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POLICY-DRIVEN INNOVATION IN REVERSE SUPPLY CHAINS FOR POST-CONSUMER PLASTIC IN PACKAGING AND ELECTRONIC WASTE

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Policy-driven Innovation in Reverse Supply Chains for Post-consumer Plastic in Packaging and Electronic Waste

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Executive Summary

This technical note examines the structure and functioning of the reverse supply chain for plastic in Ontario (Canada) and how Extended Producer Responsibility (EPR) influences this system. Specifically, we will describe the intertwined processes composing the reverse supply chain and reveal the main operational and economic challenges affecting each process, focusing on consumer products packaging and electronic waste (e-waste). An understanding of the current infrastructure for and obstacles to managing end-of-life plastic products and materials can inform important developments in managerial practice as well as policy making. The Ontario government is working towards implementing a new EPR framework to encourage innovation in reverse supply chains; however, any new policy must address several considerations to stimulate the development of a capable system.

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1. End-of-Life Plastic and the Reverse Supply Chain

Canadians generated approximately 34 million tonnes of municipal solid waste (MSW) in 2016, of which 25 million tonnes were disposed in landfills or incinerated and 9 million tonnes were recycled or composted[1] (Environment and Climate Change Canada, 2020, p. i). Plastic constituted 13.4% of MSW in Canada in 2016, for a total of 3,352 thousand tonnes of end-of-life (EOL) plastic waste produced in the country or 93 kilograms per capita (Environment and Climate Change Canada, p. 24). This wasted material has residual economic value that the reverse supply chain tries to capture.

Through a complex web of processes, a traditional forward supply chain takes a product design and turns it into a product for an end-user (Figure 1; blue dashed outline). At the end of its useful life, the product becomes an EOL item that is often landfilled or incinerated, with harm to the environment (see Exhibit 1 for common categories of EOL items and the raw materials that can be recovered from them). To avoid the environmental harm and generate financial value from the recovery of useful materials from EOL items, a reverse supply chain can be established to "close the loop" (Figure 1; red solid outline).

This technical note will focus on the reverse supply chain that manages EOL post-consumer plastic in Ontario. Although there are many sources of plastic waste (e.g., manufacturing waste, plastic containers), we focus on packaging and e-waste plastics – these are high-profile forms of plastic waste generated by individual consumers. EOL plastic is often combined with other materials within a product or comingled with other material streams upon disposal. Thus, the early parts of the reverse supply chain typically handle multiple material streams, of which plastic is one. This technical note also examines how evolving Extended Producer Responsibility (EPR) frameworks influence the functioning and systematic improvement of the reverse supply chain.

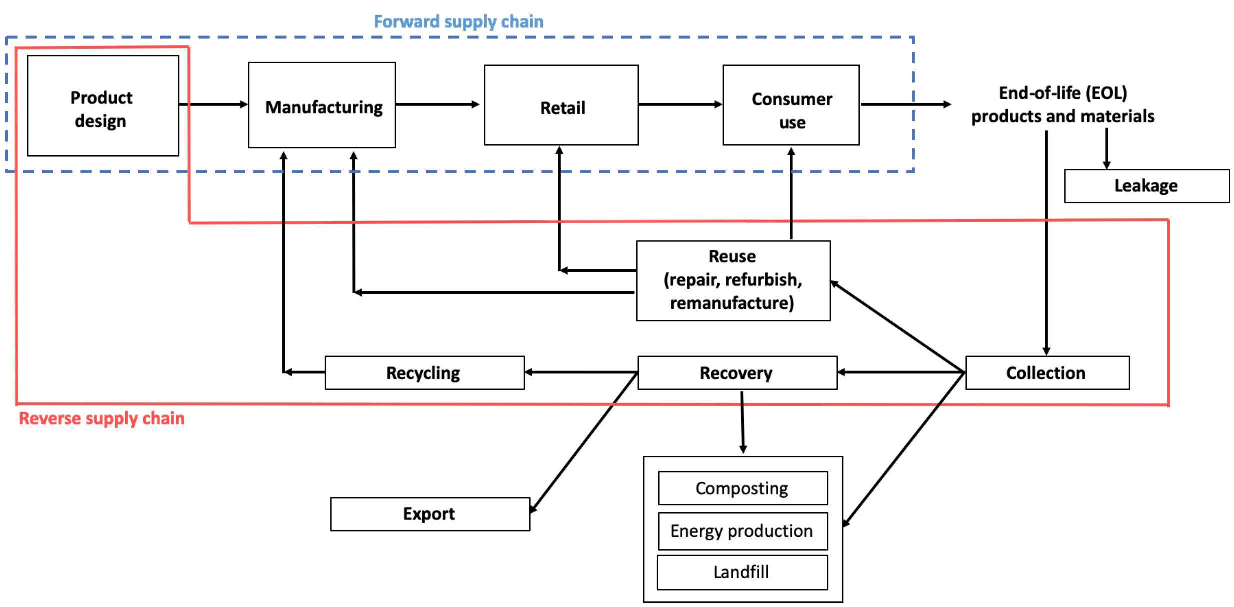


Figure 1: Forward and Reverse Supply Chains in a Circular System. Source: Created by the authors based on material in this report.

[1] Per capita equivalents: 942 kg of waste generation, 692 kg of waste disposal, and 250 kg of waste diversion.

Both traditional waste management systems and innovative reverse supply chains emerged to address negative externalities related to health and disease caused by improper waste disposal, but gradually evolved to consider environmental protection and efficient resource management as well (Wilson et al., 2012). In the reverse supply chain depicted in Figure 1, EOL products can be collected through private, public, or informal channels, with varying operational processes and performance across diverse jurisdictions and service providers. Ideally, the majority of EOL products should be repaired, refurbished, remanufactured for resale, or sent to recovery and recycling facilities to extract and transform the valuable materials into inputs for manufacturing. Incineration and landfill should only be a last resort, when products and materials cannot be reused or recycled. As recent reports and news articles indicate, however, reverse supply chains often function poorly, with products and materials often following suboptimal pathways through the system or even leaking into the natural environment.

The waste management hierarchy in Figure 2 describes the best practices for managing waste to minimize its negative financial, environmental, and health impacts. This approach was first introduced by the European Union in 1975 (United States Environmental Protection Agency, 2005); more nuanced frameworks that prioritize strategies according to different levels of circularity have subsequently been proposed (Exhibit 2) (Potting et al. 2017, p. 15). Among the Organisation for Economic Co-operation and Development countries, Canada has one of the lowest landfill tipping fees (Monahan, 2018). Moreover, the prices of goods manufactured using virgin materials are not adjusted to account for the environmental costs associated with producing those materials (Ragan et al., 2018). These and other factors, discussed in this report, constrain the functioning and improvement of reverse supply chains.

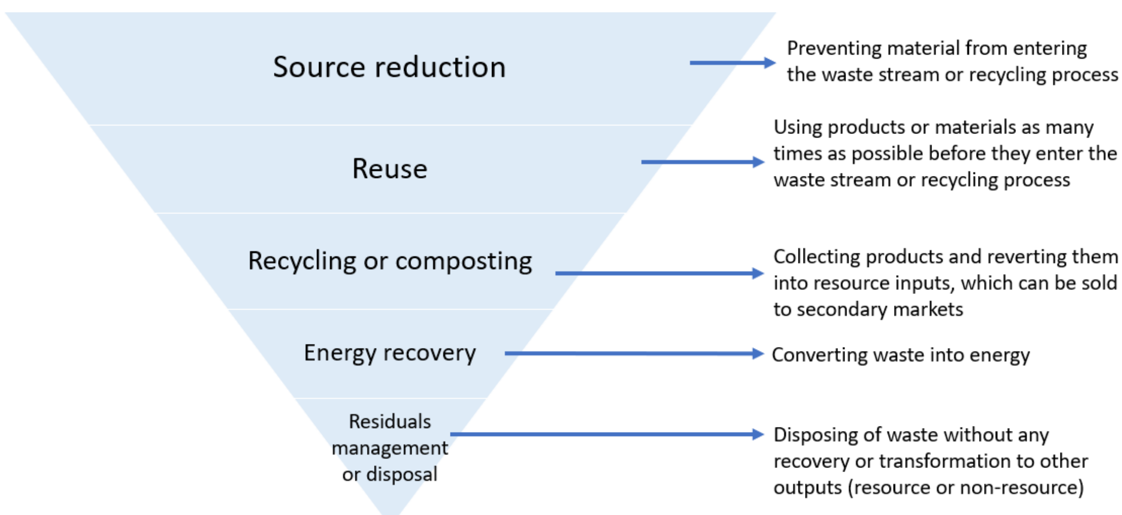


Figure 2. Waste Management Hierarchy (United States Environmental Protection Agency, n.d.; Giroux, 2014). Source: Created by the authors based on information from United States Environmental Protection Agency (n.d.) and Giroux (2014).

2. Operational Processes in the Reverse Supply Chain for Plastic

Each stage in the reverse supply chain poses its own unique challenges. Moreover, because product design, collection, reuse, and recycling are all interrelated, changes in one stage can have ripple effects throughout the reverse supply chain. In the following sections, we first discuss the operational and organizational characteristics of the processes composing a reverse supply chain, focusing on processes relevant to plastics recycling. We then examine their related challenges.

2.1 Design for the Environment

Design for the environment (DfE)[2] is a set of practices in which product design and development processes incorporate environmental considerations. Examples of such practices include designing products that (a) use fewer raw materials or use compostable, biodegradable, or recyclable materials, (b) are easy to repair or recycle, or (c) use less energy throughout the product lifecycle (Industry Canada, 2009, p. 8). Design for durability and reparability are key enablers of servicizing-business models; they were conceptualized in 2007 (Rothenberg, 2007, p. 1–9) and continue to diffuse (Hopkinson et al., 2018, p. 71–92).

In Canada, the highest rates of adoption of DfE are in the automotive, aerospace, electronics, and consumer packaged goods (CPG) industries (Industry Canada, 2009, p. 6). Nearly 50% of firms in the first three categories use DfE, compared to only 20% of CPG firms. Automotive and aerospace firms have already adopted Lean and Six Sigma principles and tools, which focus on eliminating waste or producing flawless outputs with longer useful lives. These goals overlap with those of DfE (Industry Canada, 2009, p. 4–8). Access to foreign markets requiring stricter environmental compliance motivates electronics companies to pursue DfE. End-consumer and business demands drive the shift toward DfE for CPG firms, because market segments that value environmental sustainability are expected to expand in the medium-to-long term. Most CPG firms implement DfE to improve the packaging materials used in their own supplies and upstream operations, rather than for the packaging for their own products sold to retail chains and final consumers (Industry Canada, 2009, p. 4–8). As organizations advance their sustainability goals, DfE has broadened into Design for Sustainability, which includes social as well as environmental impacts. For example, HP expanded its Planet Partners recycling program to include sourcing from Haiti, thus contributing to Haiti's economy and creating over 1,100 jobs there (Gualandris et al., 2021).

2.2 Collection

Collection is the process of aggregating the EOL materials disposed by consumers and transporting them to the appropriate recovery facility (Figure 1). Because EOL plastic is often collected with other EOL material, the collection process described here also applies to other materials.

EOL materials can be collected by public, private, and informal actors and the management of collection programs can be allocated amongst these actors with varying degrees of financial and operational responsibility. As part of the collection process, aggregation and compaction at transfer stations help to reduce transportation costs when the recovery facilities are geographically distant from collection points (Resource Recycling Systems, 2012, p. 5–7).

In Ontario, EOL items can be collected through residential waste collection programs known as Blue Box Programs. These are mostly operated by municipal governments,[3] with considerable variation in efficacy between municipalities and between provinces (Environment and Natural Resources Canada, 2018).

In parallel with public collection programs, some businesses have private collection processes, usually focused on specific products and materials. For example, in the HP Planet Partners Program for HP LaserJet print cartridges, consumers can mail back their HP ink and toner supplies or drop them off at participating stores (Gualandris et al., 2021). Recent developments in provincial EPR frameworks, examined later in this report, aim to stimulate the development of similar private collection processes, with businesses establishing their own collection networks. Tim Hortons, Burger King, and a number of local retailers are partnering with TerraCycle's zero-waste platform, Loop, and with other startups such as CirculR and A Friendlier Company, to pilot collection and reuse programs that will allow end-consumers

[2] Synonymous with “ecodesign” (Telenko et al., 2016, p. 2).
[3] Provincial and territorial authorities typically establish policies for waste management (Government of Canada, 2018).

to pay a deposit and receive reusable and returnable cups or food containers with their order (Mohan, 2020). As with the Ontario Deposit Return Program implemented at The Beer Store (The Beer Store, n.d.), when end-consumers finish their drink or meal, they can return their reusable cups or food containers at a participating restaurant and have their deposit refunded. The reusable items are then professionally cleaned and sanitized by Loop for reuse (Mohan, 2020).

Finally, informal waste collectors retrieve recyclable items that have been littered or misplaced in garbage bins and redirect them—for reuse, resale, or return—to a recycling facility in exchange for money (Jaffe et al., 2018). Many municipalities have bylaws that prohibit the removal of recyclable material from Blue Boxes (Bender, 2010; Jaffe et al., 2018), leading to confrontations between waste collectors, police, and residents. However, some nonprofit organizations have formed to support informal pickers. For example, Les Valoristes reported that its recyclers collected 380,012 containers in 2016 and United We Can reported that its service divisions collect 60,000 containers daily in British Columbia (United We Can, n.d.). The informal recycling sector promotes social and economic development by removing waste from the environment and recovering resource value (Valencia, 2019).

There is limited information available on the capacity and capabilities of the various collection processes in Canada. Accessibility to curbside public collection varies by location and material type in Canada (Exhibit 3). There are fewer and less-efficient collection programs in rural areas than in urban areas, relying more on collection depots and more limited in the variety of materials they accept. Rural municipalities have considered using compaction trailers rather than conventional tractor trailers to collect their recycling. Compaction trailers can compact 5–10 times more material than conventional trailers and reduce collection costs by up to 53.7%, but are more expensive and have longer loading times (Chari et. al, 2016).

2.3 Recovery

Recovery refers to the sorting, cleaning, and baling of EOL materials. Sorting separates heterogenous waste streams by material type and removes contaminants that may have entered the waste stream during disposal or collection. In particular, plastic is separated from other materials and different types of plastic are separated because they require different recycling activities. The contamination rate of residential recycling can vary widely. For example, in 2018, the contamination rate was only 3% in St. John's, Newfoundland but 26% in Toronto (Chung, 2018). After sorting, the differentiated waste streams are compacted into bales and sold to local or international recyclers that bid for waste; contaminants are landfilled or incinerated.

Recovery activities are typically performed at Material Recovery Facilities (MRFs) (Industry Canada, 2020). MRFs may be owned and operated under private-public partnerships or by recyclers that vertically integrate upstream in the reverse supply chain (Canadian Packaging Staff, 2017).

There were 349 MRFs in Canada in 2019 (Industry Canada, 2020) and 53 MRFs in Ontario in 2015 (Exhibit 4). Most MRFs in Ontario are clustered in the southwest, where 98.3% of the province's recyclable material is generated (Lakhan, 2015). Single-stream MRFs use multiple stages of processing to separate different types of material before shipping bales to the appropriate end-market (such as paper mills and plastics recyclers). Multi-stream MRFs are less capital-intensive because the materials they receive have already been sorted (Lakhan, 2015).[4]

Circa 2020, the electronics industry saw the development of new recovery processes that tried to address the challenge of mixed materials within one product. Some are based on the grind-and-sort principle used in extant MRF processes, but use innovative technology. Other processes introduce a disassembly step.

[4] For a video tour of the material recovery facility in London, Ontario, see https://www.youtube.com/watch?v=c2Tr-U0nALM.

For example, HP Canada and other private actors have been partnering with recyclers such as the Lavergne Groupe to redesign their products and implement recovery with disassembly. Unlike grinding and sorting, recovery with disassembly requires an investment in DfE, sophisticated equipment dedicated to specific product families, and possibly even skilled manual labor (Pagell et al., 2007). Whereas scale economies are much harder to attain, the disassembly process generates higher recovery rates than traditional recovery does.

2.4 Recycling

Recycling refers to the set of activities that transform recovered plastics into post-consumer recycled (PCR) plastic resin. Plastics recyclers further process the bales they have purchased to ensure that the feedstock meets their material requirements (Lavergne Inc., n.d.), sort recyclables that they purchase directly from waste-generating businesses, and disassemble composite products (e.g., computers, smoke alarms) for recycling (Chen, 2020) (Figure 3).

Recycling can use mechanical or chemical technologies. 97% of Canada's plastics recycling uses mechanical recycling, which shreds plastics into resin pellets while keeping the plastic polymer intact (Immell et al., 2020, 12–24). Mechanical recycling has some limitations: it cannot be applied to mixed plastics and the final PCR plastic resin is prone to deterioration after a few cycles of recycling. Chemical or feedstock recycling breaks down the polymer chains into monomers, which can be used to reform the polymers with the original tensile strength (Immell et al., 2020, p. 12–24). Chemical recycling requires relatively less sorting and preprocessing and its PCR plastic resin retains the original tensile strength of the polymers, extending the lifetime for recycling. However, it must be done on a large scale (on the order of 100 million pounds per year) to be economically viable; the facility would have to be in an area densely populated enough to keep the transportation of enough material affordable (Chen, 2020, p. 23).

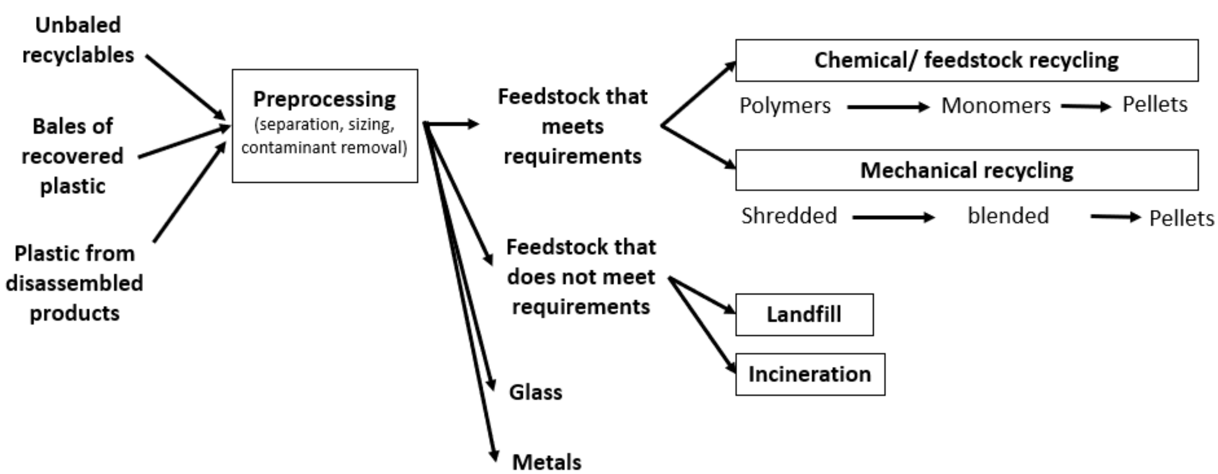


Figure 3. Recycling Process. Source: Created by the authors based on data from Hundertmark et al. (2018), Immell et al. (2020), and Kolb (2020).

There are over 200 facilities in Canada that collectively recycle 305,000 tonnes of plastic annually. Many are in Ontario, Quebec, and British Columbia, but few are operating at capacity (Circular Economy Leadership Coalition, 2019, p. 9; Solly et al., 2019, p. 6; Valiente, 2019, p. 8). Stand-by capacity for recycling exists in Canada (Exhibits 5 and 6), but it is unclear if and how this capacity can be used to process the increasing variety of EOL plastics collected and recovered.

3. Challenges in the Reverse Supply Chain for Plastic

3.1 Challenges Related to DfE

DfE remains largely underdeveloped due to five key challenges:

1) *Inherent complexity*. DfE requires assessment of complex, hidden tradeoffs and of system effects. Because the environmental impact differs at each stage of a plastic's lifecycle, not all types of decision produce the same impact on the sustainability footprint (Berg et al., 2020). For example, flexible plastic packaging is strong and lightweight, which reduces its carbon footprint and waste associated with product damage. However, its low recyclability leads to greater EOL impacts than those of packaging alternatives such as cardboard or glass (Cadman et al., 2005, p. 6).
2) *Lack of organizational resources*. DfE may require specialized knowledge or resource-intensive activities such as life-cycle assessments (Taylor & Vachon, 2018, p. 953), virtual computer-aided design, virtual product development, and rapid prototyping (Industry Canada, 2009). Lack of financial resources or human capital (especially for small to medium-sized enterprises) prevents firms from embracing DfE.
3) *Externalities and opportunity costs*. Due to the difficulty of accurately pricing and assigning financial liabilities for the environmental harm of products and materials, firms that invest in DfE may have a competitive disadvantage relative to those that don't. In turn, firms will tend to focus their sustainability efforts on improving energy efficiency and waste reduction in their internal operations in order to generate immediate cost savings, rather than on innovating on their product design (Berg et al., 2020).
4) *Lack of regulation and of industry-wide criteria*. Considering the complex tradeoffs between different actions at different stages of the product lifecycle, firms would be able to make sustainable decisions more easily if guided by best practices. But there is currently a lack of regulation and of industry-wide criteria for product design (Murray, 2013, p. 2). Criteria may also vary across industries; for example, aircraft have a long useful life while CPG products have short lifecycles. Thus, fuel efficiency may be relevant for the former while design for recycling may be a priority for the latter (Industry Canada, 2009).
5) *Local infrastructure and demand for recycled content*. The diffusion and success of DfE initiatives is influenced by the capacity and capabilities of local collection, recovery, and recycling infrastructure. This leaves us with a chicken-and-egg problem: businesses may be unwilling to design recyclable products and materials until there is infrastructure to collect, recover, and recycle them, but regulators won't build such an infrastructure until there is enough recyclable material and enough demand for recycled material to make the recycling process worth it.

3.2 Challenges Related to Collection

Two main "supply" challenges constrain the efficiency and efficacy of collection processes:

1) Consumers are the main suppliers of the reverse supply chain. Successful collection relies on consumers turning in their EOL products and materials to collection points where they can be appropriately processed. Responsible disposal behavior by consumers is hampered by the time and effort required to sort, clean, and store items made of diverse plastic materials. Confusion over the types of material accepted and proper recycling procedures in different municipal collection programs can discourage consumers from recycling altogether (HDR et al., 2020, p. 2). Additionally, storing recyclables may require too much effort; a study found that if a recycling container becomes full, 27% of the surveyed population will subsequently throw EOL items away instead of storing them until the next collection day (Lane & Wagner, 2013). Private organizations such as MeCycle are using a mobile platform to try to incentivize proper disposal in curbside and

public Blue Boxes by providing consumers with information and offering redeemable deposits (MeCycle, 2021).

2) The collection of recyclable material from consumers distributed across large areas increases logistics costs for the reverse supply chain. Besides the higher fuel costs and emissions, aggregating waste picked up from household and public bins at a transfer station in a sparse area before hauling it to an MRF can add $14–34 of operating costs per tonne of EOL (Resource Recycling Systems & Steward Edge, 2012, p. 4, 93, 324).

The recycling literature also points to the importance of stable demand in driving investment in and improvement of collection processes; the evolution of end-markets for recycled materials is influencing the lists of accepted material in municipal programs. For example, certain plastic films[5] were added to Toronto's Blue Box Program in 2015 because one of the MRFs under contract with the city developed the capability to recover these materials and the city had identified a stable market for them (General manager, Solid Waste Management Services, 2015, p. 1–5). By the same token, some materials could be removed from the recyclable list because markets no longer demanded them or demanded higher quality than was being collected (General manager, Solid Waste Management Services, 2018).

<u>3.3. Challenges Related to Recovery</u>

On the supply side, mixed collection increases convenience for consumers because they can place multiple types of recyclable in one bin, but increases sorting costs and contamination downstream in the reverse supply chain (Chen, 2020, p. 30). When material received at an MRF is too contaminated with unrecyclable items, the contaminants damage equipment or cause the entire truckload to be diverted to landfill, which increases the cost of operations and the environmental harm. Materials that are unprofitable to process will not be accepted in the recycling system. For example, composite materials, such as hot-beverage cups, are difficult to recycle. Flattened paper cups are sorted into the mixed paper stream in MRFs but contaminate this stream because the fiber of paper cups belongs to the same category as that of gable top containers. Paper cups that retain their shape continue along the conveyor with such containers until the cups are sorted into the gable top bale; however, the ink on the cups contaminates this bale (Kelleher Environmental, 2012, p. 19; PAC Packaging Consortium, 2014, p. 11).

Demand also affects investment in and improvement of recovery processes. Demand for polyethylene terephthalate (PET) bales coming out of MRFs has traditionally been strong because this material is easy to recycle. However, such is not the case for all types of plastic. After 2011–2013, when markets emerged for materials segregated into discrete resins, MRFs began moving away from making mixed plastic bales that contained plastic resins 1 to 7.[6] In addition to creating bales solely of plastics 1 or 2, MRFs capable of refined sorting began to create bales for plastic 5, the next-largest category of plastic found in a 3–7 bale (Toto, 2018). Among MRFs, the 3–7 bales are most variable in quality and are often refused by downstream recyclers. In 2019, however, EFS-Plastics, an Ontario-based plastics recycler, found end-markets for these mixed bales as well as for plastic film. The majority of EFS-Plastics's customers supply California markets, where trash liners and grocery bags must contain at least 10% and 40% post-consumer recycled content, respectively (Karidis, 2019). Demand and prices for premium-grade PET bales have also increased in the US following the proposal in 2020 of federal legislation mandating recycled content (Paben, 2020).

In summary, low collection rates of plastics in Canada, externalities, and the inconsistency of local demand from recyclers may have discouraged MRFs from investing in the technology needed to sort the more

[5] Such as milk bags, certain kinds of bread bags, and resealable sandwich bags (General Manager, Solid Waste Management Services, 2015, 1–5)

[6] There are seven plastic resin identification codes (Plastic Action Centre, n.d.).

difficult-to-recycle plastics on a large scale. The variety of packaging and materials has increased more quickly than the recycling infrastructure and packaging design teams don't often consult with reverse supply chain operators. As a consequence, MRFs are unable to profitably recover new types of packaging such as black plastic, which requires special optical sorting technology (North & Halden, 2013).

3.4 Challenges Related to Recycling

First, on the supply side, contamination makes recycling difficult. Contamination can refer to the presence of nonplastic materials such as paper, glass, and minerals in a plastic bale, but can also refer to mixing different types of plastic together. The latter may reduce the selling price of plastic bales (APR and More Recycling, 2020) and increase the preprocessing costs for recycling plants and, ultimately, may lower the quality of the PCR plastic resin produced (North & Halden, 2013). Contamination also comes from chemicals used as flame retardants; some used on older products were subsequently banned due to their toxicity to consumers or to workers in the manufacturing process. These chemicals were added to increase product safety; however, they make recycling dangerous and costly (Lake Simcoe Region Conservation Authority, n.d.; Product Care Recycling Association of Canada, n.d.).

Second, competition in international supply markets for EOL plastic poses a problem for Canadian recyclers. Until recent bans in 2019, the contaminated EOL plastic streams collected and recovered in Ontario and other parts of Canada were either shipped to developing countries, where lower labor costs and less-stringent environmental regulations allowed local recyclers to sustain their demand for Canadian EOL plastic, or were sent for incineration. For example, exported Canadian EOL plastic could be burned to extract highly valuable contaminants (metals) and produce energy, but this could emit harmful pollutants (Szeto et al., 2019). Our supposition is that, before recent bans, exporting contaminated plastic was an easier and potentially more profitable option for MRFs than improving their recovery technologies and serving local recyclers. Canadian recyclers began trying to import clean plastic to replace this volume, but may again be outbid by international recyclers (Schedler, 2017, p. 4–12). In light of this competition, some companies have created new sourcing channels. For example, HP Canada and the Lavergne Group have established operations in Haiti to collect and recover ocean-bound plastic[7] as a reliable source of EOL materials for their recycling process (Gualandris et al., 2021).

Third, there are technical challenges. Current mechanical recycling technologies can only recycle PET bottles up to five times before virgin materials must be added to maintain the plastic's physical properties. Nestlé, Inc. has scaled up the use of bio-based, renewable virgin material in mechanical recycling and is working with other industry players to develop "next-generation" or "enhanced" recycling using chemical technologies. Their chemical recycling process is not yet available on an industrial scale but, if that is achieved, would allow PET bottles to be recycled many times (Nestlé Waters, n.d.).

Fourth, demand for recycled PCR plastic resin is weak and inconsistent, due to barriers such as cost, purity, available variety, and health concerns. Specifically:

1) PCR plastic resin competes against virgin plastic resin, which benefits from an artificially low price that does not include unquantifiable environmental externalities.[8] Moreover, incorporating the use of recycled resin requires significant investments to adapt products and production processes (e.g., design for recyclability, equipment retooling). These investments require a long-term vision

[7] Ocean-bound plastic refers to mismanaged plastic waste within 50 kilometers of the shore and destined for nearby oceans.

[8] One potential benefit of recycled resin over virgin resin, however, is that the price of recycled resin is less volatile. The price of virgin resin fluctuates with the (volatile) price of oil, whereas the price of recycled resin depends on the (stable) operations of the recycling infrastructure (Gualandris & Lee, 2021).

and interorganizational trust and collaboration between recyclers and manufacturers, two factors rarely observed in practice (Gualandris & Kalchschmidt, 2016).

2) Manufacturers may be momentarily constrained as local recyclers work on expanding the limited number of colors, grades, and forms of PCR plastic resin available.
3) There is often fear that if the EOL plastic used to make the PCR plastic resin was not screened properly, banned toxic polymers could create noxious fumes during production. The condition of EOL products turned in by consumers determines the potential value of PCR plastic resin and remanufactured products (Sabbaghi et al., 2016; Agrawal et al., 2018). If consumers keep their EOL products for a long time before turning them in, those products could include hazardous substances that were allowable in the past, but have now been banned. Canada's Health Protection Branch requires manufacturers of resins for food packaging to test the physical and chemical properties of their recycled resins to demonstrate that they are comparable to virgin resin. Approving virgin resin is more straightforward because the type and additives can be easily obtained from the supplier, whereas recycled resin may no longer be food-safe due to contamination from virtually any source and to loss of durability during recycling (Immell et al., 2020, p. 26; Health Canada, 2011; Product Care Association of Canada, n.d., p. 17–18).

In a set of interviews with European consumer goods companies, 100% of senior executives claimed to prioritize sustainability, but only 5% confirmed that they had embedded it in their brands. The reasons they gave for not having done so include consumer value; lack of appropriate solutions, procurement prices, and partnerships; and misaligned operating models (Faelli et al., 2020). Colgate-Palmolive, Danone, Nestlé, Coca-Cola, Unilever, and Walmart have committed to transitioning their packaging to include 20–100% recycled plastic in the next 5 to 10 years (Valiente, 2020, p. 22). HP has recently committed to using 30% PCR plastic resin across its entire portfolio of personal systems and printers by 2025 (HP, 2019, p. 2). However, competitive pressure to maintain low costs by switching to virgin plastic when oil prices are low makes it more difficult to justify the purchase of recycled plastic.

Finally, the demand from public agencies and from end-consumers for environment-friendly products that contain PCR plastic resin is also weak and inconsistent:

1) *Public procurement by local, provincial, and federal government*. In 1995, the Canadian government identified green procurement as a priority area and, in 2006, established a green procurement policy (updated in 2018). There is also a new federal Centre for Greening Government. However, these statements have not been translated into procurement action. Sustainability is not meaningfully integrated into government requests for proposals (RFPs) or into supplier solicitation. Only 12% of the government RFPs surveyed in a recent study had sustainability as an independent criterion (Gualandris et al., 2019).
2) *End-consumers*. Whereas Canadians are becoming increasingly aware of their plastic waste and its environmental impact (McGrath, 2020, p. 16; Valiente, 2020, p. 4), they remain unwilling to compromise on price, quality, and performance for the sake of sustainability (Faelli et al., 2020). In a survey, 65% of Canadian consumers indicated that they wanted to purchase sustainable brands, but only 26% actually did so (White et al., 2019).

4. Extended Producer Responsibility (EPR)

4.1 EPR in Canada

According to the federal government of Canada, EPR is a policy approach that extends the producer's responsibility for a product to the EOL stage of its lifecycle. In 1986, EPR was itself extended to include product packaging (Stewardship Ontario, 2013, p. 11). Most EPR programs in Canada are legislated at the provincial level, but there are some voluntary programs that are not government-regulated and have been organized and funded by industry players (e.g., brand owners, manufacturers, first importers) (Canadian Council for Ministers of the Environment (CCME), 2014, p. 11; Giroux, 2014, p. 37). When a particular waste stream is not perceived to have high residual economic value but still produces environmental harm, legislation can be used to create processes to divert these materials from landfills and to increase their recovery rate (Government of Canada, 2017).

Since 1970, provinces have introduced programs with varying degrees of consumer, producer, and government responsibility to manage EOL consumer waste (CCME, 2014). The operationalization of EPR can take different forms by enforcing responsibility through payment (i.e., producers pay the costs of the reverse supply chain for the EOL plastic they inject into end-user markets) or ownership (i.e., producers are required to collect, recover, and recycle the EOL plastic, internalizing the costs of these processes). In 2009, the CCME released the Canada-wide Action Plan for Extended Producer Responsibility (CAP-EPR) to outline best practices for launching EPR programs and transitioning existing product stewardship or shared responsibility agreements into full EPR programs. As of July 2021, most provinces have legislated EPR for e-waste, paint, and automotive fluids in addition to packaging. There has been no legislation concerning single-use plastic as of 2021, but bans have been proposed. Other types of Household Hazardous Waste are not covered by legislation; some are managed by voluntary EPR programs. Responsibility for packaging, including beverage containers, is mostly shared between producers and municipalities (CCME, 2018, p. 11).

Most EPRs in Canada require annual reporting, audited financial statements, and performance monitoring metrics; however, there is variation in the designated products, guidelines, threshold exemptions, performance monitoring metrics, and auditing across provinces (Giroux Environmental Consulting, 2016). Up until 2019, most provinces had set their own EPR requirements and coordinated the reverse supply chain. Often, waste was collected by various service providers, resulting in inconsistent performance across the country. In 2020, the federal government started an initiative to harmonize all EPR programs in Canada through a national guidance document (King et al., 2020).

4.2 EPR in Ontario

The Waste Diversion Act of 2002 was established to provide consistency and stability to waste diversion programs (Province of Ontario, 2016). Three waste material groups were specified under the Act: Blue Box Waste (glass, metal, paper, plastic, and textiles—this includes packaging), Municipal Hazardous or Special Waste (MHSW) (e.g., batteries, paint, and aerosol containers), and Waste Electrical and Electronic Equipment (WEEE). Waste Diversion Ontario (WDO) was created as an umbrella organization to build and manage waste diversion programs for each material group.

For each material group, a Producer Responsibility Program (PRO)[9] was created, which then worked with WDO to draft a waste diversion program. The PRO was tasked to determine the costs of the program, establish the funding levies necessary, and collect the funds from industry participants (Peterson, 2009). It mediated the agreement between waste operators and producers on the collection of waste. It also had an outreach role: communicating with consumers about the waste-management systems available, informing them about proper waste disposal, and encouraging lower use and greater reuse.

The party responsible for waste diversion, the "producer," is considered to be the manufacturer that injected the product into the province (Environmental Registry of Ontario, 2020). If the manufacturer is not resident in Canada, the responsibility is typically passed on to a first importer (e.g., brand owner, retailer, franchise, or wholesaler). Small producers can be exempted from EPR if it would not be feasible

[9] The Producer Responsibility Program (PRO) was initially called an Industry Funding Organization (IFO). It refers to an organization (usually nonprofit) that acts on the behalf of producers to administer EPR programs.

for them to administer a program (CCME, 2014, p. 33).[10] Both large and small producers are members of the PRO for their material group.

Under the Waste Diversion Act, 2002, the costs of each waste diversion program (for the material group) are shared between the producers (through the PRO) and taxpayers. There were no targets for collection or recycling rates specified in the Waste Diversion Act of 2002.

E-waste. The Ontario Electronic Stewardship (OES) was formed in 2007 as a PRO to implement a waste diversion program for WEEE. The OES established Electronic Handling Fees (EHFs) for all regulated electronic products. The EHF was charged to consumers upon purchase and collected by OES to help defray the cost of the WEEE waste diversion program. Because the fee is charged upfront and the reverse supply chain expenses incurred later, there could be a surplus or shortage of funds, depending on the amount of WEEE collected and the actual costs of the program at the time the EOL product is collected.

Packaging. Stewardship Ontario is the PRO that administers Ontario's Blue Box Program, the waste diversion program that handles packaging (Stewardship Ontario, n.d.).[11] The program is funded 50% by industry fees collected by Stewardship Ontario and 50% by taxpayers. The Blue Box Program operates the curbside recycling collection program in conjunction with municipalities in Ontario. There was concern about the efficacy of this method, due to fragmentation and disorganization amongst municipalities, differing recycling and composting methods, and differing material acceptance policies. This heterogeneity across municipalities created confusion for consumers and producers and the program ended up doing little good for the environment (Lindsay, 2019).

In 2016, the Resource Recovery and Circular Economy Act and the Waste Diversion Transition Act replaced the Waste Diversion Act of 2002. The gist of these new Acts was to make producers fully responsible for recycling the material they introduce into the market. The Resource Productivity and Recovery Authority was formed in 2016 to replace Waste Diversion Ontario in overseeing the Blue Box and MHSW programs and the new Electrical and Electronic Equipment (EEE) program. The main implications for waste diversion programs are:

- The costs of the programs are covered entirely by producers.
- Instead of one PRO per material group, there can be many PROs that compete to offer collection, recovery, and recycling services to producers.
- There are specific collection targets for producers.
- There are specific recycling rate targets for producers.
- A third-party auditor is required to verify how much material is collected, recovered, and recycled. However, to the best of our knowledge, the Resource Recovery and Circular Economy Act and its recent amendments do not prescribe minimum quality standards for recycled plastic nor provide guidance to producers on valuable applications for recycled materials.

E-waste. Ontario launched its EEE regulation on January 1, 2021. The OES and its WEEE program ceased operations on December 31, 2021. In its place, other PROs can be and have already been formed. PROs operate in a competitive environment. They contract with producers to provide collection, transport, and processing services to enable producers to meet their regulatory obligations under EEE. EEE also moved to an Individual Producer Responsibility (IPR) model in which each individual producer (instead of the industry as a whole) is responsible for meeting its collection and recycling rate targets and covers the costs

[10] The definition of the obligated party or "producer" varies across provinces for almost all types of EOL waste, which can make life difficult for stewards in the administration of EPR programs (Giroux Environmental Consulting, 2016, p. 49–52).

[11] Stewardship Ontario also administers the waste diversion program for Municipal Hazardous or Special Waste.

of doing so. Therefore, EHS fees were eliminated. However, producers could still increase the price of products to cover their costs. Whether to absorb the cost or pass it on to the consumer was a decision each producer would have to make.

Packaging. Starting July 1, 2023, the Blue Box Program will transition to the new framework specified under the Resource Recovery and Circular Economy Act of 2016. The key change in this new act is that the producers will bear the full responsibility and full cost of operating the Blue Box Program (that is, there will be no taxpayer component) (Resource Productivity and Recovery Authority, n.d.; Province of Ontario, 2021). The new framework also specifies that producers should establish a common collection system, expand the program to cover more materials[12] and sources of waste,[13] and standardize what can be collected across Ontario (Ministry of the Environment, Conservation and Parks, 2020).

5. EPR Shortcomings and Complementary Policies

EPR transfers financial responsibility for the downstream environmental and economic costs of post-consumer waste from the public sector to the producer (Product Stewardship Institute, n.d.). It aims to tackle supply and demand challenges in the reverse supply chain by forcing producers to internalize externalities, either by paying the costs of or building their own reverse supply chain (Gui et al., 2016). It essentially leads to a privatization of EOL products and materials and related collection, recovery, and recycling processes. EPR, however, may have unintended consequences and may tackle only a subset of the challenges of the reverse supply chain. It is difficult to integrate true EOL costs into a single fee for producers or to determine adequate collection targets and responsibilities (Monier et al., 2014). Moreover, incentivizing innovation and capable functioning within the reverse supply chain may require stimulating demand among public agencies and end-consumers, actors that fall outside the jurisdiction of EPR frameworks.

The following sections provide a commentary on how eco-innovation and capable functioning in reverse supply chains could unfold and on the current shortcomings of EPR frameworks.

5.1. Supply-side Considerations

5.1.1 Responsibility Attribution and Associated Penalties

Allocation of responsibility is a key concern when designing a fair and effective EPR framework. The definition of the responsible party as well as the hierarchy used to designate responsibility varies across provinces. This variation can increase costs for producers that operate in more than one provincial jurisdiction and are thus required to develop multiple protocols for administering their EOL products and materials. This variation can also create legal confusion and opportunities for free-riding (that is, some producers do not contribute to the creation of a better reverse supply chain—by paying fees or innovating their products—but still benefit from its processes and services).

Furthermore, it is critical to distinguish whether producers' liabilities are individual or joint. Individual liability holds each producer responsible for its individual reporting and collection, while joint liability holds all producers in a particular industry, of a particular product, or of a particular material type liable if the target for this group is not met. In joint liability, the categories must be granular enough to be mutually exclusive. "Plastics," for example, would be too broad a category because producers could meet their

[12] *Ontario Regulation 101/904* set minimum requirements for collection and operation of Blue Box materials (Exhibit 4). The new regulations expand the materials list to include everything produced by producers (Ministry of the Environment, Conservation and Parks, 2020).

[13] Some sources, such as communities with populations below 5,000 and long-term care homes, are not served by Ontario's Blue Box Program (Ministry of the Environment, Conservation and Parks, 2020).

targets by collecting the dense and easy-to-collect PET bottles while ignoring the lightweight flexible packaging that is difficult to recycle. Thus, granular categories are necessary to avoid free-riding on collection and recycling rates. Administering a program based on individual liability increases the administration cost; each producer must be audited to verify compliance.

Finally, whereas public agencies and end-consumers should be required to shoulder some responsibility because their purchasing and disposal behavior influences the performance of the reverse supply chain, EPR frameworks have disregarded the role and responsibility of end-consumers, except in provinces, such as British Columbia, where consumers pay a fee for single-use packaging.

5.1.2 Verification

To ensure that an EPR system is performing to standard, auditing and monitoring must be in place to confirm that producers are accurately reporting the quantities of products they produce and recover. Because materials can be measured in different units (such as liters or tonnes) and at different points in the product’s lifecycle (as they are produced, as they are collected, and so on), a harmonized approach to collecting data and calculating recovery rates (and targets) is needed. Other benefits of standardized data collection include the ability to make comparisons across time, place, materials, and producers.

Verification is also important to prevent free-riding. A potential solution is the establishment of PROs. Producers can aggregate their responsibilities into an entity that will establish the infrastructure for reverse logistics. The largest industry players typically form PROs and provide seed funding; additional members are required to sign a commercial agreement and pay a fee to join, which could mitigate free-riding. However, there is always the risk that a large PRO will abuse its power, with the signatories who account for a large portion of the waste applying larger fees to smaller players. Therefore, anti-competitive behavior policy may also be needed.

5.1.3 Capacity-building

The right capacity and capabilities for collection and processing must be established for diverse materials and packaging design needs to be concurrent with recycling system design. For example, take-out coffee cups are theoretically recyclable but, in practice, the separation is difficult and unprofitable, hence these cups end up in the landfill. Investments could be justified based on environmental impact, existing capacity, or imbalances between market incentives. Thus, a set of principles should be developed to prioritize, categorize, and standardize investments in the reverse supply chain.

Improving the collection system and educating consumers on what materials are recyclable and the importance of avoiding contamination would increase both the volume and quality of diverted waste. Design for recyclability, such as using clear plastic (Brooks & Milner, 2019) or homogenous materials, would also increase the proportion of diverted materials that are actually recycled.

5.1.4 Timing

Time frames can affect the efficacy of EPR programs. The time between when a product was injected into the market and when the resulting EOL item was collected may not accurately represent how long the product was used and also varies across products. For example, this time period is longer for certain types of e-waste and shorter for packaging. With less and less plastic being used in new products (due, for example, to lighter and thinner packaging and electronics), EPR may help to contain the growth of EOL plastic but does little to consume the EOL plastic that accumulates in homes and the natural environment.

5.2 Demand-side Considerations

5.2.1 End-markets

EPR will stimulate the supply of recycled content, but this must be matched with increased demand if the system is to be sustainable. One potential solution is to combine EPR regulation with mandated minimum recycled content standards, through a threshold or through a sliding tax[14] (Valiente, 2019, p. 22). Given predictable and stable demand, organizations working in the reverse supply chain would have an incentive to invest in new equipment and develop innovative technologies and processes to improve performance.

Potential unintended consequences of this supporting policy include monopolies and procurement risk. If the minimum standards are too stringent, then only a few producers will be able to satisfy them, resulting in a (temporary) monopoly. This, in turn, would increase the procurement risk for buyers of recycled content, who may find themselves over-reliant on a few key suppliers for recycled plastic. Consequently, it is expected that demand stimuli for PCR plastic resin and products will be able to generate only slow, incremental change because producers will need time to build competitive reverse supply chains.

5.2.2 Finding High-value Applications across Industries and Supply Chains

After collecting and processing recyclables, the resulting raw materials need to find valuable applications within or outside the industry that produced them. For example, consider recycling PET water bottles into tee-shirts. Due to contamination during the bottle's useful life or during its collection and recovery, the recycled resin may not meet standards for food-grade applications, but may meet the lower specifications for clothing applications. End-markets for recyclable materials will need to create disintermediation and heterogeneity in the reverse supply chain to ensure that EOL materials find the highest-value and most sustainable application possible. It is currently not clear if and how EPR (or IPR) could incentivize heterogeneity and the search for high-value applications for recycled plastic. For example, due to competition under IPR, PROs may try to minimize costs, which could inadvertently lower the quality of recycled plastic and constrain its applicability.

5.3 Municipal Treatment under EPR

Under EPR and during the transition toward full IPR, municipalities may struggle to establish commercial relationships with PROs and to negotiate equitable allocation of costs and responsibilities for collection activities. A municipality that has operated a recycling program for decades may not have confidence in a newly formed PRO's ability to administer the program. If one party contracts the other to perform the collection, the fees may not cover all the costs of collection. A solution to this issue is to allot enough time to develop competitive tenders for collection services. Another approach is to allow flexibility between options; for example, a municipality could initially opt out of EPR and observe how PROs and producers perform, then change its decision later (Valiente, 2020).

[14] The tax would decrease as the proportion of recycled content increases, reaching zero at the desired performance standard.

Exhibits

Exhibit 1. Common Categories of EOL Products and the Recoverable Raw Materials

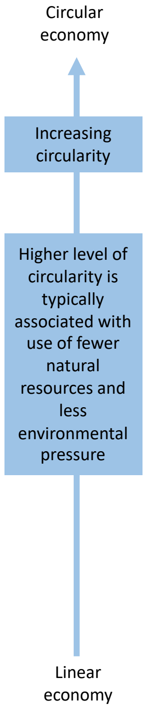
Common categories of EOL products include:

- Packaging (e.g., bottles, foil, boxes)
- Lights and thermostats
- Electronics and electrical equipment (e.g., laptop computers, televisions, cell phones, DVD players)
- Household hazardous and special wastes (e.g., paints, coatings, solvents, and their containers; fertilizers and pesticides and their containers; pharmaceuticals and sharps)
- Automotive products (e.g., used crankcase oil, filters, lead acid batteries, lamps, tires, refrigerants, anti-freeze, brake fluid, transmission fluid, and other fluids and all their various containers)
- Furniture
- Textiles and carpet
- Appliances (CCME, 2014, p. 6–7)

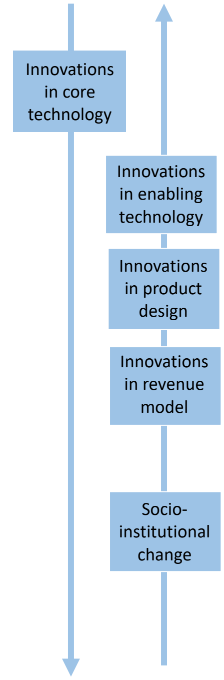
At the end of their useful lives, many of these products can reenter the supply chain in the form of raw materials such as:

- Paper and paperboard
- Metals (e.g., steel, aluminum, other nonferrous metals such as lead from lead-acid batteries)
- Plastics
- Rubber and leather
- Textiles
- Wood
- Organics (e.g., food waste, yard trimmings for compost) (US EPA, 2019, p. 6–7)

Exhibit 2. Prioritized Circularity Strategies Within the Production Chain

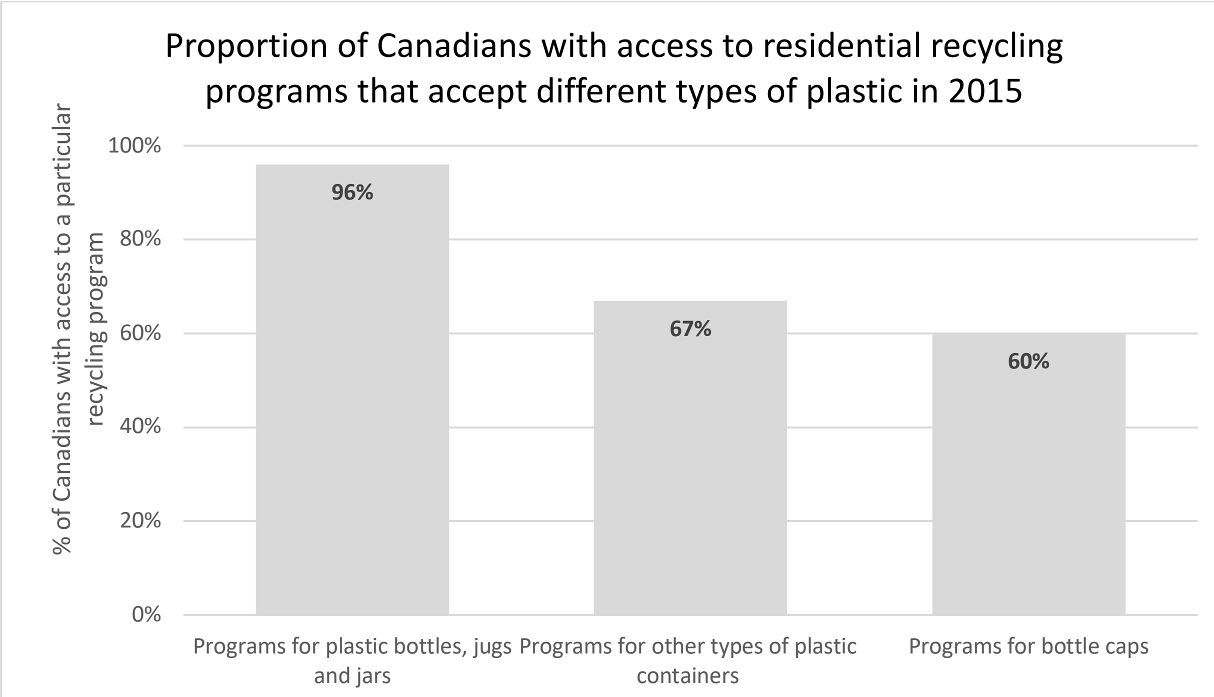


Strategies		
Smarter product use and manufacture	R_0 Refuse	Make product redundant by abandoning its function or offering the same function with a radically different product.
	R_1 Rethink	Make product use more intensive (e.g., sharing products, creating multi-functional products).
	R_2 Reduce	Increase efficiency in product manufacture or use by consuming fewer materials.
Extend lifespan of product and its parts	R_3 Reuse	Another consumer re-uses a discarded product that is still in good condition and fulfills its original function.
	R_4 Repair	Repair and maintain a defective product to restore original function.
	R_5 Refurbish	Restore an old product and bring it up to date.
	R_7 Re-manufacture	Use parts of a discarded product in a new product with the same function.
	R_6 Repurpose	Upcycle old products or use parts of a discarded product into a new product with a different function.
Useful application of materials	R_8 Recycle	Process materials to obtain the same (high-grade) or lower (low-grade) quality.
	R_9 Recover	Incinerate materials with energy recovery.



Source: Adapted from Potting et al. (2017).

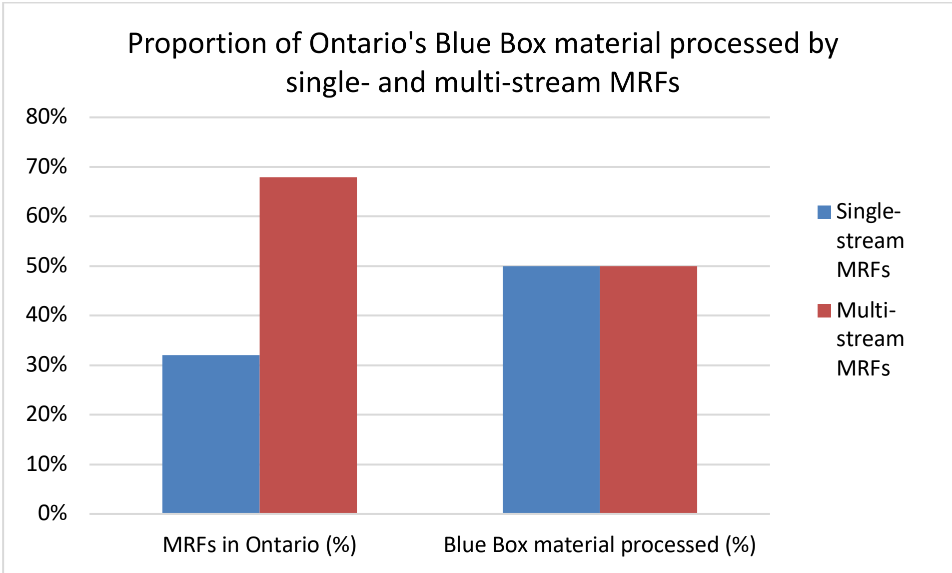
Exhibit 3. Access to Residential Recycling Programs in Canada by Material



Note: “Other types of plastic containers” includes items such as clamshell boxes, tubs, and lids.

Source: Created by authors based on data from *Recycling Today* Staff (2016, September 8).

Exhibit 4. Proportion of Ontario's Blue Box Material Processed by Single- and Multi-stream MRFs



Source: Created by authors based on data from Resource Recycling Systems and Steward Edge (2012) and Lakhan (2015).

Exhibit 5. Recycling Capacity in Canada

	PET[a]	HDPE[b]	PP[c]
Canadian plastic available for recycling (tonnes)	175,300	82,200	-
Number of operating reclamation plants	5	3	5
Combined capacity (tonnes)	150,000	45,000	46,000
Canadian post-consumer feedstock purchased (tonnes)	95,700	41,000	7,200
Capacity utilization (%)	63.8%	91.1%	15.7%
Imported post-consumer feedstock (tonnes)	37,400	-	-
New capacity utilization	88.7%	-	-

[a] Resin code #1, polyethylene terephthalate (PET), commonly used to make plastic water bottles and peanut butter jars.

[b] Resin code #2, high-density polyethylene (HDPE), commonly used to make laundry detergent bottles and milk jugs.

[c] Resin code #5, polypropylene (PP), commonly used to make take-out food trays and the plastic lids found on water bottles and peanut butter jars.

Source: Created by authors based on data from Schedler (2017).

Exhibit 6. Capacity and Capabilities for Collection and Recycling in Canada

Collection
- Plastic recovered in Canada: over 294,800 tonnes collected (2019) (Chen, 2020, p. 137–138; MacDonald, 2020) - 361,200 tonnes available for recycling (2019) (Chen, 2020, p. 137–138) (processors may import plastic)
Processing

Pre- and post-consumer plastics processed by recycling plants: 305,000 tonnes annually (Solly et al., 2019, ii)
- Range of estimates:
  o 380,600 tonnes of plastic processed (2019) (MacDonald, 2020)
  o 270,900 tonnes of recycled plastics (Solly et al., 2019, p. iii)
- Tonnes of PET recycled: 132,600 (2015)
- Tonnes of HDPE recycled: 45,000 (2015)
- Tonnes of PP recycled: 7,200 (2015) (Schedler, 2017, p. 7–12)

Capacity—maximum tonnes of plastic that could be processed by plants: - Capacity for PET: 150,000 tonnes - Capacity for HDPE: 41,000 tonnes - Capacity for PP: 46,000 tonnes (Schedler, 2017, p. 7–12)
Capacity by technology: - Chemical recycling: 9,000 tonnes recycled - Mechanical recycling: 256,000 tonnes recycled (Solly et al., 2019, p. iv)
Number of plastics recycling plants in Canada: - Over 200 recycling facilities (Circular Economy Leadership Coalition, 2019, p. 9; Valiente, 2019, p. 8) - Approximately 80 dedicated plastics recycling facilities (CCME, 2018, p. 8) - 60 major facilities for recycled resins (Solly et al., 2019, p. 8) - 35 recycling plants for plastic (ENF Recycling, n.d.b) - 65 MRFs that can sort plastic (ENF Recycling, n.d.a) - 2,170 MRFs for all materials (includes construction and demolition waste (C&D)) (McGrath, 2020) - 255 recycling facilities for all materials (includes C&D waste) (Irigoyen, 2020) Geographic concentration of these plants: - Most in Ontario and Quebec (CCME, 2018, p. 8) - 10 largest located in Ontario, Quebec, and British Columbia (Solly et al., 2019, p. iii)

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