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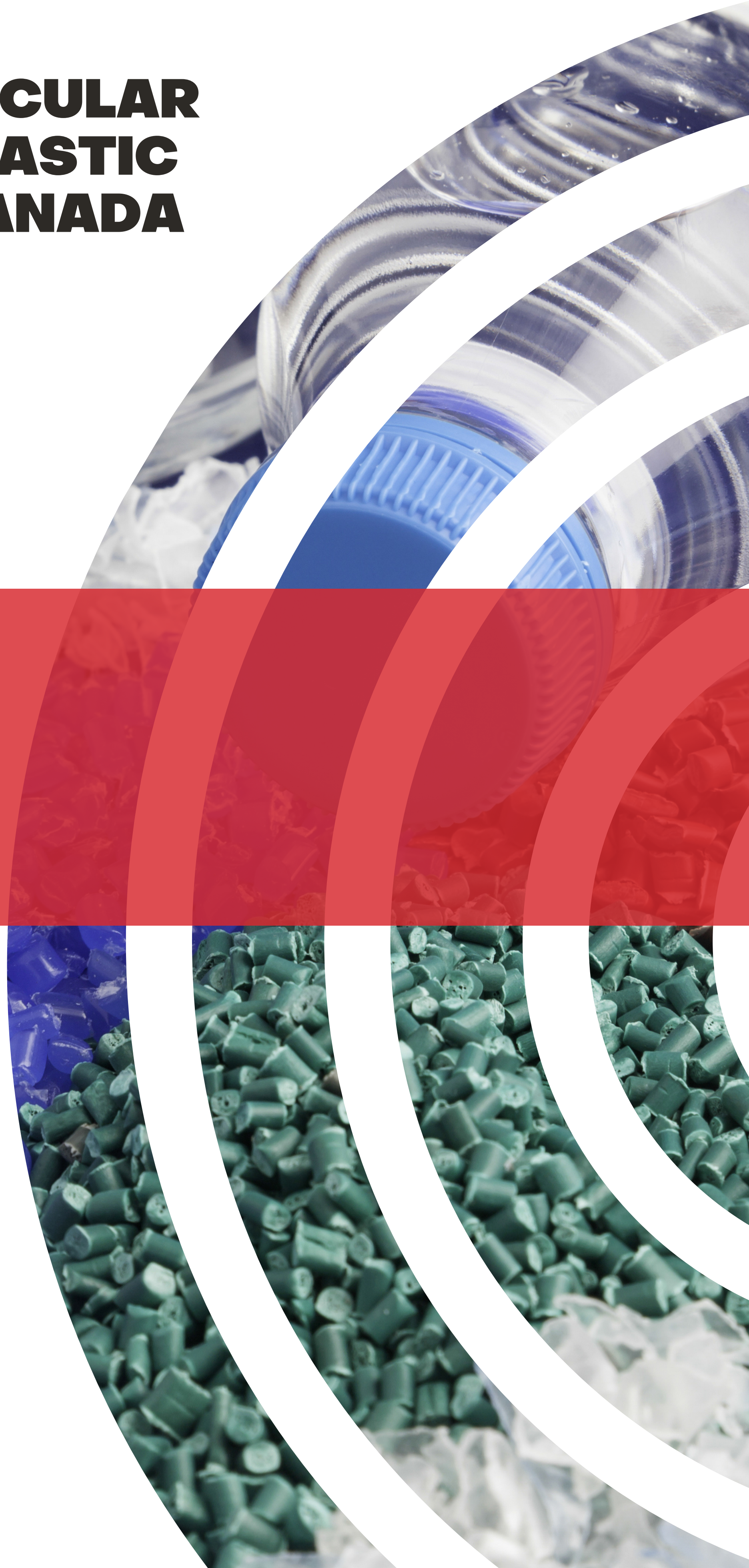
TOWARDS A CIRCULAR ECONOMY OF PLASTIC PRODUCTS IN CANADA



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Towards a Circular Economy of Plastic Products in Canada

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Acronyms and Abbreviations

AB	Alberta
ABS	Acrylonitrile Butadiene Styrene
ASTM	The American Society for Testing and Materials
BC	British Columbia
CAD	Canadian dollar
CCME	Canadian Council of Ministers of the Environment
CERI	Canadian Energy Research Institute
CIAC	Chemistry Industry Association of Canada
CMD	Catalytic Microwave Depolymerization
CO_2 H_2	Carbon dioxide and Hydrogen
CPIA	Canadian Plastics Industry Association
D-Chem	Chemical recycle of disposal
ECCC	Environment and Climate Change Canada
EEE	Electric and Electronic Equipment
EPR	Extended Producer Responsibility
ER	Energy recovery
ESG	Environmental, Social and Governance
FHDPE	Foam High-Density Polyethylene
HDPE	High-Density Polyethylene
HDPE PCR	High-Density Polyethylene Post Consumer Resin
HIPS	High Impact Polystyrene
kg	Kilogram
kt	Kilotonne
LDPE	Low-Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
MB	Manitoba
MSW	Mixed/Municipal Waste System
NB	New Brunswick

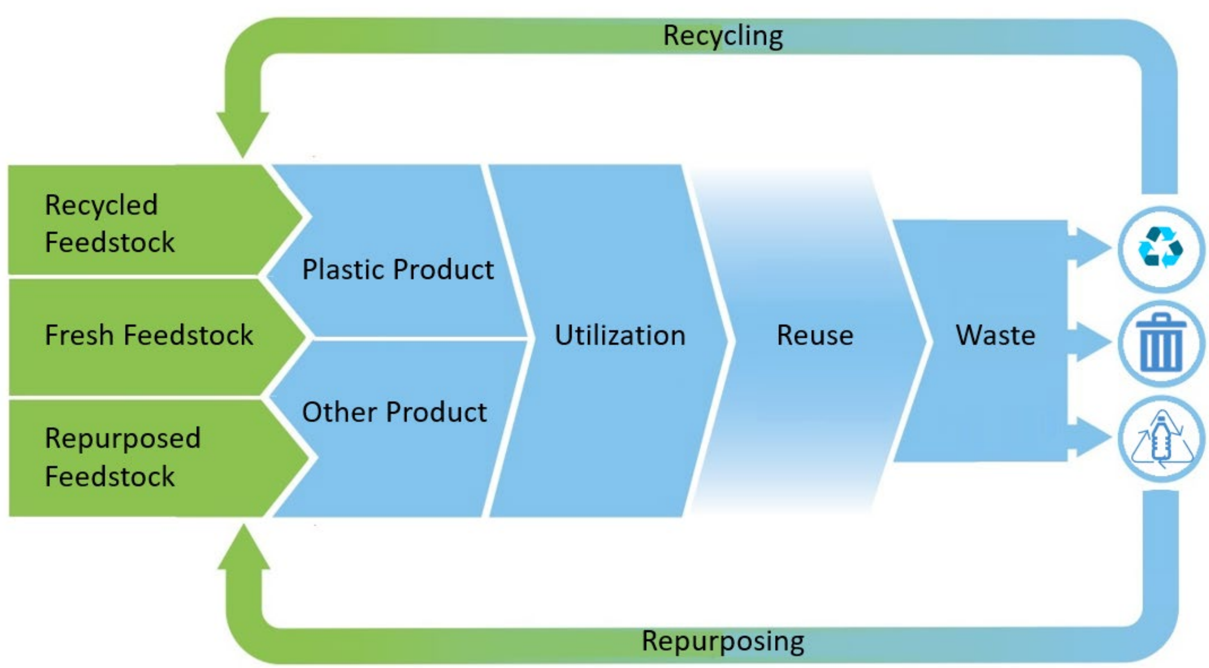
NL	Newfoundland and Labrador
NS	Nova Scotia
OECD	Organisation for Economic Co-operation and Development
ON	Ontario
OREX	Organic Extrusion Press
PA	Polyamide
PC	Polycarbonate
PE	Polyethylene
PEI	Prince Edward Island
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PS-REGEN	Polystyrene Regeneration
PVC	Polyvinyl Chloride
QC	Quebec
R-30	Thermal Resistance-30
R-Chem	Chemical recycle
R-Mech	Mechanical recycle
RP	Repurposed plastic waste
SK	Saskatchewan
SSO	Source Separated Organics
TR	Total recycled plastic waste
UR	Unrecovered plastic waste
US	The United States
YK	Yukon

Executive Summary

This study investigated plastic waste generation and management in Canada and current efforts and challenges facing the advancement of a circular economy for plastic products. Under a circular economy model, it is envisioned that feedstock for fresh plastic production could either be sourced solely from recycled waste plastics or in combination with virgin feedstock sources to supplement material flow losses and growths in plastic product demand.

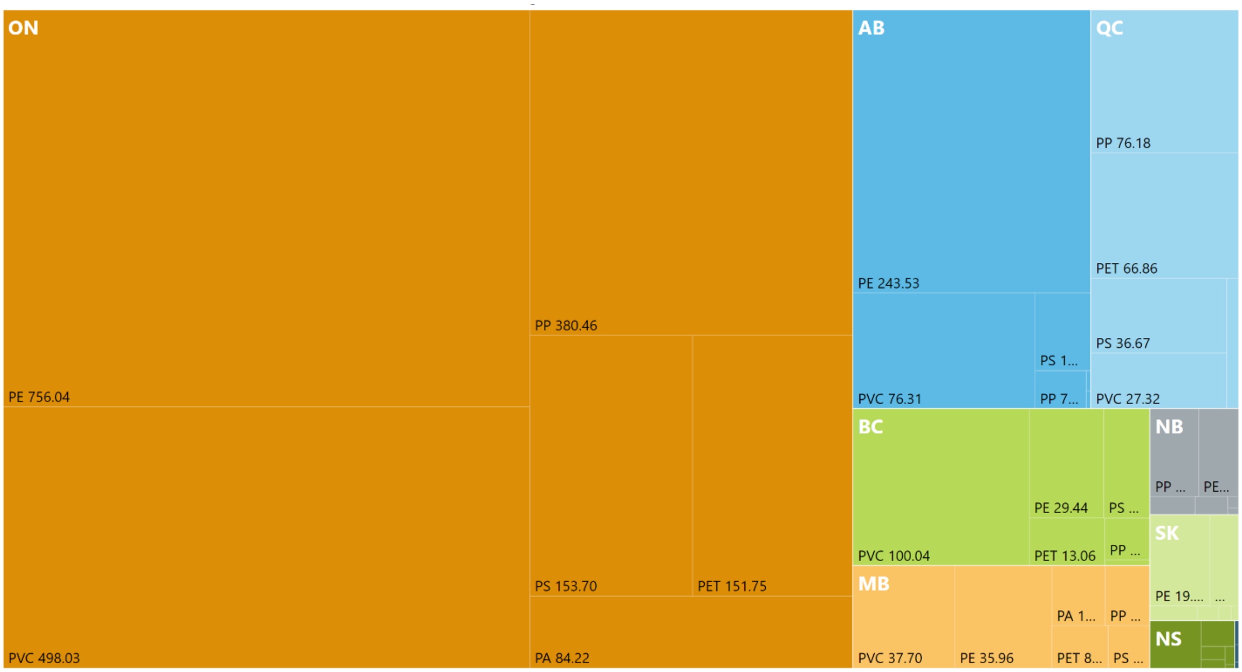
As depicted in Figure E.1, CERI classifies waste plastic flows as either disposed, recycled or repurposed. The disposal could be in landfills or result in pollution through leakages into the environment. Recycling covers the reprocessing or remanufacturing of plastic waste into the same or a different product of similar or different design and function. This includes chemical processing of plastic wastes into fuels and feedstocks. Repurposed plastic wastes are those incinerated with or without energy recovery. Prior to waste generation, some utilized plastic products may be reused (used multiple times as is, for the same function or other functions not originally intended during production). Currently, only about 10% of Canada's annual plastics consumption is recycled.

Figure E.1: Material and energy flows in a circular economy for plastics



CERI combined multiple information sources on Canadian plastics production, imports, and exports databases at both interprovincial and international markets to perform plastic materials flow analysis at both national and provincial levels for all plastics consumed in Canada in 2019. Detailed discussion is provided for the six plastic types accounting for over 98% of the total annual consumption of recyclable materials. These plastic materials include polyethylene (PE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), and polyamide (PA). Figure E.2 shows the quantities of the major plastics materials consumed in Canada in 2019.

Figure E.2: Consumption of plastic products in Canada (2019)



PE is the most consumed plastic material in Canada at about 1100 kt in 2019, followed by PVC (~760 kt) and PP (~500 kt). Quantities of PET, PS, and PA consumed are respectively about 244 kt, 234 kt, and 103 kt. Major demand locations are Ontario, Alberta, Quebec, and British Columbia. PET consumption is predominantly in Ontario and Quebec. PS, PP, and PA are also consumed more in Ontario than in other areas.

Using national waste audit data, CERI classified the entire plastic waste generation in Canada into three flow categories, including total recycled (TR), repurposed (RP), and unrecovered (UR) plastic wastes. Figures E.3 and E.4 show the quantities and proportions of plastic waste flow categories for each type of plastic material presented.

Figure E.3: Quantities of plastic waste flow categories (UR, TR and RP)

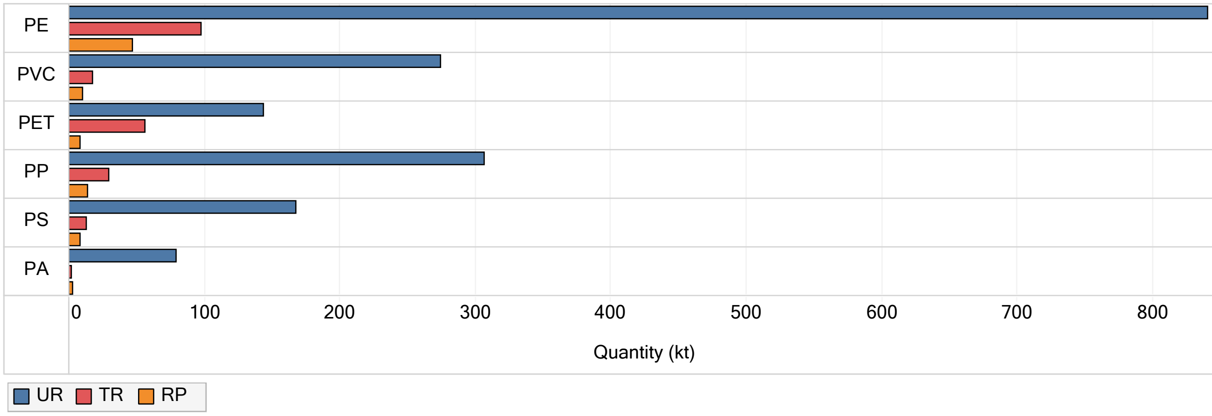
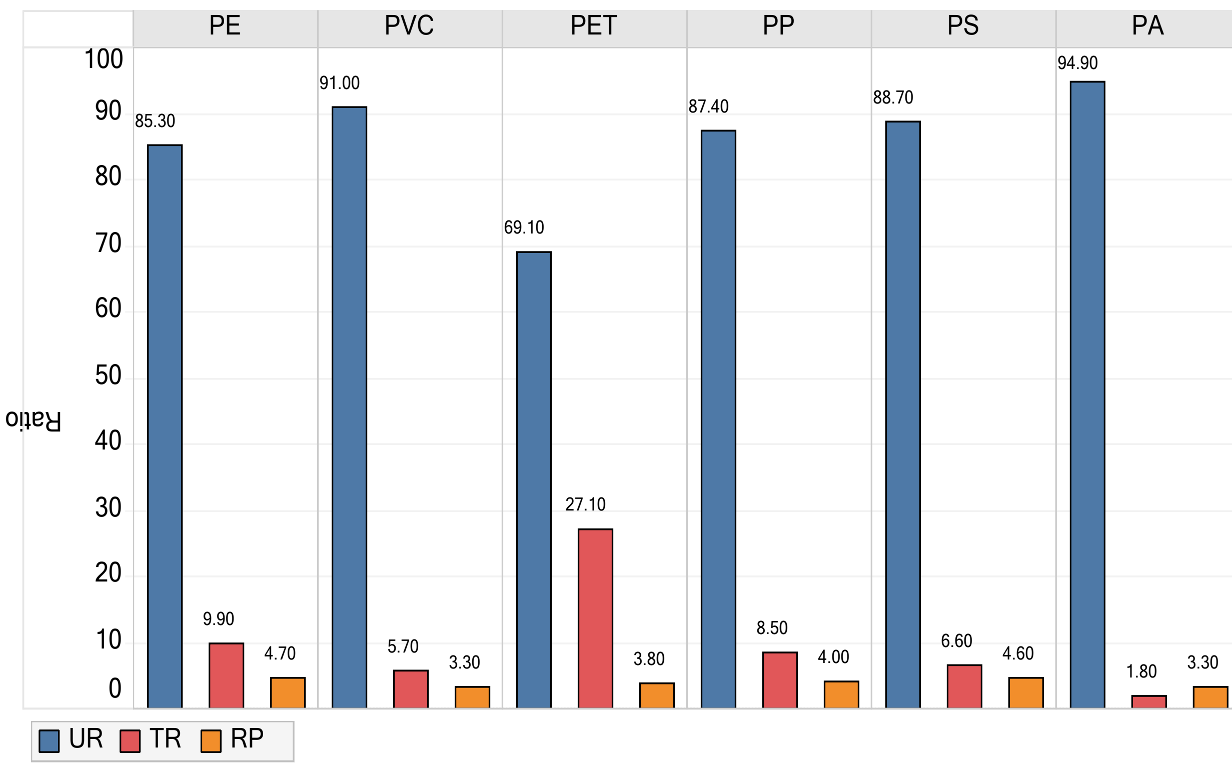


Figure E.4: Proportion of each flow category from plastic wastes generated



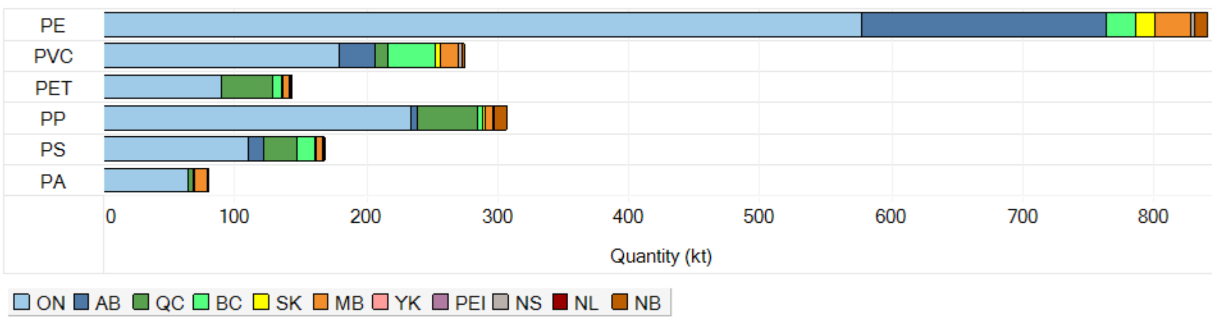
The total amount of TR in 2019 of the six plastic types is estimated to be about 215 kt, where PE accounted for about 98 kt of the recycle flow. PA has the lowest recycle volume of about 1 kt. Mechanical recycling is the predominant recycling method used, with over 90% of PET and PVC recycling done with this technology. About 80% of the PE, PP and PS recycling also utilize mechanical recycling technology.

The total quantity of waste plastics repurposed is about 90 kt, of which repurposed PE amounted to around 47 kt. In almost all cases in Canada, repurposed plastics were incinerated with energy recovery.

The quantity of UR flow for all types of plastic wastes considered is about 1810 kt, with PE, PVC, and PP having the most significant shares. For PET and PE, about 1.5% and 1.2% of their UR flow leaked into the environment, and the rest was landfilled. For the other plastic materials, the leakage to the environment ranges between 0.8-1.1%.

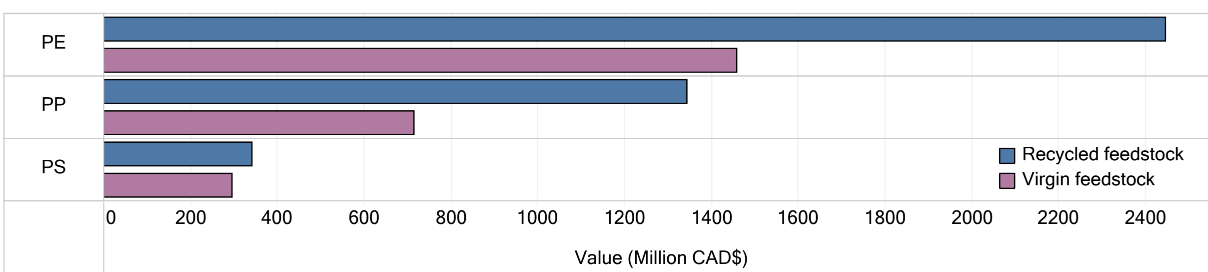
Figure E.5 shows the provincial breakdown of the unrecovered plastic waste flows in Canada. Ontario and Alberta have the highest UR flows of about 577 kt and 186 kt, respectively. Ontario, British Columbia, and Alberta generated most of the unrecovered PVC wastes in Canada. Ontario and British Columbia generated about 179 kt and 36 kt of unrecovered PVC plastic wastes, respectively. Additionally, Ontario and Quebec generated most UR flows of PET, PP, and PS plastic wastes.

Figure E.5: Provincial breakdown of UR flows in Canada



Assuming that all the evaluated UR flows are recycled, Figure E.6 compares the value of the recycled feedstock to the virgin feedstock, which would be needed under a no UR recycling business as usual. The total value of UR flows in 2019 for PE, PVC, PET, PP, PS and PA amounts to about C$ 6.7 billion. PE and PP alone contribute the values of about C$ 2.4 and C$ 1.3 billion, respectively.

Figure E.6: Potential recycle feedstock (from UR flow) and the equivalent virgin feedstock values



However, the total value of natural gas production from which the ethane feedstock – assuming gas-based technology, which is the predominant source in Canada – for PE production is separated, is estimated to be over C$ 3.5 billion. Therefore, if all the UR flows were to be recycled, this ethane production (and perhaps, some of the natural gas production as well) would need to find alternative demand in a circular economy model for the plastics market. Nevertheless, demand for plastic products is expected to continue to grow in the future, both locally and internationally, and not all waste plastics could be recycled into plastic products. This would entail supplementing the recycled products with some virgin production.

Chapter 1: Introduction

Summary

Stakeholders in government and industry are making efforts to develop and implement frameworks and action plans to reduce, reuse, recycle, and/or repurpose plastic wastes in Canada through regulation, collaboration and sensitization on best end-of-life management practices. The circular plastics economy model is considered a promising approach to control environmental pollution from waste plastics. Current plastic waste management practices in Canada are discussed, along with the evolving policy environment and the ideas behind plastic materials circularity.

1.1 Types of plastic wastes in Canada: Where is the industry now?

Since the mid of the last century, plastics production worldwide has grown more than any other manufactured material. Since the 1950s, approximately 8.3 billion tonnes have been produced globally, and almost 80% of this amount has become plastic waste, with only 23% of the waste recovered or recycled. According to the estimates, the annual global production of plastics is expected to surpass 500 million tonnes (Mt) by 2050, and up to 12 billion tonnes of plastic manufactured by that time will be lost to disposal with current recycling practices and capabilities. Plastic waste management and pollution are priority issues for world societies (ECCC 2019a; Recycling Council of Ontario 2021; BASF and Deloitte LLP 2020; Sardon and Dove 2018).

Plastic products and plastic resin manufacturing are responsible for over 5% (CAD 35 billion) of the sales in the manufacturing sector in Canada and employ about 93,000 people. Based on a 2019 study report published by the Environment and Climate Change Canada – ECCC (ECCC 2019a; 2019b), five polymer types are dominant for domestic plastic consumption: polyethylene (PE), with 3,700 thousand tonnes (kt) produced in 2017; polyvinyl chloride (PVC) with 210 kt, polyethylene terephthalate (PET), 166 kt; polyurethane (PU), 122 kt; and polyamides (PA) (116 kt). According to the study, 4.7 Mt of plastics were introduced to the Canadian market in 2017. About 70% (3.3 Mt) were discarded as waste, representing a loss in economic opportunity estimated as approximately CAD 7.8 billion/year, based on the value of virgin material. However, the lost opportunity due to the unrecovered and unrecycled plastics can increase to CAD 11.1 billion by 2030 (ECCC 2019a; 2019b).

Packaging, construction and automotive industries are major end-users of plastic (69% of the total in 2016). In contrast, packaging, automotive, textile, and electric and electronic equipment (EEE) sectors are the main generators (66% of total) for plastic waste. Durable products (those staying in use over one year, such as plastics in construction, automotive, appliances, electronics, textiles, furniture, etc.) accounted for 66% of plastics in the Canadian market and 51% of all plastic waste discarded in 2016. Nondurable products (those staying in use less than one year, such as single-use plastics, packaging products, agricultural plastics) accounted for 34% of plastics in the Canadian market and 49% of all plastic waste discarded in 2016. Out of this amount, single-use plastics are responsible for more than a third of all plastic waste, with up to 15 billion plastic bags used yearly and about 57 million straws used daily. After only a single use of plastic packaging, 95% of the material value becomes lost to the global economy (CCME 2018; ECCC 2019a; 2019b; 2020c; CIAC 2020a).

According to (ECCC 2019a), the majority of plastic waste from both durable and nondurable applications goes to landfills (86%), with 1% dumping or leaking into the environment; 4% are incinerated with energy recovery, and only 9% of waste undergoes recycling, including mechanical (8%) and chemical (1%) recycling.

Secondary plastics recycled domestically in Canada in 2016 accounted for about CAD 350 million in sales, which is only about 3.5% of the sales of primary virgin resin (CAD 10 billion). The main focus of the recycling industry includes PET, high-density polyethylene (HDPE) and polypropylene (PP), and the locations of the recycling facilities are predominantly in Ontario, Quebec and British Columbia, where the plastic waste feedstock is more accessible (ECCC 2019a). For the most common plastics in Canada and the US, the current supply of recycled plastic material meets only 6% of the demand (Closed Loop Partners 2021).

Furthermore, plastics from packaging represent 47% (1,542 kt) of the total plastic waste generated in Canada in 2016. It is the first source of value recovered plastics, with a 327 kt, or 21% value recovery rate. It is also reported to have the highest recycling rate (15%) among all sectors that utilize plastic. However, it should be noted that only about 20% of the collected plastic packaging waste undergoes sorting at a recycling facility in preparation for processing, although packaging waste disposal amounts to about 82% of plastic packaging produced (ECCC 2019a; Closed Loop Partners 2021).

Thus, the existing approach to plastics production, consumption and disposal of wastes creates adverse effects on the environment and causes substantial losses of resources, energy and value (CIAC 2020a).

1.2 Plastic waste handling and management in Canada

Possible measures for plastic waste management can be split into the following categories (IHS Markit 2020; CCME 2018):

- Performance-based approaches such as government regulations, policies and international initiatives, extended producer responsibility (EPR) programs, standards, performance agreements;
- Voluntary initiatives such as industry and major stakeholder targets and objectives, corporate (industry and NGO-led) initiatives;
- Market instruments, such as incentives, fees, taxes, deposit returns, direct investments.

Currently, there are over ten federal acts, regulations and agreements that aim to prevent plastic waste and marine litter, with the federal Waste Reduction and Management Division, Environment and Climate Change Canada, administering a number of waste-related regulations. Different policies and programs are implemented to regulate waste management in each jurisdiction at the provincial and territorial levels. Licensing and permitting of waste management operations is the responsibility of the provinces and territories. This includes recycling centres, landfills and hazardous waste facilities. All provincial/territorial jurisdictions have their own recycling councils or associations. On the municipal level, municipal solid waste collection, recycling and disposal services generally exist for the citizens. The Green Municipal Fund is another possibility to address specific plastic waste management problems at the municipal level (ECCC 2020a; Recycling Council of Ontario n.d.; ECCC 2020b; 2019).

Table 1.1 below provides a high-level summary of the key federal government regulations, policies and international initiatives for plastic waste management. The scope of regulations included in this table is not exhaustive; only the major laws and regulations are presented.

Table 1.1: Key government regulations, policies and international initiatives for plastic waste management

Name of the document/Year	Responsible party/parties	Document scope or goal
Ocean Plastics Charter[1] (2018)	Governments of Canada and other 25 member countries	Introduced by Canada as part of its 2018 G7 presidency, it contains targets and commitments for global action in five areas and is aimed at stopping plastic waste and the flow of plastics into the environment
G7 Innovation Challenge to Address Marine Plastic Litter[2] (2018)	Governments of Canada and G7 countries	To stimulate innovations to foster more sustainable use of plastic products and reduce plastic waste and marine plastic pollution, including innovations in plastics design and production, use, reuse, and management of plastic waste
The Basel Convention's plastics waste amendments[3] (2019, in force 2021/01/01)	Government of Canada	To control procedure for transboundary movements of all plastic waste and mixtures of plastic waste; waste minimization of and the environmentally sound management of wastes
Microbeads in Toiletries Regulations (2017, in force 2019/07/01)	Government of Canada	To prohibit the manufacture, import and sale of toiletries containing plastic microbeads, including non-prescription drugs and natural health products
Proposed Integrated Management Approach to Plastic Products to Prevent Waste and Pollution (2020)	Government of Canada	To ban or restrict certain single-use plastics by as early as 2021, to establish recycled-content requirements for plastic products and packaging
Greening Government Strategy (2018)	Government of Canada	To divert at least 75% of plastic waste from federal operations by 2030; eliminate the unnecessary use of single-use plastics; purchase more sustainable plastic products
Strategy on Zero Plastic Waste[4] (2018)	CCME	To contribute to achieving both a circular and low-carbon economy and reducing the impact of plastic waste on the environment
Action Plan on Zero Plastic Waste: Phase 1 (2019)	CCME	Focuses on measures to prevent plastic pollution in water bodies and research the impacts of waste plastics on the environment and the issues of consumer awareness, pollution clean-up, and effective ways to contribute to international efforts.
Action Plan on Zero Plastic Waste: Phase 2 (2020)	CCME	Focuses on actions to improve awareness of the general public for responsible and effective plastic waste management; minimize aquatic activities generating plastic

		pollution; address current pollution through capture and clean-up; develop performance metrics to guide decision-making, and support global efforts to combat plastics pollution.
Canadian Plastics Innovation Challenges (through the Innovative Solutions Canada program) (2020)	ISED	Focus on the following key areas: diverting end of life vehicle plastics from landfills; sustainable alternatives to plastic packaging; textiles and microfibers; plastics in e-waste

Notes:

1. The Chemistry Industry Association of Canada (CIAC) and the Canadian Plastics Industry Association (CPIA) offered support for the oceans and waterways component of the Ocean Plastics Charter (CIAC 2020b).
2. The American Chemistry Council, CPIA, and CIAC provided support to the Canadian federal government in their announcement of the G7 Innovation Challenge to Address Marine Plastic Litter. (CIAC 2020b)
3. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal is one of the most comprehensive environmental agreements on hazardous and other wastes globally. Canada implements the Basel Convention's plastic waste amendments through the Export and Import of Hazardous Waste and Hazardous Recyclable Materials Regulations (Plastic Action Centre 2021b)
4. The second, final phase of the Action Plan on Zero Plastic Waste was released in July 2020. (ECCC 2020c)

The acronyms in Table 1.1 stand for the following: ISED – Innovation, Science and Economic Development Canada; CCME - Canadian Council of Ministers of the Environment, CPIA – Canadian Plastics Industry Association, CIAC - Chemistry Industry Association of Canada.

It is worth elaborating on the *Proposed Integrated Management Approach to Plastic Products to Prevent Waste and Pollution*, presented in Table 1.1. In June 2019, the federal government announced new efforts to contribute to the Ocean Plastics Charter and the Strategy on Zero Plastic Waste. This propelled various actions of the Canadian government with provincial/territorial governments and stakeholders to develop EPR programs and propose an approach to the regulation of single-use plastics (ECCC 2020b). In October 2020, the federal government announced details of its proposed approach to the management of plastics, with significant changes to the regulation of plastic products in Canada aimed to reach Canada's zero plastic waste goal by 2030. The proposed steps include (Prime Minister of Canada 2019; Gilmour et al. 2020; King et al. 2020):

- banning or restricting certain single-use plastics (six plastic waste products) by the end of 2021;
- establishing a 50% recycled content target in plastic products and packaging by 2030;
- developing national targets, regulations and standards together with provincial and territorial governments to ensure producer's end-of-life responsibility for plastic products.

The Government of Canada stated that the proposed order would add plastic manufactured items to the List of Toxic Substances (Schedule 1 of the Canadian Environmental Protection Act, 1999) (Gilmour et al., 2020). It should be noted that industry stakeholders, including CIAC, advised against the proposed ban and classification of some plastic products as toxic; concerned that the label would be misleading to the public and lacks scientific justification. The government argues that it is just an act of labelling to highlight the effect of plastic pollution on the environment, but not a characterization of human health impacts of plastic products. As noted in Table 1.1, various stakeholders from government and industry have ongoing engagements geared towards establishing frameworks and action plans to drive the transition to a circular economy for plastic products both nationally and internationally (CIAC 2020b; Canadian Plastics 2020; The Canadian Press 2020).

In addition to legally binding regulations, most notable voluntary initiatives (such as industry, NGO and major stakeholders targets and objectives) include the following:

- The Alliance to End Plastic Waste (AEPW), an alliance of global companies from the plastics and consumer goods value chain, was created in 2019 and includes over 80 members worldwide. The goal of the AEPW is to develop solutions to eliminate plastic waste in the environment by advancing to a circular economy for plastics, and more than US$1.5 billion is committed to this goal over the next five years. Five companies-founding members of AEPW are also members of CIAC (CIAC 2020a; 2020b).
- CIAC's commitment to Operation Clean Sweep, an international pellet stewardship program aimed at eliminating the escape of plastic pellets from industry operations, focusing on preventing leakage into the environment and waterways, and with a goal of zero plastic resin loss (CIAC 2020a).
- CIAC and CPIA industry-wide waste reduction targets launched in 2018: a goal of to reuse, recycle, or recover 100% of plastics packaging by 2040, and an interim goal to reach 100% of plastics packaging being recyclable or recoverable by 2030 (CIAC 2020a).
- CIAC and its partners launched the Getting Plastics Right initiative in 2019. Their recommendations, among others, include a requirement for all levels of government to treat

post-consumer plastics as a resource, not a waste, and to establish the Plastic Technology Innovation Fund with an initial allocation of $200 million, operated by Natural Resources Canada (CIAC 2020b).

- In January 2021, more than 40 companies and organizations have joined the Canada Plastics Pact, launched "to end plastic waste and pollution." The partner companies represent diverse parts of the plastics value chain, from leading brands to waste management companies, government institutions, and NGOs. This is part of the Ellen MacArthur Foundation's Plastics Pact network, and Canada is the latest country to join it. The Pact brings major players to work together on ambitious goals of 100% reusable, recyclable, or compostable packaging by 2025. Other goals include ensuring that at least 50% of plastic packaging is effectively recycled or composted; and ensuring at least 30% recycled content across all plastic packaging by 2025 (SWR Staff 2021; Recycling Council of Ontario 2021).

1.3 Recyclable and non-recyclable plastics

Plastic products could be split into two large categories, thermoplastics and thermosets. Thermoplastics are plastics that can be heated, cooled and reshaped repeatedly, while thermosets are plastics that can only be shaped once. This is because thermosets polymerization creates a three-dimensional network that cannot be reshaped or recycled.

Based on the ECCC-commissioned study report, thermoplastic resins represented 4,281 kt (value of CAD 8.2 billion) in 2017. Polyethylene accounted for most of this production (approximately 3,700 kt produced in 2017), while other significant thermoplastics include PVC (210 kt), PET (144 kt), PA (95 kt), PS (80 kt) and ethylene vinyl acetate (EVA, 53 kt). Thermoset resins production in Canada accounted for 532 kt in 2017 (value of CAD 1.9 billion). Four types of thermoset resins comprised the majority of production, including urea resins (204 kt), phenolic resins (150 kt), polyurethanes (123 kt) and unsaturated polyesters (55 kt) (ECCC 2019a)

The recyclability of these two categories can differ significantly. Recyclability is a combination of the technical/technological easiness to recycle a given product and the economic viability of the recycling process (ECCC 2019b). Recyclability is assessed at the product level and consolidated by sector/resin, according to a three-level scale: low, medium or high recyclability. Depending on products and sectors, the recyclability rate will vary.

There are a number of factors that can negatively impact the recyclability of plastics, including the following (ECCC 2019b; Ellen MacArthur Foundation, World Economic Forum, and McKinsey & Company 2016; Geyer, Jambeck, and Law 2017; Jehanno and Sardon 2019; Sardon and Dove 2018; Rahimi and García 2017):

- Large utilization of thermosets, because their crosslinked polymer networks cannot be reprocessed using heat or solvents (remelted or solubilized);
- Plastic materials, contaminated with chemicals or blended;

- Use of additives in plastic products whether they act as stabilizers or modifiers. It was shown that non-fibre plastic contains 93% polymer resin and 7% additives by mass. Fillers, plasticizers, and flame retardants account for approximately 75% of all additives;
- Some additives have a direct impact on the recyclability of plastics or even might support the degradation of plastic;
- A low density of the potentially recyclable plastic (e.g., expanded polystyrene or EPS) can directly impact collection and transportation costs (e.g., shipping PS to a facility where it can be compressed in order to be transferred over long distances to be recycled and reused.)

Factors that can positively influence potential recyclability include (ECCC 2019a; 2019b):

- relatively high recyclability and large utilization of thermoplastics,
- widely implemented curbside collection of recyclable goods,
- efficient sorting technologies,
- a relatively high value of resin recycled.

Most plastics used in packaging (e.g., PET, PE, PP) have high recyclability and a relatively high value on the secondary market. While the current recycling process almost exclusively treats nondurable plastics, and more specifically, the packaging, EEE (electrical and electronic equipment) plastics and some durable goods are also recycled (through shredded mixed plastics) (ECCC 2019b). Depending on products and sectors, the recyclability rate of plastics will vary. According to the CPIA, while national access rates for plastic packaging range between 70% (for PS) and 99% (PET), with most of the resins showing an access rate of ~90%, plastic packaging has an overall output recycling rate of only 15% in Canada (More Recycling 2020). There is a high degree of uncertainty in the statement that plastics in EEE waste, which is theoretically recyclable, can actually be recycled. The reason for that is a large proportion of plastics are contaminated with additives (flame-retardants, and so on). In the automotive sector, about 85% of plastics can be potentially recycled. For agricultural plastic waste, a rate of 90% can be theoretically achieved. For other plastic waste, no more than 50% recyclability is expected (ECCC 2019b).

Regarding the packaging plastic material, there are some specifics about its labelling that should be noted. The recycling symbols on plastic packing/products do not indicate that a product is necessarily recyclable nor recycled. The number is a resin identification code that shows the kind of plastic that the material contains. Plastics with #1 (PET) or #2 (HDPE) are among the easiest plastic polymers to recycle and are the most commonly recycled plastics. Plastic packaging labelled #3 (PVC), #4 (LDPE), #5 (PP), #6 (PS) and #7 (Other Plastics) are not commonly collected in municipal recycling programs and are usually more difficult to recycle (Plastic Action Centre 2021a; American Chemistry Council n.d.).

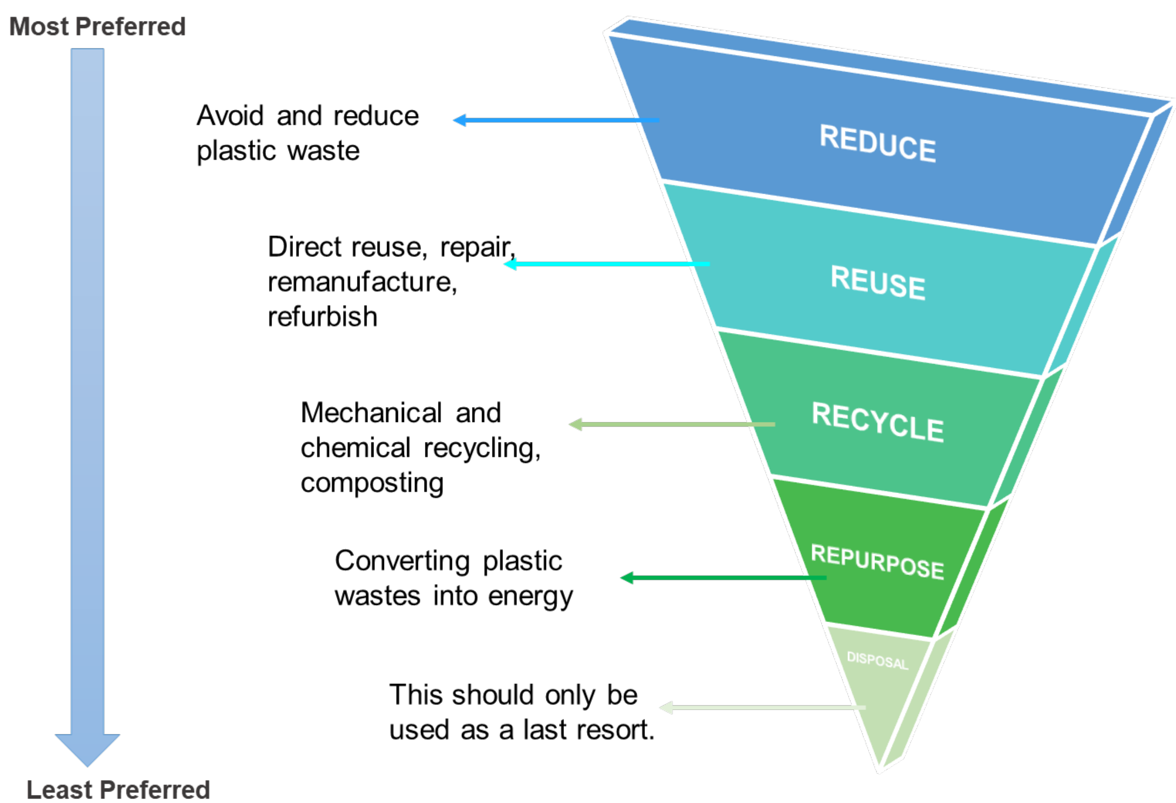
Biodegradable bioplastics and compostable plastics have surged in popularity in recent years. These are typically used in short-life applications like single-use food packaging and utensils. Biodegradability and composting are opportunity areas but pose their own unique challenges and alone will not solve the problem. Biodegradable does not necessarily mean compostable or recyclable (CIAC 2020b).

1.4 Opportunities to address the plastic waste challenge

The Canadian economy for plastics is mostly linear, where the resources are extracted, then transformed to products, used and disposed of as waste. A circular economy aims to maximize the value of natural resources and products by reducing, reusing, repairing, remanufacturing, recycling and composting materials or, as a last resort, recovering energy (repurposing) at their end of the lifecycle.

Various types of plastics waste management are presented in Figure 1.1, adapted from the waste management hierarchy as proposed by (CCME 2018; ECCC 2019a; Ellen MacArthur Foundation, World Economic Forum, and McKinsey & Company 2016). CERI has changed the 'Recovery' element in the original version of the hierarchy by CCME to 'Repurpose' because we believe that recovery should be a more encompassing element of the plastic wastes management strategy covering all actions to minimize or eliminate the release of plastic wastes into the environment. Therefore, Recovery (against the release of waste plastics into the environment) includes Reusing, Recycling, and Repurposing plastic wastes.

Figure 1.1: Hierarchy of priority in plastics management



Source: Modified by CERI from (CCME 2018)

The hierarchy in Figure 1.1. prioritizes plastic waste management options in the order from the most preferable and with the greatest value, to the least preferable and with the lowest value, including the following steps (CCME 2018; ECCC 2019a; Ellen MacArthur Foundation, World Economic Forum, and McKinsey & Company 2016):

1. Prevention (avoid and reduce plastic waste, e.g. by designing durable and reparable plastic products, reducing the use of disposable plastic). Strategies for achieving zero plastic waste and transitioning to the circular economy also include designing products for longevity and durability, the possibility to disassemble products for reuse and repair, refurbishment, and remanufacturing into new products (ECCC 2019)

2. Collection of all plastics (including using clean-up), so they are restructured back into the economy

3. Value recovery (all activities at the end of the lifecycle that regain value from plastics waste, instead of disposing of them in landfills or incinerating without energy recovery), listed below in order of preference, and from high to low value:

    - 3.1. Reuse (direct reuse, servicing and repairing products, refurbishment and parts harvesting, or RRRDR). The RRRDR represents maintenance processes that typically occur outside of industrial facilities and provide an opportunity to extend the product's useful life. This is the first option in the waste management hierarchy but the least present in Canada. While some initiatives to reuse or repair certain products containing plastics exist (e.g., for textiles, electronics, construction), they are usually fragmented and small-scale. The impact of these initiatives is difficult to quantify because some of them (such as repair and direct reuse) temporarily reduce waste by prolonging the service life of the products (ECCC 2019a).

    - 3.2. Recycle (mechanical recycling in closed or open loops to produce plastic feedstocks or resins; chemical recycling; and composting) (Ellen MacArthur Foundation, World Economic Forum, and McKinsey & Company 2016):

        - Mechanical recycling in closed loops is the most value-preserving. It keeps polymers intact and keeps the quality of the materials at a similar level by cycling materials into the same application or applications requiring materials of equal quality.

        - Mechanical recycling in open loops plays an important role as well. In this option, polymers are kept intact, but the quality and/or material properties degrade and necessitate applications with lower requirements. Aiming to achieve the highest-value applications each cycle could help increase the value maintenance and the number of possible loops. Currently, the majority of plastic packaging recycling is mechanical recycling in open loops.

        - Chemical recycling brings polymers down to individual monomers or other hydrocarbon products that can be used as building units or feedstock to produce new polymers or other chemicals and fuels. Chemical recycling technologies are not yet widespread or not yet economically viable for most common packaging plastics. However, they are an option for materials for which mechanical recycling is not possible. Further developing and scaling up chemical recycling technologies is required to enable upcycling to virgin quality and establish 'infinite' loops.

- 3.3. Repurposing plastic wastes to recover energy through incineration with heat recovery for industrial process heating or electricity generation.

4. Disposal in landfills where the wastes are left to degrade naturally or are incinerated without energy recovery.

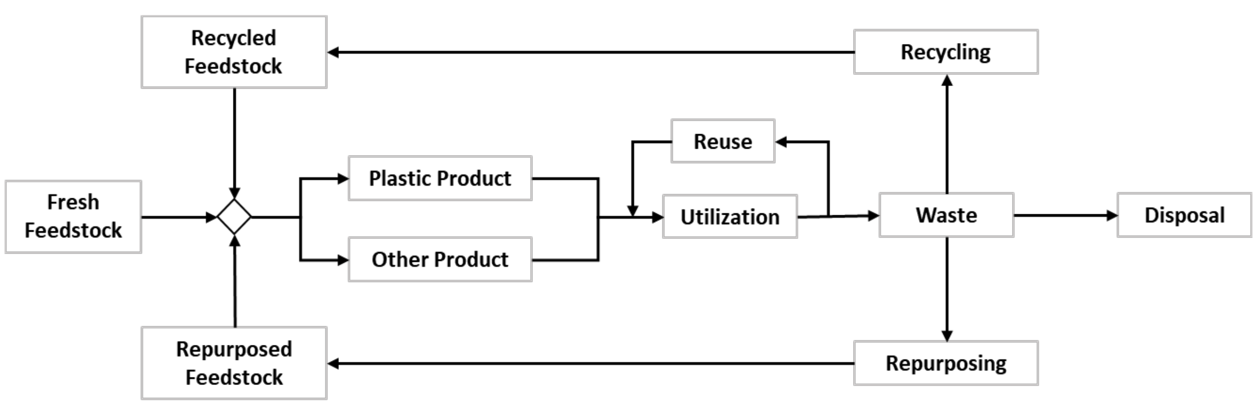
In 2018, a minimum of 306.6 kt of Canadian post-consumer (including commercial) plastic material was estimated to have been collected for recycling. Of the total volumes reported, 92% were reclaimed in Canada or the U.S., 7% were exported overseas, and the remaining 1% had a destination unknown. Plastic bottles continued to account for the majority of the recycled plastic collected. (More Recycling 2020).

1.5 Purpose and scope of the study

To address the challenges of plastic waste proliferation, a circular economy for plastics has been proposed as a viable pathway to limit or eliminate the waste disposal problem by collecting, separating, recycling, and reusing plastic products (Thunman et al. 2019). Alternatively, where recycling might face technical or economic limitations, repurposing plastic waste into other useful means such as heat energy for industrial process heating applications or electricity generation provides another route to circularity.

Figure 1.2 is an illustration of potential material flow schemes for a plastics' circular economy. Each material processing pathway has implications on the supply of feedstocks, processing technology, supply of products, value chain economic competitiveness, and environmental burdens. As observable in the figure, the reusing, recycling, and repurposing flow pathways constitute the plastic circular economy investigated in this study.

Figure 1.2: Flows of plastic materials in a circular economy



Previous studies on plastic wastes in Canada did not cover all plastic material flows in the country. A recent ECCC-commissioned study accounted for plastic materials produced and used within Canada (ECCC 2019a; 2019b; Recycling Council of Ontario 2021). This report extends the material flows accounting by incorporating import and export flows and reporting both national and provincial flows of plastic wastes. CERI also provides a detailed breakdown of flows and economic impacts for six major plastic products, including polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS), and polyamide (PA).

There is also a limitation in the scope of the existing literature on a circular economy for plastics in Canada. This study extends and updates previous plastic waste material flow analysis using the most recent 2019 data. Challenges and opportunities for circularity and the potential economic impacts of such a market are also investigated.

1.6 Study approach

All plastic material flows in Canada are quantified at both national and provincial levels using a plastics material flow model which captures local production, imports (both international and inter-provincial), and exports (both international and inter-provincial) – to calculate annual local consumption of plastic products, as expressed in the equation below:

$$\boldsymbol{Consumption = Production + Import - Export}$$

Input data to the model include CERI's database of Canadian plastics production, Canadian International Merchandise Trade (CIMT) on plastics from Statistics Canada (Statistics Canada 2019), and national plastics waste audit data from Environment and Climate Change Canada (ECCC). All plastic material flows are categorized into PE, PP, PET, PVC, PS, PA, and OTHERS. The OTHERS include numerous plastic material types with minimal contribution to the overall annual flow or whose material type was not provided in the CIMT database. This category is sub-categorized into other: thermoplastics, thermosets, bioplastics, tubes and pipes, and miscellaneous.

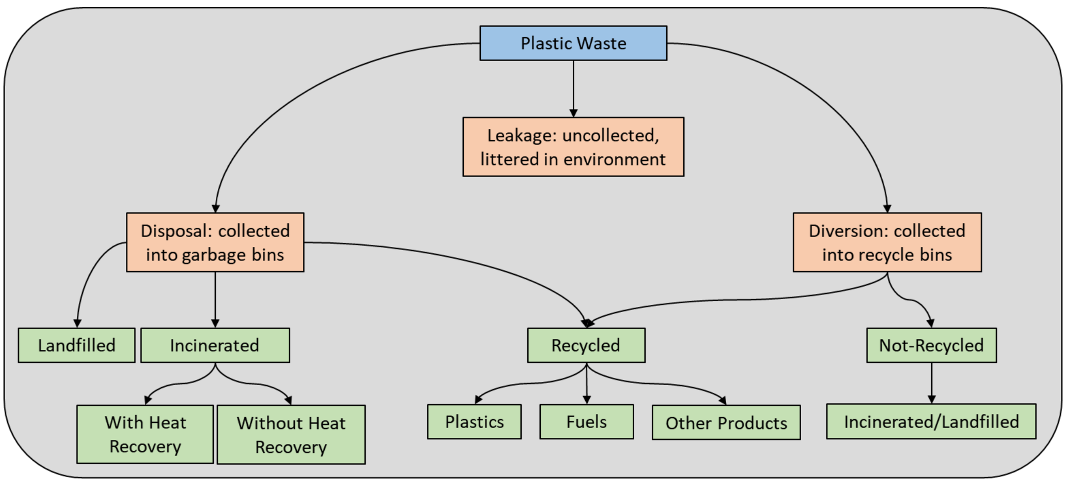
National waste audit data is used to perform a complete material flows analysis after evaluating annual plastic waste generation from the annual consumption. Figure 1.3 illustrates the flow pathways of plastic wastes generated annually in Canada (ECCC 2019a; 2019b). As depicted in the figure, a portion of the plastic waste directly leaks into the environment while the main portion is either recycled or goes to disposal[1]. In Canada, waste plastic leakage accounts for a very small portion (about 1%) of the total plastic wastes generated annually. Recycle products include plastics, fuels, and other products such as materials for construction, chemicals, and other miscellaneous recycle products.

Generally, waste plastics are either collected or uncollected after use. When they are collected, they may be placed in a garbage bin or some designated recycle bin. Uncollected plastic wastes are often indiscriminately littered in the surrounding environment after use. They may be collected during clean-ups or remain permanent pollutants in the environment.

[1] There is another stream (not shown in Figure 1.3), representing plastics in the repaired and refurbished products that is not the focus of this study.

Removing recyclable plastic wastes from garbage bins and putting them inside designated recycle bins is known as waste diversion. This increases the volume of plastic wastes exposed to the recycling value chain. However, collecting the waste in the appropriate recycling bin is only the beginning of the process because it must still be sorted into those that can be recycled using available processing technologies and those that cannot be recycled due to contamination or heterogeneities from the presence of hard to recycle composites. The technology to recycle some of the plastics might be unavailable or uneconomic for commercial applications. In this situation, repurposing the plastic wastes (incineration with or without heat recovery) is a compelling option. Otherwise, the collected plastic wastes may end up in landfills or be stored in the environment permanently.

Figure 1.3: Plastic waste material flow pathways



In most exiting commercial applications, the recycle streams are mainly processed using either chemical or mechanical recycling techniques. The disposal stream could be split into three branches:

1. Recycled from post-disposal collection
    a. Post-consumer plastics production
    b. Fuels production
    c. Other products – chemicals, construction materials, etc.
2. Repurposed via incineration
    a. With heat energy recovery
    b. Without heat energy recovery
3. Unrecovered plastic waste
    a. Landfills
    b. Leaks into the environment

In this report, CERI sub-categorized the overall waste plastic flows into three groups of total recycled (TR), unrecovered (UR) and repurposed (RP) plastics. TR consists of plastic wastes recycled from either diverted or disposed flow routes. UR comprises landfilled and leaked plastic wastes, and RP represents incinerated plastics either with or without heat energy recovery.

Chapter 2: Existing and Emerging Innovation Challenges

Summary

Generally, plastic materials can be categorized into two: thermoplastics and thermosets. Thermoplastics constitute most of the plastic products used in Canada and, in theory, they are recyclable. In practice, plastic products are usually designed and desired to have certain shape and form attributes which necessitates the inclusion of other chemicals or components during production, making the resulting thermoplastic products difficult to recycle. This challenges the goal of a circular economy for plastics but can also be viewed as where opportunities are for improving the status quo under the four themes of: economics, market, technical and regulatory. Issues of Environmental, Social and Governance (ESG) and Extended Producer Responsibility (EPR) are also presented.

2.1 Stages of the plastic waste life cycle

The lifecycle of plastics in the Canadian economy can be split into four stages: resin production, plastic product manufacturing, use phase and the end-of-life phase (ECCC 2019a). The end-of-life stage (plastic waste) can be further broken down into the following stages: waste generation, plastic diverted, plastic sent to recyclers, and recycled plastic sent to users (ECCC 2019b).

The Canadian plastics economy is still mostly linear, designed to start products from virgin resin and eventually discarded plastic. A few plastic products are designed, taking into consideration their end-of-life phase. As mentioned in Chapter 1, only 25% of all plastics discarded in Canada (3,268 kt) are collected for diversion (807 kt) (ECCC 2019a).

At the end-of-life, plastic waste can be collected for direct disposal and sent to landfills, or it can be collected for diversion (sent to a sorting facility and diverted from direct disposal). The collection rate of plastic waste for diversion (including the curbside collection, recycling depots, deposit-refund systems, etc.) greatly depends on the end-use sector. Once the plastics are collected for recycling, only 35–40% of the virgin material value is currently retained for the next use cycle (ECCC 2019a; Ellen MacArthur Foundation, World Economic Forum, and McKinsey & Company 2016).

Based on data presented in (ECCC 2019a), 4,667 kt of plastics entered the market in Canada in 2016, which is 43% more than plastic waste (3,268kt) discarded during the same year. Plastic packaging accounted for one-third (33%) of all plastics introduced to the market; however, it was responsible for almost half (47%) of all plastic waste discarded that same year. The next large sector, construction (26% of the total plastics entered the market), was responsible for only 5% of plastic waste in products discarded in Canada in the same year.

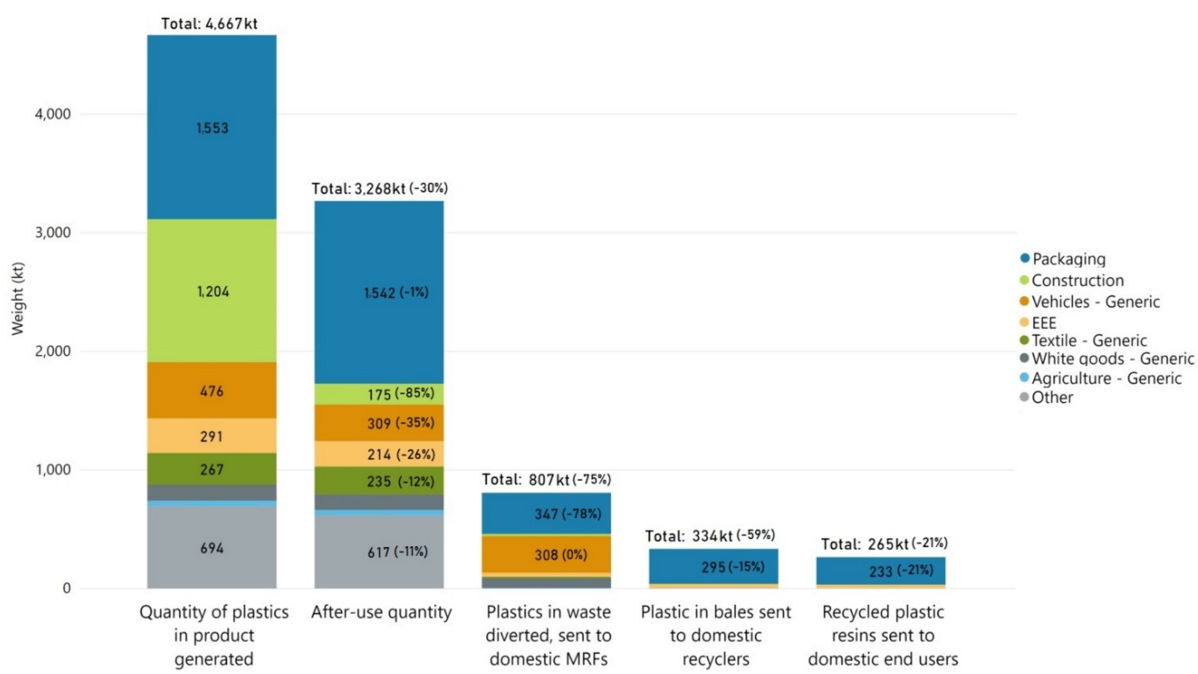
In 2016, out of 3,268 kt of plastic waste generated in Canada, 99% (3,239 kt) were collected, whereas 1% was lost due to leakage into the environment. From the collected plastic waste, 13% were diverted from landfills through three recovery options (mechanical, chemical and thermal). Mechanical recycling was the most utilized option for recovery, accounting for 8% of the waste, whereas thermal recovery accounted for 4%, and chemical recycling for 1% of the plastic waste diversion. The remaining collected plastic waste (2,794 kt or 87%) ended up in landfills (ECCC 2019a). Incineration with energy recovery (i.e., thermal recovery or waste-to-energy recovery) was the second most common value recovery option for handling plastic waste (137 kt treated in Canada in 2016). Most of these plastics were thermally recovered at five major waste-to-energy plants in Canada. These facilities can use all kinds of plastics, including those currently considered unrecyclable (e.g., thermosets and mixed plastics) (ECCC 2019a).

Another option that has not been widespread in Canada is composting. Currently, few post-consumer biodegradable and compostable plastics are streamlined through industrial composting facilities (ECCC 2019a).

While the overall value recovery rate for plastics waste in Canada averaged 13% in 2016, it varies greatly for the specific sectors, with plastic packaging accounting for 88% of plastics resins recycled (ECCC 2019a).

Figure 2.1 shows a detailed breakdown of plastic quantities generated by the various sectors at the different stages of the plastic life cycle: product generation, total waste generated, plastic diverted, plastic sent to recyclers, and recycled plastic sent to domestic users.

Figure 2.1: Quantities generated at different stages of the plastic waste life cycle (kt, 2016)



Source: Adapted from (ECCC 2019b)

Notes:

1. After-use quantity: plastic waste generated (i.e., discarded plastic entering waste stream)
2. Plastic in waste diverted: plastic diverted from direct disposal and sent to a sorting facility
3. Recycled plastic resins sent to domestic end-users: plastic mechanically and chemically recycled from diverted plastic waste.
4. Percentages indicate the decrease of one life cycle stage versus the previous one.

As it is seen in Figure 2.1, there is a 30% difference between plastic generated and plastic entering waste management streams annually. Then only 25% of that plastic enters the diversion stream (807 kt). Out of these quantities, around 50% or 334 kt will be sorted and sent to a recycling facility, the rest being discarded. Almost all plastics are affected, but it is particularly the case for packaging (-78%), where most of the plastic goes directly to disposal (incineration or landfill). A similar situation is with the construction sector (89% goes to disposal, not shown in Figure). Plastics from the automotive sector (vehicles) almost fully go through a sorting facility, but almost none of them result in recycling (ECCC 2019b). Figure 2.1 shows that in 2016, only approximately 8% (265 kt) of the after-use quantity of plastics were recycled. The rest (2,974 kt) was either landfilled (2,794 kt) or incinerated (137 kt, the vast majority being incinerated with energy recovery).

Most types of resins in Canada show diversion rates[2] of more than 10%, even thermosets. This reflects the fact that in many sectors, there are diversion systems in place. However, at the sorting facility, this rate decreases significantly for most plastics, as a recycler will generally purchase only the three main thermoplastics (PE, PP, PET). Thus, at the recycler level, the recycling rates for these three thermoplastics will be 8.3% for PE, 26% for PET and 7.6% for PP. Some other resins may have output recycling rates around 5%: PS, PVC and ABS (ECCC 2019b).

The recycling of plastic almost does not exist in the automotive and white goods sectors, even if the diversion rates are very high (almost 100% for vehicles and about 64% for white goods). Products in those sectors are collected for recycling, sent to a shredder, and finally, to a landfill after the metal content is sorted and sent to recycling. There are very limited end markets for shredder residues of mixed plastics (ECCC 2019a). Three other sectors represented in Figure 2.1 (construction, textile and other plastics) demonstrate a low collection or sorting rate and, as a result, an extremely low recycling rate.

It should be noted that post-consumer mechanical recycling mostly occurs at about ten facilities in Canada, which typically generate resins. As mentioned in Chapter 1, primarily recycled types of plastic include PET, HDPE, LDPE and PP, which almost entirely originate from plastic packaging waste (ECCC 2019a; Recycling Council of Ontario and Plastic Action Centre 2020).

[2] Diversion rate is the share of plastic diverted from direct disposal and sent to a sorting facility divided by plastics waste available for collection (ECCC 2019b)

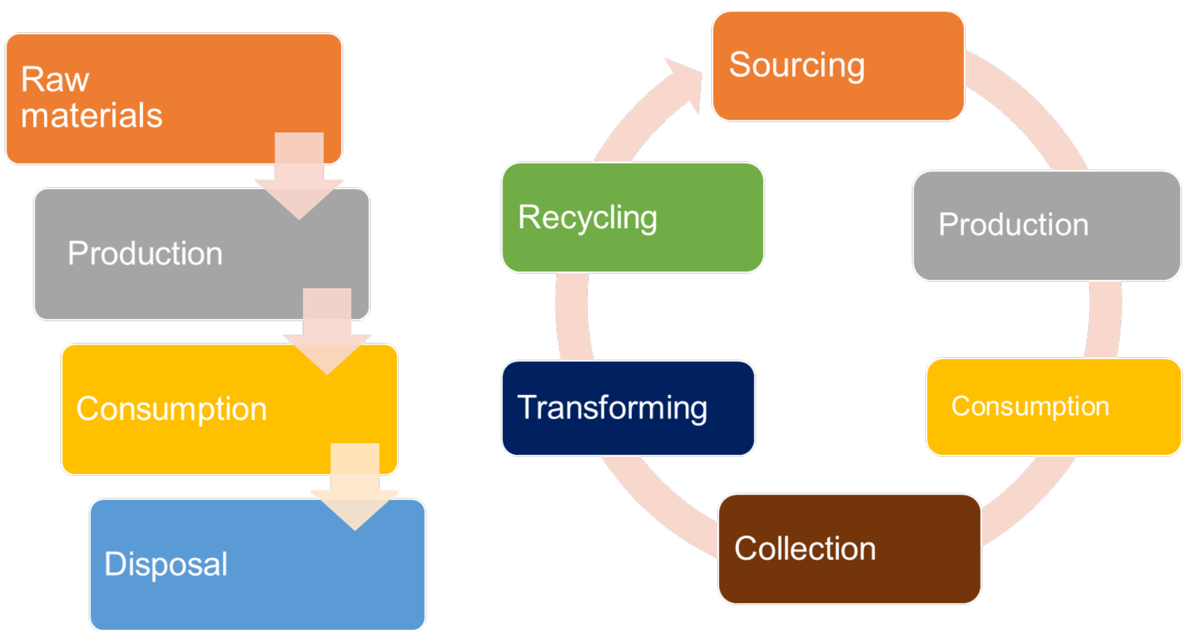
2.2 The circular plastics economy: enablers and limiters (challenges)

There are several definitions for the circular economy for plastics. All of them agree that the circular economy is an alternative to the linear economy based on the principle of "take-make-use-waste," or the economy of production and consumption. The circular economy is an economic model that uses the waste of one process as a feedstock for another process, resulting in eventually eliminating the waste; this is a "make-use-return" model. It extracts a maximum of value from resources, keeping them at their highest utility, and recovers materials at the end of their service life, focusing on the expansion of product lifecycles and positive benefits for society (CIAC 2020a; 2020b; Ellen MacArthur Foundation 2017; National Zero Waste Council 2020; ECCC 2020b). The circular economy is based on the following principles:

- preventing waste and pollution via improved plastics design and innovative business models;
- keeping useful life of products and materials as long as possible through reuse, repair, remanufacturing
- recovering resources to generate new products, and improving end of service life processing.

Figure 2.2 graphically represents principles of the circular economy of plastics in comparison with the linear economy.

Figure 2.2: Circular vs. linear economy of plastics



Source: Figure by CERI

The circular economy for plastics supports the objectives set out in the Action Plan on Zero Plastic Waste, creating 42,000 jobs and saving CAD 500 million annually (CIAC n.d.; CCME 2018).

Major challenges that create obstacles for the implementation of the circular economy model, as discussed in (BASF and Deloitte LLP 2020; ECCC 2019a; CIAC 2020b; 2020a), are summarized below:

Economics

- Competition with virgin primary plastics based on price and quality of the material (virgin material is cheaper to use due to guaranteed purity);
- The negative trade-off for the consumer, for whom it is cheaper to dispose and buy new products than to repair the old one;
- The more labour-intensive cost structure for recycled plastics producers;
- High costs of collection and processing, lack of the infrastructure to collect and process items to be recycled and recovered;

Market

- Secondary plastics supply is limited;
- Lack of viable end markets, no or insufficient market to sell the post-consumer resins;
- Lack of industrial-scale recovery options for hard-to-recycle plastics (i.e., from electronic equipment or automotive sectors);
- Competition from low-cost disposal alternatives to recycling (i.e. cheap landfilling);
- Low participation in collection and recycling programs from industrial and commercial sectors;

Technical

- Poor design of plastics (based on the linear economy model), products are often not recyclable or difficult to recycle by design;
- Low chemical recycling rate (chemical recycling technologies are not yet widespread or not yet economically viable for most common plastics);
- High level of cross-contamination for recycled plastics;
- Limitations of mechanical sorting (manual processes, inaccurate sorting, losses in sorting process, cross-contamination issues);
- Inability to reach 100% diversion or zero waste goals from mechanical recycling alone. Other waste management options of energy recovery and chemical recycling are needed to advance a circular economy;

Regulatory

- Limited economic incentives for plastics recycling and value recovery in Canada (given market prices, structures, business models and the low cost of disposal);
- Lack of consumer awareness of collection standards to avoid recycling contamination;
- Regulatory issues (policies for creating sustainable products).

There are also enablers for the circular plastics economy model that will help achieve the goal of zero plastic waste in Canada. They are summarized below, as discussed in (Ellen MacArthur Foundation, World Economic Forum, and McKinsey & Company 2016; ECCC 2019a; CIAC 2020b; ECCC 2019; Tang and Chen 2019):

Market

- Creating domestic, secondary end markets with predictable demand for recycled plastics, which are separated from virgin markets;
- Developing reclamation and logistics systems;
- Improving access to the domestic supply of recycled content;
- Fostering a collection and separation system that reduces the contamination of post-consumer plastic bales;
- Developing bio-renewable and chemically recyclable plastics market provided that specific conditions are met (energy cost, depolymerization selectivity, performance tradeoffs, etc.).

Technical

- Increasing mechanical and chemical recycling rates significantly;
- Using chemicals and additives that will enhance recyclability and reduce the use of potentially hazardous substances;
- Development of advanced identification methods and sorting technology (e.g., artificial intelligence), which will facilitate recyclability and value recovery;
- Digitalization of the manual sorting of waste streams at waste recovery facilities;
- Chemical recycling technology development, and further improvement of mechanical process recycling;
- Innovations in plastics recycling to fuels and feedstock (e.g. diesel) and chemicals via advanced conversion technologies (CIAC 2020b);
- Developing chemically recyclable plastics, which allow for recovery of the building-block chemicals via depolymerization, for repolymerization to virgin-quality plastics, or creative repurposing into value-added materials;
- Enhancing the quality of recovered plastics at the collection point and in materials processing;
- Extending plastics lifetime to reduce and delay waste generation;
- Improving circularity capability of single-use plastics;
- Energy recovery by converting hard-to-recycle plastic waste to energy;
- Future innovations to achieve more recyclability: removing additives, reversible adhesives, developing of superpolymers;

Regulatory

- Recognizing advanced recycling facilities as manufacturing facilities, not waste management facilities for permitting purposes;
- Supporting and expanding all value-recovery options;
- Supporting innovations in product designs and uses for secondary plastics;
- Involving all stakeholders in the process of plastics collection;

- Encouraging municipalities to enter long-term contracts with Canadian recyclers, ensuring raw material availability for these recyclers and the stability to invest in plants and equipment;
- Enabling regulations for creating sustainable products.

By creating value from plastic waste and using recycling and recovery options, innovator companies help move toward the circular economy model where plastics are beneficially reused (CIAC 2020b). Table 2.1 summarizes some examples of innovations and improvements supporting the transition to the circular economy of plastics in Canada.

Table 2.1: Some examples of innovations and improvements supporting the circular economy of plastic in Canada

Company	Name of program/ innovation	Type of plastics waste	Description/Summary of innovation technology
BASF	reciChain	Rigid and flexible plastic	A blockchain technology that enables better sorting of plastic waste, traceability and transparency throughout the value chain. Plastics circularity will be enabled by reciChain through three layers: physical, tracer and blockchain
BASF	ChemCycling	Hard-to-recycle plastics	Chemical recycling (thermochemical processes) of mixed or contaminated plastic waste is currently landfilled or incinerated. Obtaining syngas or oil from plastic waste, which can partially replace naphtha as feedstock to produce new chemical products
Dow Chemical, with Reynolds Consumer Products	Hefty EnergyBag	Hard-to-recycle plastics	Complement to existing recycling programs, allowing a curbside pick-up of hard-to-recycle plastics from consumers and converting plastics waste into energy, fuels and other durable products
Dow Chemical	AGILITY™ CE	LDPE	A new resin made with 70% recycled plastic is the first post-consumer recycled product to incorporate such a high percentage of post-consumer plastic waste
NOVA Chemicals and Dow Chemical	N/A	Polyethylene	Development of the all-polyethylene version (compatible with #2 HDPE recycling streams) for a stand-up pouch package for food products; development of an easily recyclable, oxygen-barrier film for food packaging.
ReVital Polymers, Pyrowave and INEOS Styrolution	N/A	Polystyrene	Advanced recycling technology that will help with recycling single-use polystyrene packaging and utilize recycled polystyrene for the manufacturing of new products and packaging
Polystyvert	N/A	Polystyrene	Unique low-temperature dissolution technology for recycling polystyrene, using essential oil as solvent, separating dissolved polystyrene from the essential oil, and obtaining a high-quality recycled product
Agilyx	N/A	Various plastics	Chemical recycling of plastic waste, at a significantly improved environmental profile, into synthetic oils, chemicals and basic monomers used to remanufacture products
GreenMantra Technologies	N/A	Hard-to-recycle plastics	Converting hard-to-recycle materials into high-value waxes and other specialty chemicals; chemical recycling of dried up writing markers collected from schools into valuable polymer additives
Parmalat Canada	N/A	PET	Converting milk packing process to using recyclable PET bottles instead of HDPE jugs

Data sources: (CIAC 2020b; ECCC 2019b; Agilyx 2020; BASF 2020; BASF and Deloitte LLP 2020; Polystyvert 2021)

2.3 Environmental, Social and Governance (ESG), and Extended Producer Responsibility (EPR) Issues

Challenges of the circular economy for plastics overlap with many critical environmental, social, economic and governance issues. Society, governments and the general public place strong attention on the current management of plastic waste. A linear economy model, especially the situation with single-use plastic, is progressively viewed as unsustainable and unacceptable. Plastic producers and converters are expected and pressured by stakeholders to find more sustainable solutions to shift to the circular economy and support plastic recyclability (ECCC 2019; CIAC 2020b; MFS 2020).

Transition to the circular economy is challenging for companies, as it requires large-scale investments in recycling capacity, technology and post-consumer infrastructure. Access to financing, especially private capital, is increasingly dependent on the industry's disclosure and management of environmental, social and corporate governance (ESG) goals. ESG issues are gaining more attention from investors and governments, and other stakeholders (The Conference Board of Canada 2020; PRI 2018).

There are some ESG issues linked with the transition to the circular economy, as currently, ESG commitments and targets are not comparable between companies. Therefore, it is difficult for investors to understand how meaningful the targets are and how to measure progress. Societies and stakeholders may have different perceptions of various technologies for the circular economy. For instance, investing in chemical recycling could be viewed as a better opportunity to respond to societal expectations than investing in waste-to-energy technologies. Another issue is that with the COVID-19 pandemic, there has been a move back to single-use plastic packaging and diminishing customer interest in reusable plastic products (ECCC 2019a; MFS 2020; PRI 2018).

Extended producer responsibility (EPR) is defined as an environmental/economic policy approach in which a producer's responsibility, physical or financial, is extended to the post-consumer stage of a product's life cycle (CCME 2009b; OECD 2019). EPR shifts responsibility (fully or partially, physically or economically) upstream in the product life cycle to the producer (brand owner, manufacturer or first importer) and away from municipalities and regional waste authorities. It also provides incentives to producers to incorporate environmental considerations when designing their products. (CCME 2009b; OECD 2019; OWMA 2013).

Shifting responsibility also guarantees that the party with the highest ability to control the environmental impacts of manufactured products (the producer)[3] carries the costs linked with their choices (CCME 2009a). EPR makes efforts to incorporate indicators associated with products and manufacturing processes' environmental characteristics into the entire product value chain rather than to focus on a single point in this chain. While the EPR principle should ensure effective waste collection and treatment with improved reuse and recycling, the collection process partially relies on the consumer/end-user (CCME 2009b).

[3] The "producer" in the context of EPR may include but is not limited to the brand owner, manufacturer, franchisee, assembler, filler, distributor, retailer or first importer of the product who sells or distributes the product (CCME 2009b).

In 2009, the CCME released a Canada-wide Action Plan for Extended Producer Responsibility pledging to work towards the development and employment of EPR programs. Those programs can differ significantly from one another and can be implemented by governments as an individual or collective producer responsibility. However, all EPR programs involve producers in the end-of-life management of their specific products, product categories or waste streams (CCME 2009b; OWMA 2013).

It should be noted that along with EPR, product stewardship programs are also used in Canada for the post-consumer management of products, and they have some critical differences in their approaches. While EPR programs identify end-of-life management of products as the producers' responsibility, product stewardship programs assign responsibility to provincial/territorial or municipal governments. Usually, they do not require a financial commitment from producers. For EPR programs, funding is provided by producers, and costs can be either internalized or passed on to consumers. In contrast, product stewardship programs use environmental fees or public funds established by legislation (ECCC 2017). The CCME supports the move toward transforming product stewardship initiatives and programs into comprehensive EPR programs (CCME 2009b).

According to the Action Plan, packaging waste was recognized as one of the priority projects for EPR, and a Sustainable Packaging Strategy was developed (CCME 2009b; 2009a). Plastic packaging is also targeted by several other programs (including deposit-refund systems for plastic bottles), mainly responsible for a relatively high diversion rate (23%) for packaging (ECCC 2019a). Some additional EPR programs (either mandatory or voluntary) in Canada apply to partial collection and recycling of plastics waste from other sectors, such as EEE and agriculture. For instance, the Canadian Electronic Products Recycling Association runs EPR programs to collect and send to recycling some targeted electrical and electronic equipment products (ECCC 2019a). There are five voluntary EPR schemes implemented on various product categories (plastics for grain and seed transportation bags, fertilizer and pesticide packaging, and some agricultural films) in the agricultural sector in a few Canadian provinces (ECCC 2019a).

Challenges, issues and constraints for EPR implementation as discussed in (OECD 2014; ECCC 2019a; CCME 2009b; Eunomia 2019) are summarized below:

- Some current product stewardship/recycling systems operated at the municipal level and private sector companies under contract with municipalities. Existing contracts can present challenges when shifting from the shared responsibility model in place to an EPR model;
- A lack of clarity on how to offer incentives to producers to redesign their products and how to reward in the marketplace proper environmental design of the product;
- Unclear and intersecting roles and responsibilities of various parties, including the relationship between governments, public bodies and Producer Responsibility Organizations (PROs);
- A lack of consistency, comparability and transparency of data, as PROs sometimes disclose limited public information on the costs handled by producers and municipalities;
- Possible issues with free-riding, a situation where some producers do not sufficiently comply with their obligations under EPR, and a lack of enforcement mechanisms;
- EPRs add the environmental costs associated with a product during the product life cycle to the market price of the product, thus increasing the price;
- Different understandings of full cost recovery by producers;

- Addressing waste prevention in EPR policies, as they create incentives for recycling, but generally do less in promoting reuse and reduction of waste, which are more preferable waste management options;
- Considering waste as a valuable resource and changing the rationale for EPR.

Chapter 3: Technologies for Plastic Waste Recovery for a Circular Economy

Summary

Existing classifications of plastic waste recovery techniques are usually limited to mechanical recycling, chemical recycling, and energy recovery. This often forces the lumping together under the same category of processes with fundamentaly different methodologies or whose recycling value (upcycling vs downcycling) are different. For example, under the existing classification, chemical recycling includes both processes for producing plastic monomers and fuels. CERI classifies recovery methods/technologies into five: mechanical recycling, chemical recycling, physical recycling, molecular recycling, and repurposing.

3.1 Mechanical Recycling Technology

Mechanical recycling involves the sorting, tolling, regrinding, and pelletizing of post-consumer thermoplastic wastes for remanufacturing plastic products. It also involves the densifying, compounding, and blending as well as slitting of post-industrial plastic wastes such as Polystyrene (PS), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), High Impact Polystyrene (HIPS), PVC, amongst other thermoplastic polymers. Products produced from this technology are usually plastic resins, pellets and flakes, sheets, repro and regrinds, and films (NAM Polymers 2016; Merlin Plastics n.d.; Kal Polymers 2015; Norwich Plastics 2012). Some technology vendors include: Merlin Plastics Supply Inc., NAM Polymers Inc., Norwich Plastics, Fraser Plastics, and Kal Polymers. The challenge with this technology is the presence of contaminants and impurities in the recycled resin, which affects the quality and attributes of the final plastic products.

Figure 3.1: The processing involved in thermoplastic polymers recycling

Collecting & Sorting

Tolling, Regrind & Pelletizing

Compacting & Bailing

Source: (Merlin Plastics n.d.). Figure by CERI

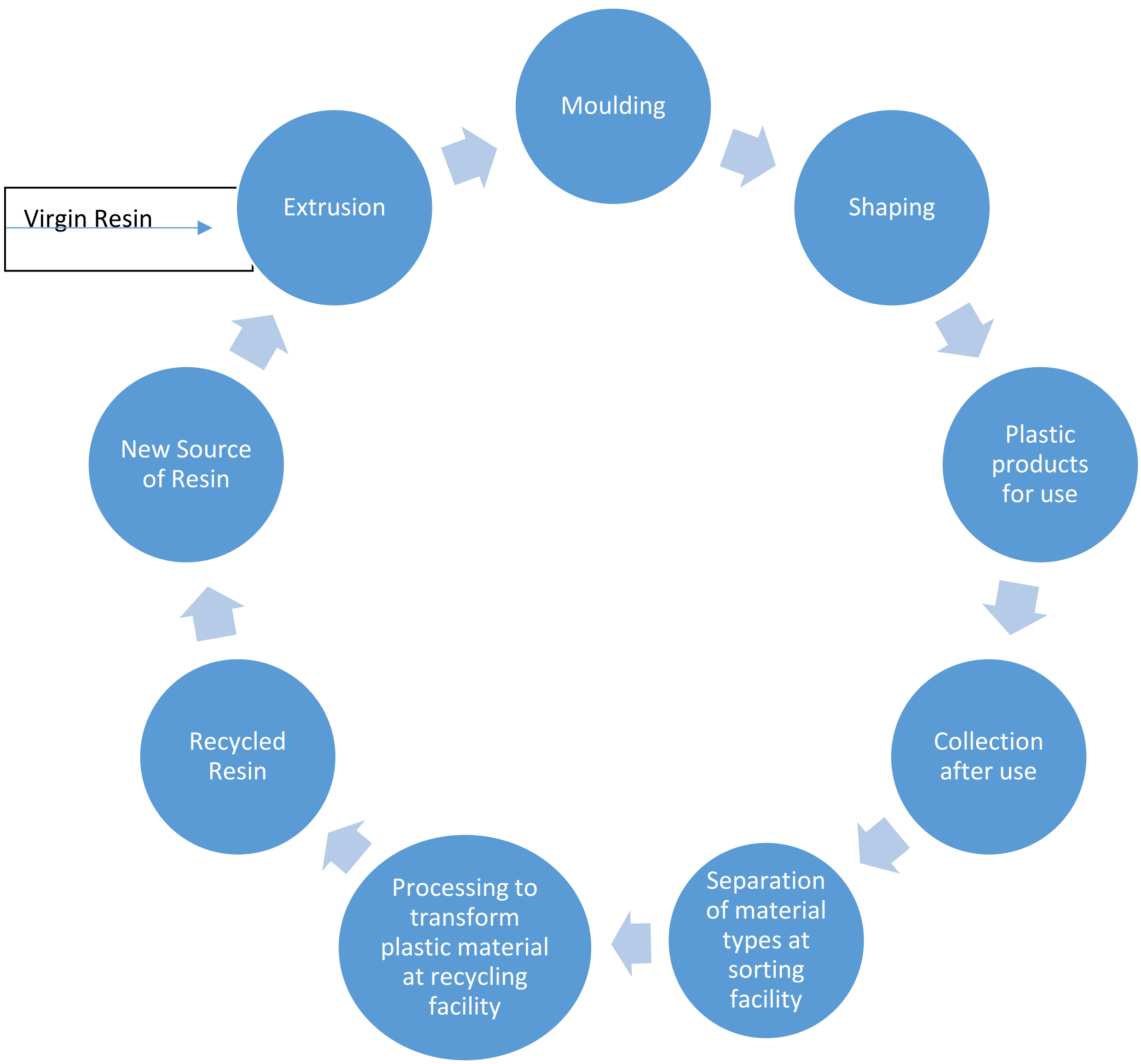
Note: Information in Figure 3.1 is current as of September 2020.

Figure 3.2: Some resulting materials from mechanical recycling of plastic products

Polypropylene | Polyethylene | Polycarbonate/Acrylonitrile Butadiene Styrene | Polystyrene

Source: (Kal Polymers 2015). Figure by CERI.

Figure 3.3: Cycle for recycling plastic wastes to new plastic products



Source: Figure by CERI.

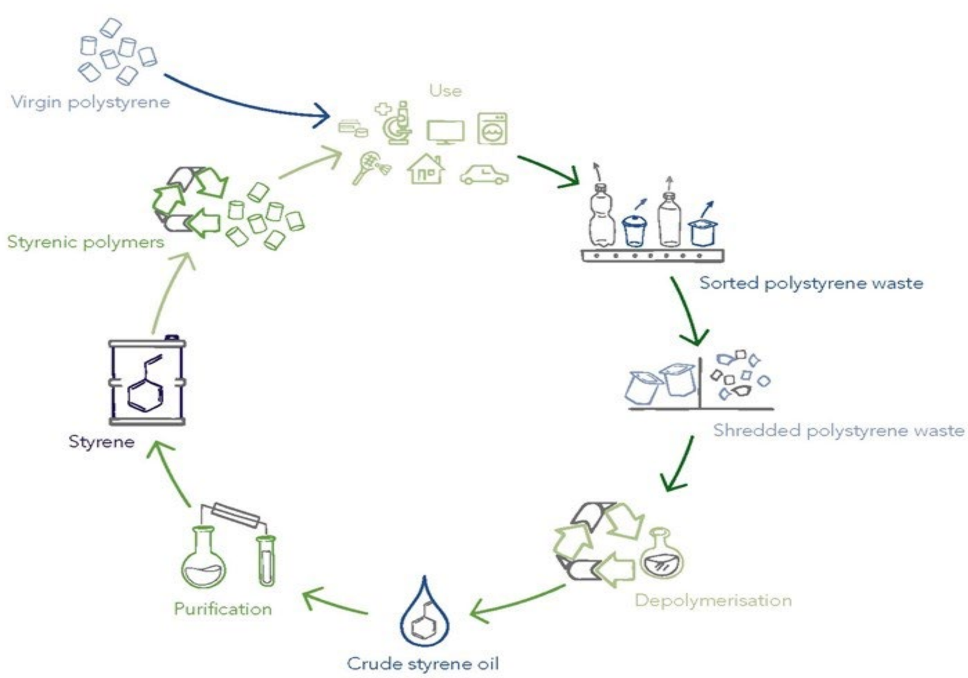
Innovations in mechanical recycling aim to minimize residual contaminants in the recycled resin by improving the collection, sorting and separation technologies to avoid mixed plastics, contaminants, or impurities in the plastic waste. Examples of the vendors are EFS Plastics, Transcontinental, Revital Polymers, GreenMantra Technologies, Soleno Recycling, and JD Composites. The produced resins are purer prime replacement for injection processes such as PP injection, PE injection, LDPE injection and HDPE injection processes with many colour variations (EFS Plastics 2021; Transcontinental 2018). The materials could also be redesigned into various products for building, roofing, tubing, and piping.

Revital Polymers uses optical sorting technology to separate various plastic material types and sort them into bales for recycling (Revital Polymers 2021). Tomra Group uses a near-infrared (NIR) sensor technology to achieve post-consumer polystyrene waste content sortation with final product purity of over 99.9% (TOMRA Systems 2020). Soleno Recycling redesigns both commercial and industrial HDPE into long-lasting pipes that could last for 100 years without damage (Soleno 2019). JD Composites recycles plastic bottles (PET) into construction materials for building sheds, eco-houses and so on. The structures are 100% recycled plastic with a continuous R-30 value certified by the ASTM of North America (JD Composites 2019a; 2019b).

3.2 Chemical Recycling Technology

This technology involves the reprocessing of post-consumer plastics such as plastic films, flexible plastics, bottles, plastic tubs and lids, and mixed rigid plastics into their basic plastic monomers that are subsequently polymerized into the polymers. Examples of such monomers are ethylene, propylene, styrene, vinyl chloride, etc. Chemical recycling enables the removal of contaminants in the recycled products because the polymer is broken down into its monomer building blocks. Examples of such technology vendors are Agilyx who licenses the Cyclyx technology for processing polystyrene waste plastics into styrene plastic monomers for remanufacturing new plastic products (Cyclyx by Agilyx 2021), GreenMantra and Pyrowave depolymerization technologies.

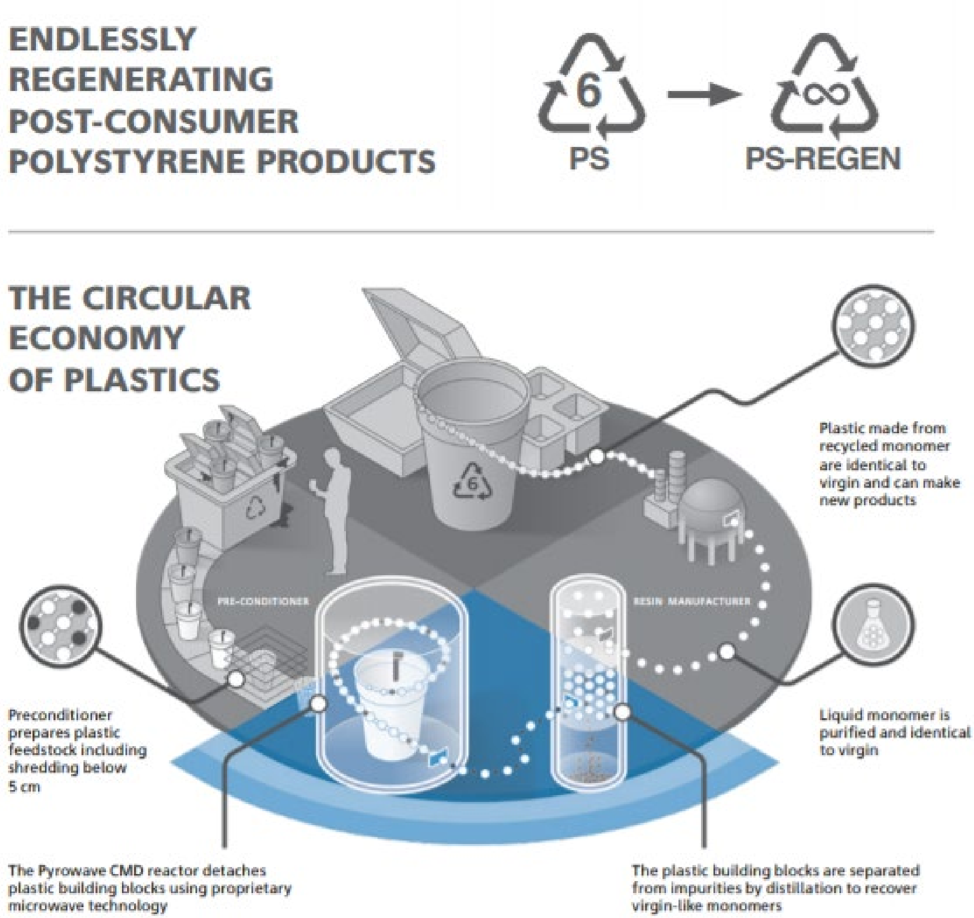
Figure 3.4: Chemical recycling of PS plastic wastes into new plastic products



Source: (Plastics Technology 2020)

Pyrowave licenses a microwave catalytic depolymerization technology for recycling post-consumer plastics of PS materials, expanded PS materials and HIPS materials such as egg cartons, disposable coffee cups, styrofoam packaging and other similar plastic wastes. The resulting product is regenerated monomers that could be used for remanufacturing the same end-of-life products or other designs of products (Pyrowave 2019). Figure 3.5 illustrates the material flows description for Pyrowave's technology.

Figure 3.5: Pyrowave's catalytic depolymerization of polystyrene products



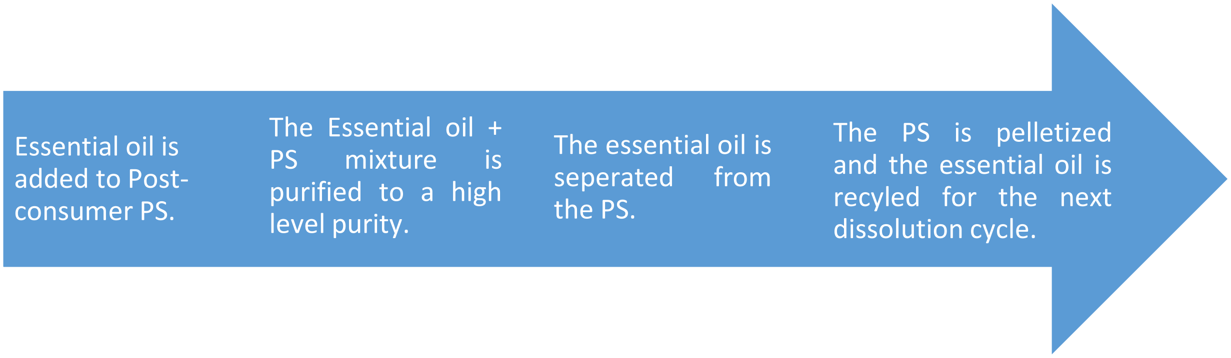
Source: (Pyrowave 2019)

3.3 Physical Recycling Technology

This process technology depends on physical attributes such as density and solubility of a component of a post-consumer plastic product to separate that component from other chemical substances in the plastic waste. This is particularly applicable to mixed- or composite plastics.

An example of this technology is the Polystyvert polystyrene recycling technology (Figure 3.6). It involves dissolving PS wastes using essential oil, a unique purification technology and a coarse filtration process to separate PS materials to produce recycled PS pellets. The PS pellets are then used to produce various plastic products.

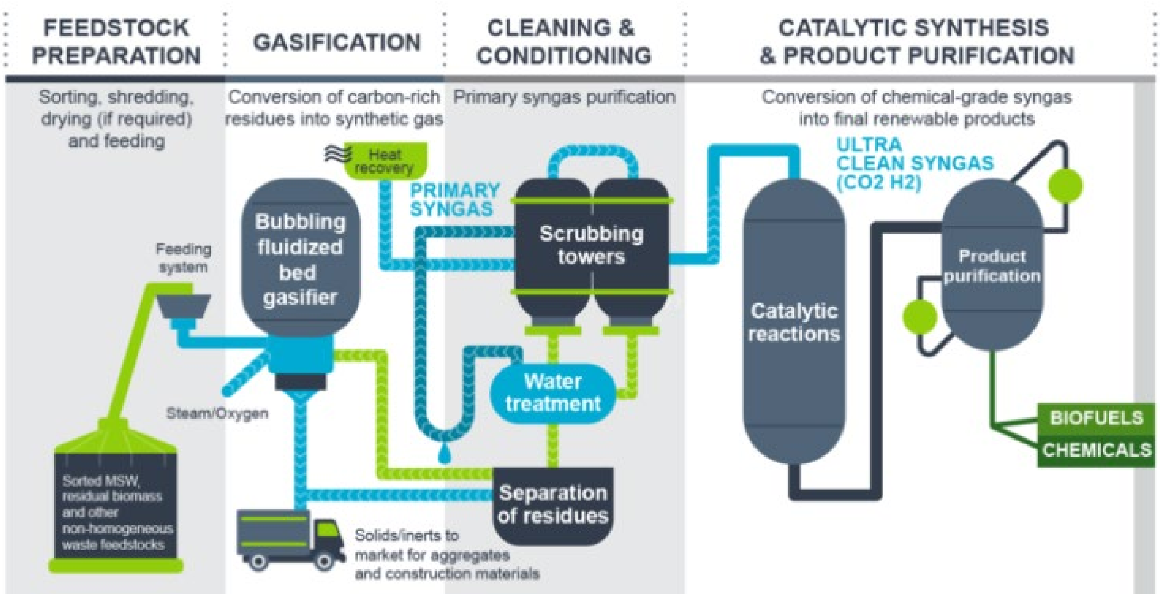
Figure 3.6: Polystyvert's polystyrene recycling process flow



3.4 Molecular Recycling Technology

Molecular recycling involves converting plastic wastes through a chemical or biochemical process into some fundamental building block molecules or fuels such as hydrogen, carbon dioxide, methane, ethane, propane, etc. An example of this type of technology is the Enerkem Carbon Cycling process technology to produce biofuels and renewable chemicals from plastic wastes such as textiles, soiled food containers, non-recyclable plastics, and wood residues. Products such as methanol and ethanol can be produced. The Carbon Cycling process diagram is shown in Figure 3.7.

Figure 3.7: Enerkem's Carbon Cycling for plastic recycling



Data source: (Enerkem 2021)

The process involves four stages: feedstock preparation, gasification, cleaning and conditioning, and catalytic synthesis and product purification. These stages work together to produce a low-carbon transportation biofuel capable of fueling over 400,000 cars on a 5% ethanol blend.

Another example of molecular recycling is biochemical recycling through anaerobic digestion by Anaergia. This technology involves separating plastics from municipal solid wastes using their trademarked Organic Extrusion Press (OREX). The plastic wastes go through a high solids anaerobic digestion process, enhancing biogas production (Anaergia 2021). Molecular recycling technologies are not considered commercial-ready by CERI. However, waste bioplastics undergo biodegradation naturally, during which landfill gas (LFG) can be recovered as a source of renewable energy from landfills equipped to capture released gases.

3.5 Repurposing Plastic Wastes

This involves converting plastic wastes into heat energy which can be applied to various uses such as electricity generation, steam or hot water generation, space heating, process heating, and various other applications utilizing heat energy. Repurposing has been proposed for various energy-intensive industrial processes such as cement manufacturing and production of steel in the hope of simultaneous reduction of the environmental impacts of plastics, energy consumption or greenhouse gas reductions for industrial processes (e.g., replace coal with plastic waste for cement manufacturing).

Chapter 4: Market Potentials and Economic Impacts

Summary

CERI combined databases on existing Canadian plastics production capacities, international plastics trade and national waste audit to quantify consumption of plastic products and plastic waste generation in Canada in 2019. PE, PVC, PET, PA, PS, and PP account for most of the national plastics production and consumption in 2019. PE, PP and PVC are the most used plastics in Canada mainly in the provinces of Ontario, Alberta, and Quebec. Only about 10% of waste plastics are currently recycled predominantly using mechanical recycling technology. However, chemical recycling technology used to recover plastic wastes from disposal. A smaller volume of the unrecycled and unrecyclable plastic wastes are repurposed in Canada through incineration with heat energy recovery.

4.1 Plastic materials flow analysis

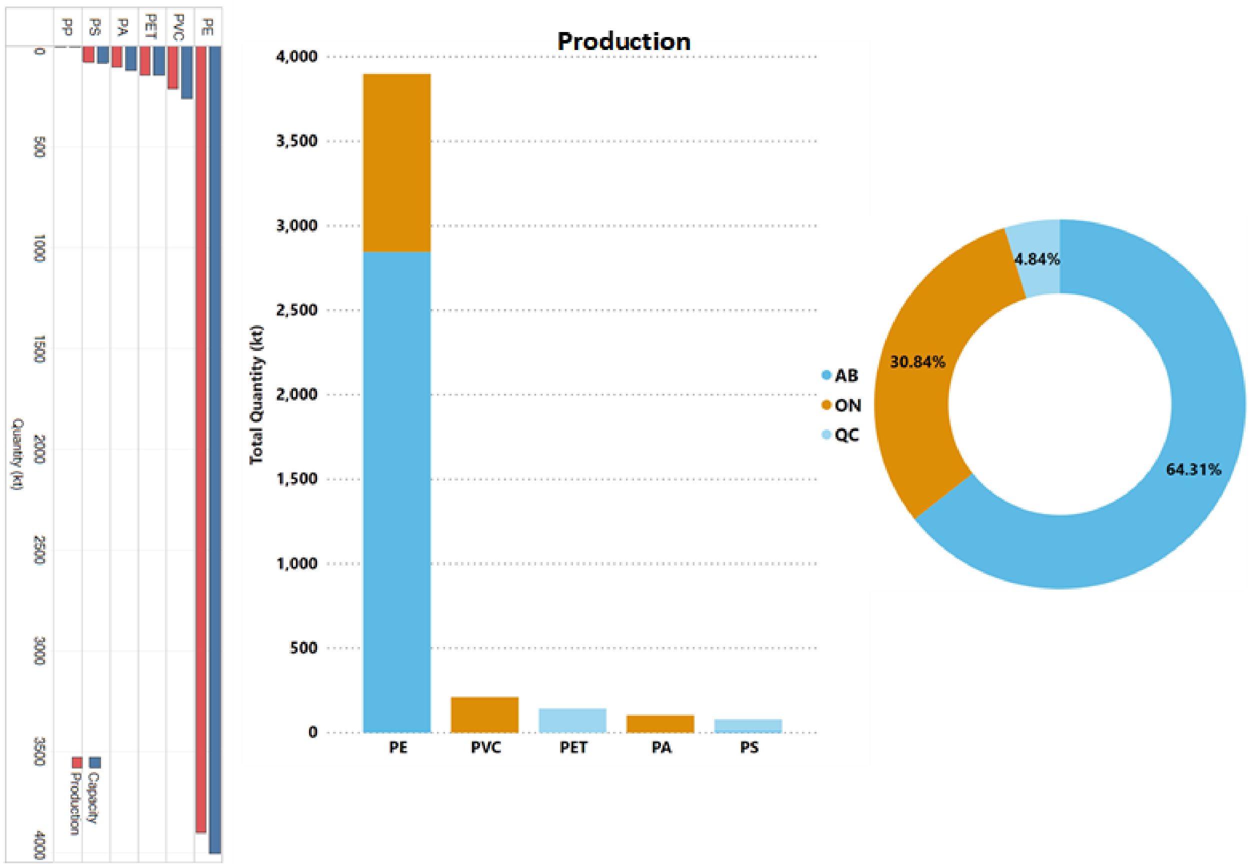
As stated earlier in the methodology section, we summarized all plastic material flows in 2019 into three groups:

- Total Recycle (TR) – which comprises of the chemically recycled (R-Chem), mechanically recycled (R-Mech), and the chemically recycled disposal (D-Chem);
- Repurposed (RP) – which consists of the incinerated disposal with or without heat energy recovery;
- Unrecovered (UR) – which includes microplastics leaking into the environment and plastic wastes dumped in landfills.

To present the compositions of plastic materials, each flow is further broken down into PE, PVC, PET, PA, PS, PP, and OTHERs. Although this study focuses on the first six categories of plastic materials, flow data on the rest of the plastic products (i.e., the OTHER category) is also presented. Figure 4.1 shows the total Canadian capacity and production for the six major plastic materials considered.

PE, PVC, PET, PA, PS and PP constitute most of Canada's plastics production (~98%) in 2019. Total production capacity was 4615 kt, with about 95% of capacity utilization reported. PE is the predominantly produced plastic resin in Canada at about 3900 kt (89%), followed by PVC (144 kt) and PET (144 kt). The shares of PA and PS in the total production were less than 3%. Alberta, Ontario, and Quebec are the Canadian provinces with local plastic resin production.

Figure 4.1: Breakdown of total Canadian plastics capacity and production (2019)

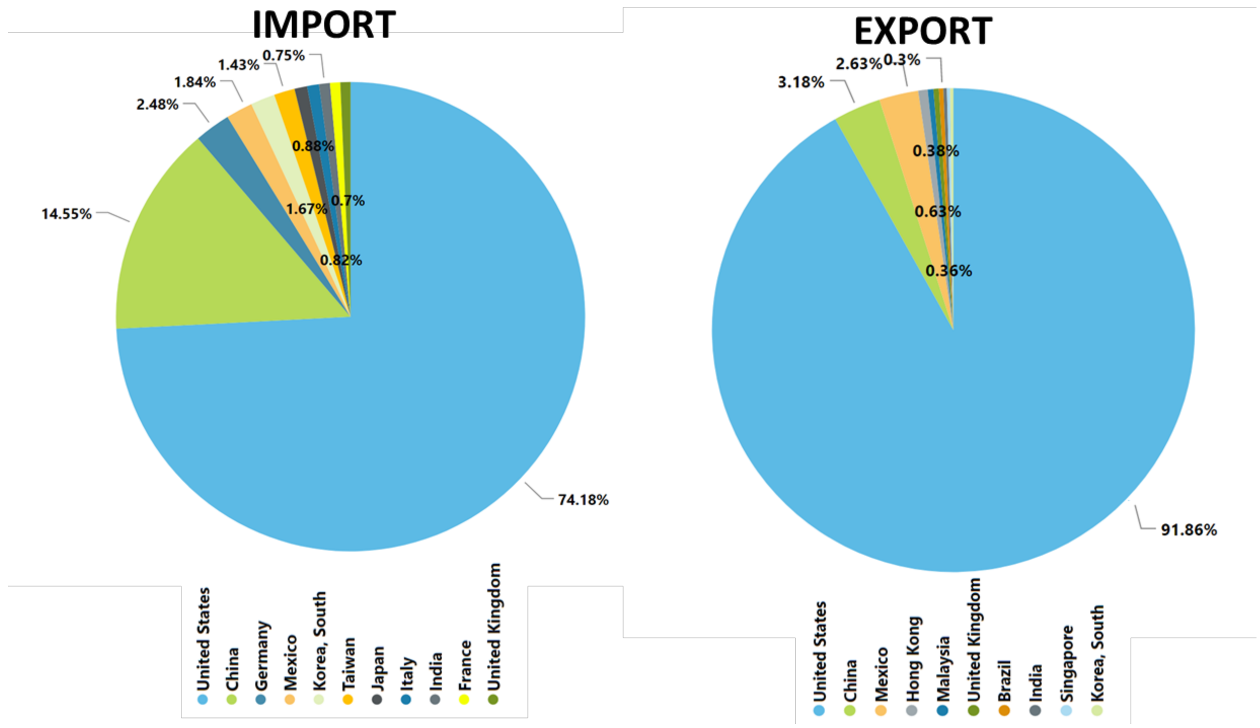


High-density polyethylene (HDPE), low-density polyethylene (LDPE) or linear low-density polyethylene (LLDPE) are the most common PE-based products made in Canada. PVC and PA are only produced in Ontario, whereas PET is only produced in Quebec. All the three provinces produce PS, although predominantly from Quebec. Additional PP and PE capacities are expected in Alberta and Ontario, respectively, by 2022.

4.2 Import and export flows of plastic products

In 2019, Canada exported about 4024 kt of mostly PE resin and imported about 1225 kt of mostly PE plastic products. PVC is the second most exported plastic material from Canada after PE. About 994 kt of PVC products were imported into the country. Export quantities of the other plastics (PP, PS, PET and PA) range between 80 to 140 kt. Figure 4.2 shows the origins and destinations of imports and exports.

Figure 4.2: Sources and destinations of imports and exports of plastics in Canada.



The United States and China are the main sources of imported plastics products into Canada. Both countries are also the destinations of most of Canada's export of plastic materials. Figures 4.3 and 4.4 show the breakdowns of imports and exports by province destination/origin and by plastic product type.

Figure 4.3: Breakdown of imports of plastics into Canada

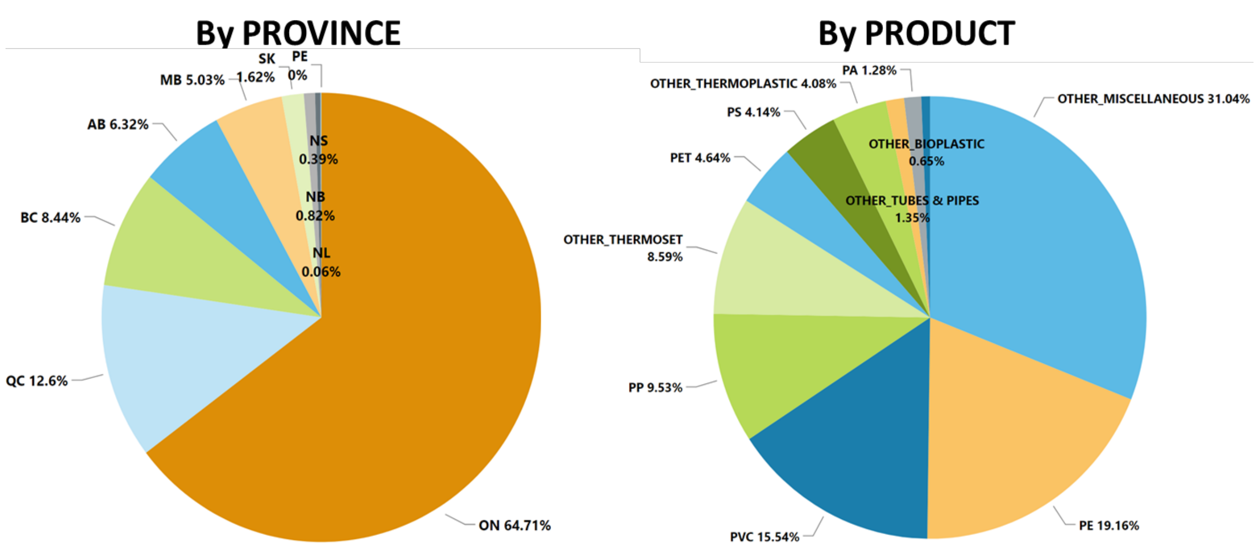
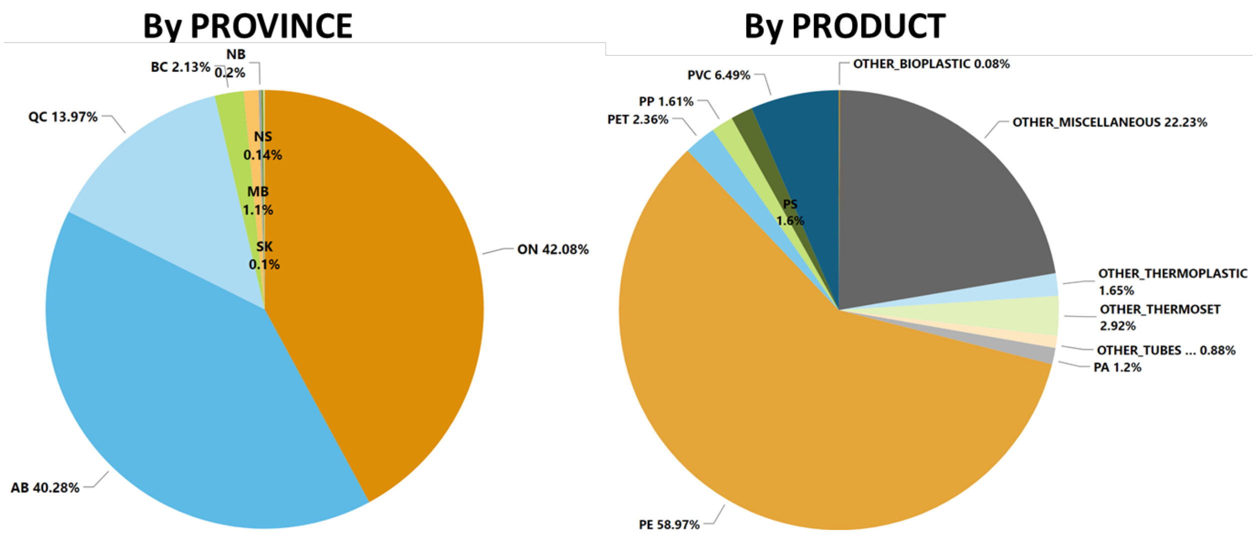


Figure 4.4: Breakdown of exports of plastics from Canada

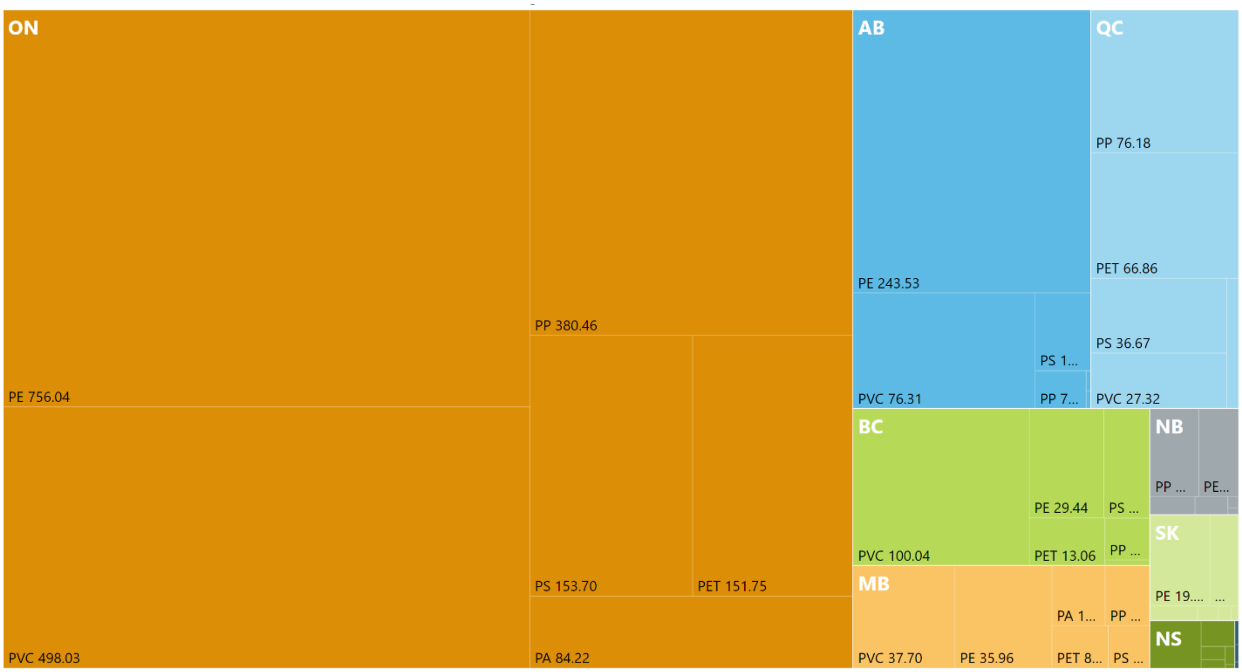


Most of the imported plastic products into Canada – which is comprised of PE, PVC, PP, and PET – go to Ontario, Quebec, British Columbia, and Alberta. Exports are predominantly from the three plastic resin-producing provinces of Ontario, Alberta, and Quebec. There are also inter-provincial exports/imports through which other provinces receive and process plastic resins into various products for local consumption and the export markets. More information on the inter-provincial and international plastics trade are available in Appendix C.

4.3 Plastic products consumption in Canada

As mentioned earlier in the study methodology section, the balance of domestic production, imports (international and interprovincial), and exports (international and interprovincial) provide the estimate of the annual consumption of plastics at the national and provincial levels. Figure 4.5 shows the breakdown of plastics consumption by material type and province in Canada.

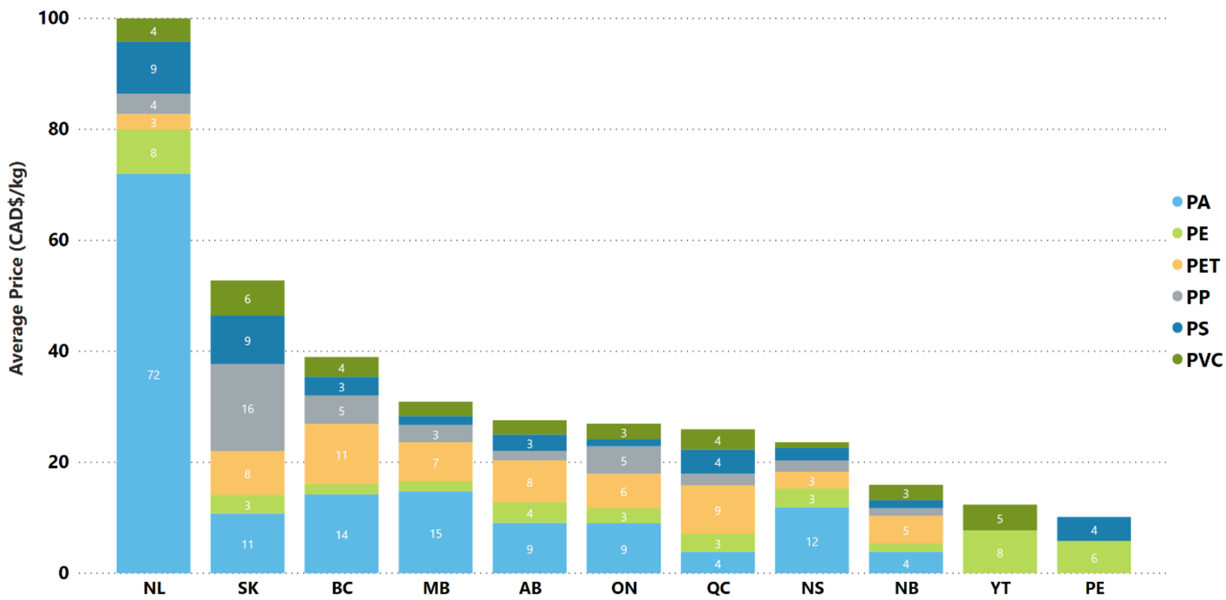
Figure 4.5: Consumption of plastic products in Canada (2019)



PE is the most consumed plastic material in Canada at about 1100 kt in 2019, followed by PVC (~760 kt) and PP (~500 kt). Quantities of PET, PS, and PA consumed are respectively about 244 kt, 234 kt, and 103 kt. Major demand locations are Ontario, Alberta, Quebec, and British Columbia. PET consumption is predominantly in Ontario and Quebec. PS, PP, and PA are also consumed more in Ontario than in other areas.

Figure 4.6 shows CERI's calculation of the average prices of each of the consumed plastic materials in various provinces. Prices of plastics can vary quite significantly across the provinces. PA has the highest average price of 72 CAD/kg in Newfoundland & Labrador. PP plastic has the highest average price of 16 CAD/kg in Saskatchewan.

Figure 4.6: Average prices of consumed plastics by province (2019)



4.4 Plastic waste generation and flow categories

By combining waste audit data with the annual plastic consumption volumes, CERI estimated the quantities of plastic wastes that are recycled (TR), repurposed (RP), and unrecovered (UR). Figures 4.7 and 4.8 show the quantities and proportions of plastic waste flow categories for each type of plastic material presented.

Figure 4.7: Quantities of plastic waste flow categories (UR, TR and RP) in 2019

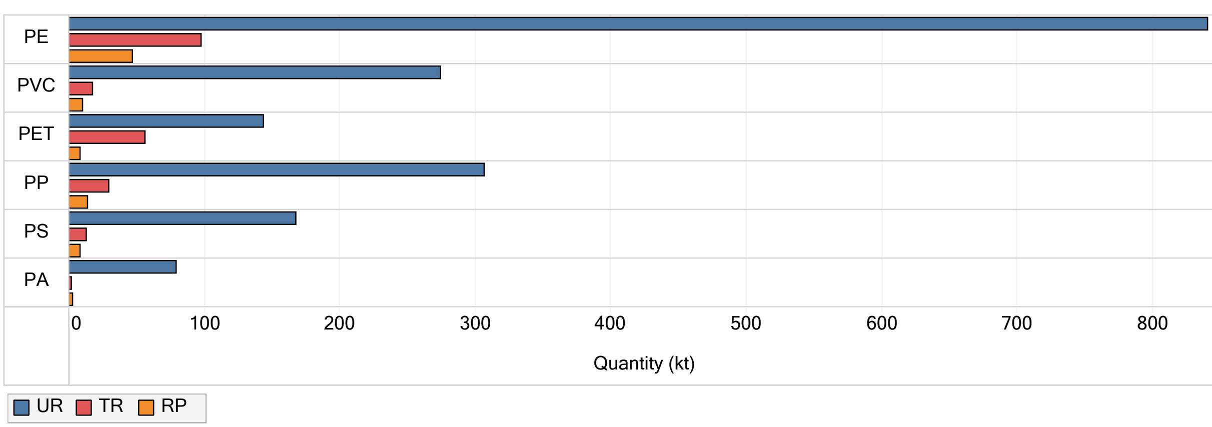
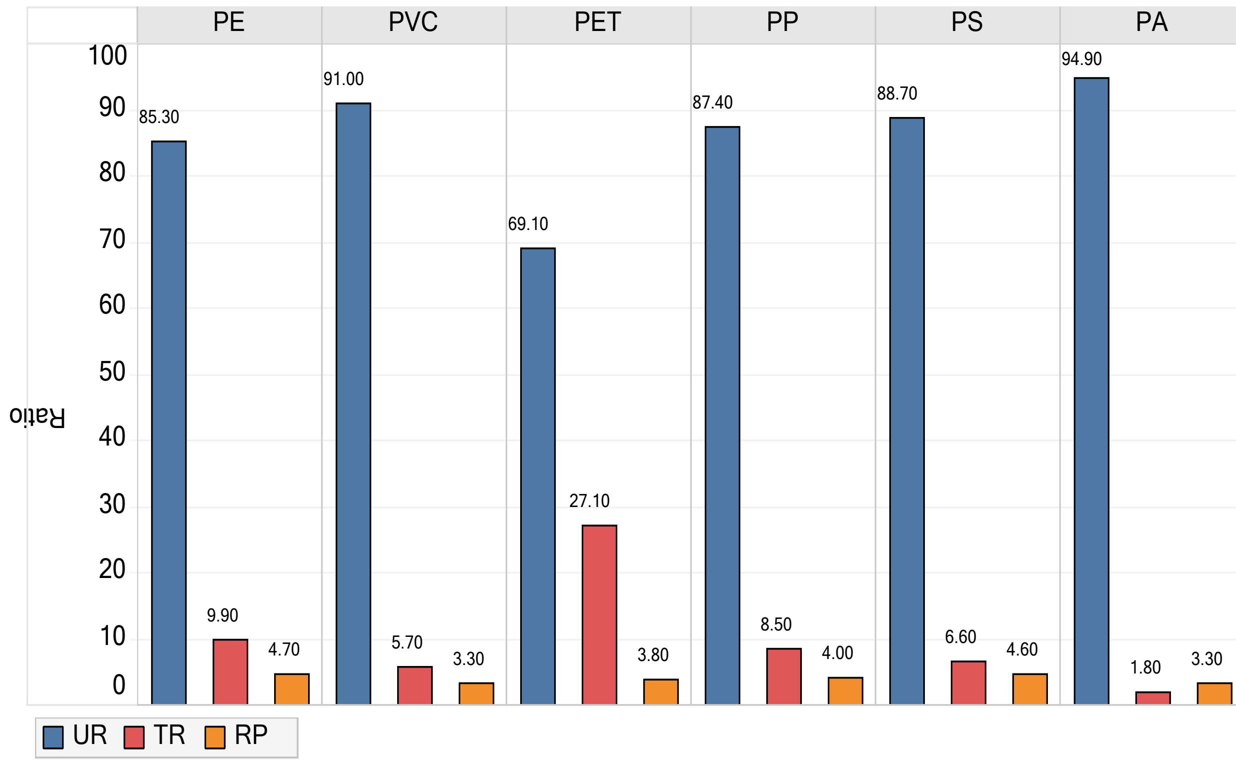


Figure 4.8: Proportion of each flow category from plastic wastes generated (2019)



The total quantity of UR flow from the plastic material types shown in the figure is about 1810 kt, with PE, PVC, and PP having the biggest shares. For PET and PE, about 1.5% and 1.2% of their UR leaked into the environment, and the rest was landfilled. For the other plastics, the leakage to the environment ranges between 0.8-1.1%.

The total amount of TR in 2019 of the six plastic types is estimated to be about 215 kt, where PE accounted for about 98 kt of the recycle flow. PA has the lowest recycle volume of about 1 kt. Mechanical recycling is the predominant recycling method used, with over 90% of PET and PVC recycling done with this technology. About 80% of the PE, PP and PS recycling also utilize mechanical recycling technology. However, only about 45% of recycled PA is based on this technology, and the rest were chemically recycled from the disposal. Chemical recycling seems to be mainly used for plastic wastes recovered from disposal than those designated for recycling. Chemical recycling from disposal accounted for about 17% of the recycled PE and PS, while for PP, PVC and PET it is respectively 12%, 8% and 5%.

The total quantity of waste plastics repurposed is about 90 kt, of which repurposed PE amounted to around 47 kt. In almost all cases in Canada, repurposed plastics were incinerated with energy recovery.

Figure 4.9 shows the TR distribution among Canadian provinces. Most recycling activities are in Ontario for all the plastics, where annual plastics consumption is also the highest. With respect to PE recycling, Alberta is second to Ontario with a TR value of about 22 kt. Quebec is second to Ontario in terms of the amounts of PET, PP and PS recycled. There is significant recycling activity in British Columbia and Manitoba for PE, PVC, and PET plastic wastes.

Figure 4.9: Provincial recycling activities (contributions to TR)

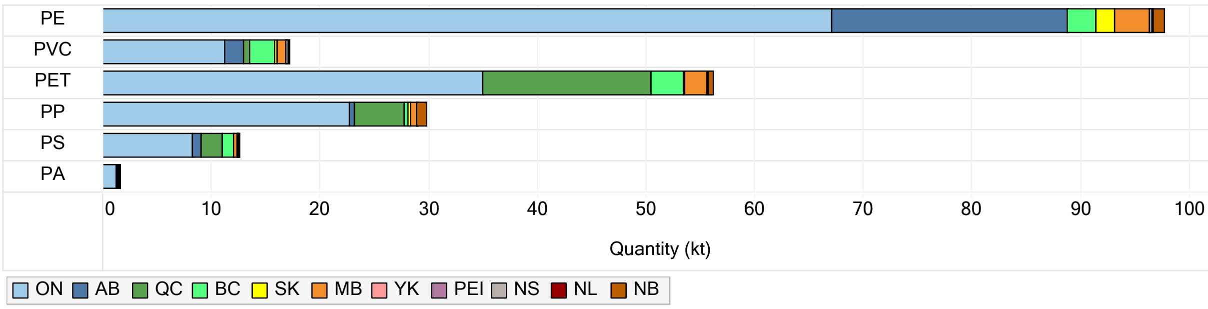
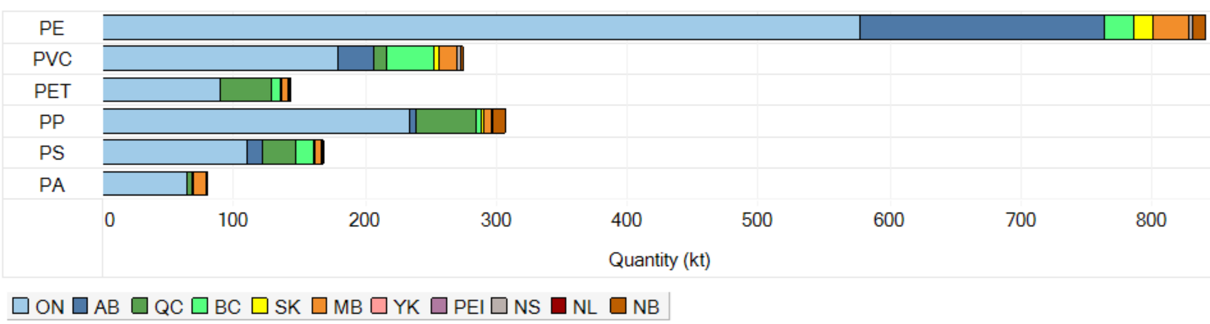


Figure 4.10 shows the provincial breakdown of the unrecovered plastic waste flows in Canada. Ontario and Alberta have the highest UR flows of about 577 kt and 186 kt, respectively. Ontario, British Columbia and Alberta generated most of the unrecovered PVC wastes in Canada. Ontario and British Columbia generated about 179 kt and 36 kt of unrecovered PVC plastic wastes, respectively. Additionally, Ontario and Quebec generated most UR flows of PET, PP, and PS plastic wastes. Provincial distributions of RP waste flows are provided in Appendix D.

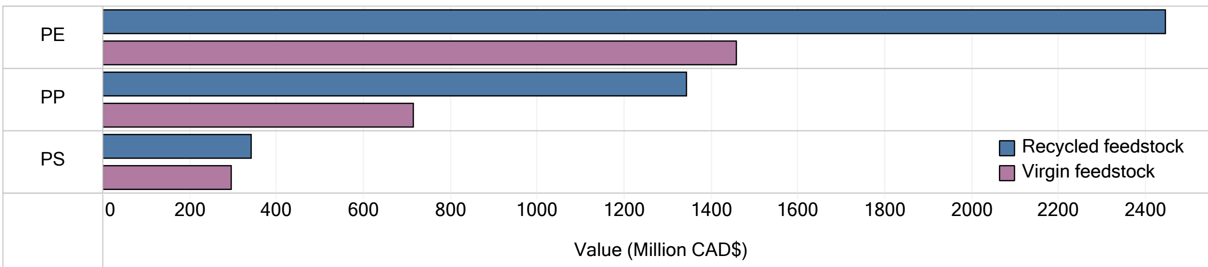
Figure 4.10: Provincial breakdown of UR flows (2019)



To quantify the market values/potentials of the UR flows, proprietary data on specific recycling pathways and technologies need to be used. Information required includes data on the plastic waste collection, diversion, sortation, recycling process, and technology to be analyzed, in addition to the economic costs (including capital investment and operating costs) required to execute each of these activities under specific circular plastic economy scenarios. CERI has the Integrated Project Economics Model (IPEM). This techno-economic assessment tool can be used to compute economic unit costs (supply costs/breakeven prices, etc.) of plastics recycling project investments. Due to the competitiveness and confidentiality of these technology data, CERI calculated the economic values of the UR flows based on the average prices of the plastic materials in each province.

Assuming that all the evaluated UR flows are recycled, Figure 4.11 compares the value of the recycled feedstock to the virgin feedstock, which would be needed under a no UR recycling business as usual. The total value of UR flows in 2019 for PE, PVC, PET, PP, PS and PA amounts to about C$ 6.7 billion. PE and PP alone have values of about C$ 2.4 and C$ 1.3 billion, respectively.

Figure 4.11: Potential recycle feedstock (from UR flow) and the equivalent virgin feedstock values



Comparing the potential recycle feedstock value (assuming 100% UR recycling) to the equivalent virgin feedstock value in Figure 4.11, it is observed that the virgin feedstock would be cheaper than the recycled feedstock by about 68.0% for PE, 88.0% for PP, and 16.0% for PS. Figure 4.11 assumes that gas-based virgin feedstock technologies are used to produce PE (from ethane) and PP (from propane). The total value of natural gas production from which the ethane feedstock for PE production is separated is estimated to be over C$ 3.5 billion. Therefore, if all UR flows were to be recycled, this ethane production (and perhaps, some of the natural gas production as well) will need to find an alternative use.

Table 4.1 shows the estimated macroeconomic impacts of potential recycling investments in a circular economy model, based on the costs of producing equivalent quantities of fresh resins from existing commercial technologies. Total direct and indirect national GDP impact is estimated to be C$ 116 million. Total tax revenue impact is expected to be about C$ 109 million, and total supported permanent jobs would be around 6441 at an average pay rate of C$ 4100 nationally.

Table 4.1: Macroeconomic impacts of recycling in a circular economy model

Plastic Type	Direct & Indirect GDP Impact (CAD million)	Direct & Indirect Tax Revenue Impact (CAD million)	Direct & Indirect Permanent Jobs Supported	Pay Rate Impact (CAD)
PE	44	42	2450	
PP	18	17	983	
PVC	19	18	1053	4100
PET	8	8	457	
PS	16	15	868	
PA	11	11	631	
Total	116	109	6441	

Chapter 5: Final Remarks

Plastics are globally used for industrial and domestic purposes. As of 2017, about 8.3 billion metric tons of plastic materials have been produced (Chen et al. 2020). They remain very useful to our society today, but the environmental burden and degradation from their end-use disposal are a challenge to the ecosystems today. Specifically, single-use plastics have a higher disposal rate due to their limited or lack of reuse value, making them prone to indiscriminate disposal and leakage into the environment. Yet, the demand for plastic products continues to grow with the economy, development, and world population.

Driving a circular economy for plastics forward will demand inputs from all players: producers, consumers, and regulators. From the design of plastic products, combining different resins or additives that create a challenge for separation of components (due to cross-contamination) during recycling can be avoided. Designing for reuse can increase the number of use cycles before a product is translated to the waste stream for recycling or is repurposed. Also, effective chemical identity tagging of products can facilitate the ease and efficiency of separating plastic wastes during collection and at sortation centers.

Consumers of plastic products need sufficient information on how to classify plastic wastes into the right bins to advance the recycling process. One of the most emphasized challenges to plastics market circularity is the poor comparative economics of recycled resins to virgin plastic resins. In this area, regulatory drivers such as “recycling or sustainability credits” can incentivize operators by lowering the cost barrier to the competitiveness of recycled plastic products.

This report highlighted five methods of plastic waste recovery, including mechanical, chemical, physical, molecular, and repurposing technologies. Due to both technical and economic limitations, only mechanical and chemical recycling have been commercialized in Canada to recover about 10.0% of plastic wastes generated annually. Repurposed plastic wastes which are typically incinerated with energy recovery in Canada, account for about 4.0% of the total recovered flows. On the resin value basis, virgin feedstock for most of the consumed plastic products in Canada is still about 40% cheaper than the recycled feedstock.

Moreover, existing recycling plants in Canada are predominantly mechanical recyclers with a few chemical recycling plants, which process diverted wastes from the disposal. Therefore, investments in research and development are expected to further drive innovation and de-risking of emerging technologies. Techno-economic assessment of emerging technologies requires that both process design and cost data be applied on a case-by-case basis to accurately quantify the price competitiveness of plastic products made from recycling systems.

In addition to the environmental benefits, developing a circular economy for plastics promises economic benefits in terms of increasing GDP, tax revenue, and employment opportunities. However, for virgin feedstock producing economies like Alberta, the circular economy model may impact natural resources production.

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Appendix A: Plastic Waste Audit Data

Table A.1 shows the ratio of plastic wastes to the consumed plastics in 2016. As seen in the table, about 89% of the consumed PE was collected as waste in 2016, whereas this ratio for PVC was about 40%. For other plastics, the ratio of the waste to the consumed plastic was situated within the range of 70-85%. In this study, it was assumed that the ratios remained almost unchanged in 2019.

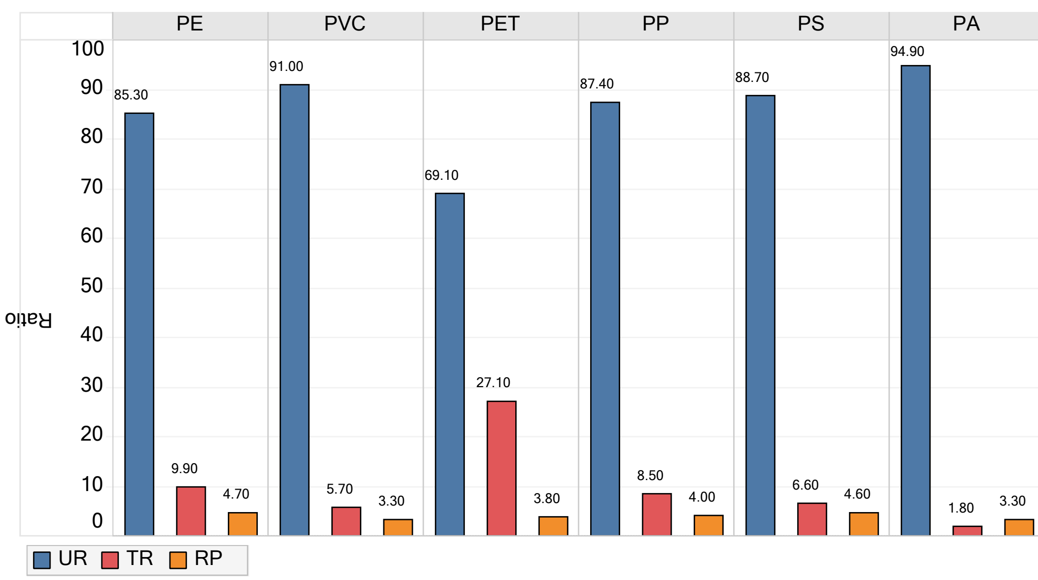
Table A.1: Ratio of plastic waste to consumed plastic (2016 baseline)

Plastic	PE	PVC	PET	PP	PS	PA
Ratio (%)	89	40	85	70	81	80

Data source: (ECCC 2019a)

Figure A.1 shows the ratio of TR, UR, and RP to the waste quantity for different plastics (ECCC 2019a). As seen in the figure, a significant portion of the waste PET is recyclable, with a TR percentage of 27.1%. The lowest recyclability belongs to PA, with the TR percentage of only 1.8%. For other plastics, the TR percentage is in the range of 5.7-9.9%. As displayed in Figure A.1, the portion of the plastic wastes that goes through incineration (RP) is between 3.3% and 4.7%, with PA and PVC having the lowest ratios and PE the highest. As expected, PET that showed the highest recyclability represented the lowest UR percentage. The UR percentage of other plastics is in the range of 85.3-94.9%.

Figure A.1: Ratio of UR, TR and RP to plastic waste generated (2016 baseline)



Appendix B: Additional Plastic Market Data

More information on the OTHERs sub-category of plastic products studied in this report is presented in Figures B.1 and B.2 below.

Figure B.1: The local import (top), international import (middle) and international export (bottom) quantities of OTHERs in 2019

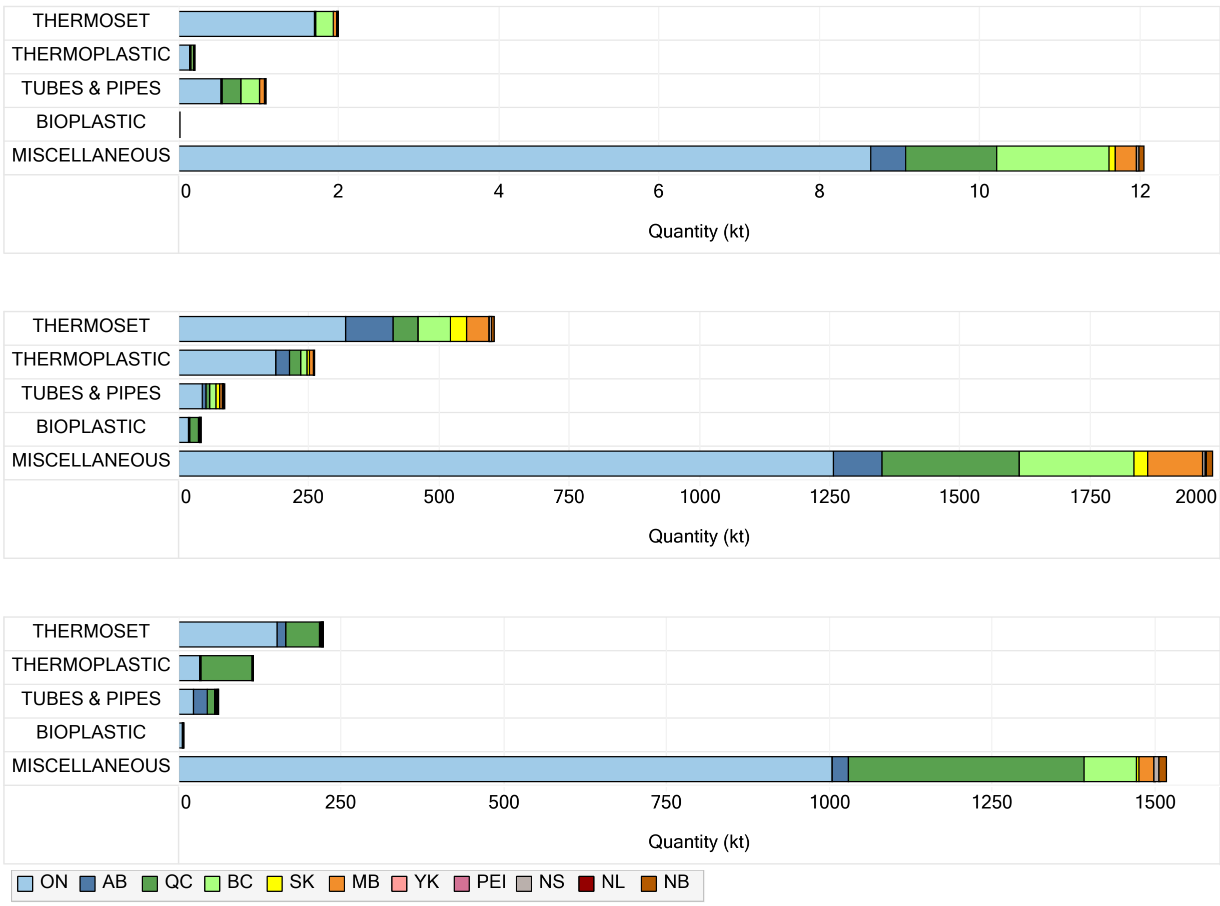
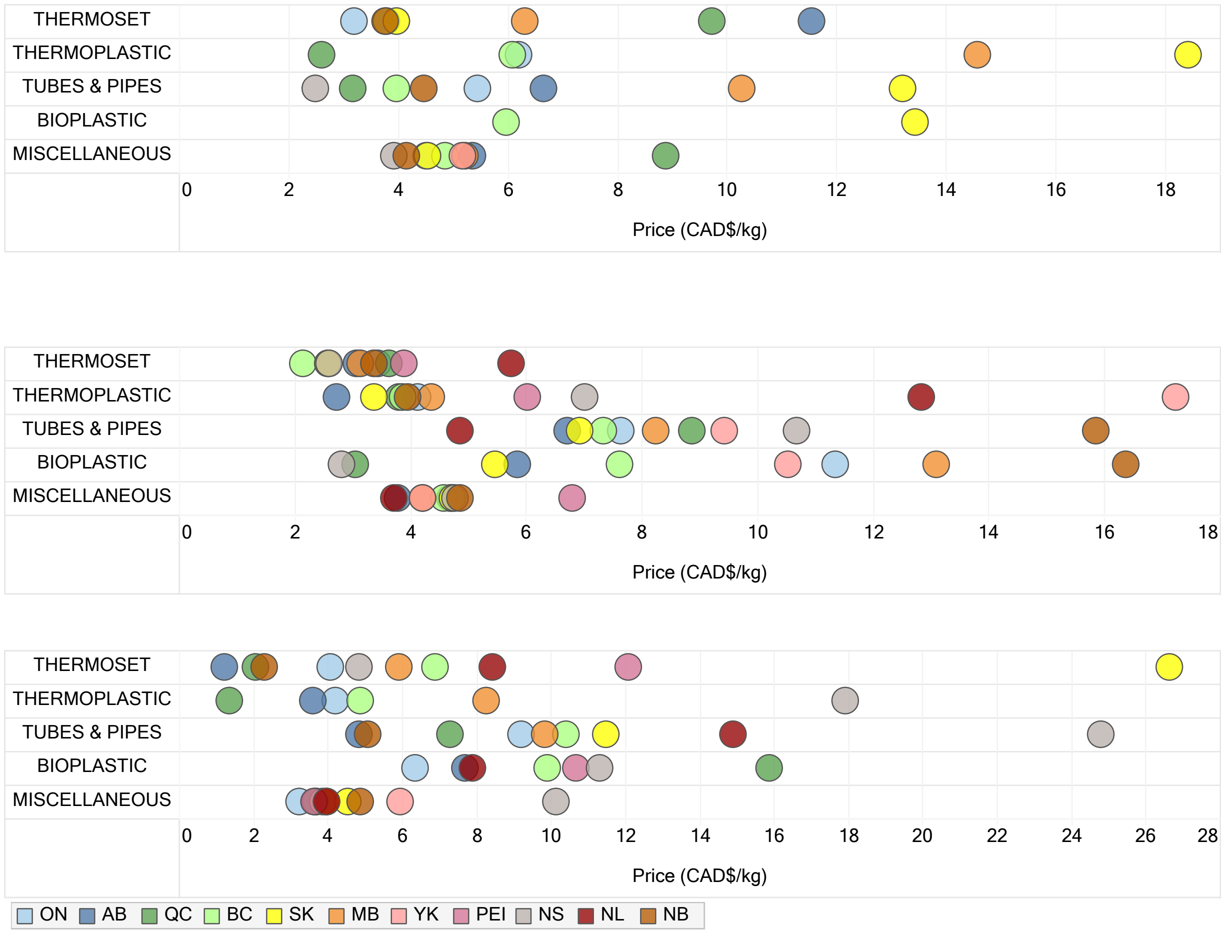


Figure B.2: The local import (top), international import (middle) and international export (bottom) average prices of OTHERs in 2019



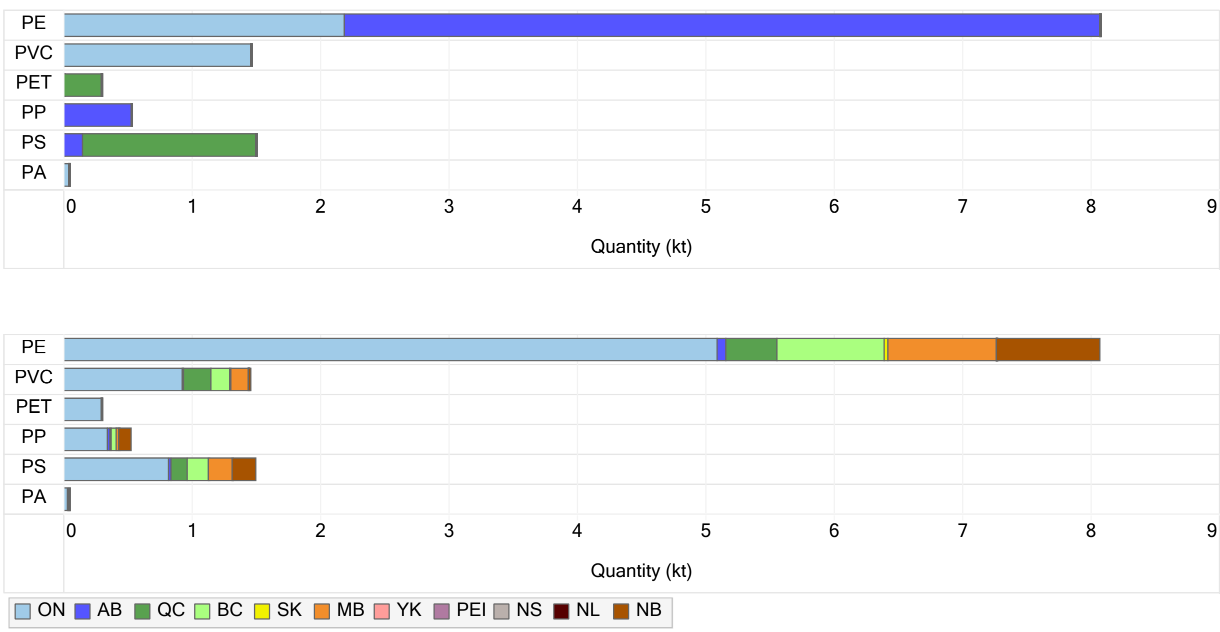
Appendix C: Interprovincial and International Plastics Trade Information

Interprovincial export/import of plastics in Canada

Apart from international export and import, plastics were locally traded between Canadian provinces as well. Figure C.1 shows the local export and import quantities in 2019.

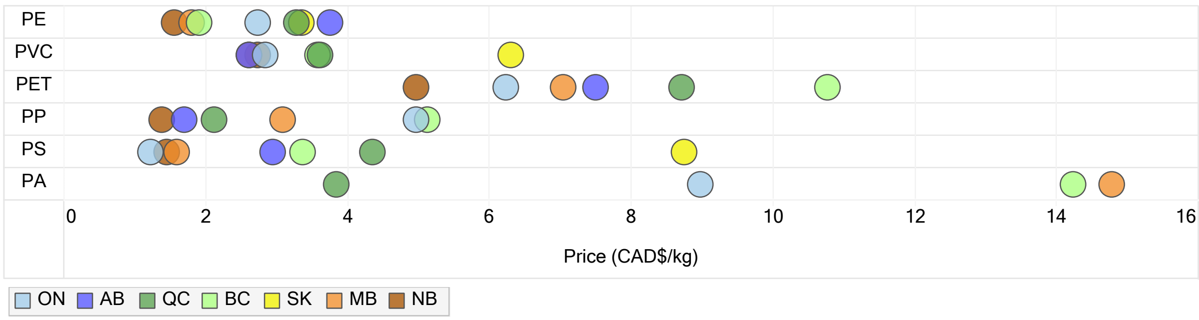
As seen in Figure C.1, ON represented the largest quantity of local import among Canadian provinces for all six plastics. In addition, ON was the only province that locally exported PVC and PA. Figure C.1 indicates that PET was locally exported only from QC to other regions in Canada. Furthermore, the leading exporters of PE within the Canadian borders are AB and ON. AB and QC were the only provinces contributing to the local export of PS in the country.

Figure C.1: The local export (top) and import (bottom) quantities in 2019



The average price for locally imported plastics is shown in Figure C.2. As seen in the figure, PA represented the broadest average price range (3.8-14.8 CAD/kg). For other plastics, the average price is within the range of 1.2-10.8 CAD/kg. Local export price was not calculated due to insufficient data. However, it is reasonable to assume that the local export price is roughly the same as the local import price.

Figure C.2: The local import average prices in 2019



International export/import of plastics in Canada

The following paragraphs discuss the most important Canadian provinces in terms of international trade, along with Canada's top trading partners.

PE: Among Canadian provinces, AB and ON made the greatest contributions to PE's international export in 2019, most of that head to the US. ON and QC took the lead in the international import of PE to the country. The US, China and Germany supplied the main portion of the imported PE.

PVC: As displayed in Figure C.3, ON and QC were dominantly ahead of other Canadian provinces in the international export of PVC in 2019. Over 96% of PVC's international export originated from these two provinces and was mostly sent to the US. France, China and Japan were the main importers of Canada's PVC after the US. The international import of PVC to ON, BC, QC and AB was significantly greater than other provinces. The US, China and South Korea were among the top three countries that provided the most significant amount of PVC for Canada.

PET: QC was known as the leading exporter of PET in the country, followed by ON; about 90% of that was directed to the US. Whereas ON was the top Canadian importer of PET, PET was mostly supplied by the US, Pakistan, China and Oman. QC, BC and MB also contributed to the international import of PET.

PP: Although Canada did not produce PP in 2019, it was involved in the PP's international trade. ON and QC took the biggest share in the international export of PP to different countries, including the US, Belgium and India. ON and QC were the largest PP importers and received over 90% of Canada's total PP imports, mostly from the US and Mexico.

PS: The main international exporters of PS were QC and ON in 2019, accounting for over 93% of the total PS exports from Canada. The US and China were the top two consumers of Canada's PS. In addition, ON was the biggest importer of PS, followed by QC, BC, AB and MB. The US, Mexico, South Korea and Taiwan were the leading PS providers for Canada.

PA: ON and MB were the two provinces that exported the most significant amount of PA from the country. The international export from other provinces was insignificant compared to these provinces. The US, United Kingdom, South Korea and China were the top four destinations for Canada's PA. The same two provinces (ON and MB) were the greatest PA importers worldwide, with the US being the chief provider. Germany, Netherland, Poland, and Thailand were the next providers.

Figure C.4 represents the average prices of the exported and imported plastics in different provinces. According to the figure, PE's export price in AB was ~1.4 CAD/kg in 2019 that is considered the lowest compared to its price in other provinces. Whereas in MB, the export price of PE was as high as ~7.1 CAD/kg. In addition, the export price ranges of PVC and PET in Canada were found to be 0.4-6.0 CAD/kg and 1.6-12.0 CAD/kg, respectively. Figure C.4 indicates that the export price of PP in SK was significantly greater than its export price in other regions. As seen in the figure, the export price of PS was lower than PA in all provinces. Figure C.4 also represents the import price of plastics in Canada, starting from ~1.5 CAD/kg (PVC in NS) and reaching up to ~10.8 CAD/kg (PA in SK).

Figure C.3: The international export (top) and import (bottom) quantities in 2019

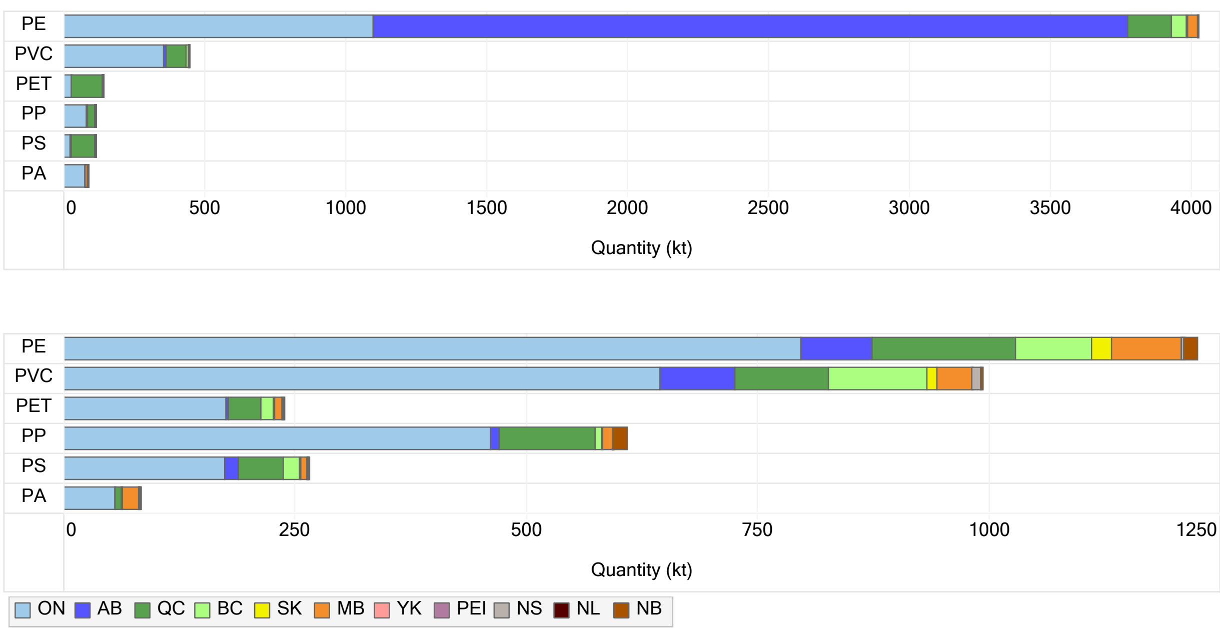
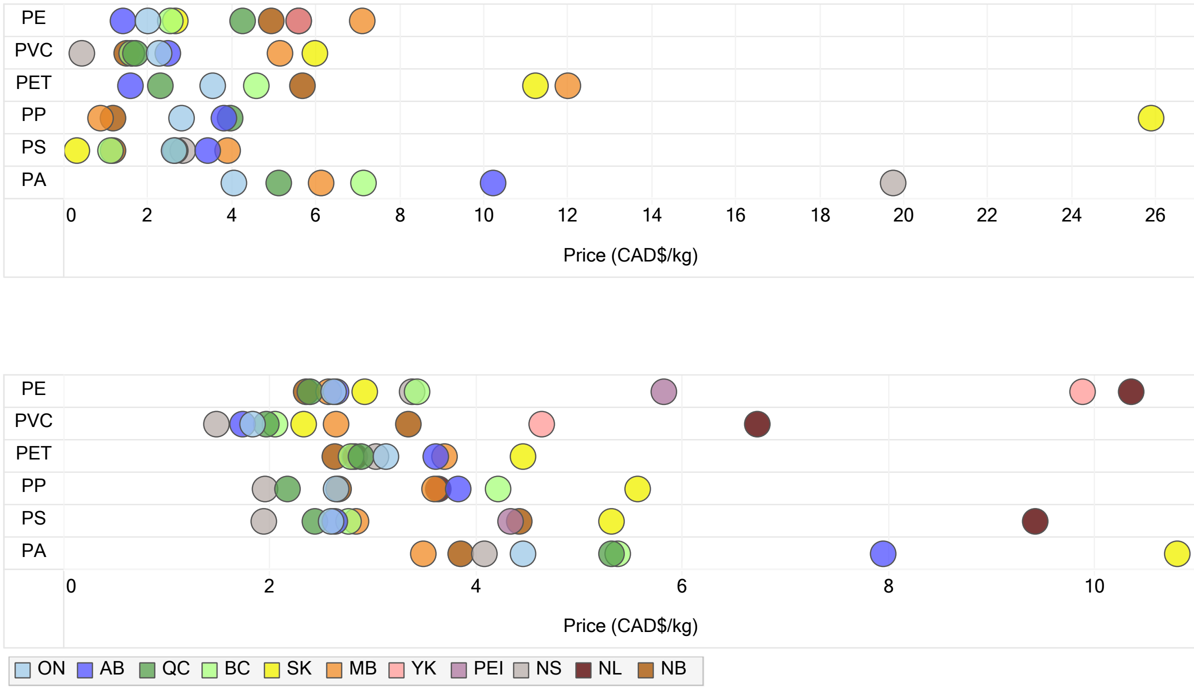


Figure C.4: The international export (top) and import (bottom) average prices in 2019



Appendix D: Additional Material Flow Analysis Information

Figure D.1: The provincial distribution of repurposed plastic wastes (RP)

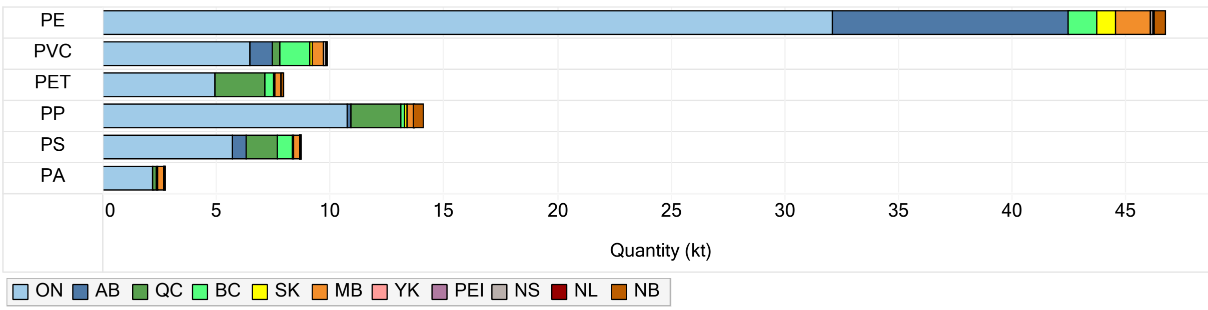


Figure D.2: UR values in 100% and 50% recycling scenarios (2019)

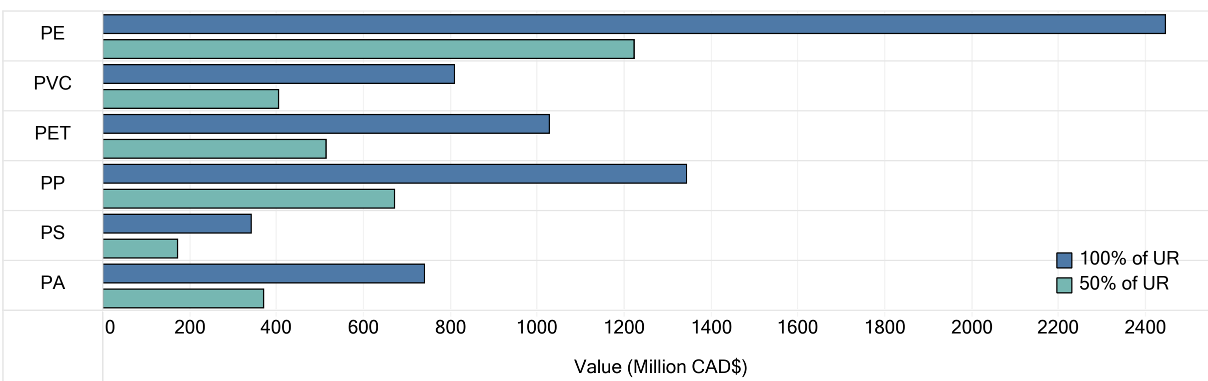


Table D.1: Plastic products categorized under groups of plastic material types (Statistics Canada, 2019)

Plastic Material Group	HS-Code	Plastic Product Types Imported/Exported in Canada
PE	392321	Sacks and bags, including cones, of polymers of ethylene
	392010	Film and sheet, etc, non-cellular, etc, of polymers of ethylene
	391721	Tubes, pipes and hoses, rigid; of polyethylene
	391610	Monofilaments >1 mm, profile shapes, etc, of polymers of ethylene
	391510	Polyethylene waste and scrap

	390461	Polytetrafluoroethylene
	390190	Polymers of ethylene, in primary forms, nes
	390140	Ethylene-alpha-olefin copolymers, having a specific gravity of less than 0.94
	390130	Ethylene-vinyl acetate copolymers
	390120	Polyethylene having a specific gravity of 0.94 or more
	390110	Polyethylene having a specific gravity of less than 0.94
PVC	392112	Film and sheet, etc, cellular of polymers of vinyl chloride
	392049	Plates, film, foil, strip, of pvc, n-cell, not reinf/lam/sup/sim combi w o mat, nes
	392043	Film & sheet, etc, non-cellular, etc, of poly of vinyl chloride, wt>=6% plasticizers
	391810	Floor, wall and ceiling coverings, etc, of polymers of vinyl chloride
	391723	Tubes, pipes and hoses, rigid; of polyvinyl chloride
	391620	Monofilaments >1 mm, profile shapes, etc, of polymers of vinyl chloride
	391530	Polyvinyl chloride waste and scrap
	390591	Copolymers f vinyl, other than vinyl acetate, in primary forms, nes
	390490	Polymers of vinyl chloride, nes, or of other halogenated olefins
	390450	Vinylidene chloride polymers
	390440	Vinyl chloride copolymers, nes
	390430	Vinyl chloride-vinyl acetate copolymers
	390422	Polyvinyl chloride, nes, plasticized
	390421	Polyvinyl chloride, nes, not plasticized
	390410	Poly (vinyl chloride), not mixed with any other substances
PET	392069	Film and sheet, etc, non-cellular, etc, of polyesters, nes
	392063	Film and sheet, etc, non-cellular, etc, of unsaturated polyesters
	392062	Film and sheet, etc, non-cellular, etc, of poly (ethylene terephthalate)
	390799	Polyesters, nes, in primary forms
	390791	Polyesters, nes, unsaturated

	390770	Poly (lactic acid), in primary forms
	390769	Poly (ethylene terephthalate), in primary forms, nes
	390761	Poly (ethylene terephthalate), having a viscosity number >= 78 ml/g, in primary fms
	390750	Alkyd resins
	390599	Polyvinyl esters, nes; other vinyl polymers in primary forms
PP	392020	Film and sheet, etc, non-cellular, etc, of polymers of propylene
	391722	Tubes, pipes and hoses, rigid; of polypropylene
	390290	Polymers of propylene, nes, or of olefins nes, in primary forms
	390230	Propylene copolymers
	390210	Polypropylene
PS	392111	Film and sheet, etc, cellular, of polymers of styrene
	392030	Film and sheet, etc, non-cellular, etc, of polymers of styrene
	391520	Polystyrene waste and scrap
	390390	Polymers of styrene, nes, in primary forms
	390330	Acrylonitrile-butadiene-styrene (abs) copolymers
	390320	Styrene-acrylonitrile (san) copolymers
	390319	Polystyrene, nes
	390311	Polystyrene, expansible
PA	392092	Film and sheet, etc, non-cellular, etc, of polyamides
	390890	Polyamides, nes, in primary forms
	390810	Polyamide-6, -11, -12, -6,6, -6,9, -6,10 or -6,12
OTHER-THERMOSET	392113	Film and sheet, etc, cellular of polyurethane
	392094	Film and sheet, etc, non-cellular, etc, of phenolic resins
	392093	Film and sheet, etc, non-cellular, etc, of amino-resins
	392059	Film and sheet, etc, non-cellular, etc, of acrylic polymers, nes
	391000	Silicones in primary forms

	390950	Polyurethanes in primary forms
	390940	Phenolic resins
	390939	Amino-resins, nes, in primary forms
	390920	Melamine resins
	390910	Urea resins; thiourea resins
	390730	Epoxide resins
	390690	Acrylic polymers, nes, in primary forms
OTHER-THERMOPLASTIC	392091	Film and sheet, etc, non-cellular, etc, of poly (vinyl butyral)
	392061	Film and sheet, etc, non-cellular, etc, of polycarbonates
	392051	Film and sheet, etc, non-cellular, etc, of poly (methyl methacrylate)
	391190	Polysulphides, polysulphones, other products of note 3 to ch, in primary forms, nes
	391110	Petroleum resins, coumarone, indene or coumarone-indene resins & polyterpenes
	390740	Polycarbonates
	390720	Polyethers, nes
	390710	Polyacetals
	390610	Poly (methyl methacrylate)
	390530	Poly (vinyl alcohol), whether or not containing unhydrolyzed acetate groups
	390529	Vinyl acetate copolymers, nes
	390521	Vinyl acetate copolymers, in aqueous dispersion
	390519	Polyvinyl acetate, nes
	390512	Polyvinyl acetate, in aqueous dispersion
	390220	Polyisobutylene
OTHER - TUBES & PIPES	391740	Fittings, of plastic, for tubes, pipes and hoses
	391739	Tubes, pipes and hoses, nes, plastic
	391733	Tubes, pipes & hoses, of plastic, not reinforced/combi w o materials, w fittings, nes
	391732	Tubes, pipes and hoses, nes, plastic, not reinforced, etc, without fittings

	391731	Tubes, pipes & hoses, flexible, plastic, minimum burst pressure of 27.6 mpa
	391729	Tubes, pipes and hoses, rigid; of plastics, nes
OTHER - BIOPLASTIC	392114	Film and sheet, etc, cellular of regenerated cellulose
	392079	Plates, sheets, film, foil and strips, of cellulose derivatives, nes
	392073	Film and sheet, etc, non-cellular, etc, of cellulose acetate
	392071	Film and sheet, etc, non-cellular, etc, of regenerated cellulose
	391710	Sausage casings of hardened protein or of cellulosic materials
	391390	Natural polymers and modified natural polymers, nes, in primary forms
	391310	Alginic acid, its salts and esters, in primary forms
	391290	Cellulose derivatives, nes, in primary forms
	391239	Cellulose ethers, nes, in primary forms
	391231	Carboxymethylcellulose and its salts
	391220	Cellulose nitrates, including collodions
	391212	Cellulose acetates, plasticized
	391211	Cellulose acetates, non-plasticized
OTHER - MISCELLANEOUS	392690	Articles of plastics, nes and articles of other materials of nos 39.01 to 39.14
	392640	Statuettes and other ornamental articles, of plastics
	392630	Fittings for furniture, coachwork or the like, of plastics
	392620	Articles of apparel & clothing access, incl gloves, mittens & mitts, of plastics, nes
	392610	Office or school supplies, of plastics
	392590	Builders' ware, nes, of plastics
	392530	Shutters, blinds, incl venetian and similar articles & parts of plastics
	392520	Doors, windows and their frames and thresholds for doors, of plastics
	392510	Reservoirs, tanks, vats, etc, of a capacity exceeding 300 l, of plastics
	392490	Household and toilet articles, nes, of plastics
	392410	Tableware and kitchenware of plastics

	392390	Articles for the conveyance or packing of goods, nes, of plastics
	392350	Stoppers, lids, caps and other closures of plastics
	392340	Spools, cops, bobbins and similar supports, of plastics
	392330	Carboys, bottles, flasks and similar articles of plastics
	392329	Sacks and bags, including cones, of plastics, nes
	392310	Boxes, cases, crates & similar articles of plastic
	392290	Bidets, lavatory pans, flushing cisterns and similar plastic sanitary ware
	392220	Lavatory seats and covers of plastics
	392210	Baths, shower-baths, sinks and wash basins, of plastics
	392190	Plates, sheets, film, foil and strip, nes, of plastics
	392119	Film and sheet, etc, cellular of plastics, nes
	392099	Film and sheet, etc, non-cellular, etc, of plastics, nes
	391990	Self-adhesive plates, sheets, film, etc, of plastic, nes
	391910	Self-adhesive plates, sheets, film, etc, of plastic in rolls <=20 cm wide
	391890	Floor, wall and ceiling coverings, etc, of plastics, nes
	391690	Monofilament, cross-section dim >1mm, rods, sticks & profile shapes, of plastics, nes
	391590	Plastics waste and scrap, nes
	391400	Ion-exchangers based on polymers of nos 39.01 to 39.13, in primary forms
	390931	Poly (methylene phenyl isocyanate) (crude mdi, polymeric mdi), in primary forms
	390591	Polyvinyl copolymers, nes, in primary forms
	390469	Fluoro-polymers, nes