plastics Recycling Europe (PRE) agreed on a definition for "recycling" in 2018 [43]. The definition has four points and reads "the product must be made with a plastic that is collected for recycling, has market value and/or is supported by a legislatively mandated programme; must be sorted and aggregated into defined streams for recycling processes; can be processed and reclaimed or recycled with commercial processes; and becomes a raw material that is used in the production of new products."

8.4 Recycled Content

The validation of recycled content in products is of key importance to the industry to ensure that claims are comparable between products and manufacturers. Under existing standards, materials are quantified based on material purchase, shipping, and waste records that are used to calculate a mass balance with manufacturers typically claiming an average or minimum recycled content. Qualifying materials as recycled content relies on the ability to trace materials to their origins, which requires manufacturers and plastic recyclers to thoroughly document materials being used in manufacturing, including their provenance. Standards developed by the European Committee for Standardization and member committees provide guidance on the traceability of recycled plastics and frameworks for the development of recycled plastics standards.

8.5 Manufacturing Related

Although there is a perception that manufacturers can use virgin or recycled plastic resin when making new products, existing manufacturing processes are not usually tooled to immediately use recycled plastics. Limitations to using recycled plastics include specific properties such as colour, clarity, strength, and flexibility. The manufactured products' required properties often limit the manufacturers' choice of certain recycled resins or virgin resins. More research and development is required to adapt existing manufacturing processes to use recycled resins. Recyclers, on the other hand, have created new manufacturing processes, specifically designed for recycled plastics. These manufactured plastic products from recyclers are creating new markets

for recycled plastics; for example, ReGen Composites in Canada is making a renewable construction block [44] and recycler Replas in Australia is making a wide range of outdoor furniture [45].

While some brands and manufacturers are starting to design their products for recyclability, these efforts need to become normalized across the industry. Manufacturers require incentives to design their products for recyclability. Front-end design choices could limit contamination and make recycled resins perform as well as virgin resins. For certain industries, plastic product specifications have been created by industry organizations to provide guidelines that increase the recyclability of plastic. A significant challenge is manufacturing plastics for use in the food industry due to health and safety requirements.

8.6 Design for Recyclability

For waste plastics to be recycled, the product must be recyclable at its end-of-life. If manufacturers follow a design standard focused on recyclability, the spent plastic products could find a closed-loop recycling market after being collected and processed. An example of this is plastic water bottles, where spent bottles are remanufactured back into plastic water bottles again and again [5]. Design specifications to help manufacturers achieve recyclability should be created product by product. These specifications can help manufacturers make design choices for a circular economy.

Colourants in plastics can make waste plastics unsuitable for closed-loop recycling. Many colours are currently in use by manufacturers, but only a limited set would be considered highly recyclable. Limiting the use of colourants is an important consideration in the development of standards that address design for recyclability.

8.7 Bales

Buyers and sellers of plastics in the recycling industry negotiate individual specifications and requirements when transferring ownership of baled plastics. These specifications identify what is contained in the bale and the level of contamination that would be expected.

Industry-based specifications have already been developed to help standardize plastic bale quality. Bale specifications are tailored for specific plastic products. A wide range of bale standards in North America are written by the APR and cover products such as plastic bottles, flexible plastic film, and rigid plastic [46]. The Plastic Recycling Corp. of California (PRCC) provides specifications for bottles, and the American Chemistry Council (ACC) provides specifications for flexible plastic film [47]. More standards are listed in Appendix B.

8.8 Labelling

There is a long history of labelling plastic products. Despite public perception, the RICs (#1 to #7) embossed on most plastic packages are not recycling instructions but rather descriptions of the resin content. More information is required to better explain to the public the meaning of existing labels on products. To be recycled, plastics must be collected from consumers at end-of-use. Improvements in labelling could assist the public in sorting these materials thereby decreasing levels of contamination.

Voluntary adoption of consistent labels are underway in the United States and Canada to minimize contamination that is unintentionally introduced by consumers. The How2Recycle® labels provide consumers with recycling instructions and comply with the U.S. Federal Trade Commission's Guidelines for Environmental Marketing Claims [48]. How2Recycle® is an initiative of the Sustainable Packaging Coalition Industry Group, a group of stakeholders working together with GreenBlue, an environmental non-profit [49].

Table 6 provides examples of standard recycling labels that are currently in use globally. These labels indicate how to recycle a product and provide the instructions consumers need to recycle correctly.

Table 7 provides examples of voluntary recycling labels that support claims about recycled content. Standards provide the structure labels can use to reflect the tracking of recycled plastics, which ensure recycling claims are met according to label requirements. The labels also communicate which organization is making the claim to consumers so that the claim can be verified. Standards exist to provide consumers with the confidence that recycling claims are meaningful.

Standards also exist to track the flow of recycled plastic as it is being recycled to avoid virgin plastic being fraudulently labelled as recycled. A relevant standard when considering recycled content in plastic products is CEN EN 15343: *Plastics – Recycled Plastics – Plastics recycling traceability and assessment of conformity and recycled content*. This standard ensures that the plastic marketed as recycled has in fact been recycled.

Several third-party environmental claims also exist. For example, Global GreenTag is a certification company assessing the overall sustainability of a product. Recognized in Australia, New Zealand, Malaysia,

South Africa, Africa, SE Asia, and 70 other countries, Global GreenTag conducts life-cycle analysis and issues ISO 14025 compliant product declarations. These certifications are also LEEDv4® compliant (140-plus countries) and BREEAM® compliant (40-plus countries). Often, specific industries will have their own environmental performance standards, as in the case of the Textile Exchange. There are also standards that support companies wanting to make environmental claims about their products. Two examples are:

- ISO 14021:2016, *Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling)*

Table 6: Examples of Standard Recycling Labels







Symbol	Required	Application	Purpose
	Mandatory	Europe	Indicates separate collection for WEEE (e.g., household appliances, computers, lighting, toys, tools, and telecommunication electronics) [50].
	Voluntary	United Kingdom	Labelling system meant to communicate simple, consistent recycling instructions on packaging. Moving towards a binary labelling system compliant with ISO 14021 [51].
 Reproduced from: https://www.ademe.fr/en/node/276874	Mandatory	France	Label placed on any recyclable household packaging or product affected by EPR [52].
	Voluntary	United States	Standardized labelling system on best available recycling instructions on certain packaging products [48].
	Voluntary	Australasia	Standardized labelling system on recycling instructions on certain packaging products [53].
 Reproduced from: https://www.jcpra.or.jp/tabid/603/index.php	Mandatory	Japan	Label indicates material is recyclable plastic [54].

Table 7: Examples of Voluntary Recycling Labels

Name of Voluntary Label	Application	Purpose
Recycled Content Certification <i>DIN</i>	Germany	Denotes that recycled content has been calculated in accordance with DIN EN ISO 14021 and traceability is in accordance with DIN EN 15343 [55].
RCS 100 <i>Textile Exchange</i>	Global	RCS 100 – Recycled claim standard by the Textile Exchange is a chain of custody standard tracking recycled raw materials. This standard is used in the textile industry and is based on ISO terminology [39].
Global Recycle Standard <i>Textile Exchange</i>	Global	Goes beyond the RCS 100 standard to verify social, environmental, and chemical processing claims in the textile industry [56].
Certified Recycled Content <i>SCS Global Services</i>	Global	Specifies the minimum percentage of recycled content contained in a product [57].
Environmental Choice Label <i>EcoLogo</i>	Canada	Confirms that a product has been designed for the environment. A product's entire life cycle is required to meet strict environmental standards [58].
The Green Dot Trademark <i>PRO Europe</i>	Europe	Denotes that a financial contribution has been paid to a qualified national packaging recovery organization [59].

- ISO 14026:2017, *Environmental labels and declarations – Principles, requirements and guidelines for communication of footprint information covers environmental footprint communications and has requirements for verification procedures*

Please refer to Appendix B for a list of additional standards related to packaging.

9.0 Opportunities for Standard-based solutions, regulatory tools, and research

Several standards-based solutions are in existence that support plastic recycling globally. Standards can play an important role in promoting the demand for the recyclability of plastics. Harmonized guidelines, voluntary standards, and regulations can also support the demand for plastics recycling. The value of standards in the Canadian recycling market can reduce barriers to plastic recycling, as identified in Section 4, including cost, quality, and supply and market demand.

In 2018, the CCME released its Canada-wide “Strategy on Zero Plastic Waste,” which calls for “working with industry towards increasing recycled content by at least 50% in plastic products where applicable by 2030” [60]. The strategy has identified the following ten “results

areas” that will drive the development of future actions and orient collective efforts towards achieving zero plastic waste:

1. Product design
2. Single-use plastics
3. Collection systems
4. Markets
5. Recycling capacity
6. Consumer awareness
7. Aquatic activities
8. Research and monitoring
9. Clean-up
10. Global action

In 2019, the CCME approved the first phase of the action plan, which identifies the government activities that will support the implementation of the strategy [61]. The action areas in Phase 1 are:

1. Extended producer responsibility
2. Single-use and disposable products
3. National performance requirements and standards



“Standard-based solutions can support actions that result in zero plastic waste for Canada.”

4. Incentives for a circular economy
5. Infrastructure and innovation investments
6. Public procurement and green operations

Standard-based solutions can support actions that result in zero plastic waste for Canada. The following section in this report discusses the main factors required to build the structure required to improve the recyclability of plastics. The supply and market demand (as influenced by cost and quality) of plastic products and appropriate plastic resins are based on the dynamics of refiners and petrochemical processors, resin producers, product manufacturers, and recyclers. In order to improve this nexus, five categories of opportunities have been described in Section 10 that follows: (1) terminology standards, (2) regulations to drive demand, (3) standards and labelling to support recycling, (4) tools to support manufacturing, and (5) innovation and technology to support recycling.

9.1 Terminology Standards

9.1.1 Defining Recyclability

There is a need to develop consensus in definitions such as recycled content and recyclability in product design. This can be achieved through developing standards and new legislation. The first step in developing standards and legislation is defining the terms being used in the documents. In the plastics recycling industry, terms needing precise definitions include *what it means for*

a product to be recycled in a circular economy because recycling does not always result in a closed-loop recycling process. There are different kinds of recycling that also need to be defined since not all methods considered recycling by some will be recognized as recycling by legislation and standards.

Standardized terminology is a priority in California where legislation and definitions for packaging and products are being developed through the Circular Economy and Pollution Reduction Act. This is the first of its kind in North America. A key outcome of this new legislation is determining what will be categorized as “recycling.” The same process has been introduced at the US federal level with the Break Free from Plastic Pollution Act of 2020.

9.1.2 Defining Chemical Recycling vs. Recovery

There is a need to evaluate the use of thermal methods in the definition for plastic recycling. Chemical recycling uses thermal conversion methods to transform plastic waste back into its fossil fuel form which could be further processed and made into a fuel or plastic resin. Many definitions of recycling do not recognize thermal conversion methods of transforming plastic waste into a fuel as a recycling method. However, some view that monomers created from plastic using conversion methods are considered a form of open-loop recycling and that any other fuel by-products can be used for circular economy purposes.

Recovery is an approach where energy is recovered from the combustion of waste. An example would be combined heat and power recovery plants that uses plastic waste as a fuel to create a source of heat and power. In Europe, these types of energy recovery plants are used to offset the use of fossil fuels. Solid recovered fuel is also used by thermal power plants and cement kilns as a substitute for fossil fuels. Determining whether thermal conversion methods such as chemical recycling or recovery are important aspects of recycling terminology need to be addressed.

9.2 Regulations to Drive Market Demand and Support Environmental Management

9.2.1 Municipal Regulatory Tools

Municipalities across North America are developing regulatory tools that are influencing the plastics manufacturing industry. Examples include bans on single-use plastic items and bans on certain products that do not contain a minimum required level of recycled plastics. These initiatives affect what can be sold or what can be provided to the customer, and how manufacturers design and/or produce their products. These are examples of municipal initiatives that can drive manufacturers to design products that can be recycled or reused multiple times, or manufactured with recycled plastics. This also increases the demand for recycled plastic.

9.2.2 Provincial Regulatory Solutions

Provincial regulations can be developed to ban certain plastic materials such as single-use plastics and products not meeting certain levels of recycled content. In some provinces, regulations have been developed that require product stewards to develop EPR programs, which include collection, processing, and proper disposal or diversion for end-of-life products. EPR programs are funded by those who use the product, and these self-funding programs help make recycled plastics more economically viable. EPR programs also increases the available supply of recycled plastics.

9.2.3 Federal Regulatory Solutions

Most EPR programs in Canada are developed on a province-by-province basis. In Europe, EPR programs

are established by the country. Having a national EPR program helps standardize definitions across the country and establish and fund collection protocols, processing, and larger-scale marketing of recycled plastics. A nation-wide EPR program would support end-of-life management of plastic products and provide economies of scale to support advanced material sorting and processing facilities. While populations in the largest provinces may generate the materials to justify the larger and more complex facilities needed to create suitable feedstocks for large-scale plastics recycling, smaller provinces and territories would not generate enough materials on their own. Coordination of sorting and processing in a few regional facilities could provide the recycling industry with more certainty for availability and consistency of feedstock for manufacturing and could increase efficiency in the recycling system.

A national EPR program could also be structured to support municipalities, regions, and provinces in collecting and sorting recyclable materials to establish desired purity levels to support a recycling or advanced recycling infrastructure in Canada. Recycling programs have not reached all areas of Canada in large part due to the high logistical cost of collecting and transporting recyclables in areas with low-population density. Even in more population-dense areas, existing municipal recycling programs face consistent budget pressures that threaten their ongoing effectiveness, consistent funding for collection programs, and sorting infrastructure.

Similar to the initiatives at the municipal and provincial levels, federal regulations can also be developed to ban certain plastic materials such as single-use plastics and products not meeting certain levels of recycled content.

9.2.4 Management of Plastic Pellets

There is a growing concern that pellets used in plastics production are being found worldwide in marine environments and on beaches due to spills during loading, transport, and storage. Programs such as Operation Clean Sweep have been developed to prevent these plastic pellets from entering the environment and several such programs are now in place internationally and nationally [62]. However, further oversight and management is required to advise companies involved

in the handling of plastic pellet material to adopt specific control measures. Further regulations to address such control measures would support the objectives of Operation Clean Sweep.

9.3 Standards and Labelling to Support Recycling

9.3.1 Bale Quality Standards

Municipalities, recyclers, and industry associations publish their own quality standards and guidelines for the bales they buy or sell. Bale standards vary by contamination level, plastic type, and colour. Test methods for bales also exist, with a separate testing method specified for each bale to confirm that specifications are met.

Marketing bales can become commoditized and drive trade, using standard global designations for the common types of bales bought and sold. The wide variety and quality of bales impact the market for recyclable products. Establishing bale standards would simplify and accelerate transactions and avoid the need for sellers and buyers to create individual specification sheets.

Examples of the various bale specifications in use today are summarized in Appendix B.

9.3.2 Colour Standards

While colourants are added to plastics to enhance aesthetics, this process drastically affects recyclability. If the colours added to plastics could be limited to a subset of standard colours, the amount of sorting by colour could be greatly reduced and the marketability of the baled plastics could be improved. For example, PET bottle design guidelines by the APR specifies that bottles must be clear, green, or blue. This is a very limited subset of how plastic PET bottles can be coloured to be considered highly recyclable. Requirements for colourant additives to support recycling can be developed through design for recyclability standards. Government procurement contracts or packaging legislation could also specify a very limited subset of colours to influence the standard products that are available.

9.3.3 Performance and Recyclability Standards

There is a need to evaluate product recyclability and product performance to ensure one characteristic is not compromised by another. Many developed standards are specific to individual products and several industry standards for certain products have also been developed. For example, the Ellen MacArthur Foundation created design for recyclability guidelines for jeans. Product-specific recyclability standards can support the expansion of designing for recyclability while ensuring product performance. Further design standards for common product categories will support effective product design and recyclability.

9.3.4 Environmental Impacts Standards

There is a lack of key performance indicators and performance measures for plastic recycling and management methods. Analytical approaches should be standardized to quantify environmental impacts. Life-cycle analysis uses quantifiable methods to assign a numerical value that would allow for comparisons across recycling methods. This will be important in ensuring that recycling methods with the most environmental benefit can obtain the highest scores.

9.3.5 Recycling Label Instructions

Standards can play a role in developing effective labels so that consumers understand how to recycle their end-of-life plastics. Effective labelling can also communicate how to prevent contamination when recycling plastics. Improved labelling with recycling instructions can provide an opportunity to educate the public on the importance of recycling and how to create a more effective process.

9.3.6 Labels for Recycled Resins

Product labels that identify the amount of recycled content used in the production of the product can help consumers better understand important recycling characteristics and make more meaningful purchasing decisions. When manufacturers use recycled plastics, and support the principles of a circular plastics economy, there are social benefits that green consumers would want to know. Stakeholders have expressed that such labels could increase the demand for these recycled products among consumers.

9.4 Tools to Support Manufacturing

9.4.1 Characteristic Comparisons

There are no standardized test methods that compare the quality of recycled resins to virgin resin. A classification standard that describes the ways recycled resin differs from virgin resin would allow manufacturers to better understand product characteristics. Recycled plastics need comparable descriptors to virgin plastics, in order to provide companies with assurances that recycled products with “near virgin” characteristics are comparable to virgin products, and an agreed-upon baseline has been developed. Existing performance standards for virgin resins could then be adapted for recycled plastics.

9.4.2 Safe Packaging

Plastic products that are made for food packaging or other health-related products are required to obtain approval from health organizations for packaging applications. The development of a Canadian standard that can specify plastic requirements and procedures for food and health-related packaging are important to ensure that safety requirements are met. In order to support the use of recycled plastic materials in packaging, further research and development is required to analyze the deviance of recycled content to that of virgin plastics. By classifying the amount of difference in a recycled plastic’s properties from the virgin levels, companies accustomed to virgin products will have a known baseline from which to operate when using recycled resins.

9.5 Innovation and Technology to Support Recycling

9.5.1 Tracking Additives

Recycled plastic can be traceable with an additive or watermark that tracks the plastic’s use and movements along the value chain. Having a fully reliable tracking method for recycled plastic is especially promising for recycled plastic that comes into contact with food since tracking will remove the health concerns about the plastic’s past use.

The BASF Corporation is testing an additive that uses blockchain technology, and Digimarc has an invisible barcode that is in use on packaging at major retailers and is currently being piloted in a European recycling

facility. These technologies hold great promise to not only increase the supply of recycled plastics but to also deter fraud and health concerns in environmental claims citing recycling content percentages.

9.5.2 Copolymer Additives for PE and PP

PE (polyethylene) and PP (polypropylene) account for two-thirds of the world’s plastic but cannot be used together to create viable secondary uses. Once PE and PP are mixed during the collection process, they need to be separated before being used as recycled content. A new tetrablock polymer is being developed by researchers at Cornell University that will enable alternating PE and PP segments so they can be used together to create a strong and versatile product.

9.5.3 Rate Sorting Technology

Research and pilot programs for new rate sorting technologies could enable MRFs to better understand what sorting methods are available and how technologies compare. For regions collecting smaller amounts of waste plastics, a better understanding of the available sorting capabilities could enable MRFs to work together to optimize sorting possibilities between smaller primary and larger secondary MRFs.

9.5.4 Low Carbon Plastics Standard (LCPS)

The development of a low carbon plastics standard (LCPS) can drive demand for increased recyclable plastic material, while incentivizing low carbon resources. As recycling plastics use less energy and lower carbon emissions in comparison to the production of virgin plastics, the use of a blended system (using both recycled and virgin plastics) could decrease the carbon intensity of plastic manufacturing. This tool could be structured to disincentive the use of fossil fuels and spur innovation. Industry experts indicated that this is perhaps the most important area of standards development (along with standards for extended producer responsibility) that the federal government can undertake in promoting a circular economy for plastics. The LCPS aims to [2]:

- Create demand for recycled plastics supplied by EPR;
- Drive innovation in plastics recycling;
- Drive renewable plastic chemistries; and
- Embed standards in government procurement.

9.6 Standards Development Prioritization

The information in this report is compiled from technical experts, internet sources, scientific literature, and interviews with stakeholders. Future opportunities to increase rates of recycled materials in products were identified by speaking with a wide variety of industry stakeholders. Stakeholders were asked to categorize standards by their feasibility of implementation in the Canadian market. The result is a summary of tools

intended to increase the use of post-consumer plastics in new products. Table 8 is organized by the type of recommended tool (i.e., voluntary standards, regulations, or research) to support the recycling of plastics, and by priority to create the recycling structure required to implement high-value improvements in the recyclability of plastics. The terms “standards” and “guidelines” as outlined within Table 8 are used interchangeably, and refer to an accredited standards-based development process.

Table 8: Recommendations for Improved Plastic Recycling

Priority	Challenge and Opportunity	Recommendations	Type (Standards, Regulations, or Research)	Reference
Terminology and Definitions				
High	<p>Terminology promotes clear communication along the entire value chain. The term “recyclable” is defined entirely differently by different people in different contexts. Some consider “recyclable” from a technically feasible point of view and others consider “recyclable” from a practical point of view.</p> <p>When defining regulations, all levels of industry and government benefit from a set of common terms. Currently, with several municipalities throughout Canada banning plastic items, the terminology is not consistent. With a common set of terminology, regulations across jurisdictions can be more easily harmonized.</p>	<p>Review existing standards (ISO, APR, PRE) for suitability or develop a new Canadian standard with definitions to support national recycling terminology:</p> <ul style="list-style-type: none"> Adopt common definitions for recycling terminology to ensure consistency at all levels of industry and government. Consult with governmental bodies to identify terminology and definitions required for regulatory action. This will provide a nationally harmonized set of terms consistently understood across all of Canada. Words commonly associated with recycling targets need definitions. For example: recyclable, post-consumer recycled content, pre-consumer recycled content, packaging reuse, and single-use plastic. 	Standards	Refer to Section 10.1 – Terminology Standards
High	<p>Numerous methods of recycling exist due to the wide array of plastics and their various uses today. Comparing the main recycling methods when making recycling decisions can lead to less overall energy use and a better fit for properties. Research exists classifying over 60 non-mechanical methods, but this classification is not in common use today.</p>	<p>Develop definitions and related processes to classify methods of non-mechanical recycling, including purification, depolymerization, and conversion technologies (e.g., to support future legislation which may constitute the legal definition of recycling).</p>	Standards	Refer to Sections 4.6 – Recycling Methods – and 4.7 – Innovative Approaches to Recycling

Priority	Challenge and Opportunity	Recommendations	Type (Standards, Regulations, or Research)	Reference
Recommendations to Improve Demand for Use of Recycled Products				
High	Extended producer responsibility (EPR) programs for many but not all plastic waste categories in Canada. Implementation of required EPR programs in Canada would require organizations that produce or use plastic products to have their plastics collected and recycled at the end of their intended use.	Develop national EPR programs to mandate the extended responsibility of the plastic product at its end-of-life, which in turn will incentivize the design for product recyclability.	Regulations	Refer to Section 10.2 – Regulations to Drive Market Demand
Medium	Plastic pellets are currently lost in the environment during transport, storage, and manufacture of plastic products. Ensuring that hauling companies and pellet manufacturers curtail this leak can be controlled by issuing permits and maintaining environmental oversight through a compliance body.	Develop regulatory requirements to minimize plastic pellet environmental leaks by defining environmental hauling and storing of pellets.	Regulations	Refer to Section 10.2.4 – Management of Plastic Pellets
Medium	Products that detail recycled content claims lack minimum acceptable levels. If tiered targets for recycled content are defined, manufacturers would have iterative and common requirements to adhere to, thus driving increased recyclable content in product development. A tiered rating system can allow for flexibility based upon feasibility.	Identify an acceptable minimum level of recycled resin in product development, to confirm that a product was created using a specific threshold of recycled resin. Design these thresholds to be used by consumer-facing labels.	Standards	Refer to Section 10.3.4 – Environmental Impacts Standards
Medium	Numerous industry standards and guidelines claim that a product has been designed for the environment and/or designed for recyclability. The opportunity to confirm compliance by a third party would help raise consumer confidence and drive corporate objectives towards designing for end-of-life.	Set a minimum conformity level for products and define format types that enable more effective post-consumer choice when looking to buy highly recyclable products. A third-party assurance would also create easier sorting and separation for closed-loop recycling.	Standards	Refer to Section 10.3.4 – Environmental Impacts Standards
Medium	Municipalities and provinces are often the driver or enabler of recycling, and should be provided with direction and scope of responsibility to help implement recycling and plastic reduction targets and objectives.	Encourage municipality and provincial-driven recycling action by identifying the role and requirements of governments in plastic recycling.	Regulations	Refer to Section 10.2.1 – Municipal Regulatory Tools
Medium	Recycling collection systems across Canada vary by province and municipality. The creation of a consistent collection method of plastic products will encourage uniform collection across the country. Consistency will reduce consumer confusion, improve bale quality and quantity, and thus increase supply and demand of recyclable materials.	Create a uniform collection system with minimum requirements for municipalities to opt into.	Regulations	Refer to Section 10.2.2 – Provincial Regulatory Solutions – and Section 10.2.3 – Federal Regulatory Solutions

Priority	Challenge and Opportunity	Recommendations	Type (Standards, Regulations, or Research)	Reference
Recommendations to Improve Demand for Use of Recycled Products				
Low	Plastic is one material of choice. Among the other materials of choice (e.g., glass, paper, metal, bioplastics), the life-cycle analysis tools to measure environmental impact are inconsistent. Having a common method of measuring environmental impact considering all different material choices will ensure a net benefit to the environment can be confidently pursued.	Develop life-cycle analysis methods comparable across all recyclable materials (i.e., to facilitate choices between materials such as paper and plastic).	Standards	Refer to Section 2.2 – The Plastics Industry (Figure 1)
Recommendations to Increase Support for Recyclers and Recycling				
High	Certain resins and products have historically been recycled in low numbers. For these resins and products, defining appropriate producer responsibility or stewardship initiatives can improve recycling rates for these respective products.	Set a product-by-product threshold to counteract low demand for certain resins by setting a level of conformity for producer responsibility/stewardship.	Regulations	Refer to Section 9.5 – Manufacturing Related and 10.2 – Regulations to Drive Demand and Support Environmental Management
High	Design guidelines for recyclability have been developed by various organizations. However, guidelines across organizations are not harmonized, nor are their specific guidelines for each product category. Improved product design can support increased recycling rates.	Develop design for recyclability guidelines and standards that address all product categories to ensure best practices for recyclability are considered in product design. The product design should be detailed to a level that manufacturers require to make design choices for a circular economy. Design guidelines should be prioritized by category and impact on the environment.	Standards	Refer to Section 10.3.3 – Performance and Recyclability Standards
Medium	Currently, buyers, sellers, and industry associations have bale standards. Improved marketing of bales and consistency of bales will commoditize, and drive trade, through the development of standard designations for the types of bales bought and sold.	Create commonly used national bale standards to commoditize trade of popular bales.	Standards	Refer to Section 10.3.1 – Bale Quality Standards
Medium	Current sorting technology is changing fast. By informing municipalities and converters which recyclers can meet their selling and buying needs, recyclers can be compared. This also creates the opportunity to begin defining and developing the secondary MRFs that have advanced sorting capabilities.	Investigate rate sorting technology by creating classifications for the technology that specify what can be sorted in the facility.	Research	Refer to Section 10.5.3 – Rate Sorting Technology

Priority	Challenge and Opportunity	Recommendations	Type (Standards, Regulations, or Research)	Reference
Recommendations to Increase Support for Recyclers and Recycling				
Medium	Thousands of colours are currently used in plastic products. If a limited number of colours were deemed recyclable, organizations making purchasing decisions (e.g., government procurement contracts) could specify the colours deemed necessary for product development. This would drive demand for products designed for recyclability.	Identify the most effective colours for recyclable plastics.	Research	Refer to Section 10.3.2 – Colour Standards
Medium	Currently, labels can cause a recyclable plastic to contaminate the caustic baths used in mechanical recycling. Setting how labels can be used to increase recyclability, including their material and adhesives, would reduce mechanical recycling contamination.	Identify a procedure or method to identify if a product label is recyclable.	Research	Refer to Section 10.3.3 – Performance and Recyclability Standards
Medium	Potentially dangerous plastic products vary based upon application. When used for food contact as opposed to general packaging use, the recycled plastic used must be very specifically traced. Classifying the prohibited items for different applications will enhance market transparency, reduce miscommunication, and speed third-party approvals for products.	Classify additives and applications which are deemed dangerous to certain products (i.e., food grade applications) through standardized test methods.	Standards	Refer to Section 10.4.2 – Safe Packaging
Low	Consumers find it difficult to understand the recycling instructions for the many different types of plastic products in the market. Labelling recyclable plastics with improved instructions would clarify how to better handle recyclable products at their end-of-use, and can result in improved recycling rates.	Develop national recycling instructions on consumer labels to ensure widely distributed plastics are directed into the appropriate recycling streams at the end-of-use. This can help to ensure manufacturers demand for recycled plastics has incoming feedstock.	Regulations	Refer to Section 9.8 – Labelling (Table 6)
Recommendations to Support Manufacturers				
High	The performance of plastic is important when designing products as needs vary greatly across uses. Standards exist for various properties. The properties of virgin plastics are very well known. Common properties need to be better understood for recycled plastics in relation to virgin materials which use the same standard performance measures	Standards to address minimum performance requirements and testing methods to describe and quantify a small, core set of properties to define “near-virgin quality” in recycled resin.	Standards	Refer to Section 10.3.3 – Performance and Recyclability Standards

Priority	Challenge and Opportunity	Recommendations	Type (Standards, Regulations, or Research)	Reference
Recommendations to Support Manufacturers				
Medium	Traditional plastics converters and manufacturers are accustomed to using virgin materials. By classifying the amount of difference in a plastics' properties from the virgin levels, companies accustomed to virgin products will have a known baseline from which to operate when using recycled resins in research and development. For example, when considering a "near-virgin" clear plastic, the amount of yellow tinge could have progressively yellow limits set.	Investigate the rate of the deviance (based on properties and characteristics) of recycled content to the recycled content's closest virgin competitor(s).	Research	Refer to Section 10.4.1 – Characteristic Comparisons
Innovative Approaches to Improve Recycling				
High	A low carbon plastics standard (LCPS) would incentivize the use of both renewable chemistries to make plastic as well as recycled content as a low carbon feedstock.	Set a LCPS to incentive a plastic circular economy that is powered by renewable energy and zero waste [2].	Standards	Refer to Section 10.5.4 – Low Carbon Plastics Standard (LCPS)
Medium	The fraudulent claim by manufacturers of recycled content in their products is a potential problem. Technology could be used to track recycled content and minimize false claims.	Develop or adopt technologies such as a blockchain tracking additive or a Digimarc invisible watermark.	Research	Refer to Section 10.5.1 – Tracking Additives

10.0 Conclusions

The use of post-consumer plastics in new products is hindered by four important factors: (1) supply, (2) market demand, (3) cost, and (4) quality. Supply chain stakeholders have expressed their recognition that customers and product manufacturers are enquiring about or requiring a certain level of post-consumer plastics in the products they procure. Supporting this evolving market demand for post-consumer plastics is a crucial step in increasing the recycling rate of plastics entering the Canadian marketplace. The following list of high-impact and high-value tools has been identified throughout the report to support the increase in market demand for post-consumer plastics:

- Review existing standards for suitability or develop a new Canadian standard with definitions to support national recycling terminology.

- Develop definitions and related processes to classify methods of non-mechanical recycling, including purification, depolymerization, and conversion technologies to support a nationally accepted definition of recycling.
- Develop national EPR programs to mandate the extended responsibility of the plastic product at its end-of-use, which in turn will incentivize the design for product recyclability.
- Set a product-by-product threshold to counteract low demand for certain resins by setting a level of conformity for producer responsibility/stewardship.
- Develop design for recyclability guidelines and standards that address all product categories to ensure that best practices for recyclability are considered in product design. The product design should be detailed to a level that manufacturers require to make design choices for a circular economy.



“Cost is often cited as one of the largest barriers to choosing recycled content.”

- Develop standards to address minimum performance requirements and testing methods to describe and quantify a small, core set of properties to define “near-virgin quality” in recycled resin.
- Establish a low carbon plastics standard (LCPS) to incentive a plastic circular economy that is powered by renewable energy and zero waste [2].

10.1 Post-Consumer Plastics Nexus: Supply, Demand, Cost, and Quality

Due to its high cost, variable quality, and limited supply, the upstream supply chain manufacturers have been unable to widely integrate the use of post-consumer plastics into their products. Cost is often cited as one of the largest barriers to choosing recycled content. The increased demand for recycled plastics is a relatively new factor that has a strong capability to drive development of plastic recycling systems.

The cost of fossil fuel influences the cost for virgin plastics. The cost for post-consumer plastics takes into consideration collection and processing costs that can be higher than virgin plastics. Addressing the financial discrepancy of post-consumer plastics may involve a national extended producer responsibility (EPR) system similar to those already established in certain parts of Canada. Although this would be an additional cost that manufacturers would need to bear, these costs would be pushed to the consumers and this could provide financial support for post-consumer plastics.

Further research will be required to better understand how such a program can be developed and implemented and will require further investigation on the quantities, characteristics, and management practices of various sectors so that programs and frameworks could be further assessed and developed. Developing systems that monetize the environmental benefits of recycled plastics should be an overarching consideration.

Post-consumer plastics need to be collected and processed before they can move up the supply chain to their end market. At most MRFs, the level of collection and processing tends to focus on the value of the plastic types that are collected, the volume available for processing, and the sorting processes that are limited by plastic type. This results in a smaller amount of post-consumer plastics being collected that are of varying quality and that contain varying levels of contaminants.

There is a need for a secondary level of processing that can improve the quality, separate the colour, and reduce the contaminants in the plastic commodities. These secondary MRFs also provide an avenue to aggregate materials to generate a critical mass necessary to sort and recover materials feasibly. Depending on the size of the MRF, this higher level of processing could increase the cost of using post-consumer plastics for remanufacturing.

In summary, the supply and market demand (as influenced by cost and quality) of plastic products and

appropriate plastic resins are based on the following dynamics: refiners and petrochemical processors, resin producers, product manufacturers, and recyclers. In order to improve this nexus, five categories of opportunities and tools have been analyzed to support the upstream supply chain: (1) terminology standards, (2) regulations to drive market demand and environmental management, (3) standards and labelling to support recycling, (4) tools to support manufacturing, and (5) innovation and technology to support recycling.

10.2 Recyclability

Plastic recyclers have expressed strong views that plastic products entering the marketplace need to be designed to be recyclable so that the collection and processing systems can recover more materials and the processing required would be less rigorous to produce a commodity that is easier to integrate into the upstream supply chain. Specialized packaging materials are highly complicated multi-layered engineering feats that are extremely difficult to process and recycle. Standards to identify recyclable products and limit the design of products that are made from difficult-to-recycle plastics should be further investigated.

Design guidelines for recyclability have been developed by various organizations [63] [64], however they are not harmonized, leading to different areas achieving different recycling rates. This is a high-impact and high-value area where more standardization should be developed.

11.0 Closing Remarks

Today's plastics industry is faced with numerous barriers to including more recycled content in newly manufactured products. Barriers fall into the categories of cost, quality, supply, and demand. Developing standards can ease some of these barriers. However, the barrier of cost remains; as does demand's connection to a perceived limited supply of recycled content. Standards to make sorting easier and increase diversion rates will alleviate supply concerns.

Prioritizing every opportunity to increase demand is a necessity to improving the plastic recycling rates. Standards to ensure that consumers can identify which products contain recycled content and which products are easily recyclable will drive consumer demand. Ongoing commitments from producers to include recycled content in their products will continue to drive brand demand, and ongoing commitments from the government to increase recycled content will ensure these brand commitments are delivered upon.

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Appendix A – Glossary

Term	Definition
Acrylonitrile butadiene styrene (ABS)	A thermoplastic historically used to make toys (e.g., LEGO® blocks), sports equipment, and automobile parts.
Antioxidant	A substance that inhibits oxidation. Used as an additive in plastic to extend a product’s life by maintaining the plastic’s strength, stiffness, and flexibility.
Engineered plastics	Engineered plastics are designed to have better weight/strength and heat-resistant properties. Examples include ABS, PC/ABC, and PC.
Expanded polystyrene (EPS)	A widely used thermoplastic polymer. Used widely in everyday applications, including packaging (including food packaging), road construction, sound insulation, thermal building insulation, fragile goods protection, windsurfing boards, and more.
Extrusion plastometer	An instrument used to determine the melt flow rate (MFR) and melt volume flow rate (MVFR) of a molten plastic resin.
Feedstock	Any raw material.
Gasification	Gasification is heating plastic waste to produce an industrial gas mixture called synthesis gas, or syngas, which can be burned to generate electricity or used to produce diesel and petrol.
Halogenated polymer	Polymers that include halogens in their structure, such as polyvinyl chloride (PVC) or polytetrafluoroethene (PTFE or Teflon). Polymers can also include polymeric or non-polymeric halogenated additives such as butadiene styrene brominated copolymer (Polymeric FR) or hexabromocyclododecane (HBCD), respectively.
High density polyethylene (HDPE)	This plastic is used to make milk jugs, detergent bottles, outdoor furniture, corrugated drainpipe, as well as trash bags.
Low density polyethylene (LDPE)	This plastic is the most common type of recycled plastic and is used to make frozen food bags, flexible container lids, and much more.
Mass flow rate (MFR)	MFR is an indication of average molecular weight. Molecules with a higher flow rate have a lower molecular weight. For example, a plastic resin with a 20g / per 10min MFR indicates a lower molecular weight than a plastic resin with an MFR of 10g / 10min.
Melt mass flow rate (MFR)	Another term for mass flow rate.
Melt volume-flow rate (MVR)	Melt volume-flow rate (MVR) is an indication of average volume.
No Objection Letter	An evaluation of recycled plastic made by a health authority stating that the health authority has no objection to the recycled plastic being used in food-grade applications.
Polylactic acid (PLA)	Polylactic acid is a polymer made from renewable resources, including corn starch, tapioca roots, or sugarcane.
Plastic additives	Items added to plastic resins to improve stability, mechanical properties, processing, aesthetics, and performances, including anti-oxidants, impact modifiers, lubricants, colourant dyes, flame-retardant chemicals and plasticizers.

Term	Definition
Plasticizer	An additive that decreases attraction between polymer chains in materials used in plastics to make materials, especially PVC, more flexible and durable.
Polycarbonate	A thermoplastic used to make CDs and DVDs, drinking bottles, food storage containers, and eyeglass lenses.
Polyethylene (PE)	The world's most widely produced synthetic plastic polymer and the most common thermoplastic. In both high density (#2) and low density (#4) forms, it is used to make plastic grocery bags, shampoo bottles, and more. Many other varieties of PE also exist, including ultra-high density molecular weight PE (UHMW) used to make cutting boards, etc. and linear low-density polyethylene (LLDPE) used for stretch wrap, etc.
Polyethylene terephthalate (PET)	This plastic is used to make water bottles, soft drink bottles, carpet, clothing, food bottles, and food jars.
Polypropylene (PP)	The world's second most widely produced synthetic plastic polymer. Common uses include packaging tubs and lids, takeout containers, and automotive battery cases, bumpers, trim, and panels.
Polystyrene (PS)	A thermoplastic that can be rigid or foamed, transparent or coloured. Common uses include cups, cookie trays, CD cases, foodservice foam products, and transportation packaging foam. High impact polystyrene (HIPS or PS-HI) is impact modified and typically used in electronics applications such as keyboards, mice, and toner cartridges.
Polyvinyl chloride (PVC)	The world's third most widely produced synthetic plastic polymer. PVC can be adjusted to meet specific needs and used to make a wide variety of products of varying strength, rigidity, colour, and transparency. Some uses include food packaging, water and sewer pipes, insulation for cables, building products, medical products, and many more leisure products.
Pyrolysis	Pyrolysis is the process of heating plastic waste without oxygen to produce synthetic crude oil, fuels, or chemical feedstocks.
Regulation	Rules issued by governmental agencies. Instructions on how laws are carried out.
Resin identification code (RIC)	The resin identification code is a number identifying the type of resin a plastic product contains. It is an international standard developed in 1988 by the Society of the Plastics Industry, Inc. and currently administered by ASTM International, ASTM D7611.
Stabilizer	A plastic additive used to ensure that products retain their physical properties during use and withstand exposure to cold, heat, and UV-light.
Standard	Guidelines outlining how to follow or complete processes. Compliance is not mandatory.
Thermoplastic	A plastic polymer that can be heated and cooled repeatedly, allowing for products to be melted and recast as new materials. Common types of thermoplastics include polyethylene terephthalate (#1), high-density polyethylene (#2), polyvinyl chloride (#3), low density polyethylene (#4), polypropylene (#5), polystyrene (#6), polycarbonate (PC), and acrylonitrile butadiene styrene (ABS).
Thermoset	A plastic polymer that cannot be reheated and cooled repeatedly and can only be shaped once.

Appendix B – Informative Annex

B.1 Open-Loop Recycling

There are many existing applications of open-loop recycling of plastics where plastics are mechanically sorted and separated then processed into different products that do not require the same material properties as the original products. Several examples of open-loop recycling are presented in Table B1.

Table B1: Plastic Recycling for Certain Products

First Use	Second Use	Company/ Organization	Comments
Grocery bags [65]	Composite pavement	K.K. Plastic Waste Management	Road building costs 3% more than traditional asphalt. Maintenance and repair companies not needed as much. The plastic waste roads are twice as durable compared to conventional ones. Indian Road Congress has guidelines for plastic waste roads (2013).
Milk jugs [66]	Toys (100% Recycled Content)	Green Toys	Green Toys has recycled 88,415,808 (and counting) milk jugs into toys.
Grocery bags & plastic film [67]	Wood alternative decks	Trex	A typical 500-square-foot deck contains 140,000 recycled plastic bags. At one point, Trex claimed it was using half the available recycled film in the United States.
Plastic bags (HDPE) [68]	Diesel fuel	U of Illinois	Pyrolysis method used. Meets nearly all fuel properties within ASTM D975 and EN 590 diesel specifications. Derived cetane number and lubricity were superior to conventional diesel fuel.
Mixed waste [69]	Start-up homes (India)	Gaias Homes	100 m ² home (earthquake & fire-proof) uses up to 2 tonnes of plastic. Cost starts at \$3,250. Unskilled labour can build in 2-5 days. Homes last for up to 500 years (estimated).
Water bottles [70]	Shoes/clothing	Unifi	PET is melted to create yarn.
Fishnets / beach plastic waste [71]	Shoes	Adidas / Parley for the Oceans	Waste is processed into yarn.
Fishing nets / ocean plastics [72]	Football jerseys for U of Miami	Adidas / Parley for the Oceans	Uniforms are made from yarn processed with 70% recycled plastic/fishing nets.

B.2 Standards Influencing Plastics Recycling

Organizations working within plastics recycling and manufacturing have taken several steps to develop standards, guidelines, and specifications meant to streamline work within the industry. Many of these documents are not universally recognized or adopted widely enough to create efficiencies in plastics recycling but they offer valuable information and frameworks for potential additional standards.

Table B2: Existing Standards

Type	Title
<p>Overarching Standards</p>	<ul style="list-style-type: none"> ▪ BSI 8001: Framework for implementing the principles of the circular economy in organisations ▪ ISO 15270 Plastics – Guidelines for the recovery and recycling of plastics waste ▪ D5033 Guide for Development of ASTM Standards Relating to Recycling and Use of Recycled Plastics ▪ CEN 15353 – Plastics – Recycled plastics – Guidelines for the development of standards relating for recycled plastics ▪ ASTM D5033-00 Standard Guide for Development of ASTM Standards Relating to Recycling and Use of Recycled Plastics (Withdrawn 2007) ▪ ASTM D7209 Standard Guide for Waste Reduction, Resource Recovery, and Use of Recycled Polymeric Materials and Products, was withdrawn with no replacement in 2015. ASTM D7209 was introduced in 2007 as a replacement for the withdrawn standard ASTM D5033 Standard Guide for Development of ASTM Standards Relating to Recycling and Recycled Plastics. <p>The standards in this report focus on those related to conventional plastics. Standards focusing specifically on bioplastics also exist, such as:</p> <ul style="list-style-type: none"> ▪ CEN 16640 Bio-based products – Determination of the bio-based carbon content of products using the radiocarbon method ▪ CEN 16785-1 Bio-based products – Bio-based content – Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis <p>As well as standards focusing on composting, including:</p> <ul style="list-style-type: none"> ▪ CEN 13432 Requirements for packaging recoverable through composting and biodegradation ▪ Austria 5810 Biodegradable plastics – biodegradable plastics suitable for home composting ▪ France 51-800 Plastics – Specifications for plastics suitable for home composting
<p>Terminology</p>	<ul style="list-style-type: none"> ▪ ASTM D883 Terminology Relating to Plastics ▪ ASTM D16000 Terminology for Abbreviated Terms Relating to Plastics ▪ European Standard EN 13440:2003: Packaging – Rate of recycling – Definition and method of calculation ▪ VDI 2343 BLATT 1 – Recycling of electrical and electronic products – Principles and terminology ▪ ASTM D4092: Standard Terminology for Plastics: Dynamic Mechanical Properties
<p>Recycled Content</p>	<ul style="list-style-type: none"> ▪ UL 2809 Environmental Claim Validation Procedure for Recycled Content ▪ DS/EN 15343 Plastics – Recycled Plastics – Plastics recycling traceability and assessment of conformity and recycled content ▪ The series of CEN publications also defines characteristics of recycled plastics in standards CEN 15344 through CEN 15347 ▪ SCS Global Services Recycled Content Standard, V7.0 – Third-party substantiation of recycled content claims – Qualifying and quantifying materials ▪ SCS Global Services Recycling Program Standard – Third-party substantiation of recycling/diversion claims – Qualifying and quantifying materials

Type	Title
Packaging	<ul style="list-style-type: none"> • ISO 21067-1: Packaging – Vocabulary – Part 1: General terms • ISO 21067-2: Packaging – Vocabulary – Part 2: Packaging and the environment terms • ISO 6590-2: Packaging – Sacks – Vocabulary and types – Part 2: Sacks made from thermoplastic flexible film (Part 1 is on paper sacks) • ISO 15867: Intermediate bulk containers (IBCs) for non-dangerous goods – Terminology • Since many of the industry commitments state that packaging must be recycled or reused, standards are being developed to define reuse. • CEN/TR 14520 – Packaging – Reuse – Methods for assessing the performance of a reuse system • Europe: CEN 13429: Reuse • Japan: JSA JIS Z 0130-3 Reuse <p>Since many of the industry commitments state that packaging must be recycled or reused, standards are being developed to define reuse.</p> <ul style="list-style-type: none"> • CEN/TR 14520 – Packaging – Reuse – Methods for assessing the performance of a reuse system • Europe: CEN 13429: Reuse • Japan: JSA JIS Z 0130-3 Reuse <p>Many standards also exist to clarify the environmental impact of packaging.</p> <ul style="list-style-type: none"> • ISO 18601: Packaging and the environment – General requirements for the use of ISO standards in the field of packaging and the environment • ISO 18602: Packaging and the environment – Optimization of the packaging system • ISO 18603: Packaging and the environment – Reuse • ISO 18604: Packaging and the environment – Material recycling • ISO 18605: Packaging and the environment – Energy recovery • ISO 18606: Packaging and the environment – Organic recycling • ISO 21067: Packaging – Vocabulary – Part 2: Packaging and the environment terms • CEN 13193: Packaging – Packaging and the Environment – Terminology • JSA JIS Z 0130-3 – Packaging and the environment
Contamination	<p>These standards identify and classify properties considered contaminants in the recycling process.</p> <ul style="list-style-type: none"> • ASTM D6288 Standard Practice for Separation and Washing of Recycled Plastics Prior to Testing • ASTM D5577 Standard Guide for Techniques to Separate and Identify Contaminants in Recycled Plastics • ASTM D5814 Standard Practice for Determination of Contamination in Recycled Poly (Ethylene Terephthalate) (PET) Flakes and Chips Using a Plaque Test • ASTM D5991 Standard Practice for Separation and Identification of Poly (Vinyl Chloride) (PVC) Contamination in Poly (Ethylene Terephthalate) (PET) Flake • ASTM D6265 Standard Practice for Separation of Contaminants in Polymers Using an Extruder Filter Test
Bioplastics	<p>The standards in this report focus on those related to conventional plastics. Standards focusing specifically on bioplastics also exist, such as:</p> <ul style="list-style-type: none"> • CEN 16640 Bio-based products – Determination of the bio-based carbon content of products using the radiocarbon method • CEN 16785-1 Bio-based products – Bio-based content – Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis <p>As well as standards focusing on composting, including:</p> <ul style="list-style-type: none"> • CEN 13432 Requirements for packaging recoverable through composting and biodegradation • Austria 5810 Biodegradable plastics – biodegradable plastics suitable for home composting • France 51-800 Plastics – Specifications for plastics suitable for home composting

B.3 Bale Specifications

The plastics recycling industry has taken several steps to coordinate common expectations for recycled materials to ease communication and compliance issues between different steps in the recycling process. One such area of work is in setting specifications for recycled plastics bales. Examples of existing specifications are summarized in Table B3.

Table B3: Existing Bale Specifications

Company/ Organization	Comments	Specifications
<p>Association of Plastics Recyclers (APR) [46]</p>	<p>Numerous bale types are specified in model standards by the APR.</p> <p>As stated by the APR: "This model is not meant to replace the specifications of individual buyers, many of whom may have different allowable contents and bale sizes. Rather, it is meant to provide a benchmark to suppliers."</p> <p>APR's Model Bale Specifications have seven standard components:</p> <ul style="list-style-type: none"> ▪ Bale Content Overview ▪ Acceptable Levels of Contaminants ▪ Contaminants Not Acceptable at Any Level ▪ Warnings ▪ Bale Size/Minimum Shipping Weight ▪ Bale Wire ▪ Storage 	<ul style="list-style-type: none"> ▪ HDPE Natural Bottles ▪ HDPE Natural Bottles Bale Audit with Test Methods ▪ HDPE Coloured Bottles ▪ HDPE Colour Bottles Bale Audit with Test Methods ▪ HDPE Injection Bulky Rigid Plastics ▪ LDPE Coloured Film ▪ LDPE Furniture Mix Film ▪ PE Ag Film Including Mulch ▪ PE Ag Film Not Including Mulch ▪ PE Clear Film ▪ PE Retail Bags and Film ▪ PET Bottles ▪ PET Bale Audit with Test Methods ▪ PET Thermoforms ▪ PP Small Rigid Plastics, PP All Rigid Plastics ▪ MRF Curbside Film ▪ Tubs and Lids, Tubs and Lids with Bulky Rigid Plastics ▪ Mixed Bulky Rigid Plastics ▪ Film Model Bale Specifications ▪ Densified Depot Grade Foam Polystyrene ▪ Densified MRF Grade Foam Polystyrene ▪ Solid/Foam Polystyrene ▪ Solid Polystyrene ▪ Bottles and ALL Other Rigid Plastics, 3-7 Bottles and SMALL Rigid Plastics (formerly known as Pre-picked) ▪ ALL Rigid Plastics, #1-7 Bottles and SMALL Rigid Plastics (formerly known as All Rigid Plastics)
<p>Plastics Recyclers Europe (PRE) [73]</p>	<p>As stated by the Plastics Recyclers Europe: "These guidelines are not made to replace the existing specifications which have been contractually agreed. They are made to provide an information benchmark to suppliers of any collected waste."</p>	<ul style="list-style-type: none"> ▪ HDPE Bales Guidelines ▪ PET Coloured Bales Guidelines ▪ PET Clear Bales Guidelines ▪ PET Clear Blue Bales Guidelines ▪ PET Light Blue Bales Guidelines ▪ PE Film Bales Guidelines ▪ PP Film Bales Guidelines

Company/ Organization	Comments	Specifications
The Plastic Recycling Corp. of California (PRCC) [74]	This organization sells over 200 million pounds of baled PET annually.	<ul style="list-style-type: none"> ▪ PET Bale Specifications
American Chemistry Council (ACC) [47]	Guidelines for businesses, recyclers, and local governments on plastic film recovery.	<p>An example is given: Preferred Bale Properties Specified:</p> <ul style="list-style-type: none"> ▪ Dimension: 72" max. ▪ Bulk Density: 15 lbs./cu.ft. minimum ▪ Strapping: Non-rusting material ▪ Integrity: Must be maintained through shipping, unloading & storage ▪ Shipping Configuration: stacked, without pallets ▪ Common Unacceptable Contaminants (subject to 2% limit) ▪ Oriented Polypropylene (OPP) ▪ Woven Polypropylene (PP) (e.g. lumber wrap, food & grain bags) ▪ Polyurethane Foam ▪ Nylon (e.g., food pkg., co-ply and cast) ▪ Polystyrene packaging (e.g. rigid foam, molded, cast sheet) ▪ Strapping (e.g., PET, PP, nylon & twine) ▪ PVC or PVDC packaging ▪ Cross-linked PE packaging ▪ Rigid plastic (e.g., bottles, jugs, containers) ▪ Glass containers ▪ Ferrous and non-ferrous metals ▪ Paper and cardboard ▪ Dirt, rock, and other inorganic grit
Merlin Plastics [24]	Agricultural plastics.	<ul style="list-style-type: none"> ▪ <10% contamination ▪ PP twine and PE film must be segregated ▪ Must be compacted/densified ▪ Agricultural plastics must be separated (PE grain bag, PE silage cover, PE bale wrap/bale bag, PE Greenhouse film, PP Twine and cordage)
EFS Plastics	Can handle high levels of contamination.	<ul style="list-style-type: none"> ▪ Plastic Film, with absolutely no paper contamination
Various Recycling Companies	Private companies will set standards based on needs.	<ul style="list-style-type: none"> ▪ LDPE, PE, PP ▪ e.g., >10% contamination ▪ e.g., 95% PE in a bale

Appendix C – List of Key Stakeholders

Interviews with 15 stakeholders across the supply chain and with 13 industry innovators were held in January and February of 2020. These interviews discussed barriers to increase recycled content in newly manufactured plastic products and possible standards to support greater recycling rates for plastic in Canada. A multi-stakeholder approach resulted in speaking with people from industry, government, and academia. Table C1 summarizes the associated organizations that provided context for proposed standards.

Table C1: Summary of Participating Organizations

Participating Organizations	
Plastic Product Manufacturer	Plastic Recycler
Large Regional Government	Material Producer Using Post-Consumer Waste
Chemical Plastic Recycler	Federal Environmental Department
U.S. Industry Trade Group	Waste to Fuel Producer
Plastic Resin and Product Manufacturer	Plastic Recycler
Plastic Product Manufacturer	Researcher
Recycler and Product Manufacturer Using Post-Consumer Waste	Provincial Plastic Recycling Association
Large Municipality	Recycling Council
Brand Manager	Federal Plastic Recycling Association
Stewardship Organization	Recycling Consultant
Chemical Producer	Policy Think Tank / Researcher
Technology and Software Provider	Provincial Recycling Authority
Bioplastic Producer	Manufacturer of Activewear Clothing
U.S. State Environmental Department	Recycling Council

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

