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Milestone Study on Plastics Waste Management in the US and Canada

Transforming Recycling and Solid Waste Management in the US and Canada

Please cite as:
CEC. 2024. *Milestone Study on Plastics Waste Management in the US & Canada*. Montreal, Canada: Commission for Environmental Cooperation. xviii + 273 pp.

Photo credit – Cover: Planters made of recycled plastic bottles by Elizabeth Romo-Rabago from Ciclomanias.
https://www.ciclomanias.com

ISBN: 978-2-89700-330-2

This study is published only in English. The executive summary is available in English, French and Spanish.

Legal deposit – Bibliothèque et Archives nationales du Québec, 2024
Legal deposit – Library and Archives Canada, 2024

Publication Details
Document category: Project publication
Publication date: December 2024
Original language: English
Review and quality assurance procedures:
Final Party review: December 2024
QA 0388.2024
Project: Operational Plan 2021/Transforming Recycling and Solid Waste Management in North America

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Table of Contents

List of Tables vi

List of Figures x

Glossary and List of Acronyms xii

Abstract xvii

Acknowledgments xviii

1 Introduction 1
- 1.1 Background to Study 1
- 1.2 Study Overview 2

2 Value Chain Overview 4
- 2.1 Value Chain Summary 4
  - 2.1.1 Plastic Components and Production 5
  - 2.1.2 End-of-life Management 6
  - 2.1.3 Recycled Plastic Market 9
- 2.2 Value Chain Actors 9

3 Market Overview 12
- 3.1 Plastic Packaging Market Overview 12
  - 3.1.1 Collection in the US and Canada 12
  - 3.1.2 Collection Challenges across the US and Canada 25
  - 3.1.3 Sorting 26
  - 3.1.4 Recycling 32
  - 3.1.5 Sorting and Yield Losses 41
  - 3.1.6 Recycling Claims and Standards 42
- 3.2 Non-Packaging Plastics Market Overview 43
  - 3.2.1 Construction & Demolition (C&D) 45
  - 3.2.2 Automotive Sector 46
  - 3.2.3 Electronics 47

4 Material Flows and Performance 49
- 4.1 Plastic Packaging 52
  - 4.1.1 Data Sources 52
  - 4.1.2 United States 52
  - 4.1.3 Canada 73
- 4.2 Material Flows and Recycling Performance: Plastics from Electronics 90

4.2.1 United States 90
4.2.2 Canada 91
4.3 Material Flows and Recycling Performance: End-of-Life Vehicles 92
4.3.1 United States 92
4.3.2 Canada 93
4.4 Material Flows and Recycling Performance—Construction and Demolition 93
4.4.1 United States 93
4.4.2 Canada 94
4.5 International Trade 95
4.5.1 United States 95
4.5.2 Canada 97
5 Secondary Markets 100
5.1 Voluntary and Mandatory PCR Targets 100
5.1.1 Voluntary PCR Targets 100
5.1.2 Mandatory PCR Targets 100
5.2 Capacity for Generation of Secondary Materials 101
5.3 Price Variability 102
5.3.1 Factors Affecting Secondary Plastic Price 102
5.3.2 Rigids #3-7 Case Study on Variable Prices 106
6 Difficult to Recycle Plastics 109
6.1 Characterization of Difficult to Recycle Plastic Packaging 109
6.2 Product Design 119
7 Policy and Regulatory Frameworks 122
7.1 United States 122
7.1.1 Federal Policy 122
7.1.2 State Policy 127
7.1.3 Local Policy 135
7.1.4 Non-Packaging Plastics Policy 136
7.2 Canada 137
7.2.1 Federal Policy 137
7.2.2 Provincial Policy 142
7.2.3 Local Policy 144
7.2.4 Non-Packaging Plastics Policy 145
8 Best Practice – Alternative Models, Policy Options, and Emerging Technologies 147
8.1 Alternative Business Models 147

8.1.1 Reuse Systems 147
8.1.2 Repair Systems 149
8.2 Policy Options 149
8.2.1 Reuse Policies 151
8.2.2 Centralized DRS 152
8.2.3 De-centralized DRS 154
8.2.4 Single-PRO EPR Programs 154
8.2.5 Multi-PRO EPR Programs 156
8.2.6 Combined DRS and EPR Systems 158
8.2.7 PCR Content Mandates 159
8.2.8 Bans, Fees and Other Measures 160
8.3 Recovery and Recycling Technology and Infrastructure 161
8.3.1 Sorting Technology: Artificial Intelligence (AI) Robotics, Near-infrared (NIR) Optical Sorters and Markers 161
8.3.2 Chemical Recycling Technology: Chemolysis and Dissolution Recycling 162
8.3.3 Mechanical Recycling Changes 163
8.3.4 Food Grade Recycled Packaging 164
8.3.5 Organic Recycling 165
8.3.6 Managing Plastic Packaging: Blockchain 165

9 Findings and Recommendations 167
9.1 Packaging 168
9.2 C&D 177
9.3 Automobiles 179
9.4 Electronics 181

Appendix 183

10 Circular Economy Definitions 183
10.1 Governments and Institutions 183
10.2 Reports/Studies 184
10.3 Organizations 185
10.4 Events and related communications 186

11 Market Overview Appendix 187
11.1 Collection 187
11.2 Sorting 187
11.3 Recycling Claims and Standards 191

12 Policy Appendix 193
12.1 Canadian Policy at the Province Level 193
British Columbia 193
Alberta 194
Saskatchewan 194
Manitoba 194
Ontario 194
Quebec 195
New Brunswick 195
Nova Scotia 196
Prince Edward Island 196
Newfoundland and Labrador 196
Yukon 197
Northwest Territories 197
Nunavut 197
12.2 Canadian DRS Programs 200
12.3 US Policy at the State Level 201
12.4 US DRS Programs 210
12.5 US EPR Programs 211
12.6 US Chemical Recycling Policy 214

13 Best Practice – Alternative Models, Policy Options, and Emerging Technologies Appendix 216

14 Material Flows Technical Appendix 217
14.1 Introduction 217
14.2 Data Sources 218
14.2.1 United States 218
14.2.2 Canada 219
14.3 General Methodology for Data Collection and Quality Assessment 220
14.4 Detailed Data Tables 220
14.5 Conventional Plastic Material Flow Methodology 221
14.5.1 United States 221
14.5.2 Canada 225
14.6 United States E-Waste, Vehicles, and C&D Material Flow Methodology 227
14.6.1 E-Waste 227
14.6.2 ELV Plastic Waste in the US 232
14.6.3 C&D Plastic Waste in the US 235

14.7 Canada E-Waste, Vehicles, and C&D Material Flow Methodology 239
  14.7.1 E-Waste 239
  14.7.2 ELV Plastic Waste in Canada 242
  14.7.3 C&D Plastic Waste in Canada 242

Bibliography 244

List of Tables

Table 1. Key actors in the plastic value chain 9
Table 2. Comparison of single-stream and dual-stream recycling in the US and Canada 13
Table 3. Single-family vs multi-family access to recycling services 16
Table 4. Access to recycling services in Canadian provinces 16
Table 5. Plastic collection rates by household type in Quebec 19
Table 6. Ten largest municipal solid waste haulers in the US and Canada by revenue (2021) 24
Table 7. Plastic waste separation technologies 28
Table 8. Identification sorting technologies 29
Table 9. The ten largest MRFs in the US and Canada (2020) 30
Table 10. Companies with collection centers and regional collection facilities 31
Table 11: Key Advanced Recycling Technology Traits 35
Table 12. Largest physical recycling facilities in the US by capacity 37
Table 13. Largest chemical recycling facilities in the US 38
Table 14. Largest physical recycling facilities in Canada 39
Table 15. Largest chemical recycling facilities in Canada 41
Table 16. Average MRF loss rates by plastic category 42
Table 17. Single stream MRF losses of PET (2015) 55
Table 18. Loss rates of PET packaging at the recycling processor stage in the US 56
Table 19. Proportion of collected HDPE in non-HDPE sorted streams 59
Table 20. Resin codes for KW Plastics 60
Table 21: Loss rates of HDPE packaging at the recycling processor stage 60
Table 22. Bottle packaging as a % of all packaging 62
Table 23. Curbside collection rate comparison in the US 63
Table 24. Composition of rigid #3-7 bale 64
Table 25. Plastic packaging in MRF reject stream 64
Table 26. Value of MRF plastic per ton by sorting levels in the U.S. 68
Table 27. Comparison of blended plastic values by sorting level and PP price in the US 68
Table 28. Plastic film end-uses in the US (2020) 71
Table 29. Quebec (Canada) bale audit study results 76
Table 30. PET and HDPE bale compositions in Quebec (Canada) 78
Table 31. HDPE products from EFS and Merlin Plastics (Canada) 79

Table 32. Rigid #3-7 audit from Calgary MRF (Canada) 81

Table 33. Recycling access for PVC, LDPE, and PS packaging by province 83

Table 34. C&D plastics waste splits in Europe 94

Table 35. Harmonized System (HS) codes related to plastics 95

Table 36. US plastics waste imports and exports (2021) 95

Table 37. The US's largest export trading partners by plastics waste grade (2021) (values in brackets indicate kilotonnes traded and value in US$, ranked by kilotonnes exported to these countries from the US) 96

Table 38. The US's largest import trading partners by plastics waste grade (2021) (values in brackets indicate millions of tonnes traded and value in US$, ranked by tonnes exported from these countries to the US) 97

Table 39. Canada—waste imports and exports of plastics (2021) 97

Table 40. Canada's largest export trading partners by plastics waste grade (2021) (values in brackets indicate kilotonnes traded and value in US$, ranked by tonnes exported to these countries from Canada) 98

Table 41. Canada's largest import trading partners by plastics waste grade (2021) (values in brackets indicate millions of tonnes traded and value in US$, ranked by tonnes exported from these countries to Canada) 99

Table 42. Reclaimer capacity associated with post-consumer plastics in the US and Canada 102

Table 43. Global, Canada, an US recyclability (according to EMF's definition and threshold) of high-level plastic packaging categories 110

Table 44. Difficult to recycle plastic packaging according to selection criteria 111

Table 45. Incongruent and preferred label materials, according to packaging base resin, and based on APR Design Guidance 121

Table 46. US Federal legislation impacting plastic waste management 123

Table 47. Recently introduced federal legislation related to plastic waste management in the US 125

Table 48. Washington PCR content requirements 131

Table 49. Oregon labeling claims authorized per packaging category 133

Table 50. Policies related to non-packaging plastics in the US 137

Table 51. Canadian Council of Ministers of the Environment (CCME) publications 138

Table 52. Coming into force of the prohibitions on the manufacture, import, and sale of six categories of single-use plastics items (ECCC, 2022) 140

Table 53. Policies related to non-packaging plastics in Canada 145

Table 54. Plastic packaging recycling and recovery rates over time in Germany 158

Table 55. PCR content mandates in California 160

Table 56. Estimated access rates in Canadian provinces and territories 187

Table 57. North America's 75 largest MRFs (2020) 187

Table 58. Major recycling standards applicable in North America and Globally 191

Table 59. Non-packaging EPR programs in British Columbia, Canada 193

Table 60. Canadian regulations related to chemical recycling at the province level 199

Table 61. Progress Transitioning to Full EPR for Consumer Packaging by Province in Canada 199

Table 62. Deposit return systems by province/territory that include plastic containers (Canada) 200

Table 63. US plastic recycling policy summary by state 201

Table 64. Summary of US state DRS programs 210

Table 65. US states with laws classifying chemical recycling as manufacturing 214

Table 66. Data sources used for United States Plastic Material Flow 218

Table 67. Data sources used for Canada Plastic Material Flow 219

Table 68. United States Conventional Plastic Detailed Waste Flow 220

Table 69. Canada Conventional Plastic Detailed Resin Flows 221

Table 70. Sample of 50 States of Recycling Data 222

Table 71. Residential vs Commercial Calculation 222

Table 72. Summary of PET Bottles Input into Recycled Tonnages 223

Table 73. Residential Proportion of Plastics 223

Table 74. Calculating "Collected" and "Post-Recycling" Tonnage 224

Table 75. Calculating Tonnage of Recycled PET Bottles 224

Table 76. Sample of Stewardship Report Recycling Data 226

Table 77. Average Calculated Non-Deposit Collection of Plastics 226

Table 78. 1960–2018 Data on Major Appliances in MSW by Weight (in thousands of U.S. tons) 228

Table 79. 1960–1980 Data on Small Appliances in MSW by Weight (in thousands of U.S. tons) 228

Table 80. 1960–2018 Data on Selected Consumer Electronics in MSW by Weight (in thousands of U.S. tons) 229

Table 81. Polymer Breakdown for Other Consumer Electronics 230

Table 82. ELV Plastics Waste by Polymer 233

Table 83. Total ELV Plastics Waste by Polymer 234

Table 84. 1960–2018 Data on Construction and Demolition Debris by Weight (in thousands of US tons)—from EPA 235

Table 85. Detailed Composition of Plastic Wastes 236

Table 86. Plastic Composition of C&D Waste from Minnesota 237
Table 87. Total Plastics C&D Waste by Polymer in EU27+2 (2010) 237
Table 88. Detailed Plastic Composition of C&D Plastic Waste 238
Table 89. Composition of WEEE by Electronics Categories 239
Table 90. Total Diverted Electronics in Canada (2020) 240
Table 91. Garbage and Depot Calculations 241

List of Figures

Figure 1. Types of plastics and their common applications 2
Figure 2. Value chain for plastic products 4
Figure 3. The waste hierarchy 6
Figure 4. Recycling program access in the US (2021) 15
Figure 5. Percentage of US population with recycling programs available for plastic packaging formats 20
Figure 6. Case Study: Residential collection methods for plastics in Washington 21
Figure 7. Percentage of Canadian population with recycling programs available for plastic packaging formats (2015) 22
Figure 8. Sorting technologies used in the plastics sorting process 27
Figure 9. Mechanical recycling flow 33
Figure 10. End-use markets for plastics 44
Figure 11. Typical composition of plastics within WEEE 47
Figure 12. Plastic waste flows in the United States (2021, in kilotonnes (kt)) 50
Figure 13. Plastic waste flows in Canada (2020, in kilotonnes (kt)) 51
Figure 14. Resin composition of plastic packaging in the US (2020) 53
Figure 15. Plastic Packaging collection pathways in the US 54
Figure 16. US collection of PET packaging (2020) 54
Figure 17. Summary of PET packaging flows in the US (2020) 57
Figure 18. HDPE packaging collected in the US (2020) 58
Figure 19. HDPE recycling collection summary (2020) 61
Figure 20. PP rigid packaging collection pathways in the US (2020) 62
Figure 21. Value of PP rigid bale over time 63
Figure 22. Flow of PP rigid packaging in the US (2020) 66
Figure 23. Collection pathways of #3-7 rigid plastics without PP in the US (2020) 67
Figure 24. Summary of rigid #3-7 packaging recycling in the US (2020) 69
Figure 25. Film recycling summary in the US (2020) 72
Figure 26. Recycling rates of plastic packaging in the US: all sectors (2020) 73
Figure 27. Plastics generated for products in Canada 73
Figure 28. Canada plastic packaging collection by pathway (2021) 74
Figure 29. Collection of PET in Canada by pathway (2021) 75

Figure 30. Summary of PET packaging flows in Canada (2021) 77
Figure 31. Collection of HDPE by pathways in Canada (2021) 78
Figure 32. Summary of HDPE recycling in Canada (2021) 80
Figure 33. Collection of PP packaging by pathway in Canada (2021) 81
Figure 34. PP packaging recycling summary in Canada (2021) 83
Figure 35. Other rigid plastics collected by pathway in Canada 84
Figure 36. Summary of other rigid plastics recycling in Canada 85
Figure 37. Film collected in curbside programs 86
Figure 38. Collection of Plastic Film by Pathway in Canada 87
Figure 39. Plastic film MRF losses 88
Figure 40. Summary of plastic film recycling in Canada 89
Figure 41. Recycling rates of plastic packaging in Canada (2020) 90
Figure 42. Plastics waste in scrap electronics—the US and Canada 91
Figure 43. Plastics waste in end-of-life vehicles—the US and Canada 92
Figure 44. Construction and demolition plastics waste in the US and Canada 94
Figure 45. Highest to lowest five-year average plastic prices in the US and Canada (2018–2022) 103
Figure 46. Range of cost of various commodity plastics in the US and Canada, 2018–2022 104
Figure 47. Average indexed values of plastic commodity prices to the US and Canada average 105
Figure 48. Northwest US secondary market pricing for rigid #3-7 bales (2018–2023) 107
Figure 49. Map of five-year average price of rigids #3-7 in the U.S. 108
Figure 50. States with chemical recycling as manufacturing legislation 134
Figure 51. Methods to increase circularity and reduce plastic waste 147
Figure 52. Four reuse models 148
Figure 53. Provincial policies for sectors and materials consisting of or containing plastics in Canada 198
Figure 54. Mass-balance approaches at the group, batch and site level 216
Figure 55. Screenshot of US auto sales from 1990 to 2021 (in millions) from Statista 233

Glossary and List of Acronyms

ABS	Acrylonitrile butadiene styrene, a common thermoplastic polymer.
ACRC	Ag Container Recycling Council (US)
ADEQ	Arizona Department of Environmental Quality (US)
AI	Artificial Intelligence
APR	Association of Plastic Recyclers (US)
ASA	Acrylonitrile styrene acrylate, an amorphous thermoplastic developed as an alternative to ABS, but with improved weather resistance, and widely used in the automotive industry.
ASR	Automotive shredder residue
B2B	Business-to-business
B2C	Business-to-consumer
BFR	Brominated flame retardants
Biobased plastics	Plastics made in part or wholly from renewable, raw materials such as vegetable fats and oils, corn starch, woodchips, straw, and recycled food waste.
Biodegradable	Something that can decay or be decomposed naturally by bacteria or living organisms into harmless products.
BOPP	Biaxially oriented polypropylene, polypropylene that is stretched in two directions during the production process to make it stronger and more transparent. It has an ideal printing surface and is commonly used for applications that require moisture resistance, optical clarity and high tensile strength e.g., labels, stickers, and food packaging.
BRCCC	Brewers Recycled Container Collection Council (British Columbia, Canada)
BUR	Biennial Update Report
C&D	Construction and Demolition
CCME	Canadian Council of Ministers of the Environment
CEC	Commission for Environmental Cooperation
CEPA	Canadian Environmental Protection Act
Chemical recycling	A broad term used to describe a range of emerging technologies that turn plastic waste back into its component polymers, monomers, oligomers or hydrocarbon products (e.g., pyrolysis and depolymerization). These technologies are often also categorized as advanced recycling or molecular recycling. Chemical recycling does not include purification which can be a complimentary technology to chemical recycling.
Compostable plastic	Compostable plastic refers to a number of polymers designed to biodegrade, in an industrial process or a home composting process, into biomass, water and carbon dioxide. Industrially compostable means that the plastic biodegrades in industrial composting or anaerobic digestion facilities and is compliant with an industrial compostability standard, such as the ASTM D6400 or EN 13432.
Conventional plastic	Plastic typically derived from fossil-based feedstocks that is not considered to be biodegradable or compostable in any reasonable timeframe.

CPP	Canada Plastic Pact
CSP	Clearing service providers
DAO	Delegated Administrative Organization
DOE	United States Department of Energy
DRS	Deposit return system
EEA	European Environment Agency
EEE	Electrical and electronic equipment
EfW	Energy from waste
ELV	End-of-life vehicle
EMF	Ellen MacArthur Foundation
EPA	United States Environmental Protection Agency
EPR	Extended producer responsibility
EPS	Expanded polystyrene
EU	European Union
EVOH	Ethylene vinyl alcohol
FDA	United States Food and Drug Administration
Food grade plastic	Plastic specifically manufactured to meet certain standards of purity, made without the use of dyes or any material that could pose a risk to human health. This is because the most acidic foods and alcohol can sometimes leach plastic additives from the container or packaging into the food, which opens up the possibility of these additives then being consumed by humans. The purity of food-grade plastic prevents this process from occurring, so that food grade products can safely be used to store most food or drink.
FTC	Federal Trade Commission (US)
GSA	General Services Administration (US)
HDPE	High-density polyethylene, commonly used for milk bottles, bleach cleaners, and most shampoo bottles.
HH	Household
HIPS	High-impact polystyrene, a thermoplastic polymer used within the sign, print and display markets due to its visual appearance.
HS	Harmonized system, a multipurpose international product nomenclature developed by the World Customs Organization that facilitates the identification of specific commodities.
HW	Hazardous waste
ICI	Industrial, commercial, and institutional
ISRI	Institute of Scrap Recycling Industries (US)
IWMC	Island Waste Management Corporation (Prince Edward Island, Canada)
LDPE	Low density polyethylene, commonly used for carrier bags, bin liners and packaging films.
LIBS	Laser-induced spectroscopy

LLDPE	Low linear density polyethylene
MDPE	Medium density polyethylene
Mechanical recycling	The process of recovering plastic waste by mechanical processes such as sorting, washing, drying, grinding, re-granulating and compounding. One type of technology categorized within physical recycling.
MMSB	Multi-Materials Stewardship Board (Newfoundland and Labrador, Canada)
MMSM	Multi-Material Stewardship Manitoba Inc. (Manitoba, Canada)
MRF	Materials recovery facility. This is a specialized facility that receives, separates and prepares recyclable materials for marketing to end-user manufacturers.
MSW	Municipal solid waste
MF	Multi-family
NFC	Near-field communication
NGO	Non-governmental organization
NIR	Near-infrared
NOAA	National Oceanic and Atmospheric Agency (US)
OBRC	Oregon Beverage Recycling Cooperative (Oregon, US)
Oxy-biodegradable / oxy-degradable / oxo-fragmentable	Plastics that are not genuinely biodegradable but fragment in nature creating microplastic pollution.
PA	Polyamide (nylon), the largest family of engineering plastics with a very wide range of applications because of their good balance of properties. Polyamides are very resistant to wear and abrasion, have good mechanical properties even at elevated temperatures, have low permeability to gases and have good chemical resistance, good dimensional stability, good toughness, high strength, high impact resistance, and good flow.
PAYT	Pay-as-you-throw, systems in which households are charged variable rates based on the volume of waste set out for collection.
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
PC	Polycarbonate, one of the most widely used engineering thermoplastics.
PCB	Polychlorinated biphenyl
PCR	Post-consumer recycled
PE	Polyethylene, a type of resin and a polyolefin and one of the world's most widely produced synthetic plastic.
PEF	Polyethylene furanoate, a bio-based polyester with properties appropriate for replacing many plastics, including PET.
PET	Polyethylene terephthalate, a type of resin and a form of polyester. PET has some important characteristics such its strength, thermo-stability, gas barrier properties and transparency. It is also lightweight, shatter-resistant and recyclable.
PETG	Polyethylene terephthalate glycol, a glycol-modified PET.

PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances, which are widely used, long lasting chemicals, the components of which break down very slowly over time. Also known as 'forever chemicals.'
PHA	Polyhydroxyalkanoate, a naturally occurring family of biodegradable polyesters.
Physical recycling	Encompasses mechanical and solvent purification recycling technologies.
PLA	Polylactic acid, a biodegradable polyester produced from lactic acid, used in wide range of service ware products and as filament for 3D printing.
PMMA	Poly(methyl methacrylate), a transparent thermoplastic used in engineering.
Polymer	A chemical compound that contains a large number of identical molecular repeating units. A plastic material is a polymer, typically modified with additives, which can be molded or shaped by pressure and temperature.
PP	Polypropylene, a recyclable polyolefin that is commonly used for margarine tubs, microwaveable meal trays, also produced as fibers and filaments for carpets, wall coverings and vehicle upholstery.
PPP	Packaging and paper products
PRF	Plastic recycling facilities
PRO	Producer responsibility organization
PS	Polystyrene
PUR	Rigid polyurethane
PVC	Polyvinylchloride
PWGSC	Public Works and Government Services Canada
R&D	Research and development
RCRA	Resource Conservation and Recovery Act (US)
RFID	Radio-frequency identification
RIC	Resin identification code
rPET	Recycled polyethylene terephthalate
rPP	Recycled polypropylene
RPPC	Rigid plastic packaging container
RRFB	Resource Recovery Fund Board (Canada)
RVM	Reverse vending machines
SAN	Styrene-acrylonitrile resin, a copolymer plastic consisting of styrene and acrylonitrile, widely used in place of polystyrene owing to its greater thermal resistance.
SF	Single family
SHW	Special handling waste. Waste generated in productive processes, which does not meet the characteristics to be considered hazardous or urban solid waste, or which is produced by large generators of urban solid waste.
SPI	Strategy for Plastics Innovation (US)
SUP	Single-use plastic
TPE	Thermoplastic elastomer, a thermoplastic polymer that exhibits elasticity similar to that of a cross-linked rubber.

UBA	Umweltbundesamt (Environment Agency) (Germany)
UDAP	Unfair or Deceptive Acts or Practices (US)
UNEP	United Nations Environment Programme
USPP	US Plastics Pact
USW	Urban solid waste, equivalent to municipal solid waste in the US and Canada. Waste generated in homes, resulting from the elimination of materials used in domestic activities, from the consumption of products, their containers, packaging or wrappings; waste from any other activity within establishments or on public roads with domiciliary characteristics, and waste resulting from the cleaning of public roads and places.
UV	Ultraviolet
WEEE	Waste electrical and electronic equipment, also known as electronic waste (e-waste).
WRRA	Waste Reduction and Recovery Act (Northwest Territories, Canada)
ZSVR	Zentrale Stelle Verpackungsregister (Central Agency Packaging Register) (Germany)
ZWW	Zero Waste Washington (Washington, US)

Abstract

This document is one of a set of three milestone studies prepared by Eunomia Research & Consulting on behalf of the Commission for Environmental Cooperation (CEC). These studies cover the markets and policy landscapes for post-consumer paper, plastics, and bioplastics waste from both residential and commercial sources in North America. Their purpose is to assess the current state of recycling in the paper, plastic, and bioplastic material markets as a contributor to a circular economy, identifying barriers to recycling and making recommendations for how to overcome these barriers and thereby increase circularity. This study focuses on Canada and the United States, and covers plastics, specifically covering plastics used in packaging, construction and demolition, vehicles, and electronics. A similar study focused on Mexico will be available in the upcoming months.

Acknowledgments

This paper was prepared for the Commission for Environmental Cooperation (CEC) by Eunomia Research & Consulting. The primary authors would like to thank supporting authors Isabelle Faucher of Isabelle Faucher Consultancy, Matthew Cotton of Integrated Waste Management Consulting LLC, Myles Cohen of Circular Ventures LLC, and Pierre Benabides of Lichens Recyclabilité, Inc. for their important contributions to this work.

The CEC would also like to thank the members of the CEC Operational Plan 2021 Project "Transforming Recycling and Solid Waste Management in North America" Steering Committee members for their support and engagement.

In addition, the CEC and Eunomia thank all interviewees and organizations that contributed time, knowledge, and data to this research.

Finally, the CEC acknowledges the staff of the CEC Secretariat involved in bringing this project to fruition: Armando Yáñez, Head of Unit; Antonia Andúgar, Project Lead; the CEC publications editors; and Michael Wou from ORIGAMI graphic designer, who assisted with the completion of the paper.

1 Introduction

1.1 Background to Study

The World Bank estimates that around 2 billion tonnes of municipal solid waste were generated in 2016, with Canada, Mexico and the United States generating 0.4–1.5 kg more waste per capita per day than the global average (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018). North America has the highest per capita plastic and paper consumption in the world. The region represents 21% of total plastics consumption (Heller, Mazor, & Keoleian, 2020) and four times the global average in per capita paper consumption (Haggith, et al., 2018).

According to the World Bank, while waste is generally managed in an environmentally sound manner in North America, globally the mismanagement of waste is polluting the oceans, clogging sewers, and causing flooding, transmitting diseases, and increasing respiratory problems, and, according to 2016 data, generating 1.6 billion tonnes of carbon dioxide.

Reducing waste and closing material loops will help minimize the environmental impacts along the value chain of resources and products, as well as presenting considerable economic opportunities. Circular economy strategies, including various recovery options, are estimated to unlock US$4.5 trillion of economic growth around the globe (Accenture, 2015). The World Business Council for Sustainable Development estimates that the global bioeconomy market could be worth up to US$7.7 trillion by 2030, with significant opportunities for circular solutions.

The transition to a circular economy and increased material recovery also offers solutions to mitigate climate change. The magnitude of avoided GHG-emissions benefits from material circularity is highly dependent on the type of material and the local circumstances for energy offsets. For example, the US EPA estimates that recycling of various paper products could result in 2.64–3.59 Mt CO_2e reduction per short ton of paper (ICF International, 2016), and a study of the Canadian plastic sector estimates that diverting 90% of the plastic waste now going to landfills could result in 1.8 Mt of CO_2e reduction by 2030 (Deloitte and Cheminfo Services Inc., 2019).

The Commission for Environmental Cooperation (CEC) was established in 1994 by the governments of Canada, the United Mexican States (Mexico), and the United States of America (United States) through the North American Agreement on Environmental Cooperation, a side agreement concluded in connection with the North American Free Trade Agreement (NAFTA). As of 2020, the CEC operates in accordance with the Environmental Cooperation Agreement, which entered into force at the same time as the new trade agreement known as CUSMA, T-MEC and USMCA in each of these three countries, respectively. The CEC brings together a wide range of stakeholders, including the general public, Indigenous people, youth, nongovernmental organizations, academia, and the business sector, to seek solutions to protect North America's shared environment while supporting sustainable development for the benefit of present and future generations.

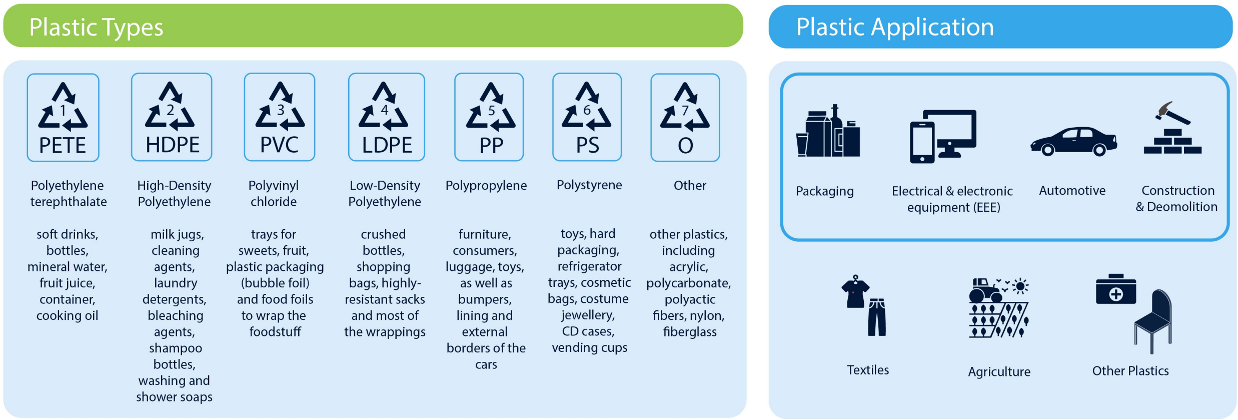
The CEC has commissioned this study as part of the CEC Operational Plan 2021 Project "Transforming Recycling and Solid Waste Management in North America,"[1] with the goal of promoting circular economy and sustainable materials management approaches and bring economic and environmental benefits to the region. This project supports Canada, Mexico and the United States in their efforts to promote circular economy and sustainable materials management approaches to encourage eco-design and thus increase product and material reuse, recovery and recycling rates.

This publication represents one of a series of three milestone studies aiming to better understand the opportunities for the recycling sector and secondary material markets for paper, plastics, and bioplastics waste. The content focuses on the US and Canada, and a separate set of these studies focused on Mexico will be available in the upcoming months. Building on the results of these milestone studies and stakeholder input, the project will carry out pilot testing projects in a second phase to assess the feasibility of innovative technologies, policies, or practices for adoption at scale across North America.

1.2 Study Overview

This milestone study covers post-consumer plastic waste from both residential and commercial sources, while the two other studies focus on paper and bioplastic waste respectively. Packaging is a significant use market for plastics, but three quarters of all plastic used in 2018 went into other markets, including construction, automotive, electronics, agriculture, textiles, and more. For the purposes of this study, we have focused on the four largest applications of plastics in the US and Canada by tonnage: packaging, construction and demolition, the automotive industry, and electronics. The specific categories of plastics and applications in which they are used are depicted in Figure 1.

Figure 1. Types of plastics and their common applications



Source: Eunomia Research & Consulting

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[1] CEC Operational Plan 2021 Project, "Recycling and Solid Waste Management in North America."

The information this study presents is designed to support stakeholder collaboration and knowledge sharing, and provide policymakers with recommendations for improving the circularity of plastics in the US and Canada. Information was gathered through secondary research analyzing existing relevant publications and databases, and primary research through consultation with key stakeholders in plastics waste management in each country. This study considers the information and data available by December 2023. Further detail on methodology can be found in the Appendix.

This study encompasses:

- An overview of the plastic waste value chain and the key actors within it;
- An overview of the plastic waste market, including collection, sorting, and recycling systems, and trade;
- Secondary markets for plastic waste;
- Difficult to recycle plastics and product design;
- Current and emerging policies related to plastic waste;
- Best practices, alternative business models, policy options, and emerging technologies; and
- Recommendations to improve the circularity of plastics in the US and Canada.

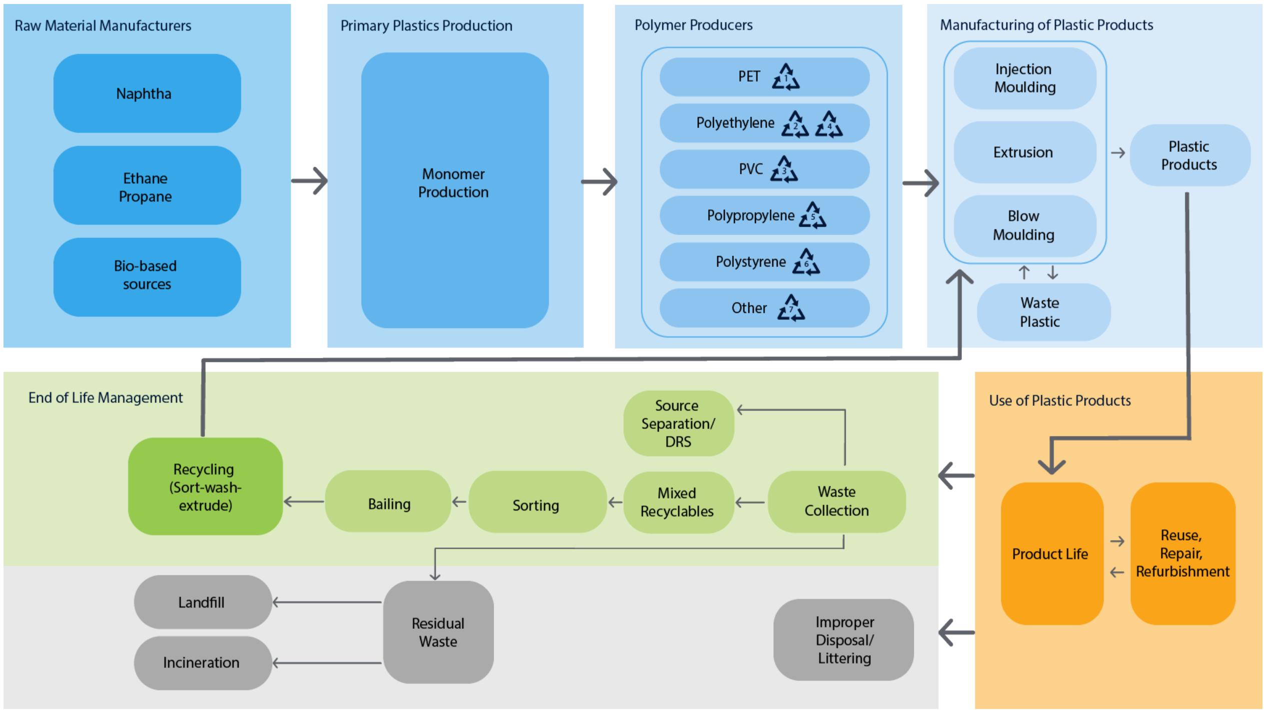
Where available, relevant market data and policy information is provided for individual federal states in the US, and provinces / territories in Canada. There are 50 federal states in the US. Canada is composed of 10 provinces and three territories.

2 Value Chain Overview

The plastics value chain is complex, with many players involved, from the extraction of primary materials to the manufacture of products from recycled materials. The process to create secondary material differs by application (e.g., packaging, electronics, automotive, and construction) and by sector (e.g., residential, commercial, industrial, and institutional). Although plastics cannot be infinitely recycled, maximizing the amount of plastic that is recycled reduces the need for raw material extraction and its associated carbon emissions. Furthermore, keeping plastic in closed or open loop systems can help reduce plastic leakage into the environment.

This section presents an overview of the linear and circular paths of plastic waste in the US and Canada and the main actors along these value chains. Figure 2 illustrates the value chain from extraction to end-of-life management for plastics.

Figure 2. Value chain for plastic products



2.1 Value Chain Summary

Each main stage of the value chain is described below. More information on the collection, sorting, and recycling processes for plastics, including non-packaging plastics, can be found in the Market Overview and Secondary Markets sections of this study.

2.1.1 Plastic Components and Production

Raw Material Production

Most plastic is derived from fossil fuels (such as crude oil and natural gas).[2] As of 2019, plastic accounted for 6% of global oil and gas consumption (Principles for Responsible Investment, 2019). The raw materials are converted from small molecular units, called monomers, and chemically bonded together to form long polymer chains. Generally, crude oil is refined to derive naphtha, while natural gas is refined to generate ethane. Naphtha is a term used to describe a group of highly volatile, flammable liquid hydrocarbon mixtures. These materials must then be processed further before they can become an everyday plastic.

Primary Plastics Production

The majority of fossil fuel-based plastics are produced by large petrochemical companies. These companies produce monomers that are polymerized into plastics in-house or sold to companies that polymerize monomers into plastics.

Manufacturing and Use of Plastic Products

Plastic feeds into many industries, including packaging, automobiles, construction, electrical and electronic equipment, consumer and industrial products, industrial machinery, textiles, and others. A variety of technologies are used to create these products, such as extrusion, injection molding, and blow molding. The duration of a plastic's use phase varies significantly depending on its application. For example, a plastic grocery bag is on average used for 12 minutes before being disposed, while the average lifespan of a car is 12 years (Surfrider Europe Foundation, 2018) (S&P Global Mobility, 2022). Products need to be designed for recycling if they are to be collected, sorted, and recycled. Section 6.2 explores product design opportunities and other measures, such as lightweighting, to reduce the quantity of waste material.

Reuse

Reuse as it relates to plastics encompasses many different sectors, such as refill and reuse systems, repair and refurbishment, and share and swap initiatives. These systems and initiatives extend a product's lifetime, keeping it in use repeatedly and avoiding the emissions and waste associated with the extraction of new virgin materials or processing required to recycle materials. For example, refill and reuse systems can reduce the use of single-use plastics through products such as plastic water bottles or restaurant takeout containers. Some organizations, such as electronic repair shops, focus on the repair and refurbishment of products that contain plastic. Many plastic-containing products, such as automobiles, have significant and well-established second-hand markets. There are also increasing numbers of zero waste or refill stores that sell products with minimal packaging and programs, often on the local level, that offer sharing initiatives for community members such as tool libraries or swap events.

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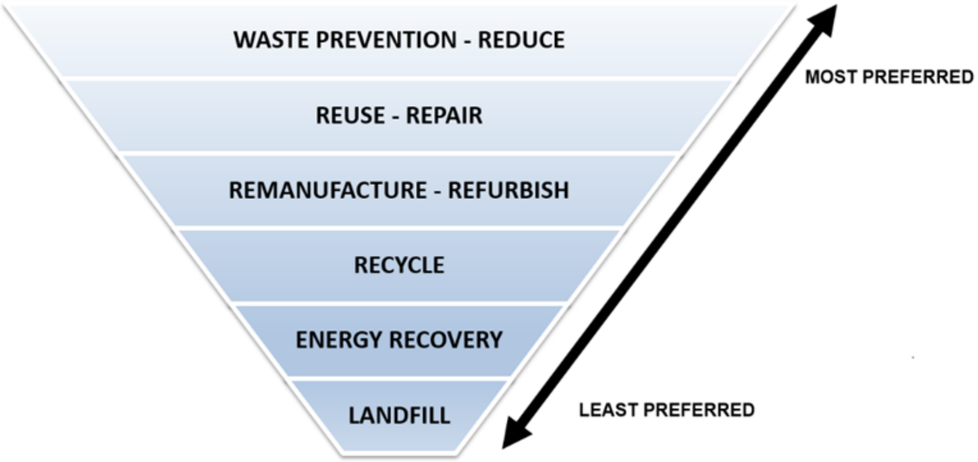
[2] Some plastics are bio-based, meaning that the feedstock comes from plants, not fossil fuels. This report focuses on traditional fossil-fuel based plastics. For more information on bioplastics, refer to the Bioplastics Milestone Study Report.

2.1.2 End-of-life Management

Plastic end-of-life management has various routes, as depicted on the waste management hierarchy in Figure 3. The waste hierarchy outlines an order of preference for waste management options with respect to their environmental impacts. Options that are best for the environment are at the top of the hierarchy, with less preferable options lower down, although it should be noted that the order can shift depending on context. In all circumstances, preventing waste in the first place is the preferred option. Incineration without energy recovery and landfill are typically the least desirable options and are not considered consistent with a circular economy. The role of incineration with energy recovery (waste-to-energy) in the circular economy is debated, but it is preferred to landfilling in the waste hierarchy.

Figure 3. The waste hierarchy



Source: (Government of Canada, n.d.)

Notably, the hierarchy does not currently include chemical recycling, the role of which is still evolving within the circular economy. Chemical recycling is not as widespread as mechanical recycling, and some types, such as plastic to oil to fuel, are not considered part of the circular economy.

The technology falls into three main categories: solvent purification, chemical depolymerization, and thermal depolymerization. Solvent purification is considered a physical recycling process that results in plastics. Chemical depolymerization can produce plastic or fuel, while thermal depolymerization processes primarily produce fuel. These different technologies are explained further Section 3.1.5, but it is important to note that not all chemical recycling technologies are fully circular, specifically those that convert plastic to fuel. The role of chemical recycling technologies that process plastic to oil back to plastic is also still evolving. In 2021, according to an article published by Reuters, there were 30 chemical recycling projects globally, all of which were still operating at a small scale or had shut down. The majority were significantly behind their commercially announced schedule (Reuters, 2021). This is largely because the methods for measuring recycled content in chemical recycling processes vary. Currently, the mass balance accounting method, which is discussed in more detail in Section 8.3.3, is widely accepted as the most robust accounting method.

The pathways for different plastics depend on many factors, including the type of plastic product, the availability of collection systems, the capacity of sorting and recycling facilities, and related policy and regulation. The following sub-sections discuss the different end-of-life management options for plastics.

Physical Recycling

Before being recycled, plastic packaging waste (such as plastic bottles and containers) is collected through systems such as, but not limited to, municipal curbside recycling, incentivized collection programs, recycling drop-off centers, and retail takeback programs, or by waste pickers operating in the informal waste collection sector. Collected plastic packaging is sorted manually or mechanically, often at a materials recovery facility (MRF), to maximize the harvesting of valuable materials. Though less common than MRFs, plastics may also go to specialist plastics sorting facilities, called plastics recycling facilities (PRFs), which typically receive partly sorted plastics. Section 3.1 of this study provides detailed information on collection and sorting systems in the US and Canada.

The plastic recycling process depends on the initial composition of the product. There are two main types of recycling: physical recycling (which includes mechanical recycling and purification technologies) and chemical recycling (sometimes referred to as advanced or molecular recycling). Physical recycling is an emerging term that aims to differentiate recycling technologies "whereby plastic waste materials are recycled back into plastics without altering the chemical structure of the materials" (Plastics Recyclers Europe, n.d.). Solvent purification is considered a physical process, as it does not break chemical bonds, but instead uses solvents to clean the plastic resin of color and additives (Closed Loop Partners, 2021). Solvent purification uses the principle of solubility to selectively separate plastic polymer from any other materials contaminating the plastic waste. Once the purification process is complete, the polymer is extracted from the solution and placed in a non-solvent to re-solidify the polymer for recovery.

Chemical Recycling

Chemical recycling technologies include chemical and thermal depolymerization processes:

- **Chemical Depolymerization** – Processes by which a polymer chain is broken down using chemicals. Once the depolymerization has occurred, the monomers are recovered from the reaction mixture and purified to separate them from contaminants, leaving the pure monomer.
- **Thermal Depolymerization** – Also known as thermal cracking and thermolysis, this is the process by which a polymer chain is broken down using heat treatment. There are two main approaches to thermal depolymerization, delineated by limited use of oxygen as a reagent within the process. ***Pyrolysis***, also known as *thermal cracking*, utilizes high temperatures in the absence of oxygen, while ***gasification*** employs low volumes of oxygen to aid the degradation process. This includes variations on the pyrolysis technique. The degradation pathway typically involves scission of bonds at random positions in the polymer chain, as opposed to the controlled breakdown of chemical depolymerization. This means that the resulting

> pyrolysis oil usually comprises a variety of hydrocarbon products that require further purification before it can be used as a feedstock for polymer production in, for example, a steam cracker. ***Catalytic microwave depolymerization*** is essentially pyrolysis using microwaves, followed by the purification of the monomer by distillation. The use of microwave energy to increase both temperature and reaction speed can provide more control to reach higher conversion rates for the polymer.

Once this depolymerization has occurred, the monomers are recovered from the reaction mixture and then purified. These clean monomers can then be manufactured back into recycled plastic. These processes are more energy intensive processes than physical recycling and result in lower yields of recycled content. Chemical recycling processes are still considered immature with few examples of at-scale production.

Section 3.1.5 provides more detail on the various recycling technologies and systems currently present and emerging in the US and Canada.

The collection, sorting, and recycling of plastic waste varies between the construction, electronics, and automotive sectors. Plastics used for applications in these sectors are often integrated with other materials and may require disassembly, shredding, and/or sorting in the recycling process; further details are included in Section 3.2 of this study.

Energy Conversion

Waste-to-energy processes burn waste, including plastics, as a fuel to generate electricity. Incineration produces greenhouse gas emissions and dioxins, thus making it a less desirable management pathway for plastics.

Thermal depolymerization (pyrolysis and gasification) is a form of chemical recycling used to process plastics; it creates outputs that can be used as inputs for recycled plastic products but can also result in fuels that are eventually burned rather than turned into plastics again. For instance, pyrolysis can produce diesel fuel, which is not part of the plastics value chain, or it can produce naphtha, which can be used to produce recycled plastics. The naphtha is sent for steam cracking before being manufactured back into plastics.

Landfilling

Landfilling is one of the least desirable management pathways for plastic in the waste hierarchy. Depositing plastic in a landfill can cause the leaching of toxins and chemicals into the soil and waterways, including groundwater. Landfilling is an inefficient disposal method because many plastics will remain in the ground for thousands of years without decomposing. Limited landfill space may lead waste management companies to use alternative means to manage disposed material, such as waste-to-energy methods in the future (Principles for Responsible Investment 2019).

2.1.3 Recycled Plastic Market

Global Markets

Recyclable plastic waste is traded on the global secondary commodities market. There are different bale grades of recycled plastics, determined by factors such as how the material was collected and processed. Countries and regions that operate plastic waste collection systems rely on domestic and export markets to move the material. Demand for recycled plastics is growing annually; this can be partially attributed to policies, targets, and goals set by private companies to increase recycled content in products and packaging. Within the US and Canadian plastics trade market, the US and Canada are net importers of plastic waste. Interestingly, between the US and Canada, the US is a net exporter of plastic waste as Canada has proportionally more infrastructure to manage it. Section 5 of the study provides detail on plastic markets and pricing.

Closed and Open Loop

In closed loop systems, the recycling process returns plastic waste into the original product or packaging. However, as this is not always possible, minimizing the fraction sent to landfill or converted to fuel is still important. In open loop systems, downcycling often occurs and plastic recycled from packaging may be used in secondary products, such as building materials, automotive parts, lubricating greases, textiles, or other lower-grade packaging (Schyns, 2021). Virgin plastic is being displaced in both closed and open loop systems, thus supporting the circular economy.

2.2 Value Chain Actors

The plastics value chain is complex and can vary depending on plastic type and application. However, the actors are consistent across plastics industries. Table 1outlines these key actors and their roles.

Table 1. Key actors in the plastic value chain

Actor	Role
Raw Material Manufacturers	In the linear economy, the key role of these companies is to ensure an uninterrupted supply of raw materials for other actors across the value chain. Oil and gas companies operate refineries where crude oil is transformed into various useful chemicals. In the refining process, it is normally heated in a furnace and later distilled into lighter components called fractions.
Chemical Companies	Refined petrochemicals from the oil and gas industry are sold directly to chemical companies that specialize in extracting high value chemical products. Naphtha is one of the hydrocarbon fractions that can be refined from oil and then processed in a steam cracker to produce various other hydrocarbons, including ethylene and propylene. Natural gas can also be processed into natural gas liquids (NGLs) (e.g., ethane and propane), which can be processed in a stream cracker to produce the same monomers (albeit in different proportions).
Polymer Producers	Many chemical companies are key actors in the conversion of monomers into polymers. In the polymerization process, light olefin gases such as

Actor	Role
	ethylene and propylene (i.e., monomers) are chemically bonded into chains to produce polymers.
Plastic Compounders	Most companies making polymers tend to sell relatively few polymer types, which contain only basic additives needed to keep the polymer from degrading during processing. However, when combined with different additives or barrier properties, thousands of unique polymer types can be created. Additives may also be added polymers that convey a range of desired properties. For example, they can serve as flame retardants, UV stabilizers, processing aids, and colorants. Essentially, polymer compounding companies possess the knowledge and equipment to alter the features of polymers according to the requirements of plastic product manufacturers. However, many of the compounds used in additives are also produced by the chemicals industry.
Plastic Converters	Converters produce polymer-based, semi-finished and finished products for the full range of industrial and consumer markets. Converters primarily make use of several tried-and-tested plastics manufacturing processes, including injection molding, extrusion, blow molding, rotational molding, and vacuum forming.
Waste Management Industry	Municipalities, extended producer responsibility organizations, and private sector waste management companies set up infrastructure to collect and sort plastics. The pathways for post-consumer plastic waste differ depending on whether the product is generated from the commercial, industrial, or residential sectors, and may also differ from pre-consumer or post-industrial waste. Post-consumer plastic packaging may go through MRFs to be separated into different polymers, whereas plastics that are part of electronics goods may be separated by grinding the whole item, for example. Section 3 of this study provides additional information on the collection and sorting systems used to manage plastics.
Retailers and Reuse Service Providers	Retailers and other service providers can help extend the lifespan of plastic products by providing reuse, refill, repair, or refurbishing services.
Plastic Recyclers	Plastic recyclers are responsible for recycling sorted waste plastic products to produce a polymer pellet or a finished product, depending upon the type of process. Section 3 of this study provides detail on physical and chemical plastic recycling processes.
Government	Local, regional, and federal governments set policy, regulation, and targets that impact the plastics production and recycling industries. In some jurisdictions, local governments directly manage collection themselves. In jurisdictions with Extended producer responsibility or DRS programs, governments can have additional roles that support the management of those systems. Government also plays a role in setting standards, such as approving plastics for food contact applications. Section 7 of this study details the relevant policies across the US and Canada.
Product / Packaging Producers	Producers can drive the recycled plastics market by increasing demand for it. Many brands have set targets to (1) increase the recycled content of their products and/or packaging, and (2) increase the percentage of their plastic packaging that is reusable, recyclable, or compostable. Non-profit organizations, such as the Ellen Macarthur Foundation, set industry commitments to increase recyclability and recycled content, which private companies can join as signatories. Private companies may also form a

Actor	Role
	producer responsibility organization (PRO) to meet their obligations under an EPR system.
Industry Associations	Trade associations and consortia provide industry data on plastics, support the development of circular solutions for plastics, and work to align actors in the plastic value chain to make progress towards circularity in the industry.
Standards Agencies and Certification Organizations	Product claims pertaining to the recycled content of plastics are generally difficult for producers or consumers to verify without certification that the material is recycled. Standards and certification bodies can be regional or global and provide verification of the origin of product components, input and output materials, and the conditions under which they are produced. From a consumer's perspective, this provides assurance of the claims made regarding the percentage of recycled material included in products. More information on the different standards and certification programs can be found in Section 3.

3 Market Overview

The collection of recyclable materials in the US and Canada can vary widely by geographic location, jurisdictional regulatory authority, existing infrastructure, and local population density. Plastic recycling collection is different for single-family households, multi-family households, residents in rural areas, and Industrial, Commercial, and Institutional (ICI) properties. The informal waste collection sector also plays a role in collection.

Across the US and Canada, waste often must be transported considerable distances from the point of use or disposal to treatment locations. Therefore, access to recycling programs is not uniform, with residents of multi-family buildings less likely to have curbside collection services and more likely to have no access to services at all. Ensuring convenient and widespread access is crucial to maximize the amount of plastic captured in collection systems and improve plastic recycling rates. However, it is important to acknowledge that waste plastics with no secondary market will not be targeted for collection for recycling, because the recycled material lacks value.

Effective sorting of collected plastic waste is crucial to achieve high recycling rates. Sorting aims to minimize the presence of contaminants such as paper, metals, glass, and organic matter that can make plastic unsuitable for recycling. Many MRFs use a combination of manual sorting and mechanical technologies, such as optical sorters and robots, to sort plastic waste. Plastics are sorted and baled into various grades at MRFs. The US and Canada have large, vertically integrated MRFs with extensive sorting capacities. These high capacity MRFs also have technology and equipment that reduces the need for manual labor and are investing in equipment and new technologies like AI to further improve sorting.

Once collected and sorted, plastics are taken to a reprocessor, where they are further sorted, reduced in size, washed, and extruded. The quality of the recycled plastic produced is influenced by the type of recycling technology (e.g., mechanical or advanced recycling technologies), the quality of the feedstock, and the level of contaminants present in the bales. Higher quality recycled plastic can be used in more applications, such as food grade plastics, and allow for closed loop recycling.

3.1 Plastic Packaging Market Overview

This section of the study focuses on the collection, sorting, and recycling infrastructure for plastic packaging (such as plastic bottles and containers) in the US and Canada.

3.1.1 Collection in the US and Canada

Plastic waste is often transported considerable distances from the point of discarding to disposal or treatment locations. The types and extent of collection programs provided vary widely and are influenced by geographic factors, jurisdictional regulatory authority, existing infrastructure, and local population density. The different collection types, access to collection, what materials are collected, and costs of collection are described in the following sections.

Collection System Types

Curbside Collection

Curbside recycling collection is generally either single- or dual-stream in the US and Canada, while some programs in Canada are multi-stream. Single-stream recycling means that all recyclable plastic is collected for recycling with other recyclable materials, such as glass, household metals, and paper, in the same receptacle (e.g., bag, cart, box). Some municipalities also have a separate stream for glass (as broken glass is a common contaminant for other material streams). PET, HDPE, and PP bottles, jugs, and jars are the most commonly included materials in curbside collection; more information on the collection rates of different plastic types is included below in this section.

Table 2. Comparison of single-stream and dual-stream recycling in the US and Canada

Single Stream	Dual Stream
Metal, glass, plastic, and paper all commingled together	Metal, glass, and plastic separated from paper stream
+ Consumer convenience and potential for higher participation - Need for additional sorting stages - Potential for higher contamination resulting in lower market value	+ Purer material streams and less contamination resulting in higher market value +Less sorting needed - Potential for reduced participation

Municipalities manage collection themselves, contract with private waste hauling companies, or require residents and businesses to contract directly with haulers. The frequency of curbside collection of recyclables varies; it may be the same days as normal garbage collection, once a week, once every two weeks, or once a month. Municipally provided curbside recycling services also vary in that some are available solely to residents of single-family dwellings, while others are also available to some or all residents of multi-family dwellings.

The majority (87.4%) of single-family curbside services are provided via community-level contracts or municipal departments in the US (Sustainable Packaging Coalition, 2022). Access to 12.6% of curbside programs is by opt-in or subscription (as opposed to community-level contracts or municipal collection). These programs usually have lower participation rates than contracted services, potentially due to subscription cost and lack of awareness of the programs (Sustainable Packaging Coalition, 2022).

Drop-Off Programs

Some jurisdictions, in tandem with or instead of curbside services, provide drop-off centers for recyclables. Drop-off services are more common in rural areas, often at the county level, where residents have the space to stockpile recyclables and drive them to drop-off locations. Often it is less economical to commission curbside collection in geographically sparse communities. However, some urban and suburban areas offer drop-off centers as well, most frequently for items that are not accepted in their curbside system, such as WEEE, but also plastics such as expanded polystyrene (i.e., Styrofoam), flexible plastics, and films.

Store drop-off programs have been the primary means of recovering post-consumer clean and dry bags, film, and wrap for more than 20 years (BagandFilmRecycling.org, n.d.). Around 18,000 stores (less than 2% of all retail establishments) in the US take back flexible film (Clarke, 2021). About 90% of households are within 10 miles of one of these locations. In some states, certain retailers and most grocery stores are legally required to offer plastic film collection points for residents. Retailers usually consolidate the material with other films, like pallet wrap, at their distribution centers and then sell the material to companies making products like composite lumber.

In regions with a DRS in place, there are often additional ways to drop off materials covered under the system. DRS for beverage containers, described in detail in the Section 7, work by adding a small extra deposit on top of the price of a beverage, such as those in plastic/glass bottles and aluminum cans, which is refunded to the consumer when they return the empty container for recycling. DRS use reverse vending machines (RVMs), bulk return points (for larger quantities of containers), and manual returns to collect empty drinks containers for recycling.

Industrial, Commercial, and Institutional (ICI) Sector

While residential waste streams are similar in composition from residence to residence, the commercial waste stream can vary significantly depending on the type of business. ICI recovery of plastic can be significant when businesses generate large volumes of plastics that can be collected efficiently and effectively, but low when the volumes are small and therefore it is less economical to sort on site and organize separate collection processes. For most businesses, paper and cardboard are the largest segments of the recyclable waste stream; more detail on paper recovery from the ICI sector can be found in the Paper Milestone Study.

There is less public information on recycling in the ICI sector, because it is typically structured around individual business-to-business (B2B) commercial agreements. Still, many jurisdictions mandate businesses and institutions to contract for recycling collection. More commonly in the case of smaller cities or for smaller businesses, jurisdictions gather plastic waste through normal municipal collection. Plastic waste from the ICI sector is generally collected through one of the following channels:

- Municipal collection as part of the collection of recyclables from small ICI generators; these are delivered to an MRF processing municipal recyclables.
- Private collection services, which deliver waste to one of the following:
    - An MRF processing municipal recyclables;
    - An MRF processing ICI recyclables only; or
    - Directly to a plastics recycler.

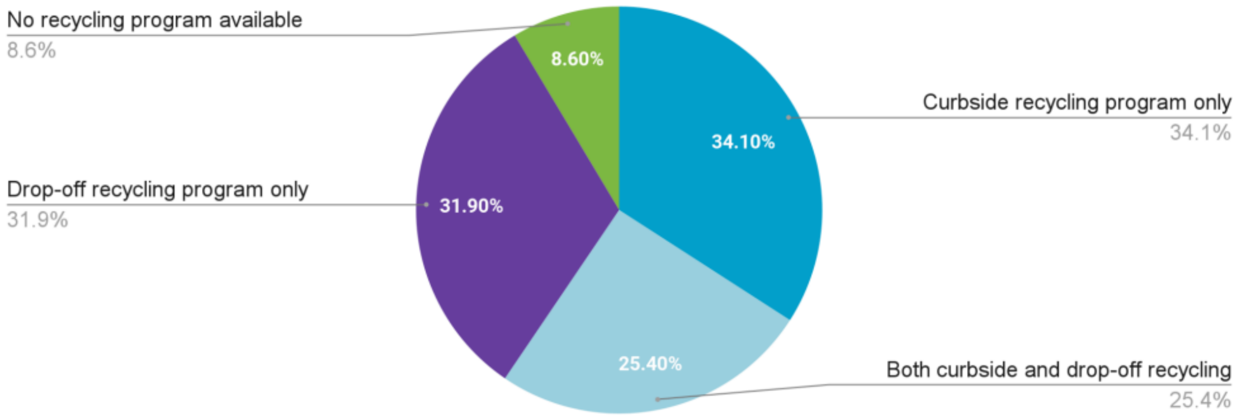
Access to Collection

Access to recycling collection is unequal, as is access to garbage collection for all residents across the US and Canada. Commonly rural areas have less access to recycling services than larger, densely populated cities. Rural areas typically have dispersed populations, making curbside collection more difficult and costly. They are either served by drop-off centers or have no access to recycling altogether. Accessible and convenient recycling services are a crucial part of any successful recycling program. The following sections outline the available information about recycling access in Canada and the US.

Access in the United States

Across the US, residential recycling programs are available to approximately 91% of the population (see Figure 4) (Sustainable Packaging Coalition, 2022). The Recycling Partnership has reported that "40 million U.S. households experience no or inequitable access" to recycling collection, equivalent to more than two out of every five people (The Recycling Partnership, 2021).

Figure 4. Recycling program access in the US (2021)



Source: (Sustainable Packaging Coalition, 2022)

In the US, approximately 70% of the occupied dwellings are single-family homes while approximately 25% are multi-family dwellings. While most US residents do live in single-family homes, recycling rate goals are unlikely to be met without the participation of multi-unit dwellers (who disproportionately have access only to drop-off recycling centers). The availability of different service types varies between residents of single- and multi-family dwellings, with multi-family residents less likely to have curbside recycling available, and also more likely to have no services available at all, as shown in Table 3.[3] The kinds of plastics included in these recycling programs are explored in the following section.

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[3] Notably, for this study by the Sustainable Packaging Coalition, multi-family residents that receive services via private commercial hauling services were not considered to have any service available because it cannot be determined how many residents actually have recycling available at their residence. Single-family housing typically refers to a detached dwelling in which one household resides. However, in recycling programs, "single-family services" are often offered to residents in buildings with 2-8 residential units. Multi-family housing refers to buildings with more than one residential unit. For recycling program purposes, the definition of multi-family may vary from one community to another.

Table 3. Single-family vs multi-family access to recycling services

Type of Recycling Program	Recycling access for residents of multi-family dwellings	Recycling access for residents of single-family dwellings
Curbside recycling program only (including subscription curbside in areas where this is the method of single-family service provision)	19.1%	39.6%
Drop-off recycling program only	46.0%	26.3%
Both curbside and drop-off recycling programs	11.6%	30.7%
No recycling programs available	23.3%	3.4%

Source: (Sustainable Packaging Coalition, 2022)

Access in Canada

Access to residential recycling programs varies vastly across Canada. Ontario, Quebec, New Brunswick, Nova Scotia, Newfoundland and Labrador, Prince Edward Island, Saskatchewan, Alberta, British Columbia, Manitoba and Yukon have curbside recycling collection for some of their population. In the Northwest Territories, access to recycling is via drop-off centers only. There is no access to recycling in Nunavut. Recycling access for each of the provinces and territories with recycling programs is summarized in Table 4 below. Estimated access rates for each province are included in the Appendix.

Table 4. Access to recycling services in Canadian provinces

Province / Territory	Description of Access
Ontario	Under Regulation 101/94[4], communities with a population over 5,000 must provide residents with blue box services that are as convenient or more than waste disposal services – so if it provides curbside garbage collection, it must also provide curbside recyclables collection. If garbage is accepted at a waste disposal site, recyclables must be accepted at drop-off center. In 2020, according to RPRA's 2020 Datacall Report, of the 250 municipalities and First Nation communities who completed the Datacall (representing about 96% of Ontario's total population), 5,175,266 households received curbside services and 198,290 households received only drop-off services, the latter representing about 3% of households (Resource Productivity & Recovery Authority, 2020).

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[4] O. Reg. 101/94 Recycling and Composting of Municipal Waste states "A local municipality that has a population of at least 5,000 shall establish, operate and maintain a blue box waste management system if the municipality is served by a waste management system owned by or operated by or for the municipality that collects municipal waste or accepts such waste from the public at a waste disposal site.

Province / Territory	Description of Access
Quebec	In 2004, 97% of the population was served by recycling collection. Of that, 85% were served by curbside collection and 12% by a drop-off system, primarily offered to residents of multi-family buildings and rural areas (RECYC-QUÉBEC, 2006). As of 2022, according to RECYC-QUÉBEC, 99% of the population has access to recycling, with about 1% of them served by drop-off centers only. This 1% is made up of small municipalities (under 1500 inhabitants and generally less than 1000 inhabitants, all located more than 100 km from Montreal or Quebec City). In most cases, these municipalities have remained in charge of service delivery (with no grouping of services) (Lafrance, 2022).
New Brunswick	Approximately 70% of households receive recycling collection services[5], including both curbside and drop-off. Where curbside recycling collection services are not provided, some municipalities offer drop-off centers or mobile collection events that accept packaging and paper. According to one government official (Leblanc, 2022), the majority (about 95%) of single-family households in New Brunswick have access to curbside collection of recyclables now that the City of Saint John has initiated a program for this.
Alberta	Albertans who live outside urban areas are less likely to have access to curbside garbage collection and/or recycling services and may rely on permanent or mobile drop-off centers. 68% of Alberta households have a collection service provided or managed by their municipality with the remaining 32% hiring their own, private services, or relying on drop-off centers. In large municipalities, 79% of households have collection services provided or managed by their municipality. In medium municipalities, it is 73%, while in small municipalities it is 57% (Eunomia Research & Consulting, 2019).
Saskatchewan	Saskatchewan has low population density, with most people residing outside urban centers. Currently, 84% of households have access to the EPR program. Information on access to curbside collection versus drop-off centers was not available and is noted as a research gap.
Manitoba	An estimated 86% of residents in Manitoba have access to curbside recycling services (Landmark Planning & Design, 2021). The remaining households are served by drop-off centers for recyclables.
Newfoundland and Labrador	Although the province has the lowest population density of any in Canada, 82% of households currently have access to curbside blue bag programs. The programs cover residents of the eastern, western, and central regions of Newfoundland. There are currently no formal blue box programs for five Newfoundland sub-regions or the four regions of Labrador (MMSB, 2022).
Nova Scotia	In Nova Scotia, 100% of the population with access to curbside garbage collection also has access to curbside recycling collection. Collection is two-stream: paper is collected in one blue bag and containers and film in a second blue bag (Kenney, 2022).

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[5] Circular Materials Atlantic, New Brunswick Stewardship Plan for Packaging and Paper (Draft for Consultation), 2022 – Table 3.1. A consultant for Circular Materials Atlantic indicated that comments received through the consultation process provided corrections to the baseline data in the draft plan, but that these corrections were not publicly available.

Province / Territory	Description of Access
British Columbia	In 2021, 99.3% of households had access to recycling services via the RecycleBC program (which includes curbside collection, multi-family collection, and drop-off only). According to RecycleBC's 2021 annual report (RecycleBC, 2022), 1,586,000 households (HHs) (both single-family and multi-family) were served by curbside collection (78%), and 442,000 HHs were served by drop-off centers only (22%). The vast majority of curbside collection programs are located in southern BC. As outlined in its proposed Packaging and Paper Product Extended Producer Responsibility Plan 2023-2028 (RecycleBC, 2022), RecycleBC has established the following criteria for determining whether a municipality is eligible for curbside collection: the community has a minimum population of 5,000 residents and a curbside garbage collection program is in place and operated by the municipality. Unincorporated areas are eligible to receive curbside collection provided they meet the above two conditions, as well as two more: the proposed service area has a minimum household density of 0.42 households/hectare and there is a maximum distance of 20 km between proposed Service Area Sections.
Prince Edward Island	All residents have access to monthly recycling collection. Households place their recyclables in transparent blue bags. Drop-off locations are also available to supplement the monthly collection service.
Yukon	Access to recycling is mainly only at drop-off centers, except in Whitehorse, Yukon where there is an opt-in private curbside recycling collection service 'Whitehorse Blue Bin Recycling'.
Northwest Territories	Access to recycling is only at drop-off centers.
Nunavut	There is no access to recycling in Nunavut.

Limited data are available on access to and performance of recycling in multi-family buildings compared with single-family properties in Canada. Most multi-residential households, e.g., 80% in Ontario (Office of the Auditor General, Ontario, 2021), have municipal garbage and recycling collection, which is counted as residential waste in data, with no distinction between single- and multi-family properties. However, access is not the main barrier to recycling for residents of multi-family buildings. For example, even though 98% of all buildings sampled in Metro Vancouver have access to recycling bins, the recycling rate for multi-family buildings was at 40% compared with over 60% for single-family buildings.

A report from the Continuous Improvement Fund points out several factors that affect recycling at multi-family buildings, such as the inconvenience of recycling compared to garbage disposal, insufficient bin capacity, lack of repercussions for improper recycling, the belief that maintenance fees cover waste management services, and inadequate education and outreach (KPMG, 2007). This is supported by academic studies, where there is general consensus that residents of multi-family buildings recycle less than residents of multi-family buildings (DiGiacomo, 2018). While data for the whole of Canada is not available, the tables below present the collection rate for plastics, categorized by building type, for Ontario and Quebec.

According to a 2021 waste composition study in Ontario, collected rates are lower in multi-family than in single-family buildings, at 41.6% and 67.4% respectively (AET Group Inc., 2022). In Quebec, multi-family buildings also present a lower performance than single-family buildings, but to a lesser degree, as presented in Table 5, below (RECYC-QUÉBEC, 2021).

Table 5. Plastic collection rates by household type in Quebec

Household Type	Plastics collected rate
Urban single-family	35.5%
Rural single-family	38.3%
Two to five units, multi-family household	36.4%
Multi-family	29.0%

Source: (RECYC-QUÉBEC, 2021)

What Plastics are Collected

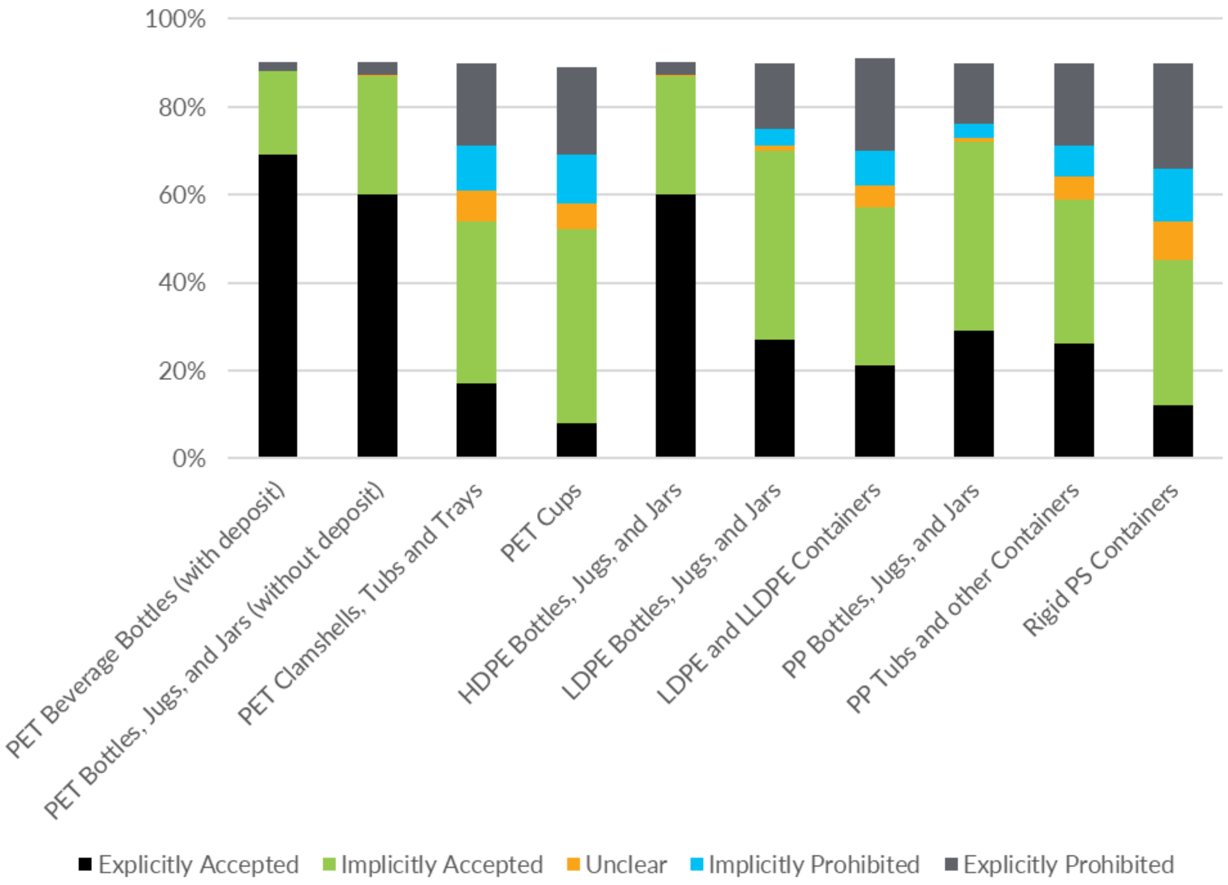
The types of plastics accepted by collection systems can vary across states and municipalities. What materials are accepted in local collection systems is based on various factors, such as MRF requirements, commodity market prices, contracts, policy, and more.

Though some areas have comprehensive recycling systems and others have minimal ones, generally certain plastic types are widely accepted in collection systems. These most commonly collected plastics include PET (e.g., water bottles, trays), HDPE (e.g., milk bottles, shampoo bottles), and PP (e.g., yogurt tubs, margarine tubs). In regions with access to specialized recycling facilities, collection programs may also accept LDPE (e.g., plastic bags), PVC (e.g., plastic trays, wraps), and PS (e.g., plastic cutlery), though this is less common. The least commonly collected plastic packaging is often flexible plastics (e.g., chip bags), as their complex layers make them much more difficult to recycle. However, as recycling technologies advance, more plastic types are being collected and recycled, and this will only improve in coming years. The following sections provide an overview of the available information on what kinds of plastics are collected in recycling programs in the US and Canada.

Plastics Collected in the United States

The percentage of US population with access to recycling programs for certain plastic packaging formats is shown in Figure 5 (Sustainable Packaging Coalition, 2022). The percentages do not add up to 100% because 9% of US residents do not have access to any recycling program.

Figure 5. Percentage of US population with recycling programs available for plastic packaging formats

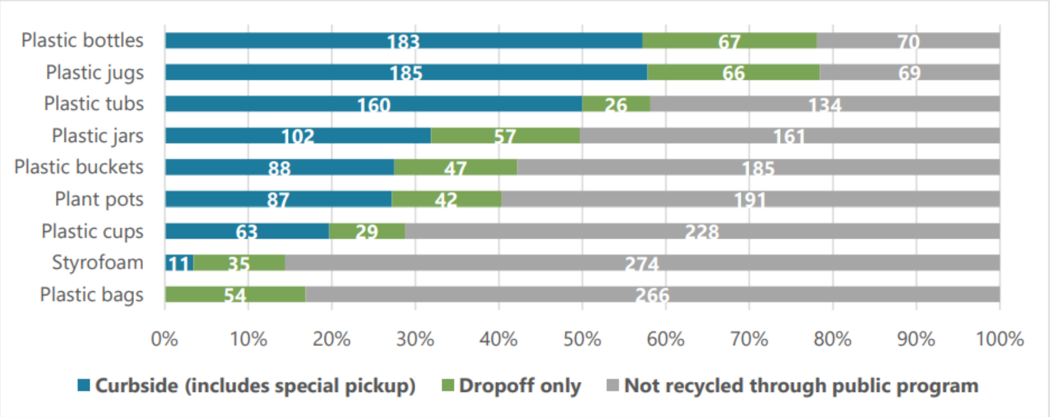


Source*:* (Sustainable Packaging Coalition, 2022)

Figure 5 focuses on the most commonly collected types of plastic packaging and thus does not cover less commonly collected plastics, such as flexible films. Generally, comprehensive data on the percentage of the US population with recycling programs for all plastic types is not readily available. However, Washington, a state with good data availability, can serve as a case study, as shown in Figure 6.

Figure 6. Case Study: Residential collection methods for plastics in Washington

As of 2020, around 2.8 million (89%) of Washington's 3.2 million households have access to residential curbside collection of recyclables, including plastic packaging, as a universal service provided alongside (and paid for through) garbage collection service (embedded), a mandatory subscription service, or an optional subscription service. As with service-level requirements, the list of designated materials to be collected for recycling is set by each local government. Whether a material is designated depends on multiple local factors, including recycling collection costs, distance to MRFs, existence of reliable recycling markets, and other considerations. A report published by Zero Waste Washington (ZWW) in 2019 documented the types of materials collected by residential recycling programs across the state's 385 distinct service areas. The figure below illustrates the prevalence and methods of collection for the specific types of plastics included in the ZWW survey.



Source: Adapted from Figure 4 from Zero Waste Washington, *The State of Residential Recycling and Organics Collection in Washington State*, November 27, 2019; updated to reflect changes to collection of plastic bags in multiple jurisdictions as of Jan 1, 2020.

Source: (Cascadia Consulting Group, Eunomia Research & Consulting, 2020)

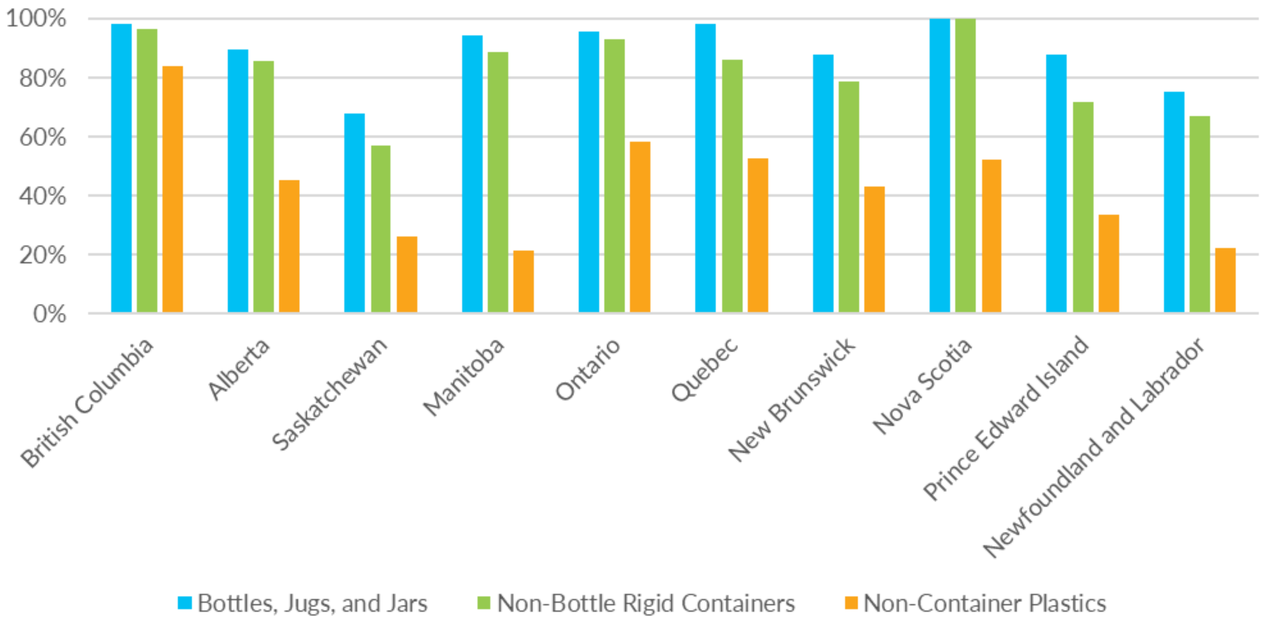
Most curbside recycling programs do not currently accept plastic bags, film, and wrap because they can damage recycling equipment and contaminate bales. Flexible packaging can also be difficult to recycle as it contains layers of different materials, often including paper and aluminum.

The Recycling Partnership has a Film & Flexibles Coalition working to identify solutions for these difficult to recycle materials, as does the Materials Recovery for the Future (MRFF). Both are tackling the lack of available curbside recycling of films and flexibles (The Recycling Partnership, 2021) (MRFF, 2023)., Some companies have found success offering subscription collection services directly to residents to fill the gaps in what the municipal curbside program accepts. For example, the private company Ridwell offers subscription plastic film collection (along with other items like batteries and light bulbs) to residents in Seattle, Portland, Denver, Twin Cities, Austin, and the East Bay area.

Plastics Collected in Canada

Like the US, what plastics are accepted in recycling systems vary regionally. Figure 7 below provides an overview of residential access to recycling programs for different plastic packaging types by province as of 2015 (CM Consulting, 2016).

Figure 7. Percentage of Canadian population with recycling programs available for plastic packaging formats (2015)



Source: (CM Consulting, 2016)

Generally, all types of rigid plastic packaging are accepted in the residential curbside collection system, with some exceptions such as PS or coffee pods. When not accepted in curbside collection, rigid plastic like PS can be accepted at a drop-off center (e.g., British Columbia and Quebec).

Access to recycling for polyethylene film and bags is 93% in British Columbia and 90% in Quebec. Roughly half of Ontario (53%), Nova Scotia (52%), and New Brunswick (47%) can recycle all film and bags. Saskatchewan, Manitoba, and the other Maritime provinces continue to show low rates for this material. While many regions accept retail shopping bags, they do not accept all kinds of flexible film plastics (e.g., PE may be included, but PP may be excluded). Nova Scotia and Prince Edward Island have universal collection of retail shopping bags and all other provinces are over 50%, except for Saskatchewan, Manitoba, and Newfoundland and Labrador.

Collection Costs

Generally, communities incur two types of costs with waste collection programs: capital costs (e.g., vehicles, waste containers, equipment, etc.) and operating and maintenance costs (e.g., labor, leasing, utilities, etc.). Costs of waste collection vary depending on many factors, including:

- Type of collection (drop-off center, curbside single-stream, curbside dual-stream);
- Operational procedures (maintenance, training, fuel cost, etc.);

- Capital investment (carts, buildings, and infrastructure for drop-off centers, etc.);
- In-house collection or subcontracted collection;
- Whether or not profit markup is included;
- Whether or not ICI materials are included, partially or totally;
- Subcontract duration and quantity collected (regrouping or not); and
- Population density.

Single-family residents usually pay for recycling system costs through rates to service providers, either directly or indirectly through costs embedded in garbage rates. Residents of multi-family residents sometimes pay these costs directly through utility fees charged by building managers or indirectly as part of their rent payment.

Some cities in the US and Canada have implemented pay-as-you-throw (PAYT) systems, in which households are charged variable rates based on the volume of waste they set out for collection. PAYT system can be structured so that: (a) residents pay a certain rate based on the number or size of bins they put out for collection; or (b) residents must dispose of their trash in official municipal trash bags or trash bag tags, which they can purchase at local retail stores.

Businesses with access to recycling services generally pay for recycling system costs through rates to service providers, either directly or indirectly through costs embedded in garbage rates. As with multi-family building residents, some businesses that lease their space sometimes pay these costs through utility fees charged by building managers as part of their rent. Commercial recycling system costs have faced similar market dynamics as residential recycling, with declining commodity values driving up net system costs.

Collection Costs in United States

Collection costs vary from state to state as well as city to city. Overall, collection costs averaged US$67/household (HH) and US$277/metric tonne (MT) in the United States in 2022. In urban areas, collection costs averaged US$72/HH and US$283/MT for single-family homes and US$29/HH and US$151/MT for multi-family buildings. For rural single-family households, average costs were higher at US$101/HH and US$396/MT.

Collection Costs in Canada

Collection costs vary significantly from province to province as well as within the provinces themselves. In BC, the average cost of collection is C$46/HH for curbside, C$29/HH for multi-family, and C$427/MT for drop-off services (RecycleBC, 2020). In Ontario, the average cost of collection is C$819/MT and C$76/HH (Resource Productivity & Recovery Authority, 2020). A study of Ontario's dual- and single-stream systems found average collection costs to be lower in the former, at C$67/HH and C$90/HH, respectively. In Quebec, collection costs averaged C$167/MT in 2016 (Eco Enterprise Quebec, 2016). In Nova Scotia, the average collection cost was C$28.71/HH in 2021 (Nova Scotia, 2021).

Contracting

Many jurisdictions arrange for solid waste collection, processing, and disposal services through contracts with private companies. Across the US and Canada, municipally contracted collection services are the most common way recycling services are provided. In the US, almost 80% of municipalities contract with private companies to provide solid waste collection to their residents (Waste Today, 2019). Generally, residents will pay a utility fee to their municipality, are charged within property taxes, or pay directly to the hauler. Some municipalities charge one fee for all services or state that residents are receiving recycling services for free, while others charge for each service.

There are many waste collection companies in the US and Canada, some of which operate regionally and some of which have international operations. The four largest waste haulers by revenue in the US and Canada, as of 2021, are: Waste Management Inc., Republic Services Inc., Waste Connections Inc., and GFL Environmental Inc. These companies are involved in various aspects of waste management and recycling, including collecting, transporting, processing, and disposing of a wide range of waste materials from residential, commercial, and industrial sources. They operate in multiple states and have a significant presence in the waste management industry. The largest 10 haulers in the US and Canada are listed in Table 6.

Table 6. Ten largest municipal solid waste haulers in the US and Canada by revenue (2021)

Company	Annual Revenue (2021)	Employees	Headquarters
Waste Management (WM)	US$14.5 billion	44,900	Houston, Texas
Supplies 21 million customers in the US and Canada. These include commercial, residential, and industrial clients. It currently has 293 landfill sites, 346 transfer stations, 146 recycling facilities, and over 26,000 active trucks in its fleet.			
Republic Services	US$9.4 billion	36,000	Phoenix, Arizona
Provides non-hazardous solid waste collection, waste transfer, waste disposal, recycling, and energy services. It currently has 204 transfer stations, 343 collection operations, 195 active landfills, 90 recycling facilities, and 7 treatment plants.			
Waste Connections	US$4.9 billion	16,000	The Woodlands, Texas
Provides waste collection, transfer, disposal and recycling services, primarily of solid waste. Key services include commercial recycling, yard waste removal, solid waste collection, WEEE and recycling, and dumpster rentals.			
GFL Environmental	US$3.4 billion	14,400	Vaughn, Ontario, Canada
More than 135,000 industrial and commercial customers. Offers liquid and solid waste management and a variety of environmental services. Specializes in the recycling of oil, oil filters, waste solvents, anti-freeze, and other liquid products.			
Recology	US$1.2 billion	3,600	San Francisco, California
Formerly known as Norcal Waste Systems. Focuses on sustainability initiatives and has the biggest organic compost facility in the US. Also owns 40 subsidiaries that help serve the needs of its customers			

Company	Annual Revenue (2021)	Employees	Headquarters
across the US. Was acquired by Republic Services in 2022, therefore this listing will not reflect its current standing.			
Waste Pro USA, Inc.	<US$900 million	4,000	Longwood, Florida
Operates in 10 southeastern states and serves more than two million residential and 40,000 commercial customers from over 80 operating locations. It has a fleet of over 2,900 trucks and maintains approximately 300 exclusive municipal contracts and franchises.			
Casella Waste Systems	US$192 million	2,300	Rutland, Vermont
Provides resource management services to residential, commercial, municipal, and industrial customers, primarily in the areas of solid waste collection and disposal, transfer, recycling, and organics services. It provides integrated solid waste services in seven states: Vermont, New Hampshire, New York, Massachusetts, Connecticut, Maine, and Pennsylvania.			
Rumpke Waste & Recycling Inc.	US$883 million	1,400	Colerain Township, Ohio
Offers residential and commercial waste collection services, with facilities in Ohio, Kentucky, and Indiana.			

Source: (Waste Today, 2021)

Note that this list defines haulers as "those that own their own vehicles to collect waste and transport it for processing." Special waste collectors like Clean Harbors and Covanta Holdings Corporation have been included, though they do not operate residential collection services.

3.1.2 Collection Challenges across the US and Canada

Challenges with Plastic Collection

There are many challenges associated with plastic packaging waste collection. Multi-family residences are often underserved, and rural areas typically have little or no automatic curbside collection or drop-off programs with low participation rates. Moreover, each local jurisdiction decides what materials are acceptable for recycling, which confuses consumers and can increase contamination within recycling streams. The plastics included in collection programs are generally those that have value and can be economically sorted. (The secondary market for different plastics is explored in Section 5.) Contamination is a growing problem with curbside recycling, as it lowers the purity of collected materials and reduces their value on the market. (Section 6 of the study provides greater detail on which types of plastic packaging are problematic and why.)

Best Practices in Plastic Collection

Plastic waste collection rates depend on many local factors, including governance, geography, population density, consumption patterns, and public awareness. Specifically, these factors include:

- Universal access to curbside recycling for both SF and MF households.
- The reduction of solid waste services (e.g., bag or bin limit, reduced frequency of collection).
- Appropriate size and number of recycling collection containers for the collection frequency and the projected volume of recyclables.

- The provision of convenient and consistent options for capturing overflow materials (for example, drop-off centers).
- Well designed, -funded, and -implemented promotion and education programs.
- Consistent enforcement of waste regulation (e.g., contamination, set out times).

3.1.3 Sorting

A MRF separates and prepares recyclable materials for marketing to end-user manufacturers. MRFs generally use a combination of manual (human) sorters and mechanical technologies (such as optical sorters or robots) to sort plastics. The ability to sort a product's waste output depends on its form, material, and rigidity. The different sorting systems' types, technologies, and capacity for dealing with plastic waste in the US and Canada are described below.

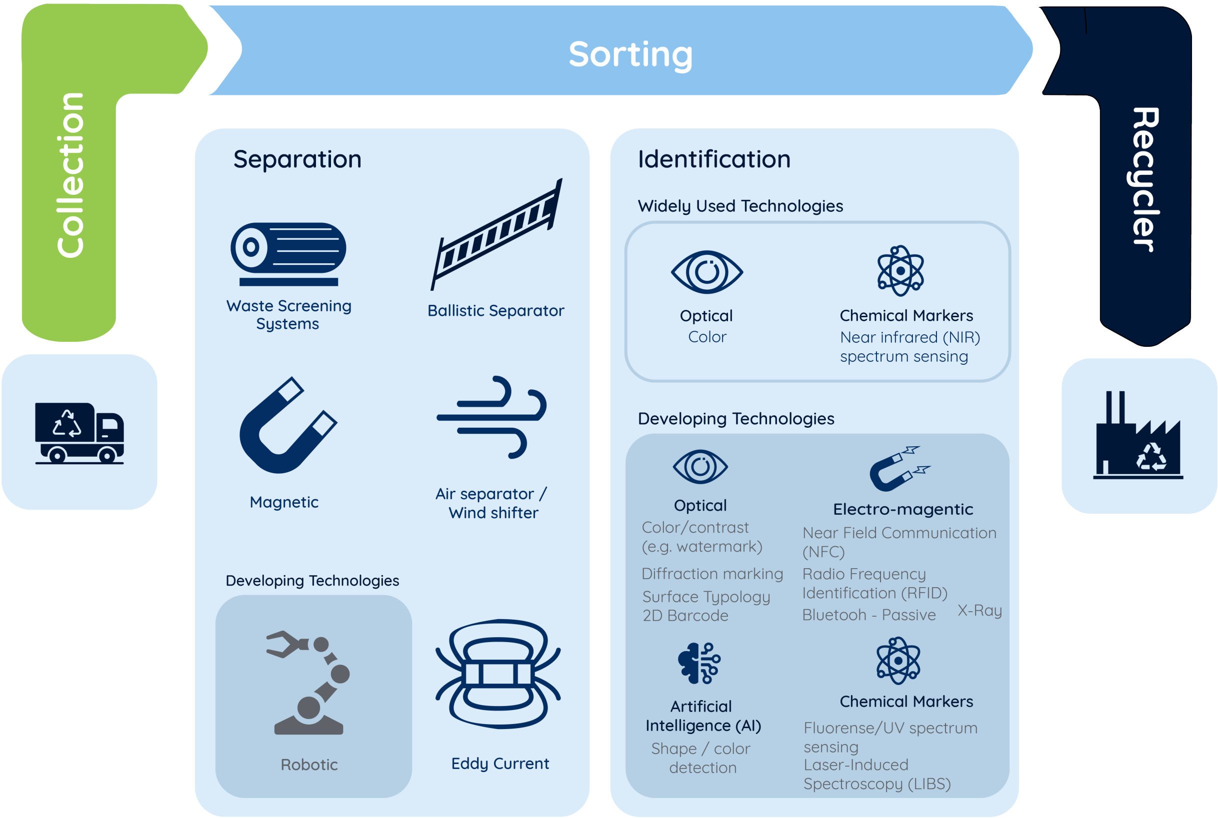
Sorting Process

The sorting system and type of machinery vary for each MRF. Plastic waste is usually sorted through a series of steps, including sorting on size (either manually or via sieves), eliminating foreign materials (like metal and glass), and sorting on plastic materials. The general process generally is described below:

1. At the MRF, trucks unload the commingled recyclables onto the tipping floor. They are placed on a conveyor belt, which distributes the material for inspection and separation.
2. Through the combined work of automated machines and staff, different material types are sorted from the commingled recyclables. These sorting technologies, discussed in more detail below, recognize target items by shape, color, or specific material composition.
3. Once sorted and separated from the commingled recyclables, the various plastic types are transported along conveyor belts to be baled. Bales, such as the recycled polyethylene terephthalate (PET) bales shown at right, are then transported to recycling facilities.

Sorting centers in the US typically must sort their plastics from a single-stream recycling collection. Film is sometimes manually sorted at the beginning of the process, to avoid contaminating the fiber stream, while other times it is separated after metals and fiber with a vacuum, ballistic separator, or wind shifter. Figure 8 below outlines common sorting technologies for plastics.

Figure 8. Sorting technologies used in the plastics sorting process



Sorting Technology

Sorting technology falls into two categories: separation and identification technology. Separation technology is used to physically move different types of material away from each other. By removing certain materials from the plastics stream, sorters can increase the purity of the plastics bales. Identification technology can recognize different material types or their specific qualities, but it generally requires some separation technology to then move the material based on that classification.

The most commonly used technologies are Near Infrared (NIR) sorting and positive sorting. NIR measures the wavelength signature of the plastic to distinguish between the plastic resins (APR, 2018). Its main limitation is the inability to distinguish color, which increases the amount of contamination coming from difficult to recycle opaque resins (APR, 2018). Positive sorting involves recognizing, selecting, and ejecting a target product (and only that product) from the rest of the stream, typically using air chutes. Though it is less automated, negative sorting focuses on removing contamination from the stream and is often used in manual sorting processes. Many traditional MRFs rely on negative sorting, but advanced robotics are often configured for positive sorting.

MRFs are increasingly moving to automated and robotic sorting and away from manual labor. As of 2019, there were approximately 100 robots in use across the US and Canada (Paben, Rapid Adoption, 2019). "This is largely due to labor shortages for sorters, the cost of labor, technology improvements, as well as more MRF operators becoming familiar with the technology and its benefits" (Pyzyk, 2019). Some MRF operators use the machines to plug labor gaps when they have trouble filling manual sorting and picking positions (Pyzyk, 2019). Safety is another frequently mentioned reason to automate MRF sorting lines. Waste streams, conveyors, and processing equipment can create health and safety hazards. However, some aspects of the sorting process will always require human labor. For example, automated systems may not be ideal for presorting because it is difficult to program robots to extract random contaminants like bicycles, fire hoses, or wires (Pyzyk, 2019).

Leading manufacturers of robotic sorting equipment in the US and Canadian market include AMP Robotics, Bulk Handling Systems, Machinex, Waste Robotics, and ZenRobotics (Pyzyk 2019). Technologies are integrated into existing sorting systems both by retrofitting existing facilities and by building afresh. In some cases, technology retrofits can become more costly than starting from scratch with an entirely new system (Pyzyk, 2019).

As mentioned above, various sorting technologies are employed to improve sorting processes and efficiency. Not all are specific to plastics; some target other materials, the removal of which increases the purity of the plastics bales. An overview of separation technologies is given in Table 7 and identification technologies are outlined in Table 8.

Table 7. Plastic waste separation technologies

Technology	Description
Waste screening systems	Screening is the most standard form of separating solid waste, depending on its size, by using one or more screening surfaces such as rotary drum screens or various vibrating screens.
Ballistic separator	A ballistic separator is a mechanical device that consists of two oscillating paddles. These move rigid waste items to one end and flexible items to the other, allowing finer materials to fall through the mesh. The rigid items can be bottles, containers, or cans while the flexibles may be paper, card, newspapers, and films (British Plastics Federation, 2023).
Air separator / Wind shifter	Materials are scattered on a vibration screen on a conveyor. Air blown from nozzles pushes the light materials (e.g., plastic films, paper) forward and heavier materials (e.g., glass, metals) fall and are separated.
Magnetic	A magnet separator removes ferrous materials such as tin, iron, and steel from other materials. Materials can be passed over a tabletop magnetic separator or a suspended magnetic separator will hover over them to remove unwanted material. Magnetic separators can also be cylinders through which objects pass.
Eddy Current	These remove non-ferrous materials such as aluminum and copper from other materials. Non-ferrous materials pass over the shell containing rotating magnets, which creates eddy currents. In turn this creates a magnetic field around the metals, repelling them from the magnet (British Plastics Federation, 2023).
Robotic	Cameras and high-tech computer systems trained to recognize specific objects include the robotic components over conveyor belts to detect and interact with materials they are programmed to capture. Robots are not generally viewed as a replacement for optical sorters, but rather a supplement that can work collaboratively to achieve a higher-quality output. They are often placed on a line after optical sorters to control quality (Pyzyk, 2019).

Table 8. Identification sorting technologies

Technology Type		Description	Examples of Existing Providers	Capable of Mass Sorting
Chemical Markers	Near infrared (NIR) spectrum sensing	NIR is used to sort different polymer types and is the most widely used technology for plastics sorting. It relies on the different reflectivity of polymers and distinguishes between their individual wavelength signatures to separate them.	TOMRA, PellenC, Stardust Secured	Yes
	Fluorescence / ultraviolet (UV) spectrum sensing	Tracer-based sorting uses fluorescent pigments incorporated into the plastic substrate or in the packaging sleeve, which are visible under UV light during the sorting process (Lange, 2021).	Nextloopp, Polymark, ErgisMark	Yes
	Laser-Induced Spectroscopy (LIBS)	The pulsed laser beam focuses on the surface of the sample. A few nanograms of material are evaporated, ionized, and a small plasma spark is created. The radiation of the plasma is captured and processed in the spectrometer. Present atomic emission lines (a kind of chemical fingerprint) provide information about the item's chemical composition (Thomson, 2022).	Steinert	No
Optical	Color	A color sorter can distinguish between colored and colorless PET and HDPE flakes and separate flakes by color. Plastic color separators can be used to separate mixed-color plastics, potentially upgrading bales.	TOMRA, MSS	Yes
	Color / contrast (e.g., watermark)	Digital watermarks—codes integrated into the design of the packaging—can be detected by cameras on high-speed sorting lines.	Digimarc, R-Cycle	Yes
	Surface typology	Embossed systems are detectable by cameras and light. This is a simple and cheap solution to sorting.	Digimarc, Filigrade	Yes
	2D barcode (e.g., QR)	Digital codes, often 2-D barcodes, contain information on the material in the packaging and if/how to recycle the item. Primarily useful for consumers to increase the likelihood of plastic waste going to the right collection system.	Reath, Polytag	No

Technology Type		Description	Examples of Existing Providers	Capable of Mass Sorting
Artificial Intelligence (AI)	Shape / color detection	AI uses deep learning methodologies to detect certain material types. Cameras and high-tech computer systems trained to recognize specific materials will instruct robot arms to target these.	Grey Parrot, AMP, TOMRA	Yes
Electro-magnetic	Radio Frequency Identification (RFID)	Very thin, small RFID chips can be embedded in food grade plastic packaging so that sorters use RFID scanners to locate that valuable material.	PragmaticIC	No
	Near Field Communication (NFC)	Very thin, small NFC chips can be embedded in food grade plastic packaging so that sorters can use NFC scanners to locate that valuable material.	PragmaticIC, Germark	No
	X-ray	X-rays can see through the materials, recognizing different material densities, components containing halogens, and organic components (Magnetic Separations, n.d.). X-ray can be useful when sorting very dirty bottles or containers covered in labels that other technologies, such as NIR, cannot see through.	PellenC	No

Source: (Recycling Inside, 2023)

Material Recovery Facilities (MRFs)

There are over 600 MRFs in North America. Table 9 provides a list of the 10 largest (all located in the US and Canada), ranked according to shipped tonnages in 2020. Additional detail can be found in the Appendix to this Study, which lists the 75 largest MRFs across North America (also all located in the US and Canada). MRFs have varying loss rates depending on factors that are discussed in more detail in Section 3.1.6.

Table 9. The ten largest MRFs in the US and Canada (2020)

#	Plant Operator	MRF Location	Est. Total Tonnage Shipped (2020)
1	Sims Municipal Recycling	Brooklyn, New York, US	230,600
2	GFL Environmental	Toronto, Ontario, Canada	218,850
3	Waste Management Inc.	Hodgkins, Illinois, US	215,445
4	Republic Services	North Las Vegas, Nevada, US	208,000

#	Plant Operator	MRF Location	Est. Total Tonnage Shipped (2020)
5	Waste Management Inc.	Hopkins, Minnesota, US	184,102
6	Waste Management Inc.	Elkridge, Maryland, US	180,183
7	RWS of Southern California (Republic)	Anaheim, California, US	178,000
8	S.W. Authority of Palm Beach County	West Palm Beach, Florida, US	169,400
9	Waste Management Inc.	Pembroke Pines, Florida, US	167,666
10	Rumpke Recycling	Cincinnati, Ohio, US	163,404

Source: (Recycling Today, 2021)

There is limited data available on total sorting capacity in the US and Canada, as the information is decentralized and often withheld by MRF operators. In the US, total MRF capacity for plastic waste was 5,383 tons per day in 2016. On average, an MRF operates 256 days each year, so the estimated annual capacity for US MRFs to sort plastic waste was approximately 1,378,000 tons in 2016 (Eunomia Research & Consulting, 2020).

Table 10. Companies with collection centers and regional collection facilities

Name of Company	Number of collection facilities	Type of plastic waste collected	Type of generation	Capacity (T/year)
Petstar	10	PET	Post-consumer	98,838
Green Mind	NA	PET	Post-consumer	65,000
Morphoplast	65	PET	Post-consumer	25,550
Grupo Alen	5 programs	PET, HDPE, PP	Post-consumer	NA
Alcamare Recycled Polymers	14	PET, HDPE, PP	Post-consumer	170,000
Grupo Simplex	NA	PET	Post-consumer Post industrial	
INNPLAREC	6	PET, HDPE, PP	Post-consumer Post industrial	18,000
LYRBA	2	PET, HDPE, PP, LDPE, PVC, PS, PC	Post-consumer Post industrial	100,000
Glezco ERS del Occidente	5	PP, HDPE, HIPS, LDPE, PET, PVC, ABS, PC	Post-consumer Post industrial	NA
Rennueva	6	PET, HDPE, LDPE, PP, PS	Post-consumer Post industrial	NA

NA: Data Not Available on the websites.

Sources: (Green Mind, n.d.) (Morphoplast, n.d.) (Alcamare, n.d.) (Innplarec, n.d.) (Lyrba, n.d.)

Sorting Revenue

The value of sorted plastics depends on a series of fluctuating factors, such as supply, demand, energy and transport costs, etc. The bale cost also depends largely on the quality of material it contains. Industry organizations, such as the Association of Plastic Recyclers (APR) and the Institute of Scrap Recycling Industries (ISRI), publish guidelines for the recycling market on the acceptable quality of different baled commodities. Additional details on the markets for sorted plastic waste is included in the Secondary Markets section.

3.1.4 Recycling

Physical Recycling

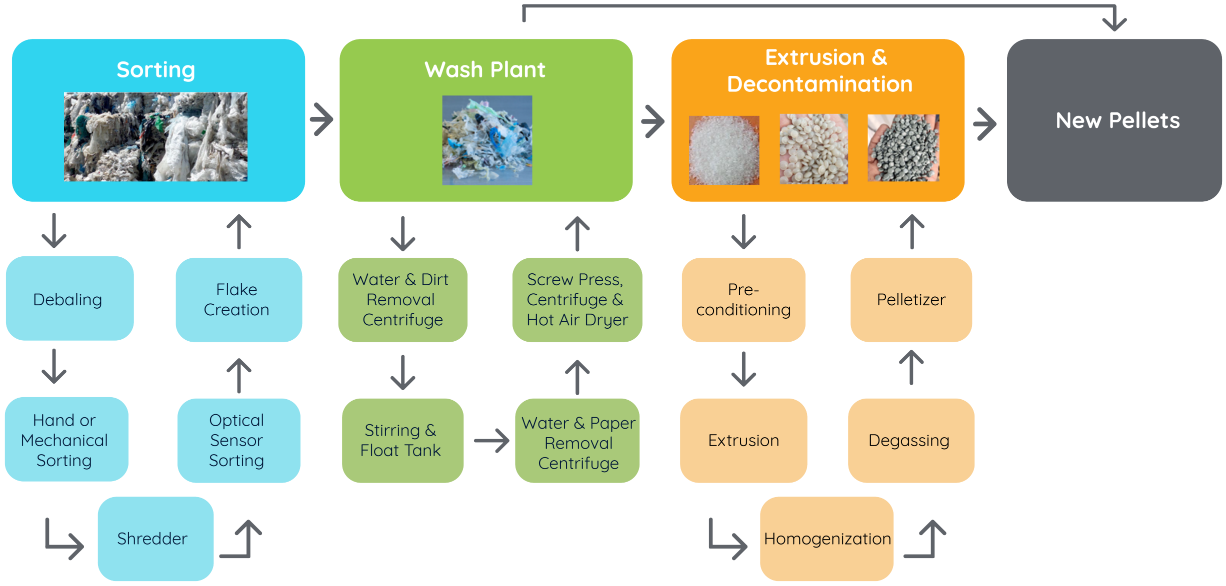
Physical recycling includes mechanical and solvent purification. This is an emerging term that aims to differentiate recycling technologies "whereby plastic waste materials are recycled back into plastics without altering the chemical structure of the materials" as opposed to chemical recycling that produces monomers or oil for further plastic production (Plastics Recyclers Europe, n.d.).

Mechanical Recycling

Currently, plastic waste is processed mainly using mechanical recycling, the process of recovering plastic waste by mechanical processes such as sorting, washing, drying, grinding, re-granulating, and compounding. This process is described below and shown in Figure 9:

1. Resizing: After being sorted, plastics are sized down. Shredders and granulators with industrial blades perform rotational cutting to break plastic into smaller particles. This increases the surface area of the waste so that it is easier to process, reshape, and handle (Berry, 2022). The resized plastic pieces can also be used for other applications without further processing, such as an additive to asphalt, or can be sold as raw material (RTS, 2020).
2. Washing: After sorting and cutting, the plastic pieces are washed to remove traces of dirt and contaminants, which vary from paper and glue to sand and grit. Certain mixed plastic types can also be separated in water.
3. Dry Separation: With dry treatments, plastic is differentiated based on air classification, sorting thinner materials from thicker ones. Apart from size and shape, plastic can also be separated by other features. Heat can be applied to separate materials by melting point, while fluorescent or ultraviolet light helps to divide them according to color or their ability to absorb light (Berry, 2022).
4. Extruding and Compounding: During this stage, machines known as compounding lines or extruders melt plastic regrinds down into pellets. While this can often involve incorporating different additives to transform the plastics into high quality, reusable materials, plastic is most easily distributed and remanufactured in pellet form (Berry, 2022).

Figure 9. Mechanical recycling flow



Currently, mechanical recycling operations mainly focus on recovering rigid packaging (like bottles); its use for flexible packaging and films is less common. Advanced recycling technologies are expanding to increase the range of plastics that are recyclable at scale, as described in the following section.

Purification

This uses the principle of solubility to selectively separate plastic polymers from any other materials contaminating the plastic waste. Once the purification process is complete, the polymer is extracted from the solution and placed in a non-solvent to re-solidify it for recovery. The purification process does not change the polymer on a molecular level.

Chemical Recycling

Chemical recycling (also known as advanced recycling or molecular recycling) is being considered for materials where mechanical recycling is not feasible. Chemical recycling encompasses different technologies that use heat and enzymes to break down plastic waste to create polymers, monomers, oligomers, or hydrocarbon products. As stated above the process of chemical recycling falls into two broad categories:

- Chemical Depolymerization—Processes by which a polymer chain is broken down using chemicals. Once the depolymerization has occurred, the monomers are recovered from the reaction mixture and purified to separate them from contaminants, leaving the pure monomer.
- Thermal Depolymerization—Also known as thermal cracking and thermolysis, this is the process by which a polymer chain is broken down using heat treatment. There are two main approaches to thermal depolymerization, delineated by limited use of oxygen as a reagent within the process. Pyrolysis, also known as thermal cracking, utilizes high temperatures in

the absence of oxygen, while gasification employs low volumes of oxygen to aid the degradation process. This includes variations on the pyrolysis technique. The degradation pathway typically involves scission of bonds at random positions in the polymer chain, as opposed to the controlled breakdown of chemical depolymerization. This means that the resulting pyrolysis oil usually comprises a variety of hydrocarbon products that require further purification before it can be used as a feedstock for polymer production in, for example, a steam cracker. Catalytic microwave depolymerization is essentially pyrolysis using microwaves, followed by the purification of the monomer by distillation. The use of microwave energy to increase both temperature and reaction speed can provide more control to reach higher conversion rates for the polymer.

Chemical recycling is being considered as a supplement to mechanical recycling. Each technology carries certain advantages and challenges, as outlined below:

- Complexity of downstream product integration: Since advanced recycling breaks plastics down to monomers, polymers, and polyolefins, additional processes are needed before they can be made into new plastic products; these are often separate from the chemical recycling facility. Offtakers who will feed the output back into the value chain are essential to ensure that chemical recycling is having its intended impact and leading to a new product of value. The complexity of this additional processing varies by technology and output.
- Virgin-equivalent recycling: Though mechanical recycling allows plastic to be re-manufactured into new products, the plastic is degraded through each subsequent cycle through the recycling stream, leading to changes in color and other characteristics; this can limit its subsequent use. Material is also lost in each cycle and the quantity gradually decreases. Chemical recycling aims to enable the manufacture of products with characteristics that are indistinguishable from virgin plastic.
- Production of food-grade polymers: Certifications by government agencies are needed to qualify packaging materials as safe for food contact. One of advanced recycling proponents' most touted claims is that creating food-grade polymers via chemical recycling is easier than through mechanical recycling; this is a benefit to brands seeking to incorporate recycled content into their packaging material.
- Removal of contaminants and additives: Some plastics are treated with additives to give them certain properties, while others become contaminated with whatever product they contain before entering the recycling process. Chemical recycling can deal with these non-target materials with varying degrees of success.
- Pre-sorting and/or pre-treatment required: To supplement mechanical recycling, chemical recycling can process harder-to-recycle plastics that can be mixed with other materials. The extent to which sorting, or treatment is needed before feedstock enters the chemical recycling process will greatly affect the cost of the system and its ability to deal with more complex waste streams.
- Environmental performance: The process of chemical recycling is entirely different from that of mechanical recycling. Understanding of its environmental impact is still in the early stages. Energy use is the most important aspect, along with yields of recycled material produced from feedstock. The EPA has reported that a single plant in Oregon produced approximately 226 metric tonnes of hazardous waste in 2019, which consisted of benzene, lead, cadmium, and chromium compounds (NRDC, 2022).

- Verification of chemical use and by-products: Advanced recycling processes use potentially hazardous chemicals and create by-products that can be hazardous or environmentally damaging. Understanding the impacts of these materials is crucial to a full cost-benefit analysis of the technology.

Table 11 below compares solvent purification, chemical depolymerization, and thermal depolymerization.

Table 11: Key Advanced Recycling Technology Traits

Technological Claim	Solvent Purification	Chemical Depolymerization	Thermal Depolymerization
Complexity of downstream product integration	Direct — produces polymers	Indirect — produces monomers that require integration into existing virgin value chain	Indirect — polyolefins produce hydrocarbons that require purification before integration into existing virgin value chain. PS can go direct to monomer.
Virgin-equivalent recycling is possible	No — thermal degradation is likely as in mechanical recycling	Yes — however, losses are variable depending upon specific technology	Yes — but not without significant losses in each recycling loop
Food grade polymers can be produced	Not likely	Yes — polymers indistinguishable from virgin	Yes —polymers indistinguishable from virgin
Removal of contaminants/ additives	Limited/specific	Yes — although relatively 'clean' inputs are needed to ensure viability	Yes — this is inherent to the process
Pre-sorting and/or pre-treatment required	Yes — relatively clean, homogenous plastic waste is required to achieve high yields and non-fuel-based outputs. Contamination handling capabilities are not generally well understood or communicated		
Environmental performance	Lack of verified environmental performance data for the majority of technologies		
Verification of chemical use and by-products	Lack of clarity regarding the solvent types and associated hazardousness for larger scale technologies	Lack of transparency regarding inputs/by-products and their potential	Lack of clarity as to the recycling of by-products and reagents as part of the process

Source: Eunomia Research & Consulting, 2020, "Chemical Recycling: State of Play."

While chemical recycling is marketed as having the capacity to handle more contaminated feedstock than mechanical recycling, each technology and operator will have a feedstock specification that is required to ensure optimal operation and to reduce the need for any sorting at the facility. While technologies like pyrolysis, a type of conversion, can take a mix of PE and PP, they have specific requirements in terms of the contaminants they can accommodate (such as polyvinylchloride (PVC), ethylene vinyl alcohol (EVOH), and PET). Such technologies thus cannot handle some types of plastics, such as bales of #3-#7 post-consumer plastics, especially if they are used to produce outputs for creating new plastics.

There are limited numbers of these technologies currently operating at scale despite the interest and investment in the sector, which is mainly driven by legislative and producer demand for recycled content. Some NGOs consider this greenwashing, in part because—despite various announcements—very few commercial-scale facilities are contributing to circularity. NGOs are concerned about the classification of fuel-producing advanced recyclers as recycling facilities; they are also concerned when the outputs, which may in part be fuel, contribute to recovery or recycling targets, even if these fuels may be displacing virgin equivalents. Robust cost benefit analyses of the environmental impacts of chemical recycling facilities have not yet been conducted. Early analysis of the economic viability of chemical recycling at scale has yielded negative results.

While these technologies are often marketed as closed loop recycling, there are in fact many products from these processes and there is extensive discussion both in the US and Canada and Europe on how to measure recycling rates when chemical recycling technologies are part of the process to ensure that products such as fuels are not included in recycling rate calculations.

Section 6 of this study provides more detail on difficult to recycle plastics and what technologies and design strategies might improve their recyclability. Section 8.3.3 gives an overview of the mass-balance discussion currently taking place.

In summary, collaboration between physical (primarily mechanical) recyclers and chemical recyclers is useful to increase plastics recycling and develop more circular and collaborative plastic supply chains. Working in tandem, these physical and chemical recyclers can recover a wider range of plastic waste and produce an expanded range of plastics and products that can be directed to the most appropriate market.

Capacity of Existing Facilities

Across the US and Canada, a large number of mechanical recycling facilities specialize in processing certain plastic types. This section outlines the capacity and distribution of commercial-scale plastic recyclers across the US and Canada.

United States

The largest physical recyclers of plastic waste in the United States are listed in Table 12. Among these, mechanical recycling plants are the overwhelming majority. The average capacity of a mechanical recycling plant is approximately 80,000 tonnes per year (Recycling Magazine, 2022). The overall mechanical recycling capacity in the United States has been reported at approximately 3 million to 6.7 million tonnes per year (ICIS, 2021) (Circularity in Action, 2020). As shown in the table, Proctor and Gamble is the only company with solvent purification technology operating at comparable scale to mechanical recyclers (Purecycle Tech).

Table 12. Largest physical recycling facilities in the US by capacity

Processor Name	Location	Plastic Types Processed	Capacity (MT/year)
Trex	Winchester, VA. Fernley, Nevada.	Film	170,000
KW	Troy, AL Bakersfield, CA	HDPE natural PP Tubs, Lids and Bottles HDPE Pigmented (colored) PP Bulky Rigids HDPE Bulk Rigid PP Battery Chips	113,000 of HDPE 113,000 of PP
Avangard Innovative	Houston, TX Waller, TX	PE film	54,000
EFS Plastics	Listowel, Ontario. Hazelton PA.	PE film, HDPE, PP, Mixed #3-7	50,000
EFS Plastics	Hazelton, PA	Mixed Plastics [#3-7] PE Film (store takeback and curbside) #2, #4, #5 Tubs and Lids #5 PP rigids #2 HDPE Bottles	30,000-50,000
Republic	Las Vegas, Nevada	PET focus initially	50,000
Proctor and Gamble (Purecycle Tech)	Ironton, OH	Polypropylene – Solvent Purification	45,000
PreZero	Jarupa Valley, CA Westminster, SC	Grades A & B LDPE/low linear density PE (LLDPE) film Mixed Plastics 3-7	36,000
Merlin	Turlock, CA	PET	27,000
Northwest Polymers	Molalla, Oregon	ABS, HDPE, LDPE, LLDPE, medium density PE (MDPE), PC, PP, PS, PVC, thermoplastic elastomers (TPE)	20,000
Circulus	Riverbank, CA	LDPE film	18,000
Buckeye Polymers	Sebring, Ohio	PP	15,000
Petosky Plastics	Hartford City, Indiana	PE Film	15,000

Processor Name	Location	Plastic Types Processed	Capacity (MT/year)
Clean Tech Incorporated	Dundee, Michigan	PET, HDPE	3 billion bottles per year
Nuvida Plastic Technology, Inc	Monmouth Junction, NJ	HDPE, PP, PET	600 million containers
Adams Plastic LP	Rolling Meadows, Illinois	ABS, LDPE, PA, PC, PET, PP, PS, PVC	Unknown
B&B Plastics Inc.	Rialto, CA	Acrylonitrile butadiene styrene (ABS), HDPE, high impact PS (HIPS), LDPE, polyamide (PA), polycarbonate (PC), PET, PP, PVC, Styrene-acrylonitrile resin (SAN)	Unknown
CANUSA Hershman	St. Albans Vermont. Wellford, SC.	Mixed #3-7	Unknown
Custom Polymers	Charlotte, NC	PE, PET, PP	Unknown
Denton Plastics	Portland, Oregon	HDPE, LDPE, PP, PS, other plastic and commercial PE film	Unknown
Jamplast, Inc.	Ellisville, MO	Industrial waste plastics	Unknown
Plastic Materials Inc.	Macedonia, Ohio	ABS, HDPE, LDPE, PA, PC, PP, PS, PVC	Unknown
Revolution	Salinas, CA Terre Haute, IN Mesquite, TX	Agricultural, industrial and post-consumer film	Unknown
TKO Polymers	Atlanta, GA	Film	Unknown
Vancouver Plastics	Vancouver, Washington	Plastic Film	Unknown

Source: Eunomia Research & Consulting

The largest chemical recyclers in the United States are listed in Table 13. Despite strong investments and efforts in research and development, chemical recycling remains in its infancy globally and most of the facilities are not at a commercial stage.

Table 13. Largest chemical recycling facilities in the US

Processor Name	Location	Plastic Types Processed	Technologies	Capacity (MT/Year)	Development Stage
Brightmark Energy	Ashley, IN	Mixed plastics	Thermal depolymerization	100,000/ Fuel	In commissioning

Processor Name	Location	Plastic Types Processed	Technologies	Capacity (MT/Year)	Development Stage
			(Pyrolysis)		
Eastman (Polyester Renewal Technology)	Kingsport, TN	Mixed plastics	Chemical depolymerization	100,000	Not known
Alterra Energy (formerly Vadxx)	Akron, OH	Mixed plastics	Pyrolysis	19,800/ Fuel	Not known
Nexus	Atlanta, GA	Mixed plastics	Thermal depolymerization (Pyrolysis)	16,500/ Fuel	Not known
Aquafil (ECONYL)	Phoenix, Arizona	Nylon Textiles (carpet, fishing nets, fabric scraps)	Chemical depolymerization	12,500	Not yet operating at scale

Source: Eunomia Research & Consulting

Canada

The largest mechanical recyclers for residential post-consumer plastics in Canada are presented in Table 14. It is difficult to assess these recyclers' sources and the percentages sourced from pre- and post-consumer waste, as this varies significantly.

Table 14. Largest physical recycling facilities in Canada

Recycler	Location	Plastic type processed	Technologies	Capacity (MT/Year)
Merlin Plastic, BC	Delta, BC	#2, #4, #5	Unknown except usual mechanical recycling equipment	Unknown
Merlin Plastic, AB	Calgary, AB	#1	Unknown	Unknown
Fraser Plastics, BC	Maple Ridge, BC	#2	Unknown	Unknown
EFS-Plastics	Lethbridge, AB	#2, #4, #5	Unknown except usual mechanical recycling equipment	10,000 (Heffernan 2022)
EFS-Plastics	Listowel, ON	#2, #4, #5	Unknown except usual mechanical recycling equipment	20,000 (Staub 2019)
ReVital Polymers	Sarnia, ON	#2, #4, #5	Sorting line with optical sorters	Unknown

Recycler	Location	Plastic type processed	Technologies	Capacity (MT/Year)
			Recycling line: unknown except usual mechanical recycling equipment	
Blue Mountain Plastics	Shelburne, ON	#1	Unknown	Unknown
Plastrec	Joliette, QC	#1	Optical and mechanical sortation Usual mechanical recycling equipment, and Solid State Polycondensation	Unknown
Soleno	Yamachiche, QC	#2	Unknown except usual mechanical recycling equipment	Unknown
RPM Eco	Blainville, QC	#2, #4, #5	Usual mechanical recycling equipment Specific water treatment process (primary, secondary and tertiary)[6]	Unknown
Plastimum	Sherbrooke, QC	#2, #4, #5, #6	Unknown	Unknown
Evergreen	Amherst, NS	#1	Sorting line with optical sortation equipment Recycling line: unknown	Unknown
Polystyvert	Montréal, QC	PS	Purification	Pilot scale plant in progress

Source: Eunomia Research & Consulting

Despite strong investments and efforts in research and development, chemical recycling remains in its infancy globally and most of the facilities are not at a commercial stage. The table below presents the list of the most developed technologies and facilities. Note that Waste-to-Energy or Plastic-to-

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[6] The company process materials from Cleanfarms and EPR for hazardous type products such as used oil, therefore require a specific water treatment process.

fuels facilities (e.g., Enerkem, Edmonton, AB; Sustane Technologies, Chester, NS) are not recognized as recycling by many Canadian jurisdictions.

Table 15. Largest chemical recycling facilities in Canada

Recycling Technology/ Facility	Location	Processed Plastic Types	Recycling Technology	Stage of Development
Nova Chemicals/ Enerkem	Edmonton, AB	PE (#2, #4)	Thermal depolymerization (Pyrolysis)	Pilot scale reactor (NOVA Chemicals Corporation 2022)
GreenMantra Technologies	Brantford, ON	PE, PP, PS	Thermal depolymerization (Pyrolysis)	Commercial facility in operation
Imperial	Sarnia, ON	PE, PP	Thermal depolymerization (Pyrolysis)	Commercial facility in operation at parent company (Exxon Mobil, Baytown TX)
Loop Industries	Terrebonne, QC	PET	Depolymerization	Pilot scale plant
Pyrowave	Valleyfield, QC	PS	Depolymerization	Pilot scale plant

Source: Eunomia Research & Consulting

3.1.5 Sorting and Yield Losses

Material loss can occur at the MRF as well as at the processor, and loss rates vary for different packaging materials. Eunomia's 2021 report, *The 50 States of Recycling*, found that these yield loss rates range from 3 percent to more than 20 percent across packaging types. Sorting losses for plastic packaging have been reported as low as 2% and as high as 35%. At MRFs, sorting losses occur when sorting equipment or manual pickers miss material or when collected material is not of sufficient quality to be marketed (e.g., if it is too highly contaminated).

Sorting equipment can miss material due to:

- Issues related to packaging design (e.g., black plastics cannot be detected by optical sorters).
- Packaging size (e.g., material can be too small to be detected and is left in the residual stream).
- Residues of the product on the packaging preventing it from being correctly separated. Residue rates for some packaging types, like yogurt cups, are likely to be greater than for others such as beverage containers.
- Non-target material impacting the shape of a container—for example, it may flatten 3-D items, reducing the ability of the MRF equipment to effectively recognize and separate it into the correct stream.

Sorting losses differ by facility and depend on its scale of operation and process design, the degree to which the MRF is operating effectively (within design parameters, with well-maintained sorting equipment, and sorting speeds), and the fluctuation in prices for different grades of sorted material. Processing losses can also be due to moisture, dirt, labels, coatings, caps, and glues.

One 2015 study tested five MRFs in the US, one processing dual-stream recycling and four processing single-stream, to determine their loss rates by material type (RRS 2015). The average loss rates for MRFs by plastic type are shown in Table 16.

Table 16. Average MRF loss rates by plastic category

Plastic Category	MRF Loss Rates
PET Bottles	13.3%
PET other rigid	47.4%
HDPE Bottles	21.1%
PP	35.1%
Rigids #3-7	35.1%

Source: (RRS 2015)

3.1.6 Recycling Claims and Standards

Recycling and Recycled Content Targets Set by Private Companies

Brands and retailers globally have made public commitments to (1) increase the recyclability of their products and packaging and (2) increase the volume of recycled plastic content in their products and packaging in the coming years. Two of the largest public commitments are made under the US Plastics Pact and the Ellen Macarthur Foundation's (EMF) Global Commitment.

Brands that commit to the US Plastics Pact have pledged to make all plastic packaging 100% reusable, recyclable, or compostable; to recycle or compost 50% of plastic packaging; and to use an average of 30% recycled content in all packaging by 2025 (U.S. Plastics Pact n.d.). Similarly, the EMF Global Commitment includes the following aims:

- Ensure 100% of plastic packaging is reusable, recyclable, or compostable;
- Increase the share of post-consumer recycled content target across all plastic packaging used;
- Decrease the use of virgin plastic in packaging;
- Take action to move from single-use towards reuse models where relevant; and
- Eliminate problematic or unnecessary plastic packaging (Ellen MacArthur Foundation n.d.).

Though voluntary, commitments to use recycled content in plastics help fuel growth within the plastics recycling industry to meet the increasing demand for recycled plastic.

Verification of Recycling Claims

Recycled content standards vary, but their primary purpose in general is to trace and verify recycled content. This can be done through a supply chain or within a facility through document review and in some cases, site audits. Standards also aim to ensure that process is transparent and credible. To ensure consistency, traceability, transparency, and accurate accounting, recycled content standards specify the chain of custody requirements and allowances from the point that the plastic becomes waste to the point that it is fed back into the manufacture of a new product (Eunomia Research & Consulting, 2021).

The Bureau de Normalisation du Québec (BNQ) is in the final stages of developing a recycled content standard BNQ 3840-100 (Alberta Plastics Recycling Association 2022). The draft standard sets out an equation for calculating recycled content, evaluation, and claim verification and how the different chain of custody models can be used. In January 2023, the BNQ launched a public consultation period on the draft standard.

The mass balance approach establishes a set of rules for how to allocate the recycled content to different products to be able to claim and market the content as “recycled.” There are several methods for allocation, each of which impacts the end recycled content claim and is therefore an important consideration. Section 8.3.3 provides more information on mass balance.

Commitments to increase recycled content are currently being met through mechanical recycling processes. However, stricter requirements to include high percentages of recycled content in different goods in the future are likely to increase demand for recycled material through chemical recycling processes. Some factors that are increasing the use of standards and certification programs include:

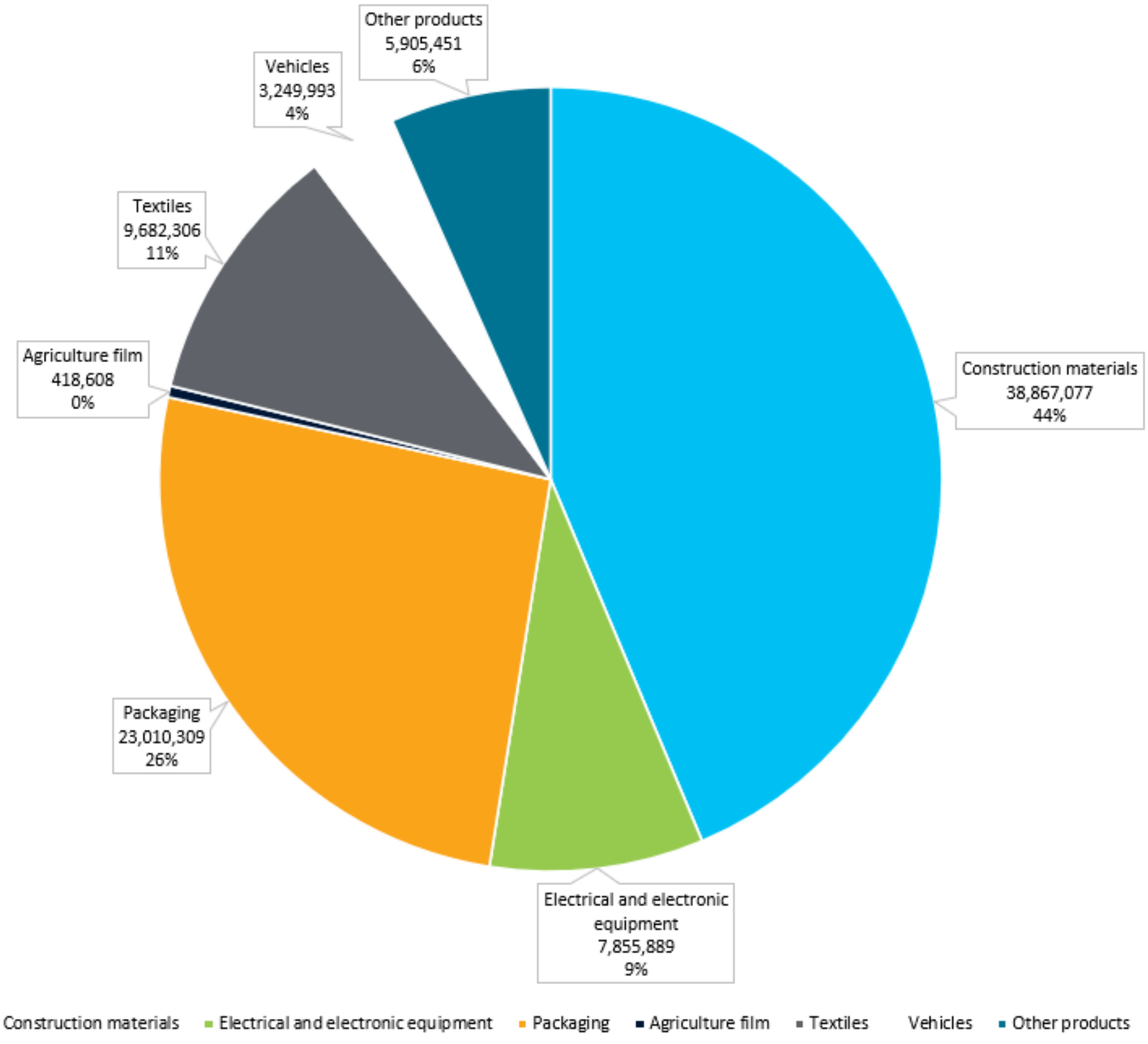
- Legislation: Minimum recycled content mandates are driving the demand for certification in this area.
- Customer requirements: Business-to-business (B2B) companies are more likely to be certified than business-to-consumer (B2C) companies that rely on supplier attestations.
- Corporate values: Use of recycled content in products, and therefore certification, is being driven by demonstrating achievement of publicly stated corporate environmental, social, and governance commitments (Eunomia Research & Consulting, 2021).

Some of the major recycling certification standards related to plastics and used in the US and Canada are summarized in the Appendix.

3.2 Non-Packaging Plastics Market Overview

Packaging is the second largest use market for plastics, with three quarters of the plastic put into use in 2018 going into other markets, as shown in Figure 10 for Canada and the US.

Figure 10. End-use markets for plastics



Source: Eunomia Research & Consulting, 2023

These different applications of plastics result in many different plastic products, some with short lifetimes (disposable service ware, trash bags, diapers), medium lifetimes (clothing, tools, electronics, furniture, small appliances), and long lifetimes (large appliances, automobiles, buildings) (Heller et al., 2020). This means that materials retired from long-lifetime products were designed and manufactured potentially 50 years ago or more, and some material and product innovations will not appear in the disposal stream until many years hence (Heller et al., 2020). For example, the construction sector is an important end-use market (accounting for 26% of plastic put on the market). However, it is not yet a large plastic waste generator (5%), given that plastics have relatively recently started to be used in construction and so are still embedded in buildings (ECCC, 2019). In the future, as buildings are demolished and remodeled, we can expect to see a growing percentage of plastic in that waste stream.

The types of plastics, their use, and their ability to be collected, sorted, and recycled vary between industries as well. This section of the study provides an overview of the collection, sorting, and recycling infrastructure for common plastic applications other than packaging. As data for plastics used in sectors other than packaging is generally less available, the following sections are not divided by country, but grouped together. Additionally, non-packaging plastics, in general, follow similar value chains across the US and Canada.

3.2.1 Construction & Demolition (C&D)

Construction and demolition (C&D) waste includes discarded building materials, packaging and rubble generated during building and structure construction, renovation, and demolition. In Canada, C&D waste represents as much as one third of municipal waste streams according to Public Works and Government Services Canada (PWGSC).

Several C&D waste composition studies have found roughly 1% (equivalent to 5.4 million tonnes) of C&D waste to be plastic (Napier, 2016) (Cascadia Consulting Group, 2006) (Minnesota Pollution Control Agency, 2020) (Green Seal Environmental Inc. n.d.) (DSWA, 2016). There are relatively limited data on the composition of C&D wastes, but regional jurisdictions and municipalities have developed standards to classify the various waste types within C&D.

Modern building methods are increasingly using plastics so it is likely the percentage of plastic in future C&D waste will increase (Statistics Canada, 2023). This increased use is largely in the form of PVC and HDPE used for piping, house wraps and siding, trim and window framing, flooring, and plastic-wood composites, as well as rigid polyurethane (PUR) used primarily as insulation.

Increasing in popularity is a new approach called “adaptive reuse”. This refers to repurposing existing buildings and structures for a new use such as updating historical landmarks for commercial businesses (MasterClass, 2021). In the age of urbanization and infrastructure growth, this is a way to reduce the materials being purchased and disposed of. Additionally, it offers more economical ways of developing structures while still introducing labor to the economy and increasing the circularity of the industry.

End of Life Management

Estimates indicate that of the building materials waste generated, 10–15% become waste during construction; the remaining 85–90% becomes waste when that part of the building is demolished (Zero Waste Design, n.d.). Of C&D waste collected in the US, there is an estimated 70% that goes to sorting centers with the remaining 30% going directly to landfill, often to be used as alternate daily cover (NEWMOA, 2006) (Franklin Associates, 1998). Based on the Pilot Physical Flow Account, by Statistics Canada, roughly 16.7% of the collected C&D waste will be diverted (Statistics Canada, 2023).

C&D waste sorting facilities receive debris generated from construction, remodeling, repair, or demolition of structures, buildings and roads, and land clearing. This includes waste materials such as concrete, brick, soil, wood, wallboard, tile, roofing shingles, and asphalt pavement. A C&D waste sorting facility might store these wastes, process them to extract recyclable or reusable materials, store recovered materials, or carry on any combination or all of these activities.

There are an estimated 3,500 operating facilities that process C&D debris materials in the United States according to the trade journal, C&D Recycling. Of waste sent to sorting centers, a 2016 study on C&D debris management indicated that only 3% of plastics were recovered (DSM Environmental Services, 2017).

Some recovered C&D material can be reused. Organizations recover a wide range of materials from C&D, such as windows, doors, and shingles, which are often made of metals, wood, and asphalt, but often contain plastics in some form. Unwanted and underused goods are then redistributed through local organizations for reuse. Increasing numbers of manufacturers are offering takeback programs for their products, such as carpet, and ceiling tile.

Separation and recovery of plastics specifically within C&D materials at end of life is challenging as building demolition typically produces mixed waste with low fractions of plastics. Further, C&D waste is often contaminated—with paint, adhesives, or fasteners—and potentially toxic (Zero Waste Design n.d.). In general, challenges include:

- Lack of outlets for the recovery of certain materials;
- Complex transport of materials to appropriate sorting or recovery centers due to large size, weight, or other constraints;
- Space constraints on site to sort at the source;
- Higher management costs for some kind of materials; and
- Materials sometimes mixed, causing higher risk of contamination.

3.2.2 Automotive Sector

Marin C Heller, et al. estimated that the North American automotive sector used over 4% of generated plastics in the production of new automobiles in 2017 (Heller et al 2020). As estimated in Section 4, in 2020 the automotives sector occupied roughly 3% of the generated plastics. Plastics in automobiles have increased over the past decade, representing an estimated 9–14% of the material weight of light vehicles (Heller et al., 2020) (European Commission, 2018). This growth has been due primarily to lightweighting efforts and new applications of engineering resins (Heller et al., 2020). At the same time, the newest cars on the market are entering the next era of automotive technology, with electrification as a key development in the industry (Statista, 2023). As the number of electric vehicles (EVs) increases, it will have an impact on the automobile recycling industry since EVs have fewer parts than internal combustion engine (ICE) vehicles. Additionally, there is an increasing use of plastics within EV batteries themselves, due to their relatively lower cost and lighter weight to metallic components (Geiselman, Plastics trim EV batteries' weight, boost safety, 2022).

End of Life Management

Most cars are sold on the secondhand market before being dismantled for recyclable or reusable parts. In fact, the North American used car market is almost 2.5 times larger than the new car market (Frost & Sullivan, 2016).

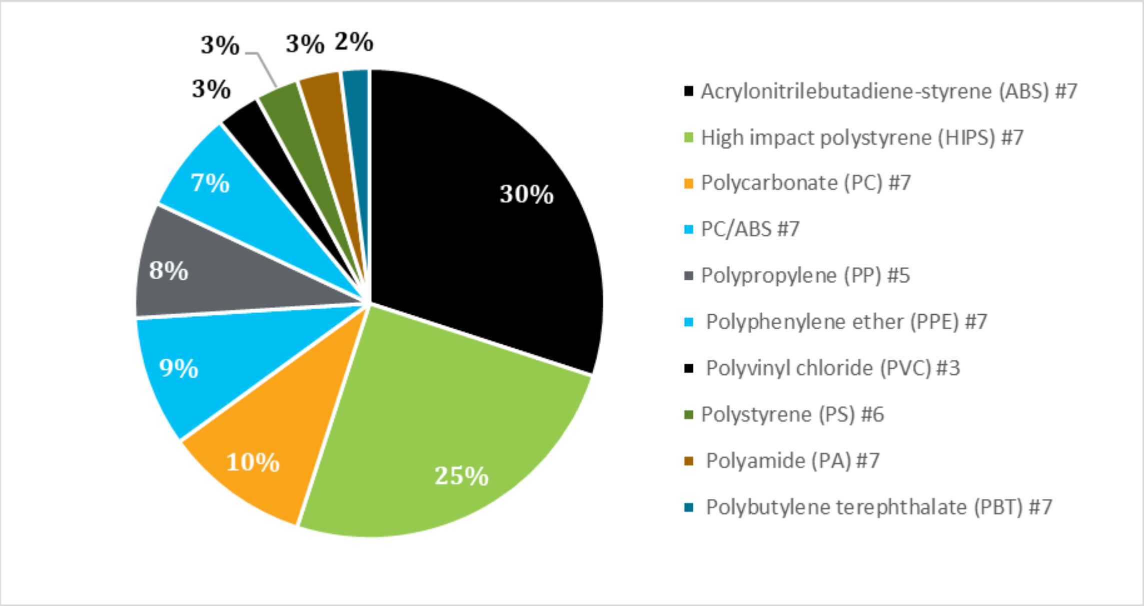
It is usually more cost-effective and less labor-intensive to crush and shred vehicles or appliances for metal recycling than to dismantle parts, including plastic parts. Over 95% of End-of-Life vehicles in the US are recycled for their metals content, but it is not yet economically efficient to dismantle and recycle the plastic parts of vehicles in most cases. When end-of-life vehicles are recycled by shredding via shredder plants, there is a large amount of residue left over. Referred to as automotive shredder residue (ASR), it contains mostly non-metallic materials like plastics, rubber, wood, paper, textile, leather, or glass.

The majority of automotive plastics currently end up in ASR as small pieces mixed with other materials (Heller et al., 2020). Separation and recovery of plastics in ASR is challenging: 39 different types of basic plastics and polymers are commonly used to make cars today, and state-of-the-art separation technologies are very capital intensive. In the automotive sector, the absence of end markets for the plastic contained in cars, which are often blends or potentially contaminated by automotive fluids and additives, reduces the incentives for recyclers to explore this avenue (ECCC 2019). Recycling of non-metallic residues from ASR has been limited historically due to the presence of polychlorinated biphenyls (PCBs) and other toxic substances, such as mercury, lead, cadmium, chromium, arsenic and polyvinyl chloride (Keller n.d.).

3.2.3 Electronics

Waste Electrical and Electronic Equipment (WEEE), also known as electronic waste (e-waste), includes a wide range of products, such as appliances, computers, televisions, phones, lighting, electronic tools, and much more. Plastics content in WEEE is estimated at 20% to 33% which varies depending on the type of electronic item (Heller et al 2020). For example, plastics contribute around 38% to total material usage in smartphones, of which the most common is PC (Singh, Characterizing the Materials Composition and Recovery Potential from Waste Mobile Phones: A Comparative Evaluation of Cellular and Smart Phones, 2018). The composition of plastics within WEEE can vary, but typical breakdown of plastics in electronics is depicted in Figure 11.

Figure 11. Typical composition of plastics within WEEE



Source: (Heller et al., 2020)

End of Life Management

There are several steps involved in the recovery of plastics from WEEE.

1. WEEE is collected separately from residual waste and sent to a WEEE treatment plant where some manual disassembly occurs, for plastics, generally the larger, higher-value components.
2. The WEEE then may be processed by a shredder.
3. The recovered mixed plastic fraction from the shredder can then be sent to thermal energy recovery or a plastics recycler.
4. The plastics recycler processes the waste to produce a secondary raw material.

The heterogeneous combination of plastic types along with the variation in fastener styles, paints, and molded-in metal parts makes WEEE recycling difficult. In addition, mechanical recycling of WEEE is often complicated by the presence of toxic halogenated flame retardants, which may form carcinogenic substances such as polybrominated-dibenzo-dioxins/furans during treatment (Yang 2013). The recycling of plastic containing brominated flame retardants (BFR) represents a major challenge for WEEE recycling because of the costs related to the separation of plastic containing polybrominated-diphenyl-ethers (PBDEs) and polybrominated-biphenyls (PBBs) from other plastic. Recycled plastic with PBDE and PBB content higher than 0.1% cannot be used for manufacturing of any products, including electrical and electronic equipment (EEE) (Forti, 2020). As such, much of WEEE is either landfilled or exported to Asia, although the number of countries still willing to accept shredded mixed plastic waste from EEE waste recyclers is decreasing.

It is important to note that, depending on the condition of the product, some WEEE can be refurbished or reused, thus extending the product's lifetime and avoiding landfill. Many electronics brands, distributors, and repair companies have trade-in programs to facilitate the resale of secondhand electronics.

4 Material Flows and Performance

This section focuses on the material flows of plastic in the US and Canada. The section is organized by plastic application type, as follows, and includes information on each country's material flows:

- Plastic Packaging
- Electronic Plastic
- End of Life Vehicles
- Construction & Demolition Plastics

The final section, Section 5.5, focuses on the trade of plastics, as a significant proportion of plastic waste is traded internationally.

The Sankey diagrams below illustrate the material waste flows that have been modelled for the US and Canada based on primary and secondary research conducted for this study. The waste flows begin when plastic waste is generated then move through the following nodes: (1) collection method; (2) sorting method; (3) processing; and (4) whether the waste has been recycled.

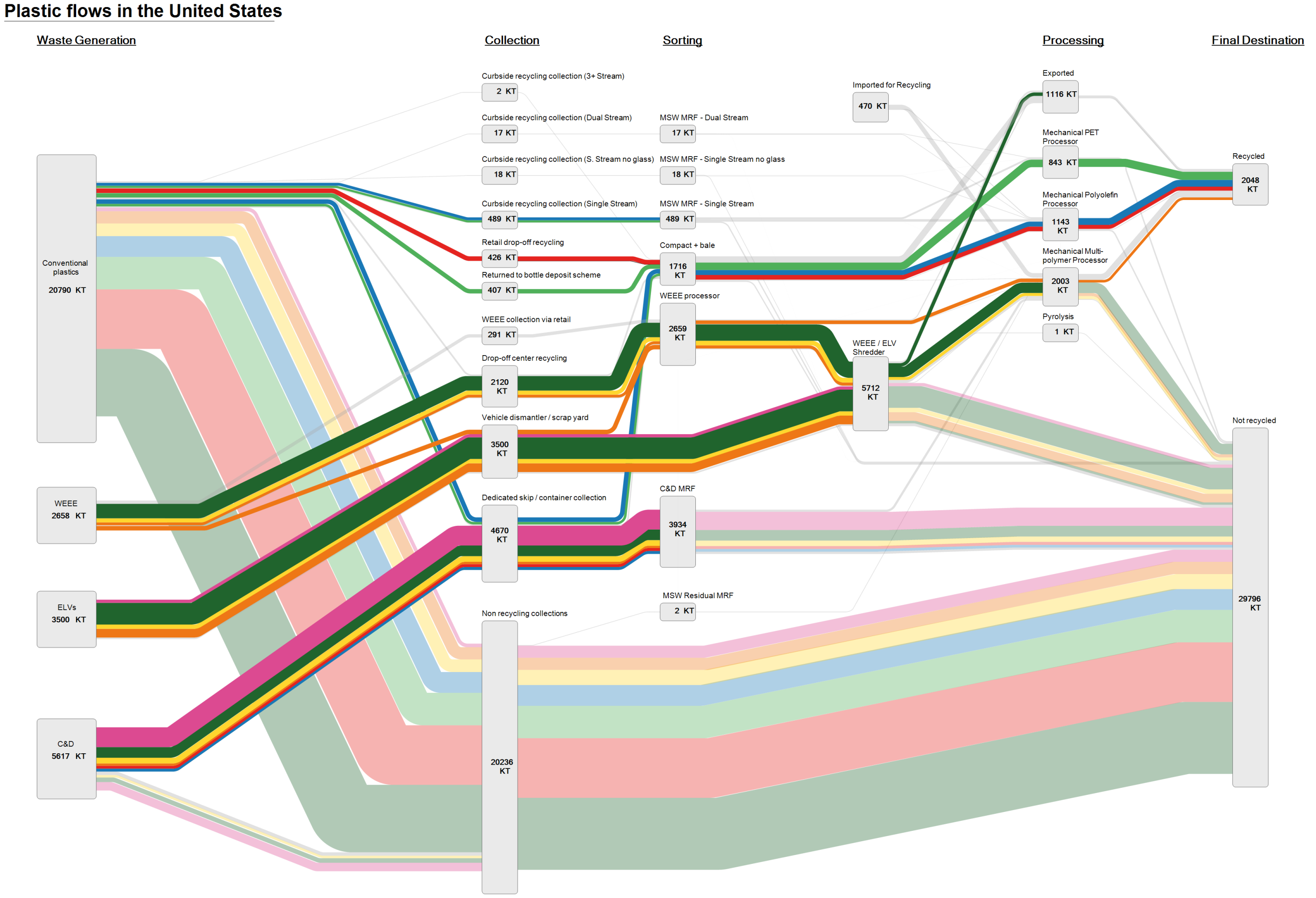
For the following end-use industries:

- Plastic packaging (conventional plastics)
- Waste from electrical and electronic equipment (WEEE)
- End of life vehicles (ELVs)
- Construction and demolition (C&D)

These Sankey diagrams include the flow of plastic waste as trade, entering and leaving each country. For the US and Canada, it was assumed that plastic being imported would likely go to a processer due to the cost of transporting this material across borders, as opposed to being landfilled. Consequently, in the diagrams these nodes have been called "Imported for Recycling." However, there is no way to track whether the material exported would go to a processor or be landfilled so this material has been labeled "Exported."

Plastic resin types have been distinguished throughout the diagram by color to aid in tracking where infrastructure is present for the material types. Where the tonnage of material moving through nodes is considerably lower than other sections of the Sankey, these resins have been combined into a "Multiple Resins" category to maintain visibility of all flows.

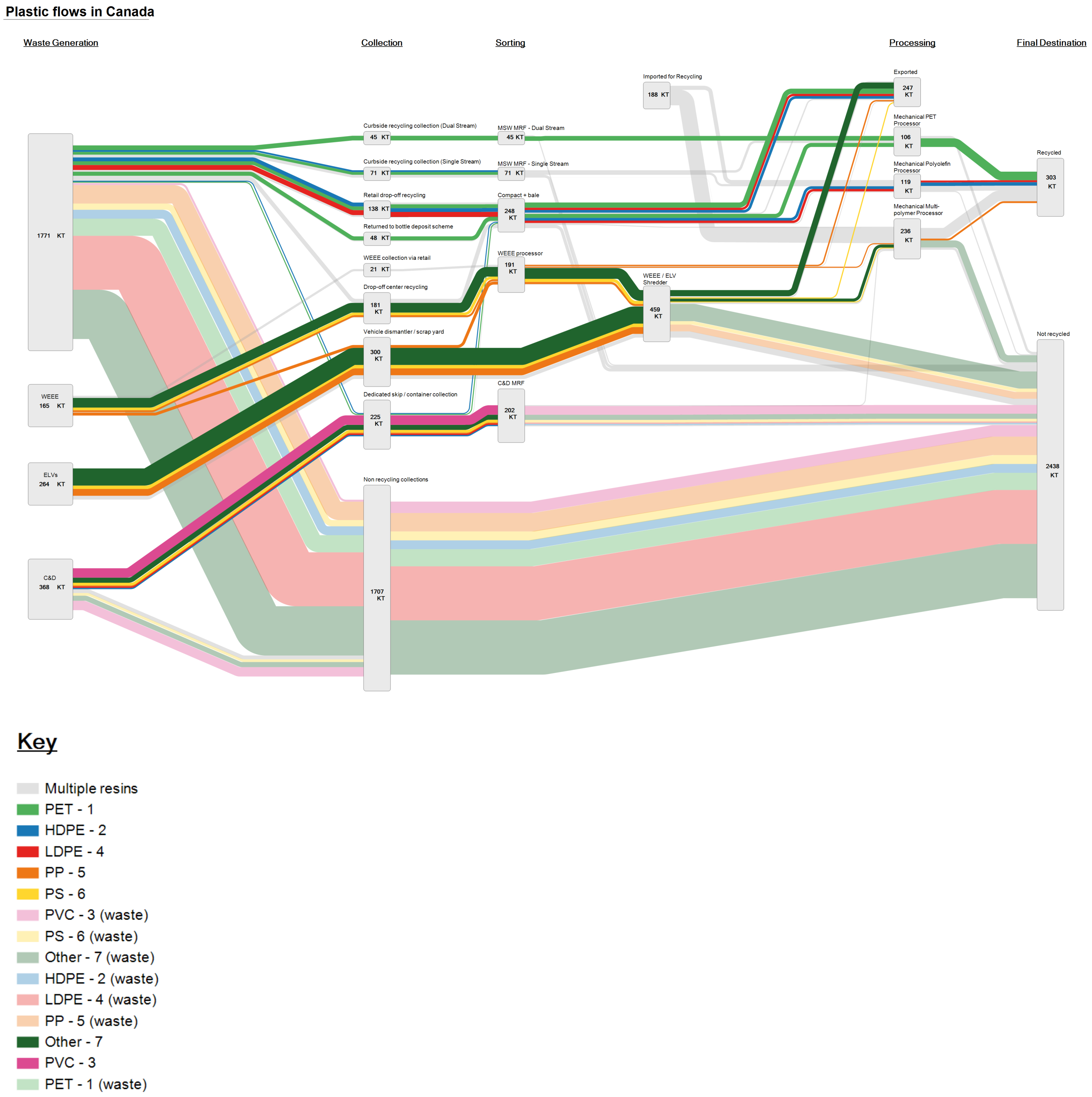
Figure 12. Plastic waste flows in the United States (2021, in kilotonnes (kt))



Key

- ⬜ Multiple resins
- 🟩 PET - 1
- 🟦 HDPE - 2
- 🟥 LDPE - 4
- 🟧 PP - 5
- 🟨 PS - 6
- 🟪 PVC - 3 (waste)
- 🟨 PS - 6 (waste)
- 🟩 Other - 7 (waste)
- 🟦 HDPE - 2 (waste)
- 🟥 LDPE - 4 (waste)
- 🟧 PP - 5 (waste)
- 🟩 Other - 7
- 🟪 PVC - 3
- 🟩 PET - 1 (waste)

Figure 13. Plastic waste flows in Canada (2020, in kilotonnes (kt))



4.1 Plastic Packaging

4.1.1 Data Sources

To calculate the plastic packaging material (includes bottles and liquid containers) for the US and Canada, several data sources were used to derive the following data points:

- Tonnes of material collected, sorted, and recycled
- The proportion of material collected through different collection streams
- The proportion of material collected from the ICI versus residential streams

For the United States, the basis of the recycling tonnages was calculated using the following reports:

- Eunomia 50 States of Recycling Report, which provides tonnages recycled and generated of different plastic packaging materials
- APR/Stina Annual Plastic Recycling Reports, which provide insight into the sector from where collected material originate
- The Sustainable Packaging Coalition's Centralized Study on Curbside Access Report, which allows for estimating the tonnage of material collected via residential curbside versus drop-off collection
- EPA data from EPA's Advancing Sustainable Materials Management Report, which supplemented data from Eunomia's 50 States of Recycling Report

For Canada, recycling tonnages were calculated using the following data and reports:

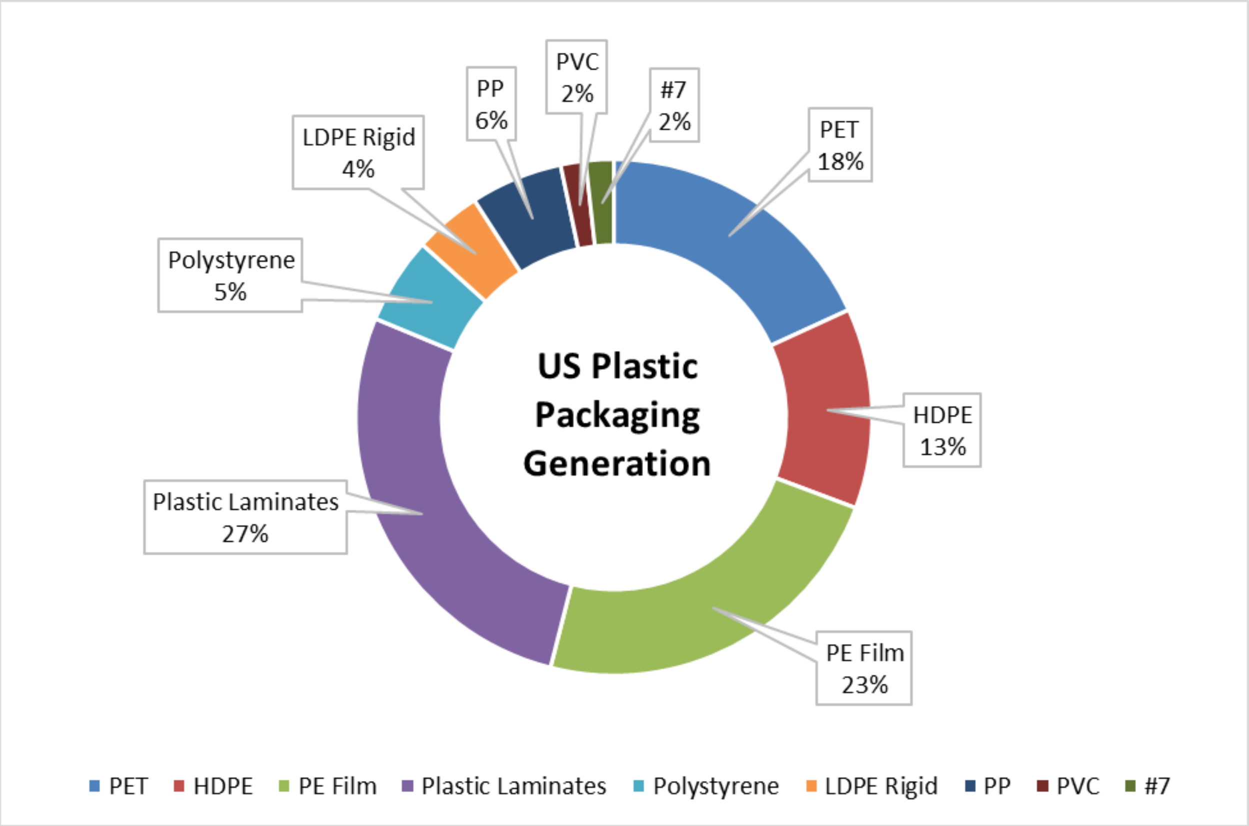
- Annual Provincial Extended producer responsibility (EPR) reports for 2021 (e.g., RecycleBC Annual Reports, Stewardship Ontario Annual Reports), these given data on the tonnages marketed for the residential sector in Canada
- Provincial recycling and disposal data retrieved via FOIA requests, these were used to supplement provinces which did not have detailed annual reports
- StatCan Data, StatCan provides high-level recycling tonnages for the commercial and residential sector
- MORE Recycling's 2018 National Postconsumer Recycling report, similar to the US, this provides insight into the tonnage of material collected by each sector

4.1.2 United States

Overall Generation in the US

An estimated 21 million tonnes of single-use plastics and plastic packaging were generated in the US in 2020 across all generators. The breakdown by resin is shown in Figure 14 below.

Figure 14. Resin composition of plastic packaging in the US (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

Plastic laminates, also considered multi-resin and multi-material plastics, have the highest share of plastic generation in the US. This category includes multi-resin and composite films. PE film is the second largest category in terms of quantities of plastic generated. The largest category of rigid plastic is PET at 18% (3.8 million tonnes), followed by HDPE at 13% (2.6 million tonnes).

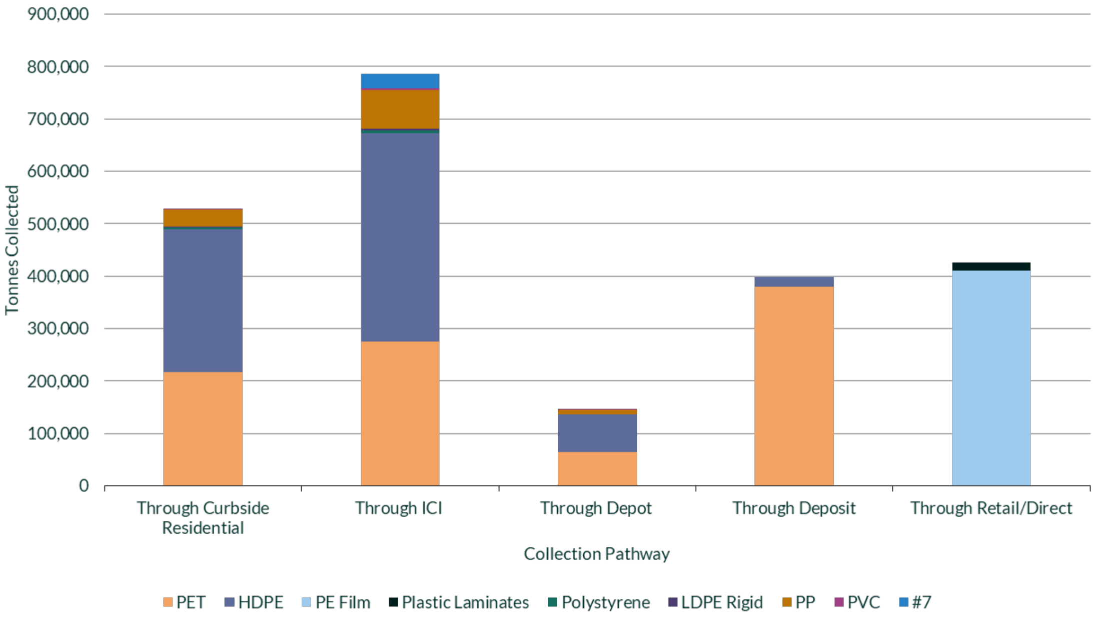
US Collection Methods

Collection of plastic material varies by sector and plastic application type. Plastic packaging that is sold into and consumed by the municipal solid waste sectors (e.g., either sold to and consumed by households and commercial consumers) is collected primarily through the following methods:

- Residential curbside collection
- ICI curbside collection
- Drop-off center collection
- Retail/direct collection
- Deposit return

In the United States, an estimated 2.2 million tonnes of plastic packaging are collected for recycling. Figure 15, below, shows each of the different pathways through which these plastics are collected for recycling.

Figure 15. Plastic Packaging collection pathways in the US



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

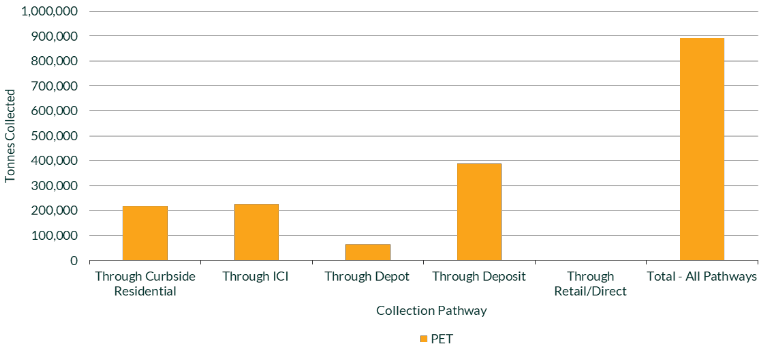
US Polyethylene terephthalate (PET) Packaging

An estimated 3.78 million tonnes of PET packaging are generated in the US annually. As mentioned in Section 3.1, PET is one of the most widely collected plastics in the US.

PET Collection

24% of PET packaging is collected for recycling either through residential curbside, ICI curbside collections, drop-off center collections, or deposit collections. PET is 18% of all plastic generated, but 40% of all plastic packaging collected for recycling. The tonnage of PET collected through different pathways can be seen below.

Figure 16. US collection of PET packaging (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

An estimated 43% of the PET packaging that is collected in the United States is collected through deposit programs. 10 out of 50 states in the US have deposit programs with varying scope, for example Massachusetts does not include water in their program. Adding together the population in each of the 10 deposit states, an estimated 28% of the US population lives in states with a DRS but as stated not all of these include all beverages in PET or HDPE. Despite these programs only covering 28% of the population and not, in all cases, covering all beverages in PET, they are responsible for 43% of PET collection.

Curbside residential and ICI collections account for similar amounts of the PET collected at an estimated 217,000 tonnes (24% of all PET collected) and 225,00 tonnes (25% of all PET collected), respectively. 64,000 tonnes or 7% of all PET collected is collected through drop-off programs.

Altogether, 893,000 tonnes of PET packaging are collected for recycling. This is prior to any sorting or recycling losses.

PET Post-Collection/Sorting

The collection method determines what process comes next for PET packaging. Curbside commingled collected material is sent to sorting facilities to be sorted into PET bales. Collected deposit materials may go straight to a recycler or brand, or they may need an intermediate counting/conditioning facility to be verified or bulked.

In both collection cases, there are generally additional PET packaging losses at each of the sorting stages. For single stream material, the most common collection method for residential curbside programs, PET packaging can be lost to both the residue stream and other material streams, predominately the paper stream at the MRF stage, as seen below.

Table 17. Single stream MRF losses of PET (2015)

Material	% of Single Stream Input to Mixed Paper Commodity	% of Single Stream Input to Newspaper Commodity	% of Single Stream Input to Residue	Total loss to Paper and Residue
PET Bottles	9%	1%	3%	13%
PET Thermoforms	34%	0%	8%	42%

Source: (RRS 2015)

For source separated collection methods (e.g., dual stream collection, deposit return systems), material would not be sorted into paper commodities, reducing the risk of PET packaging loss to the fiber streams.

Across all collection methods, Eunomia estimates 6% of PET packaging is lost at the sorting stage. Because 43% of PET packaging is collected through deposit programs, the overall sorting loss rate for PET packaging is lower than what is indicated in Table 17 above.

The additional 6% of target material losses relates to a tonnage of 52,000. 52,000 tonnes is 1.4% of all PET packaging generated in the US. Therefore, an additional 1.4% of potentially recycled content material is lost at the sorting stage. After sorting, there is an estimated 841,000 tonnes prepared for recycling, or 22% of all PET packaging generated.

PET Recycling

PET packaging that is prepared for recycling is sent for mechanical recycling in the US. PET recyclers purchase PET bales from MRFs, as well as take material from DRS programs. As mentioned in Table 12 in Section 3.1.4, the largest mechanical recyclers for PET in the US are primarily:

- Clean Tech Incorporated (in Michigan), which focuses on deposit material,
- Republic in Nevada with an estimated 50,000 tonnes capacity,
- Nuvida Plastic Technology, Inc. (in New Jersey), with a focus on containers,
- B&B Plastics Inc., in California,
- Custom Polymers in North Carolina

PET is generally turned into regrind, resin, or flaked material. Depending on the quality of the PET packaging in the recycled material, the recycling output can go to new packaging applications. Dirtier, less valuable material can be sent to strapping or carpet applications. The carpet industry has historically been the primary end market for PET prior to voluntary and legislated recycled content requirements being set for the beverage industry.

There are further material losses at the recycler stage. Eunomia estimated the following material loss rates for PET packaging at the recycling stage based on previous research.

Table 18. Loss rates of PET packaging at the recycling processor stage in the US

PET Packaging	Loss Rate at Processor
DRS PET Bottles	12%
Non-DRS PET Bottles	16%
PET Other Rigid	39%

Source: Eunomia interviews with PET recyclers

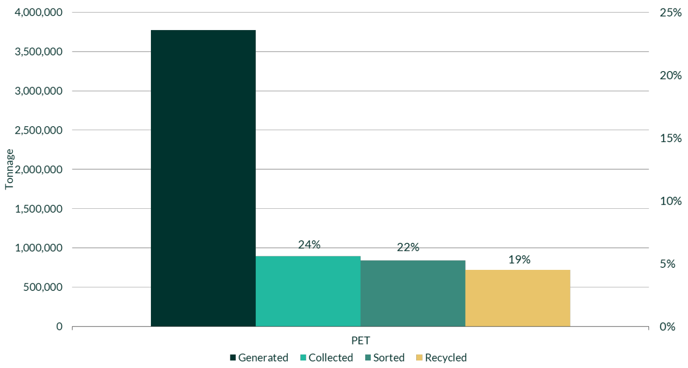
Altogether, an estimated 17% of PET which is sent for recycling is estimated to be lost at the recycling stage. This relates to 120,000 tonnes of PET packaging which is lost at the recycling stage. 120,000 tonnes of material is 3% of all PET material generated in the US. Therefore, after the recycling stage, the recycled content pool has decreased from 22% at the sorting stage, to 19% after the recycling stage. This 19% could also be considered the recycling rate of PET packaging in the US.

PET Summary and Potential for Circularity

Of the PET packaging generated in the US, 24% is collected for recycling, 22% is sorted/prepared for recycling, and 19% is recycled. The tonnage of material recycled is 720,000 tonnes. For PET packaging to reach 30% recycled content nationally, 1.13 million tonnes of PET packaging must be used as PCR for new packaging. This means there is currently a PCR shortfall of at least 410,000 tonnes of PET. Assuming the same loss rates and same streams of supply to the market from curbside and deposit collection systems, at a minimum, 57% more PET packaging would have to be recycled to reach 30% recycled content. This assumes that all PET collected for recycling is recycled into new bottles, which is not the case, as rPET is also used for strapping and carpeting. An increase in DRS systems, whereby the material is owned by the producers, would reduce the ability of other markets to access the material, making the targets easier to achieve. Additionally, DRS systems tend to have lower loss rates, minimize the necessary increase in supply to reach the 30% recycled content benchmark.

A summary of the PET packaging flows can be seen in Figure 17 below.

Figure 17. Summary of PET packaging flows in the US (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

Voluntary recycled content goals generally state they want 30% of all plastic packaging to be made with recycled content (US Plastics Pact 2021). PET packaging is estimated to be around 5-8% PCR currently in the United States, which would suggest that in order to reach 30% recycled content, the collection rate of PET packaging would have to triple, as the PCR content is around one third of the total percentage currently collected (24% collection rate to 5–8% PCR) (US Plastics Pact 2020).

US High density polyethylene (HDPE) Packaging

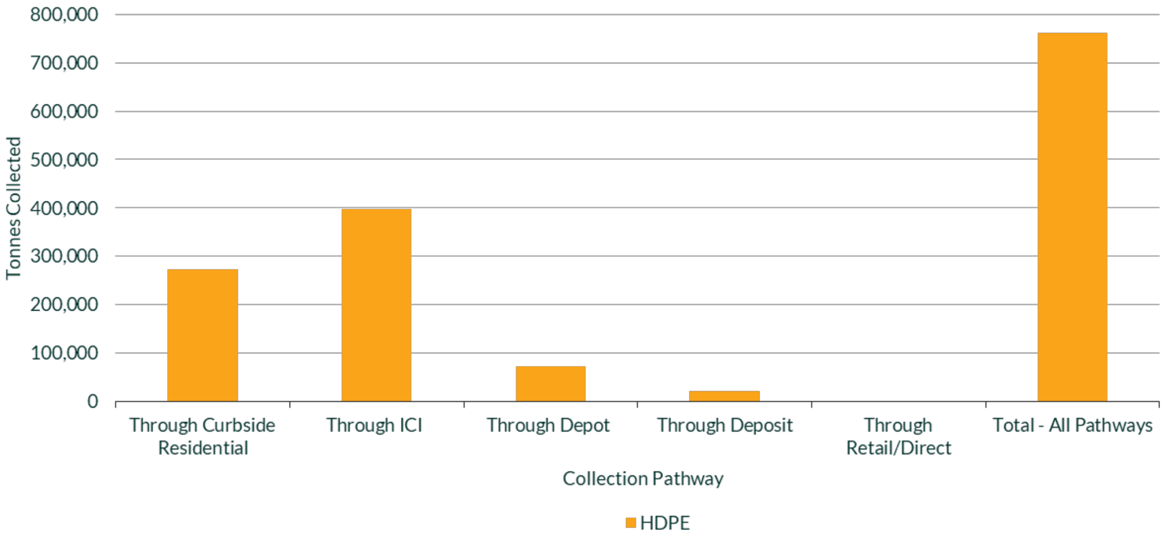
An estimated 2.6 million tonnes of HDPE packaging were generated in the US in 2020. The generation of HDPE is split between HDPE bottles and other HDPE rigid packaging.

HDPE Collection

761,000 tonnes of HDPE packaging are collected for recycling in the US, giving a collection rate of 29%. HDPE is the second-most collected plastic packaging behind PET. PET accounts for 40% of all plastic packaging collected for recycling in the US, while HDPE accounts for 34%. Together, PET and HDPE account for an estimated 74% of the plastic packaging collected in the US.

The tonnage of HDPE packaging collected through each pathway is shown below:

Figure 18. HDPE packaging collected in the US (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

As seen above, ICI collections account for the greatest amount of HDPE collected (52% of all HDPE collected). This may be because residential curbside collections are less likely to accept non-bottle HDPE, while ICI collections are not as strict. ICI collections are more likely to have a larger quantity of source separated material, and as such recyclers may be less intensive to produce a commodity of bulkier HDPE to deliver to a recycler than a municipal mixed curbside collection. As seen in the Washington recycling access case study in Figure 6, plastic jars and tubs are collected at lower frequencies than plastic jugs. Although not a like for like comparison of HDPE bottles versus HDPE other rigid packaging, this data gives an indication that HDPE other rigid packaging is not as desired in residential collections as HDPE bottles, which is most likely linked to markets, availability and value once sorted. HDPE other rigid packaging cannot be recycled into food contact grade packaging, and therefore has less value assigned to it, whereas HDPE bottles can be recycled into food contact grade or non-food contact grade packaging, offering significantly more flexibility.

Unlike PET, deposit programs account for the least amount of tonnage of HDPE collected (3% of all collected). HDPE bottles are less likely than PET bottles to be beverage containers (Eunomia 2022). As a result, a lower proportion of HDPE bottles are under deposit, as a proportion of all HDPE, compared to PET beverage bottles as a proportion of all PET.

In total, 29% of HDPE packaging is collected for recycling in the US, the highest among plastic packaging.

HDPE Post-Collection/Sorting

Similar to PET, HDPE is collected via curbside collections and sent for sorting at a sorting center, where potential losses into the residue and paper stream can occur. Additionally, because proportionally less HDPE packaging is collected through source separated methods, there is potential for greater losses at the sorting stage.

Table 19. Proportion of collected HDPE in non-HDPE sorted streams

Material Type	% to Mixed Paper	% to Residual	Total to Non-Plastic Streams
HDPE Bottles	8%	5%	13%
Non-Bottle HDPE	3%	32%	35%

Source: (RRS, 2015)

As seen above, HDPE bottles are relatively efficient at the sorting stage when compared to non-bottle HDPE with a similar efficiency to PET bottles (13%) at the sorting stage. A lower proportion of non-bottle HDPE is missorted into the paper stream (3%) compared to non-bottle PET (34%). Non-bottle PET is generally flatter than non-bottle HDPE, and thus has a better chance at being picked off by a MRF's 2D screen at the front-end of the sorting process, with the process mistaking the non-bottle PET as a fiber material.

In total, an estimated 111,000 tonnes, or 15% of the HDPE packaging collected, is assumed to be lost at the sorting stage. This is markedly higher than the calculated sorting loss rate of collected PET packaging (6%), primarily due to the lower proportion of HDPE packaging collected through deposit programs. This loss rates relates to a drop from the collection rate (29%) to a sorted/prepared for recycling rate of 25%. This is a 4-percentage point drop from collection to sorted, compared to a 2-percentage point drop for PET packaging.

At the sorting stage, the percentage of HDPE packaging for recycled content drops from 29% to 25% of all HDPE packaging generated.

HDPE Recycling

Like PET, mechanical recycling is the most established recycling outlet for HDPE packaging. One of the largest mechanical recyclers in the US, KW Plastics in Alabama, takes in most of the HDPE packaging in the United States. KW takes sorted HDPE packaging in multiple forms, including:

1. HDPE Natural Bales
2. HDPE Pigmented Bales
3. HDPE Bulky Rigid Bales

KW takes in this material and produces six different recycled HDPE resins which vary based on their color and physical properties. The six different resins KW produces are shown in Table 20.

Table 20. Resin codes for KW Plastics

Resin Code	Resin Description	Characteristics	Applications
KWR101-150	Natural Homopolymer HDPE Resin	Natural color, high stiffness, impact resistance	Blow molding, extrusion, blown film
KWR102	Mixed Color Copolymer HDPE Resin	Good impact strength, includes 7% PP	Not given
KWR102-8812	Copolymer HDPE Resin, pre-colored black	High strength, stiffness, pre-colored dark black	Large part blow molding and extrusion, approved for Chrysler, Ford Motors, General Motors, Toyota, Hyundai, Kia, Mistubishi, Nissan vehicles
KWR105-7252	Copolymer HDPE Resin	Good impact strength	Injection molding
KWR105M2	Copolymer HDPE resin	"Superior toughness", available as mixed color and pre-colored black	Injection molding
KWR105M4	Copolymer HDPE Resin	"Exceptional toughness", mixed color and pre-colored black, 15% PP.	Injection molding

Source: (KW Plastics, 2017)

Of the resins shown above, three are meant for injection molding, two are meant for blow molding and extrusion, and one does not list its applications. As KW plastics has a majority of the market share in the US, most of the HDPE packaging prepared for recycling is likely going into one of these six different types of resins.

Table 21: Loss rates of HDPE packaging at the recycling processor stage

HDPE Packaging	Loss Rate at Processor
HDPE	9%

Source: Eunomia interview with HDPE recyclers.

There are losses at this stage of the process as well. HDPE material is taken in, flaked, and then turned into a pellet. The losses at the processing step for HDPE are estimated to be 9% of the target material. This is lower than the 11% for PET packaging, with the difference potentially being in the structural integrity of PET thermoforms, which tend to crack during recycling, making them unusable (Navedo 2022).

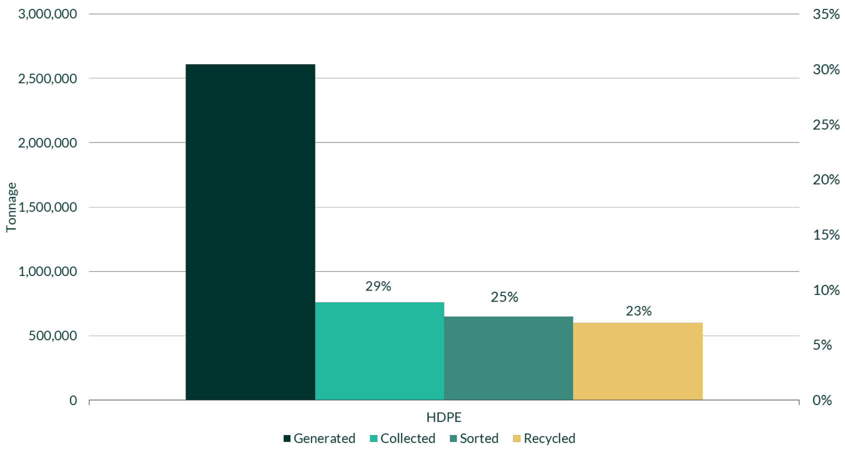
9% of sorted material being lost at the recycling stage equates to 52,000 tonnes, or 2% of all HDPE packaging generated. Therefore, another 2 percentage points are lost, so HDPE goes from a sorted rate of 25%, to a recycled rate of 23%. This means that if all recycled HDPE packaging were converted into new packaging, the highest PCR content the US could achieve is 23% (assuming use of only domestic tonnage).

HDPE Summary and Potential for Circularity

HDPE packaging has the highest recycling rate of plastic packaging resins (23%). 30% recycled content is common voluntary or legislated target. If all recycled HDPE were turned into new packaging, only 31% more HDPE would need to be recycled to reach 30% PCR. However, Closed Loop estimate that only about 1/3 of recycled HDPE becomes new packaging material (Closed Loop Partners, n.d.). This means that the current PCR level for HDPE packaging is 8%.

A summary of the HDPE packaging recycling flows in the US can be seen below.

Figure 19. HDPE recycling collection summary (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

US Polypropylene (PP) Packaging

1.2 million tonnes of PP rigid packaging are estimated to be generated in the US annually. Although PP rigid packaging is the third largest quantity of rigid plastic, it does not have similar recycling levels to PET and HDPE, as detailed here.

Collection of PP Rigid Plastic

PP rigid plastic is accepted in fewer residential curbside collections than PET and HDPE packaging (see Figure 5). 87% of the US population has access to recycling programs which accept PET and HDPE bottles (Sustainable Packaging Coalition, 2022). Of the US population, by contrast, 72% has collection of PP bottles (Sustainable Packaging Coalition, 2022). Furthermore, PET non-bottles, HDPE non-bottles and PP non bottles are all accepted in recycling programs for between 50 and 60% of the US population (Sustainable Packaging Coalition, 2022). However, the non-bottle category is a greater proportion of the PP packaging generation than it is for PET and HDPE packaging which impacts on the total recycling rate.

The table below shows the bottle versus non-bottle generation per capita for PET, HDPE, and PP.

Table 22. Bottle packaging as a % of all packaging

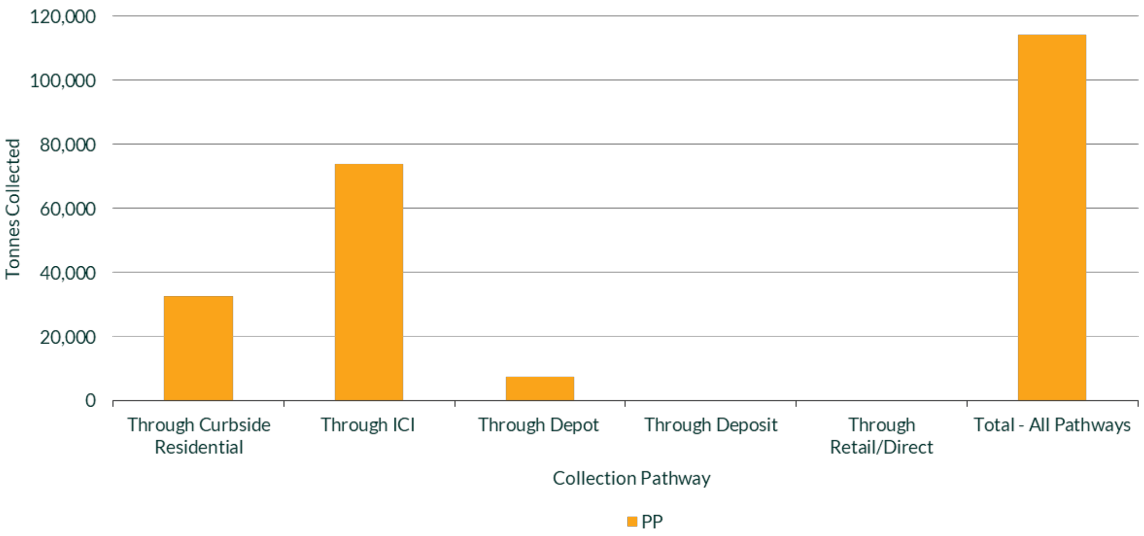
	PET	HDPE	PP
Bottle Packaging Generated (million tonnes)	2.8	1.5	0.08
Total Packaging Generated (million tonnes)	3.8	2.6	1.2
% of Packaging that is bottles	75%	58%	7%

Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

The fact that PP is accepted in less curbside programs is likely to contribute to the lower collection for recycling rate. PP Packaging is also more likely to be in a format that is less conducive to traditional recycling. The EPA estimates that 1.83 million tonnes of PP is in plastic packaging, while 1.73 million tonnes are in packaging material. For contrast, 3.86 million tonnes of PET is in packaging related material, while 770 thousand tonnes of PET are in non-durable goods.

A summary of the collection pathways for PP rigid packaging is shown in Figure 20.

Figure 20. PP rigid packaging collection pathways in the US (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

ICI collection, similar to HDPE, is the greatest source of collected PP packaging. 65% of PP packaging is collected through the ICI collections, compared to 52% for HDPE and 25% for PET. PP is less likely to be packaging material that is accepted in residential curbside collections than PET and HDPE are. As a result, more material is collected via the ICI sector. The absolute quantity collected through curbside residential programs is markedly lower for PP packaging than for PET and HDPE. This can be seen in Table 23.

Table 23. Curbside collection rate comparison in the US

	PET	HDPE	PP
Kg/capita collected through curbside residential programs	0.654	0.824	0.098

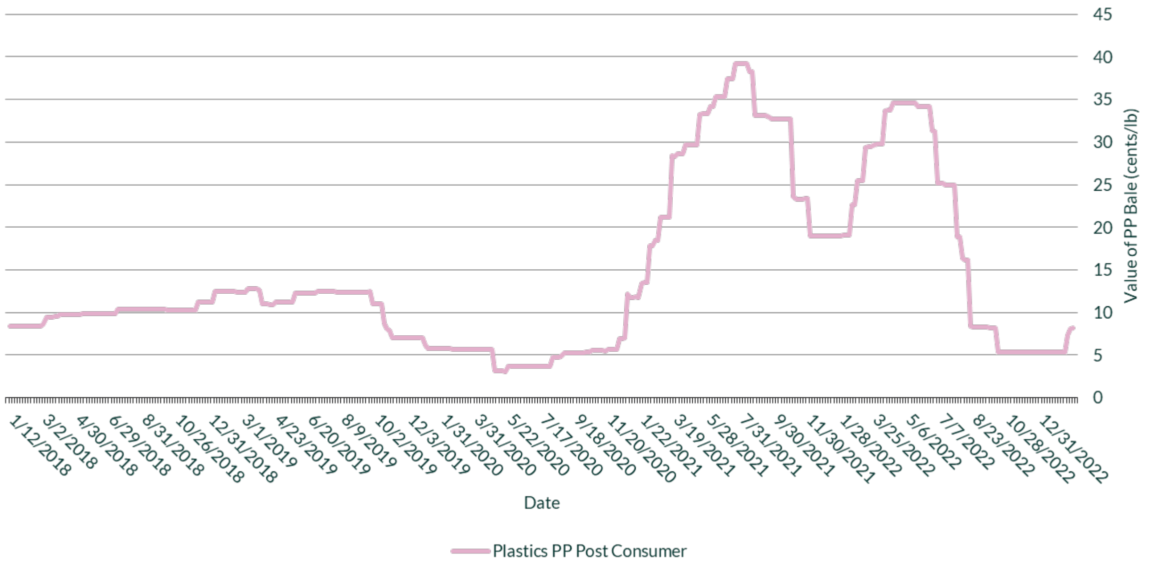
Source: Eunomia Calculations

All the pathways together lead to a collection rate of 10% for rigid PP packaging. This is lower than PET (24%) and HDPE (29%) and means there is a limited amount of PP packaging collected that could be turned into PCR for new packaging.

PP Rigid Post-collection/Sorting

At the sorting stage, PP rigid bottles are generally sorted into a #3-7 mixed rigid bale, so traditionally has not been sorted into its own baled commodity (Circularity in Action 2020). However, between the start of 2021 until the summer of 2022, PP bales had a very high value when baled on their own. As a result, MRFs began to sort PP into their own baled commodities. The price of a PP bale between 2018 and 2022 can be seen in Figure 21.

Figure 21. Value of PP rigid bale over time



Source: RecyclingMarkets, 2023

When sorted in a rigid #3-7 bale, PP is baled together with other resins. The Association of Plastics Recycler (APR) has published a study on the composition of a #3-7 bale. The composition is ordered from largest category to smallest category in the table below.

Table 24. Composition of rigid #3-7 bale

Resin	% of Rigid #3-7 Bale
PP	31%
PET	22%
HDPE	15%
Fines/Contamination	13%
Other plastic (no resin code)	11%
Non-Rigid Plastic	4%
PS	2%
PVC	1%
PVC	1%

Source: Association of Plastic Recyclers, 2021.

Furthermore, as an example, in King County's MRF Material Flow Assessment, PP packaging was the largest component of plastic in the MRF reject stream at 4.2% of the entire MRF reject stream. This would indicate that there is potential opportunity to improve sorting to capture more PP rigid packaging in the US, if there is sufficient market demand.

Table 25. Plastic packaging in MRF reject stream

Packaging Type	% of MRF Reject Stream
PET Packaging	3.2%
HDPE Packaging	0.8%
LDPE Packaging	0.1%
PP Packaging	4.2%
PS Packaging	0.2%

Source: King County, 2020.

No specific PP rigid sorting losses could be identified, therefore Eunomia used similar loss rates to non-bottle HDPE packaging. An estimated 31% of collected PP packaging is therefore lost at the sorting stage, or 35,000 tonnes nationally. This is 3% of all PP packaging generated, meaning that the collection rate decreases from 10% to a 7% sorted rate.

The pool of PCR PP packaging decreases by 3 percentage points post-sorting, such that after sorting, a maximum PCR content of PP packaging of 7% is achievable based on the supply of collected and sorted tonnage.

PP Rigid Packaging Recycling

Similar to HDPE rigid packaging, a majority of sorted PP rigid packaging is recycled by KW plastics. KW has a letter of no objection (LNO) from the US Food and Drug Association (FDA) for one of its recycled PP pellets. However, KW requires PP to be sorted out from the rest of a rigid #3-7 bale before it accepts the material. PP packaging therefore either must be sorted into its own commodity at MRF to be accepted by KW, or a third party would have to separate the PP from a rigid #3-7 bale. Some Plastic Recovery Facilities (or "PRFs") have attempted to fill this gap by taking in mixed plastic commodities and further separating into resin types. However, variable commodity markets have led some of these PRFs to restructure or shut down (Staub, 2021).

Additionally, there are no PP rigid recyclers west of the state of Texas in the US. Therefore, there is a potential PP recycling gap in the United States.

One solvent purification company, PureCycle Technologies, has stated it will step in and begin taking a significant amount of post-consumer rigid PP packaging (PureCycle, 2022). However, there have been some potential setbacks, largely financial, to the initiation of this technology as a recycling outlet (Bruggers, 2023).

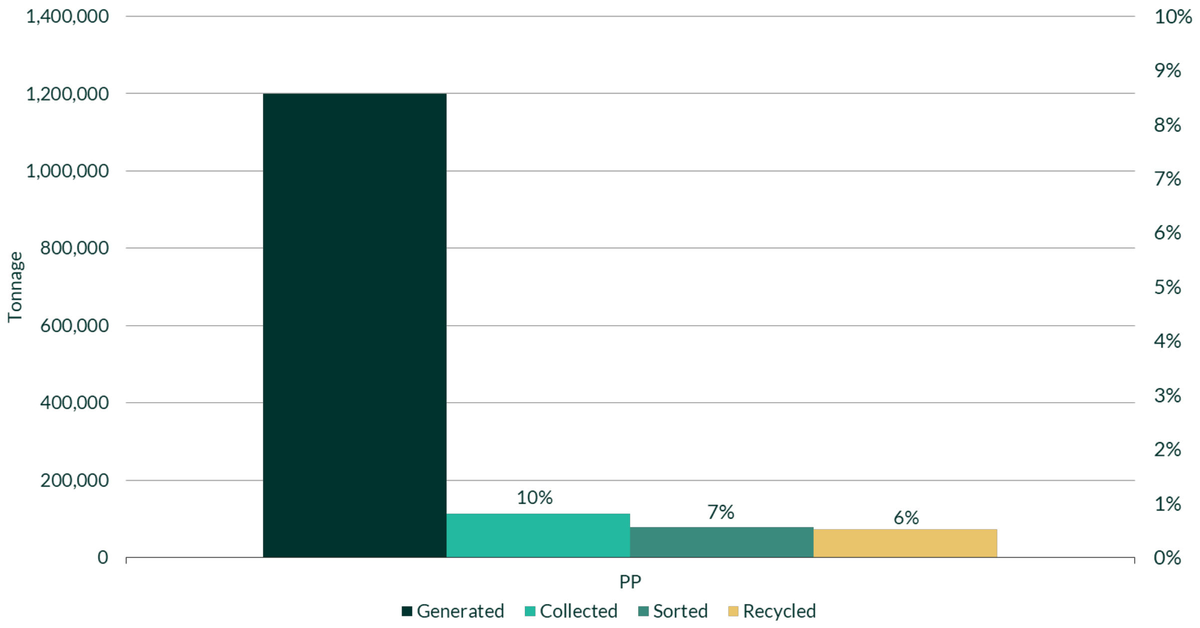
Other players, such as Champion Polymers, take in both PP and PE into their recycling system to create new septic tanks. Champion Polymers receives material from MRFs, and as recently as 2020 from PRFs as well (Polymers, 2020).

In the recycler stage, Eunomia estimates that 10% of sorted PP is lost. This 10% relates to 7,100 tonnes, or 1% of all PP packaging generated. This means that the sorted rate of 7% decreases to a recycled rate of 6%.

PP Summary and Potential for Circularity

10% of PP rigid packaging is collected for recycling in the US, while 7% is sorted for recycling, and 6% is actually recycled. This means that the maximum PCR content for PP rigid packaging in the US could be 6% if all the recycled PP rigid packaging went into new PP rigid packaging. To reach 30% PCR, at least 360,000 additional tonnes of PP packaging would have to be recycled. Assuming the same level of loss rates as what is currently estimated, 575,000 tonnes of PP packaging material would therefore need to be collected for recycling. A summary of the waste flows can be seen in Figure 22.

Figure 22. Flow of PP rigid packaging in the US (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

US Other Rigid Plastics (PVC, LDPE, PS, #7)

Other rigid plastics include polyvinylchloride (PVC), low density polyethylene (LDPE) rigid, polystyrene (PS) and #7 plastics. Each of these four rigid plastics have limited recycling outlets as compared to PET, HDPE, and PP.

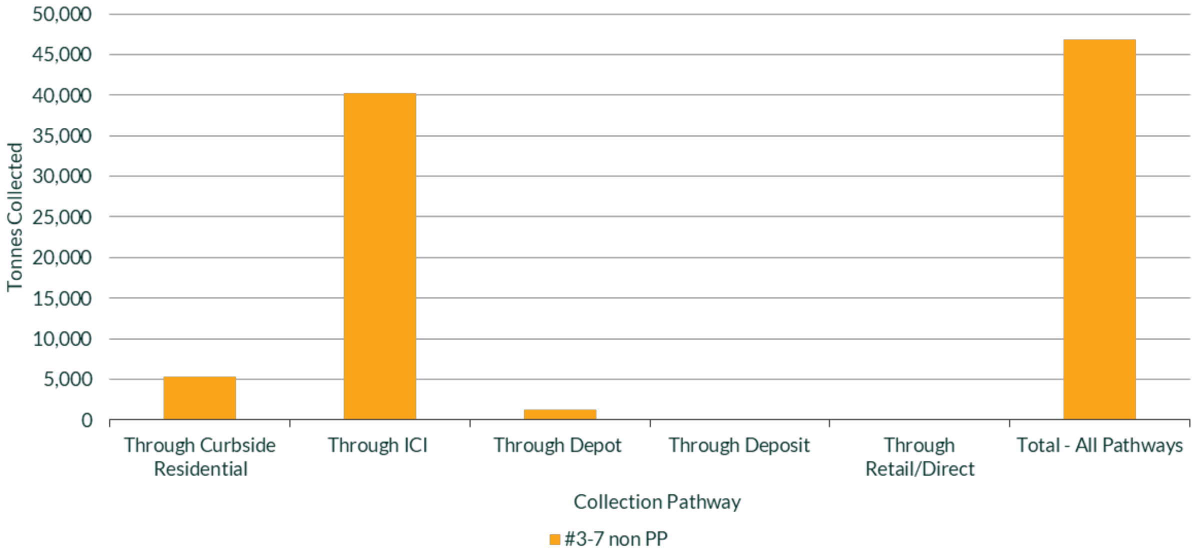
Other Rigid Plastics (PVC, LDPE, PS, #7) Collection

These plastics are collected in lower frequencies in residential collections when compared to PET, HDPE and PP. Rigid PS containers are the least accepted rigid plastic that the Sustainable Packaging Coalition surveyed in their 2021 study on the availability of recycling services, as lower than 50% of the US population had access to recycling services that accepted rigid PS. LDPE rigid containers were accepted at slightly lower rates (70% for bottles, 57% for non-bottles) as PP packaging (72% for bottles, 59% for non-bottles). The Sustainable Packaging Coalition study did not survey for the acceptance of PVC or #7 plastic acceptance.

Of these plastics, the #7 category (which includes unmarked resins, mixed resins, and other unidentifiable plastics) is collected in the highest quantities at an estimated 28,000 tonnes. The next highest is PS packaging at 10,000 tonnes, followed by PVC (5,000 tonnes) and lastly rigid LDPE (4,000 tonnes).

The figure below shows the pathway of collection for each of these resins.

Figure 23. Collection pathways of #3-7 rigid plastics without PP in the US (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

As this material is accepted in lower frequencies in residential collections, a high percentage of the collection material (estimated 86%) is collected through commercial/ICI collection systems. In total just over 45,000 tonnes of this material are collected for recycling, this relates to a 2% collection rate for this subset of plastic. As a result, only 11% of the material is potentially available for use as PCR for new packaging.

Other Rigid Plastics (PVC, LDPE, PS, #7) Sorting

As with rigid PP packaging, other rigid plastics are generally purchased by reclaimers in a segregated resin bale. In 2021, 81.4% of non-bottle rigid plastics were sent to reclaimers in a resin segregated bale. 64% of this material was collected in a commercial, resin segregated collection (i.e., did not need additional sorting).

However, unlike rigid PP packaging, the post-consumer recycling markets for other rigid plastics are not as strong even when separated by resin. Separate revenue lines have not been consistently tracked by Recyclingmarkets.net for PS, LDPE rigid and #7 plastics. The only published revenue line is for polystyrene EPS which has a 5-year average of 2 cents per pound. This is 14 cents lower than the five-year average price for separated PP rigid plastics.

The low prices and opaque nature of the secondary markets for this class of rigid plastics may contribute to a lower level of acceptance of these materials at MRFs.

Additionally, there are concerns about some of these plastics damaging the value of other streams at the MRF stage as well. In particular (ASTRX, 2019):

- PS can be sorted into a fiber bale, damaging the value of that bale;
- PVC labels or products can lead to a discolored end product, leading to a lower value of the output bale.

The potential for these plastics to be problematic at the MRF may not justify additional sorts which can sort out the plastics into their specific resins. APR state that sorting out PP from the rest of these plastics may take 17 total sorts at the MRF. However, to sort out each resin individually, it may take as many as 29 total sorts (APR, n.d.). Using APR's Sort for Value calculator, adding more sorts may not actually increase the blended value of plastics at a MRF, based on current market conditions, as shown in Table 26.

Table 26. Value of MRF plastic per ton by sorting levels in the U.S.

	MRF Outputs	Value per Ton
Some Sorting	#3-7 plastics, mixed HDPE bottles, PET bottles	US$307
Moderate Sorting	#3-7 bottles and small rigid plastic, mixed bulky rigids, HDPE colored bottles, HDPE natural bottles	US$311
High Sorting	Same as above, plus PP small rigid plastic and disposal of other plastics	US$305
Highest Sorting	Same as above, all PP rigids are sorted together, HDPE injection bulky rigids are also sorted separately.	US$300

Source: (APR, 2023)

As seen above, the value per ton peaks at the moderate sorting stage, which groups all rigids #3-7 together. As discussed in the PP rigid section, strong markets for separated PP packaging could bring the High sorting category into closer parity with the Moderate sorting value per ton, as shown in Table 27.

Table 27. Comparison of blended plastic values by sorting level and PP price in the US

Material Prices	Default	Higher PP Value per Ton (20 cents/lb)
Moderate Sorting Plastics Value	US$311	US$311
High Sorting Plastics Value	US$305	US$310
Highest Sorting Plastics Value	US$300	US$312

Source: (APR, 2023)

However, there is not enough value in the other #3-7 materials to justify additional sorting for those. As seen in the table, this material is disposed of by the tool.

As a result of everything discussed in this section, only an estimated 3,300 tonnes of material are sorted through MRFs, while 29,000 tonnes are sorted/prepared for recycling from other source separated streams. This relates to a total sorted rate of 1%. Therefore, the maximum PCR available after the sorting stage is 1% for this group of material.

Other Rigid Plastics (PVC, LDPE, PS, #7) Recycling

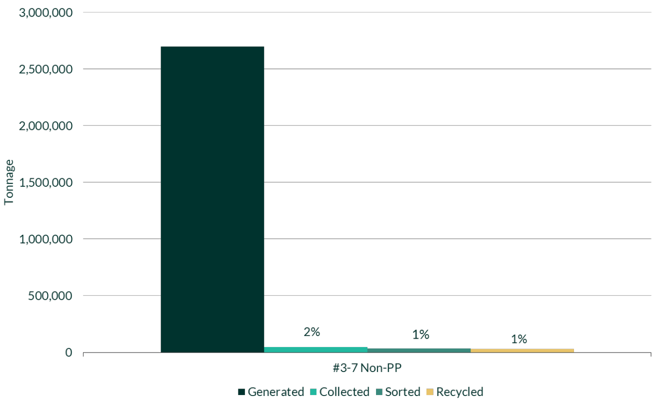
Other rigid plastics recycling in the United States is limited. The total estimated recycling capacity for all non-bottle rigid materials is 544,000 tonnes (US Post-Consumer Plastic Recycling Data Dashboard, 2021). This includes PP rigid capacity as well. KW plastics has a PP rigid capacity of about 230,000 tonnes. Subtracting this capacity from the total 544,000 tonnes would yield a total #3-7 capacity of 314,000 tonnes. This figure is still generous, however, as there are other PP rigid recyclers who may be a part of it. 314,000 is 12% of the total generation of this class of material. However, only an estimated 32,000 tonnes reach reclaimers, and only 29,000 are estimated to become new material, or about 1% of generation. Therefore, a maximum of 12% of material could be recycled and used as PCR; however, the reality is that only about 1% is actually available as PCR.

Furthermore, the end markets for this material generally include non-packaging markets (US Post-Consumer Plastic Recycling Data Dashboard, 2021). These markets include automotive products, pallets, crates and other similar durable goods. The actual resin available for PCR in packaging for this material group may then be closer to 0% than to 1% as a result.

Other Rigid Plastics (PVC, LDPE, PS, #7) Summary and Potential for Circularity

2% of other rigid plastics are collected for recycling, while 1.2% is sorted for recycling, and an estimated 1.03% is actually recycled. As discussed above, the material which is recycled is generally used for non-packaging applications. The PCR potential for this material class is therefore likely between 0 and 1%. This may be part of the reason why the US Plastics Pact has targeted a few of the resins in this material class for elimination in their portfolio in order to reach their 30% recycled content goal. Rather than attempting to get enough of this material recycled to reach the recycled content goal, the Pact has stated it can shift material from these resins into more readily recyclable material (US Plastics Pact, 2021). A summary of the flows of this material can be seen in Figure 24.

Figure 24. Summary of rigid #3-7 packaging recycling in the US (2020)



Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

US Plastic Films

Plastic film is just slightly the majority of plastic packaging generated, as it accounts for an estimated 51% of all plastic packaging generation. Over 10 million tonnes of plastic film are generated in the US annually. Generated film is divided into polyethylene (PE) film (4.8 million tonnes) and composite/laminated plastic (5.2 million tonnes). Plastic laminates and PE film are each the first- and second-most generated format/resin of plastic material. The third-largest plastic resin generated is PET at 3.8 million tonnes.

Plastic Film Collection

Plastic film is rarely, if ever, collected in residential curbside collections in the US (The Recycling Partnership, 2021). Plastic film is generally seen as contamination by MRF operators and is therefore not included in commingled or even dual stream recycling collections (ASTRX, 2019). Residential films are therefore most often collected through retail takeback programs. The vast majority of plastic film collection, however, is through dedicated source-separated, direct commercial recycling. The collection method for films is therefore near universal: the film must be brought to a central location by the consumer in large enough quantities, free of other material streams, and then bulked before it is transported away in a collection vehicle. The initial "collection" of films (e.g., the consumer returning retail bags), is technically free of charge to the waste management system. In total, an estimated 410,000 tonnes of PE film are collected for recycling. Nearly two-thirds of this tonnage is collected through direct commercial collection, while one-third is returned through retail takeback. Only an estimated 16,000 tonnes of plastic laminates/composite plastic film are estimated to be collected for recycling.

The collection rate for PE films by itself is estimated to be 8% (410,000/4,800,000), while the plastic laminate collection rate is estimated to be <1% (16,000/5,200,00). The total film collection rate is therefore 4%. In terms of reaching PCR goals, there will need to be a robust increase in film collection to reach enough collected film to achieve 30% PCR content.

Plastic Film Sorting

Because plastic film generally is not included in curbside collections, relatively small quantities of material pass through a MRF. Plastic film can be problematic for MRFs, particularly if there has not been ample enough investment in sorting technologies at the material recovery facilities. A few issues which plastic film can cause at the MRF stage are:

- Lack of sorting technology can cause film to clog machinery, requiring hand removal
- Plastic film can be missorted into paper streams, lowering the yield and value of a fiber bale
- MRF film is generally dirtier than source separated film, and operators can have difficulty finding end markets for this material
- Sorting requires either investment in technology, or manual sorting, both methods are costly to operators

The conclusion for recycling film through MRFs, therefore, is that it can be costly. In 2017, RRS estimated that the cost to outfit 100 US sorting facilities with film sorting equipment would be US$3–5 million per MRF. On a per tonne basis, the cost to sort and market film maybe close to US$1000/tonne (Reclay Steward Edge Inc., 2016).

All of these factors play into MRFs not wanting to accept film in their lines, and as a result, there are relatively small tonnages of material sorted through MRFs. Direct retail collections, both from the residential and commercials sector, are delivered directly to a recycler, and therefore do not undergo secondary sorting. Because of this direct nature, no sorting losses are estimated for film that has been collected for recycling, and thus a total of 426,000 tonnes of film are prepared for recycling.

Plastic Film Recycling

Plastic film recycling in the US is limited to clean PE film. Key players in the plastic film recycling market in the US include Avangaard Innovative in Texas, and EFS plastics in Hazelton, PA. Both facilities flake and pelletize recovered PE film to be sold to converters. Other recyclers, such as Trex Industries, receive plastic film and create substitute lumber for use in decking and lawn furniture. Whether material ends up at a facility which creates new pellets versus lumber and lawn furniture and exports can depend on a variety of factors such as:

- Purity of the collected material—film with composite plastics does not have as strong domestic markets
- Transportation distance and cost of transportation—film may have to be sent to whichever facility is most cost effective to transport to
- Color of the collected material—colored PE film is less likely to become new packaging, its end markets include trash bags and lumber (Recycler Interview, 2021)

RSE USA estimated the splits shown in Table 28 for the end markets of collected PE film in the United States.

Table 28. Plastic film end-uses in the US (2020)

	PE Film	Other Film
Film Manufacturer	21%	0%
Composite Lumber Manufacturer	22%	1%
Other Product	6%	22%
Export	51%	78%
Total	100%	100%

Source: RSE USA, 2020.

In total, an estimated 366,000 tonnes of film are recycled in the United States. 352,000 tonnes of this material is PE film, while 13,800 tonnes other/laminated/composite film. This relates to a total film recycling rate of 3%, while the recycling rate for PE film on its own is 7%. At most, the PCR content for PE film could currently be 7%. However, as mentioned in the table above, just under a quarter of the reclaimed PE material may become new resin, while the rest is turned into lumber, another product, or exported. It is difficult to verify what happens to recycled material when exported.

A majority of reclaimed film is estimated to be exported. While the reclaimer for film might be based in the United States, the end use for the material could be outside of the US.

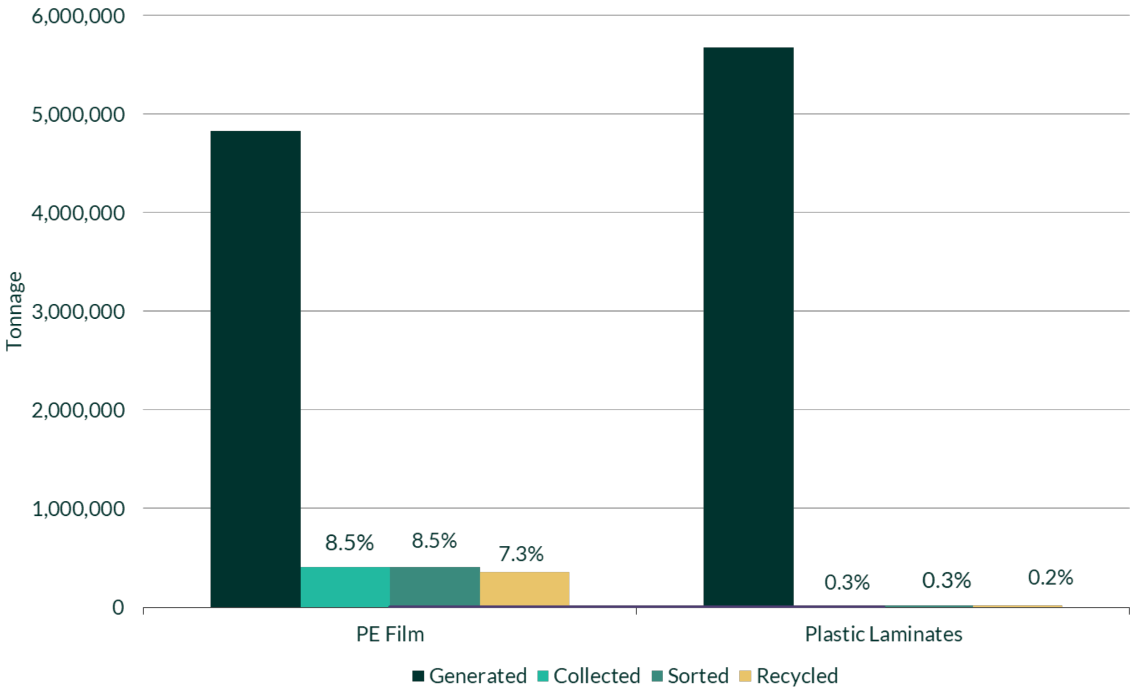
Plastic Film Summary and Potential for Circularity

Just over 10 million tonnes of plastic film are generated in the US. Of this material, 4% is collected for recycling, and 3.5% is recycled. The maximum PCR available for the plastic film market is 366,000 tonnes. However, not all of this material is recycled into new plastic resin for packaging, meaning the true tonnage available for PCR will be lower. 2.8 million more tonnes of plastic film will have to be recycled in order to reach 30% recycling of plastic films. This means the current recycled tonnage of film would have to increase by 8.5x what is currently recycled. As film is so ubiquitous in its use, the industry is exploring ways which could increase the recycled content of film, such as:

- Shifting resins from composite/laminates into single-resin PE
- Potential new recycling outlets such as chemical recycling

However, the results of such initiatives are yet to be determined. A summary of the plastics film recycling chain in the US can be seen in the figure below.

Figure 25. Film recycling summary in the US (2020)

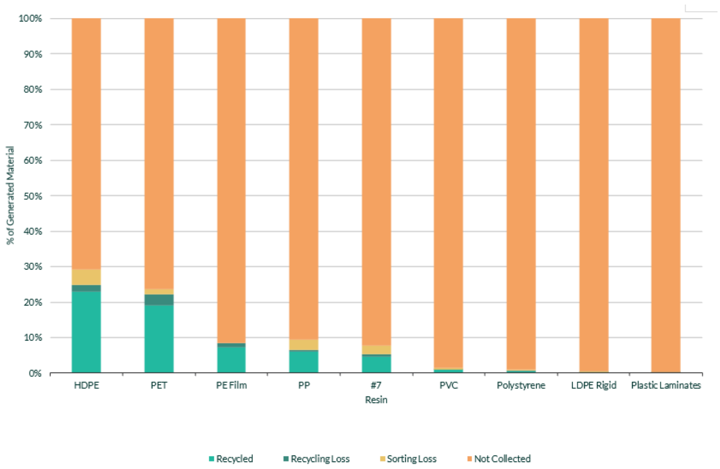


Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

Plastic Packaging Summary in the United States

The chart below shows the end fate of plastic material at different stages of the waste management system, including tonnage not collected for recycling, tonnage lost at the sorting stage, tonnage lost at the processing stage, and lastly the percentage of each resin which is reprocessed.

Figure 26. Recycling rates of plastic packaging in the US: all sectors (2020)



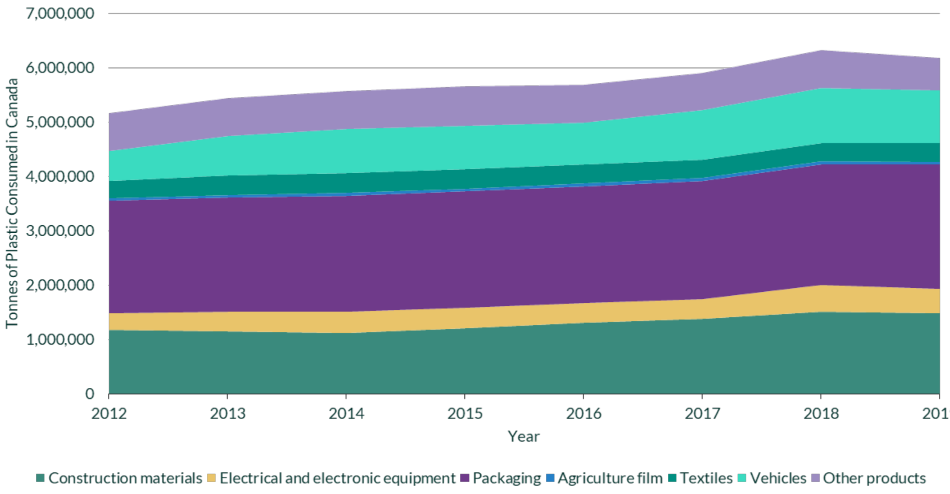
Source: Eunomia Calculations, EPA Data, (Eunomia Research & Consulting, 2021), (Stina Inc., 2020), (Sustainable Packaging Coalition, 2021)

4.1.3 Canada

Overall Generation in Canada

In 2019, Statistics Canada estimated approximately 6.2 million tonnes of plastics in products produced for Canadian consumption generated (Statistics Canada, 2023). As seen in Figure 27, plastic packaging represents the largest end use for these plastics at 37%. Plastic in products used for construction comes in second at 24%. Plastic generated for other products is the only category that has seen a decrease (-15%) in generation, between 2012 to 2019. All other product categories have demonstrated growth in consumption since 2012, with plastics produced for vehicles increasing the most at 78%.

Figure 27. Plastics generated for products in Canada



Source: (Statistics Canada, 2023)

Canada Collection methods

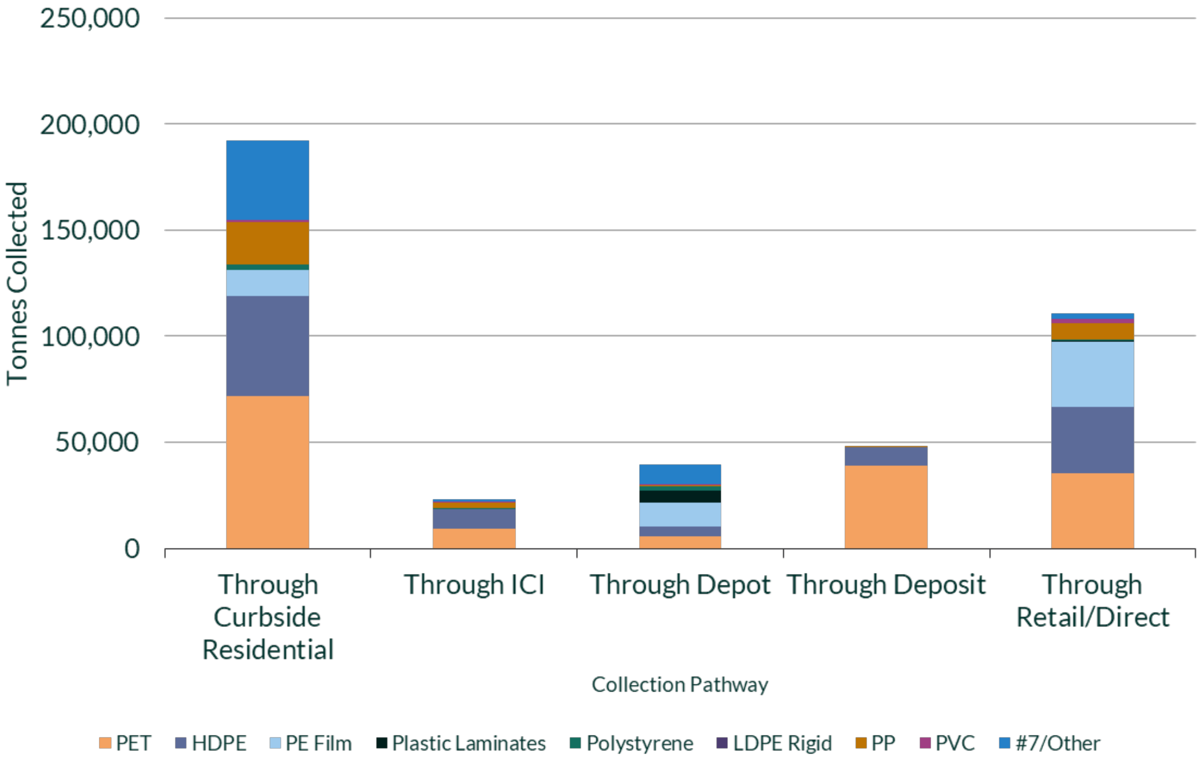
Collection methods in Canada are similar to those in the US, however Canada has wider acceptance of plastic materials in curbside collections. For example, PE film is collected at relatively similar levels through retailers as it is through curbside and drop-off center collections. In the US, there is little to no collection of plastic films through residential collection pathways. In total, just over 440,000 tonnes of plastic material are collected for recycling in Canada. Figure 28 shows the primary collection pathways for plastic material in Canada, along with the resin composition of each of those pathways.

It should be noted that the definitions for retail/direct are slightly different for the US and Canadian data. "Through ICI" for the Canadian data refers to commingled collection, while "retail/direct" refers to any source separated collection, non-deposit collection (including ICI and retail). The source data for collection methods in Canada separates ICI collection into two buckets:

- ICI commingled
- ICI source separated

The US source data does not, thus they are separate in the Canada data, but not in the US data.

Figure 28. Canada plastic packaging collection by pathway (2021)



Source: (Eunomia Calculations), (StatCan Data, 2021), (Provincial Stewardship Reports), (Stina, 2018), (National Postconsumer Recycling Report)

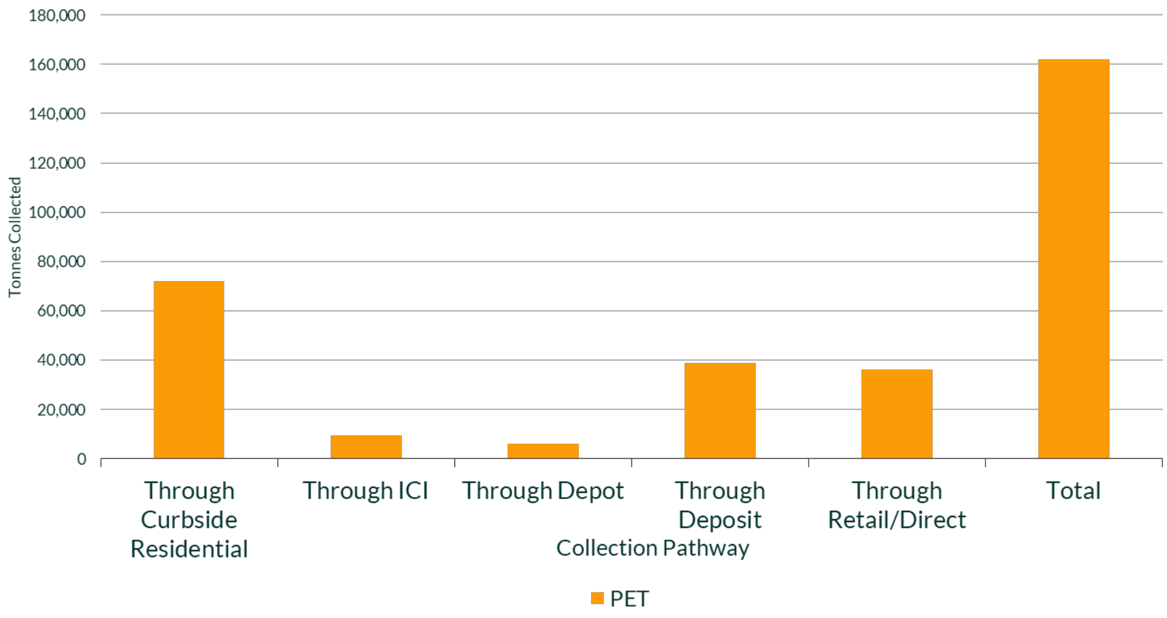
Canada Polyethylene terephthalate (PET) Packaging

327,000 tonnes of PET packaging are generated in Canada annually. As in the US, DRS programs target PET bottles, however PET thermoforms must be collected through curbside and ICI collections.

PET Collection

Similar to the US PET is frequently collected in curbside collection programs. However, DRSs are more prevalent in Canada than in the US and these programs generally include a wider range of beverages, which maximizes the ability to collect PET. The notable exception is Ontario, which only as a DRS for alcoholic beverages. Altogether, an estimated 162,000 tonnes of PET are collected for recycling in Canada. This relates to a 50% collection rate for PET and is 37% of all plastic packaging collected for recycling in Canada.

Figure 29. Collection of PET in Canada by pathway (2021)



Source: (Eunomia Calculations), (StatCan Data, 2021), (Provincial Stewardship Reports), (Stina, 2018), (National Postconsumer Recycling Report)

Residential curbside recycling collects the most PET in Canada. Deposits are second at 40,000 tonnes. As the most populous province, were Ontario to implement a deposit program, it is likely that deposit return programs would account for the most PET collected in Canada.

PET Sorting

PET which is collected through deposit maybe be collected combined with aluminum cans. As a result, the PET bottles must be separated from the aluminum cans at a reconditioner. This is the case in Quebec.

For curbside materials, PET must be sorted into a PET bale at a MRF. Quebec recently conducted a bale audit study to identify the purity of output PET bales. The results are shown in the table below.

Table 29. Quebec (Canada) bale audit study results

Portion of Bale	Description	% of Bale
Generally Accepted Plastics	PET bottles and other compatible PET	63%
Generally Tolerated Plastics	Opaque PET, some HDPE bottles and tolerated levels of metal, fibers	31%
Generally Refused Plastics	PVC, non-bottle HDPE, LDPE, PS, PLA, films, cartons, glass and other non-target material	2%
Metal	Metal material	<1%
Fiber	Fiber material	2%
Glass	Glass material, including bottles	0%
Other	Other non-target material	2%

Source: (RECYC-QUÉBEC, 2021)

As seen in the table above, roughly 94% of a PET bale is an accepted commodity.

In addition to bale purities, there are loss rates of target materials. This is discussed further in the US PET Sorting section.

In total, an estimated 155,000 tonnes of PET is sorted for recycling in Canada annually. This relates to a sorted rate of 48% for PET and a sorting loss rate of 4%. The sorting losses are estimated to be slightly lower in Canada, as there is a greater amount of dual stream collection and ICI source separated collection.

PET Recycling

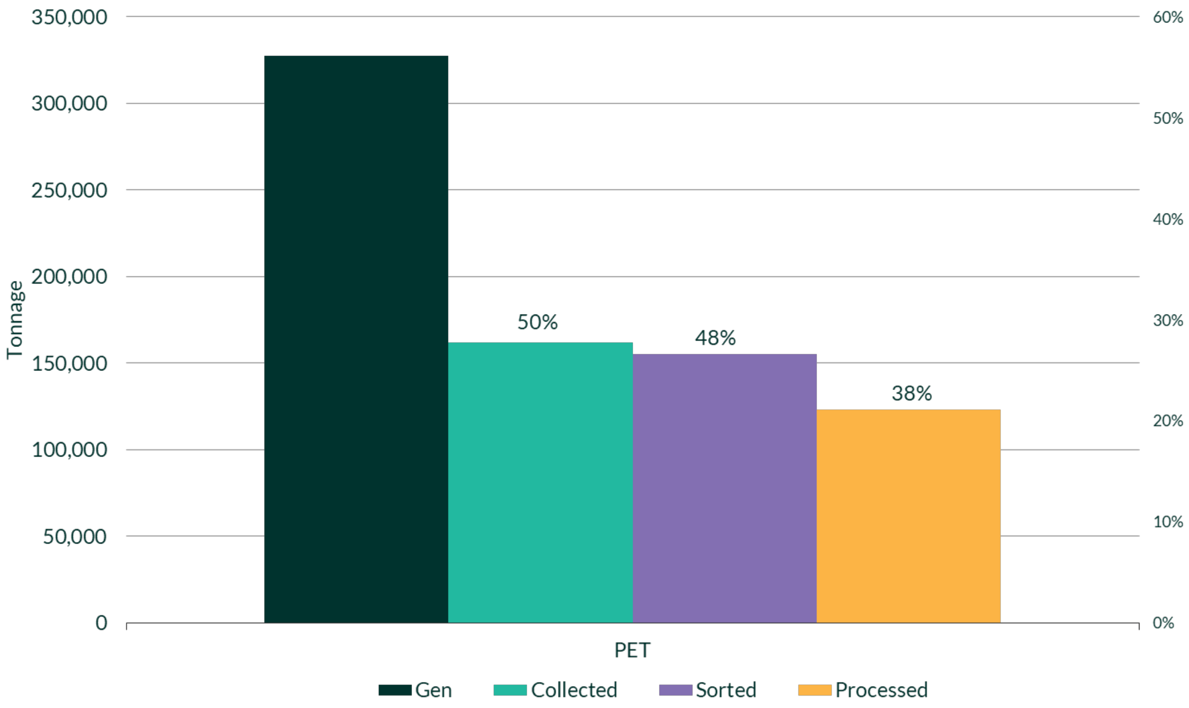
Large PET recycling players in Canada include Merlin Plastics and Plastrec. Both recyclers produce food grade rPET. There are more limited recycling markets for opaque PET however, Recyclers in Canada are designed to recycle clear PET rather than opaque PET. Merlin for instance does not recycle green PET with its clear PET, both are separate commodities that go into different end applications (Plastics 2022). The main end products for recycled PET are food and non-food grade packaging, as well as synthetic fiber markets for textiles and carpeting.

In total, an estimated 123,000 tonnes of PET is recycled in Canada. There is a smaller portion (about 10,000 tonnes) of sorted PET, which is exported or sent to waste-to-energy. This yields a recycled rate of 38% for PET in Canada. This rate is slightly lower than what the Canada Plastic Pact estimates for PET, as they estimate 46% of PET is recycled. The differences most likely have to do with the study year of the data (CPP report was using 2019 data, CEC study is using 2021 data), as well as the CEC study accounting for exports and material sorted but sent to waste-to-energy.

PET Summary and Implications for Circularity

In total, 38% of PET in Canada is recycled. This means that the maximum PCR content for PET packaging could be 38% in the country. However, because not all rPET is used for packaging purposes, some is used in fiber applications, the true PCR content will be lower than 38%.

Figure 30. Summary of PET packaging flows in Canada (2021)



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report_

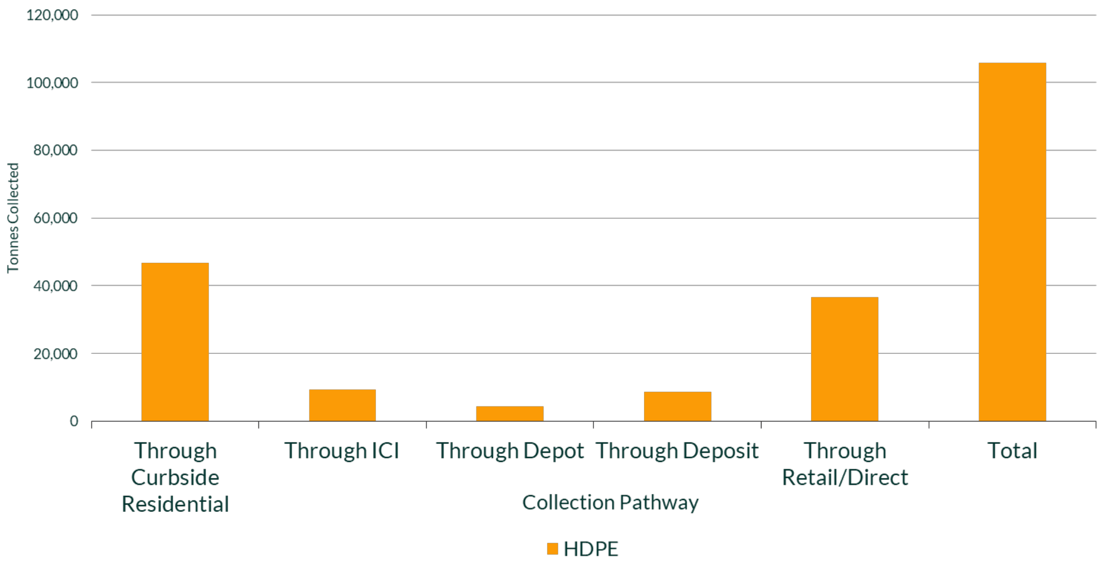
Canada High-Density Polyethylene (HDPE) Packaging

Around 161,000 tonnes of HDPE packaging is generated in Canada annually. This is 9% of all plastic packaging generated in Canada.

HDPE Collection

In total, an estimated 106,000 tonnes of HDPE packaging is collected for recycling. HDPE bottles are also under deposit in most Canadian provinces: however, a smaller percentage of HDPE packaging is beverage containers compared to PET. As a result, only 8% of HDPE packaging is estimated to be collected through deposit programs, compared to 24% for PET. All HDPE collection pathways are shown in Figure 31.

Figure 31. Collection of HDPE by pathways in Canada (2021)



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports: Stina 2018), (National Postconsumer Recycling Report)

Similar to PET, curbside residential accounts for the most HDPE packaging collected, followed by source separated ICI collections. The total collection tonnage of 106,000 relates to a collection rate of 65% for HDPE packaging.

HDPE Sorting

Like PET, curbside HDPE is sorted into its own bale at MRFs. There is evidence that HDPE bales are higher in purity than PET bales, and thus demand a higher market value than PET bales. The table below shows the bale purity comparison between PET and HDPE bales from Quebec MRFs.

Table 30. PET and HDPE bale compositions in Quebec (Canada)

	PET Bale Composition	HDPE Bale Composition
Generally Accepted Plastics	63%	89%
Generally Tolerated Plastics	31%	5%
Generally Refused Plastics	2%	2%
Metal	1%	1%
Fiber	2%	1%
Glass	0%	1%
Other	2%	3%

Source: (RECYC-QUÉBEC, 2021)

The "Generally Accepted" row for HDPE bottles is 89%, compared with the PET composition of 63%. Both PET and HDPE have the same combined percentage of material in the Accepted and Tolerated figure. Both materials have steady markets, however the higher percentage of "Generally Accepted" material in an HDPE bale may contribute to the overall higher material value of Natural HDPE (50.51 cents/lb) and colored HDPE (18.71 cents/lb) when compared to PET bales (15.48 cents/lb) (RecyclingMarkets, 2023).

The evidence that the higher value for HDPE is due to recycling collections restricting HDPE collection to bottles, rather than bulky HDPE, is not quite borne out by access statistics. In 2015, 95% of households had access to HDPE bottle recycling, and a similar 94% had access to HDPE non-bottle rigid recycling (CPIA, 2016).

In total, an estimated 91,000 tonnes of HDPE is sorted/prepared for recycling in Canada annually. This represents 56% of the HDPE generated, and a sorting loss of 13.8%.

HDPE Recycling

HDPE recycling in Canada is again dominated by Merlin Plastics; however, another large recycler, EFS Plastics, is also a consumer of sorted HDPE bales. Merlin plastics is located on Canada's West Coast, while EFS is in Ontario. Both recyclers produce HDPE pellets for extrusion and blow molding applications. A comparison of products from the two companies are shown in Table 31.

Table 31. HDPE products from EFS and Merlin Plastics (Canada)

Product	Merlin Plastics	EFS Plastics
Natural Pellet	Yes	Not stated on website
Colored Pellet	Yes	Yes
Injection Black Pellet	Yes	Yes

Source: (Merlin Plastics, 2023); (EFS, 2023)

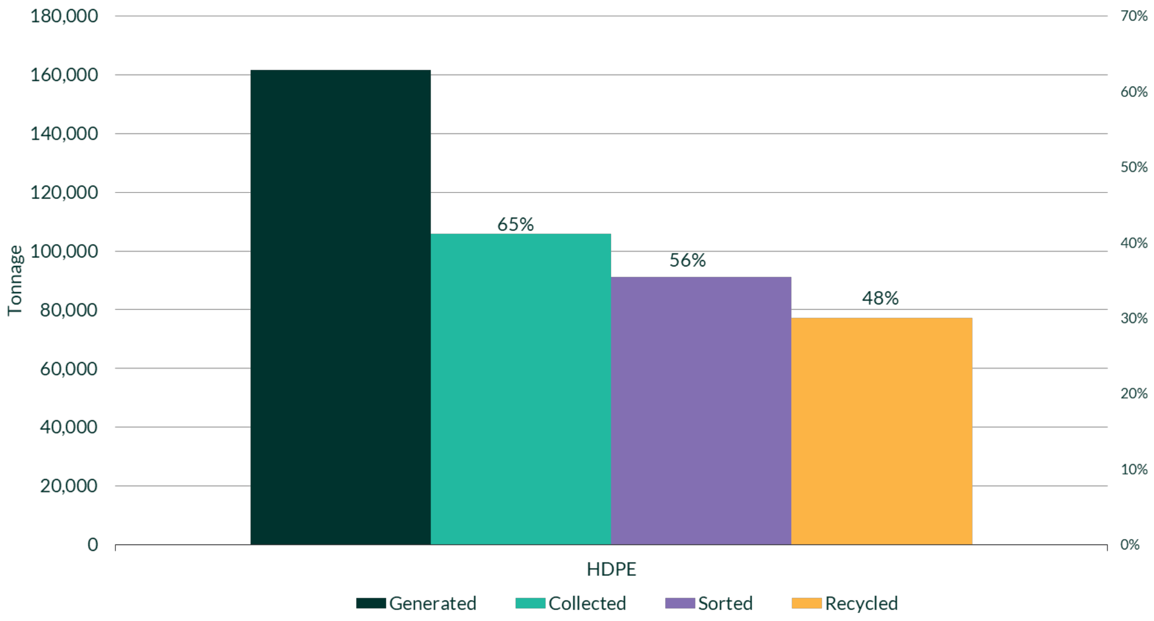
Both recyclers produce recycled pellets for sale to converters to be turned into new products. A third recycler, Soleno Plastics in Quebec, recycles HDPE resin for use in their own production of drainpipes, rather than sales to the open market. Other end markets for the recycled pellets include food and non-food grade packaging, drainpipes and plastic lumber.

In total, an estimated 77,100 tonnes of HDPE packaging are recycled in Canada annually. This relates to a recycling rate of 48%.

HDPE Summary and Implication for Circularity

Some 65% of generated HDPE packaging is collected for recycling in Canada. Of this, 56% is sorted, and 48% is recycled. This means that the maximum PCR content for HDPE packaging in Canada could be 48% based on the current recycling rates. However, the Canada Plastic Pact state that they currently only have a PCR content of 13% for HDPE bottles, and 2% for HDPE other rigid packaging (Canada Plastics Pact 2020). This is contrasted with 28% for all PET, which is similar to the calculated recycling rate for PET in Canada. The figure below shows a summary of the HDPE packaging flows in Canada.

Figure 32. Summary of HDPE recycling in Canada (2021)



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

Canada Polypropylene (PP) Packaging

An estimated 200,000 tonnes of PP packaging is generated in Canada annually. That is 11% of all plastic packaging generated in the country, slightly higher than HDPE and lower than PET.

PP Packaging Collection

Deposits are not as frequent for PP packaging materials as they are for PET and HDPE. Alberta accepts mixed plastic beverage containers in its DRS program; however, this is a relatively low tonnage compared to the rest of the program.[7] The greatest collection methods for PP packaging therefore is through curbside residential programs and direct source separated ICI collections.

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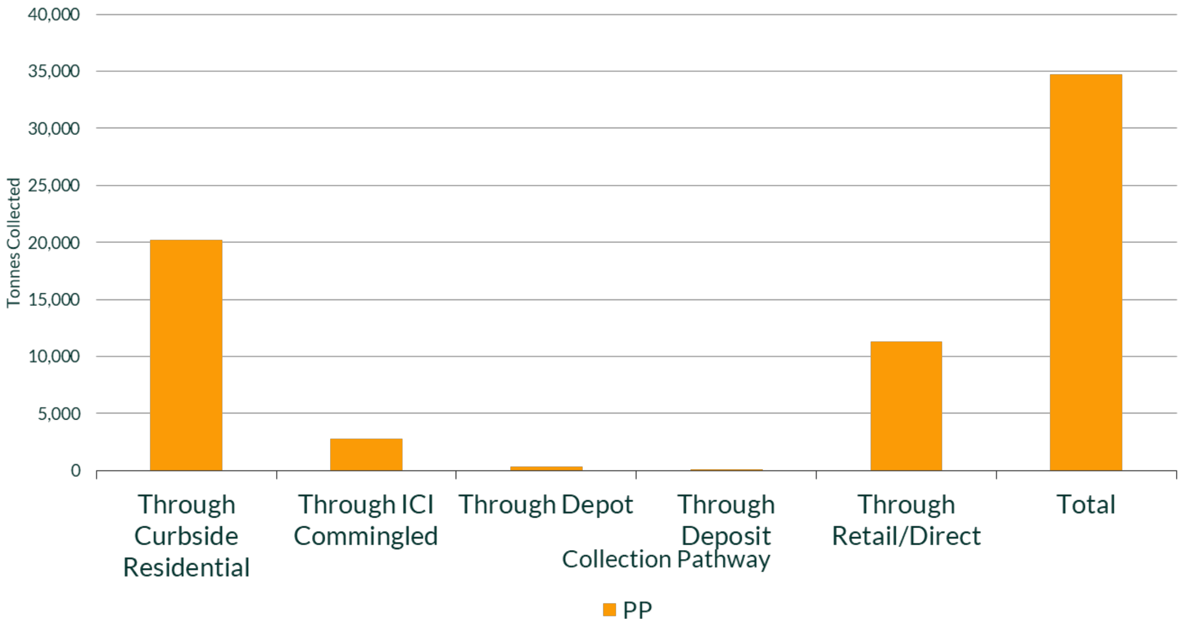
[7] Data received by the Beverage Container Management Board (BCMB).

Figure 33. Collection of PP packaging by pathway in Canada (2021)



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

In total, 35,000 tonnes of PP packaging is estimated to be collected for recycling in Canada. This relates to a collection rate of 17% for PP and is 8% of all plastic packaging collection for recycling. The collection rate of 17% for PP is about double the collection rate estimated for the US (9.5%). In 2015, 94% of the Canadian population had access to PP non-bottle rigid plastic recycling, whereas in the US, only 59% of the population had access to "PP tubs and other containers" recycling.

PP Packaging Sorting

As in the US, sorting of PP is generally first seen in a rigid #3-7 bale. Unlike PET and HDPE, PP will be sorted into a mixed #3-7 Bale along with other plastics. A rigid #3-7 audit from Calgary's Cascades MRF revealed the composition breakdown shown in Table 32.

Table 32. Rigid #3-7 audit from Calgary MRF (Canada)

Material	% of Bale
PET	16%
HDPE	23%
PVC	0%
LDPE	3%
PP	33%
Other Plastic	6%

Material	% of Bale
Fiber	8%
Metal	5%
Glass	1%
Garbage	4%
Total	100%

Source: Calgary MRF Data (obtained via email with Sharon Howland)

As seen above, one-third of the rigid #3-7 bale is PP rigids. Unlike in the US, two of the large processors in Canada (Merlin Plastics and EFS) will accept bales in rigid #3-7 form. They each have internal sorting operations that will separate the bales into the materials they want. Sorting PP into its own bale at the MRF stage then would not appear to be as necessary in Canada as in the US.

PP Packaging Recycling

As mentioned in the sorting section above, two large plastics recyclers (Merlin Plastics and EFS Plastics) each receive rigids #3-7 bales without the resins separated. There are certain bale composition restrictions, however, that the bales must meet. For instance, EFS state that their rigid #3-7 plastic bale input must be a minimum of 55% HDPE, LDPE or PP. Other rigid plastics can be up to 40% of the bale, and non-plastic material cannot exceed 9%.

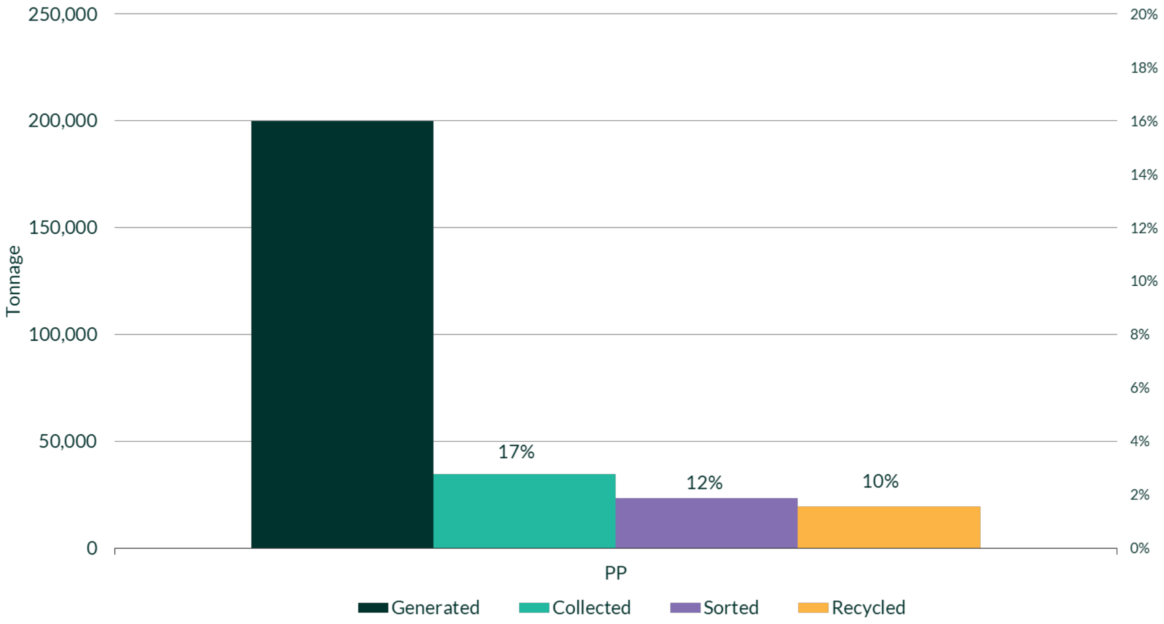
Rigid plastics #3-7, therefore, must be sorted to a sufficiently high enough standard at the MRF stage to reach the recyclers in Canada.

Merlin Plastics produces black and mixed color PP pellets, while EFS produce PP for injection molding applications. End products for PP packaging in Canada include automotive goods, durable goods and specialty products. In total, an estimated 24,000 tonnes of PP packaging are recycled in Canada, or 10% of generation.

PP Packaging Summary and Circularity

Some 24,000 tonnes of PP packaging are estimated to be recycled in Canada. This is 10% of the PP packaging generated in the country. However, it would appear the majority of this material is not making its way back into packaging applications. The Canada Plastic Pact reports a 1% PCR rate for the PP in its packaging portfolio (Canada Plastics Pact, 2020). It seems that, in addition to increasing the collection of PP, additional steps must be taken to ensure the material can be turned back into packaging. The figure below shows a summary of the PP flows in Canada.

Figure 34. PP packaging recycling summary in Canada (2021)



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

Other Rigid Plastics (PVC, LDPE, PS and #7) in Canada

Approximately 262,000 tonnes of other rigid plastics (PVC, LDPE, PS and #7) are generated annually in Canada. Unlike in the US, several of these plastics are consistently targeted in recycling collection programs as they are mandated under EPR.

Other Rigid Plastics Collection

In 2015, CM Consulting reported the recycling access rates for PS non-bottle rigid, PVC and LDPE rigid packaging by province, as shown in Table 33.

Table 33. Recycling access for PVC, LDPE, and PS packaging by province

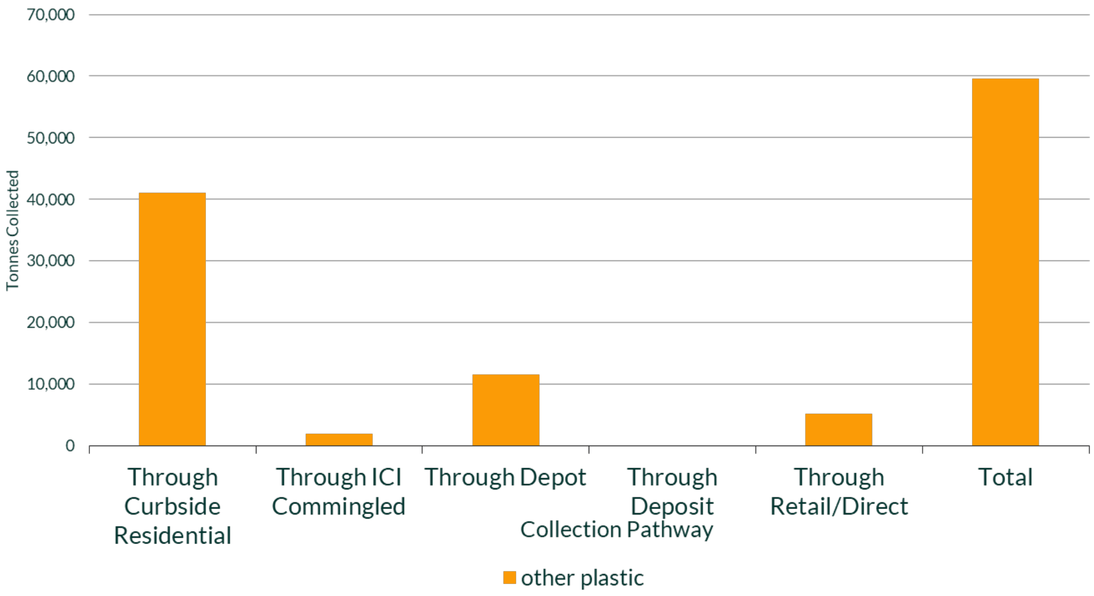
Province	PVC Non-bottle rigid	LDPE Non-bottle Rigid	PS Non-bottle rigid
British Columbia	94%	99%	94%
Alberta	85%	85%	84%
Saskatchewan	57%	57%	57%
Manitoba	71%	84%	64%
Ontario	90%	92%	93%
Quebec	88%	99%	18%
New Brunswick	61%	77%	49%
Nova Scotia	100%	100%	100%

Province	PVC Non-bottle rigid	LDPE Non-bottle Rigid	PS Non-bottle rigid
Prince Edward Island	100%	100%	0%
Newfoundland and Labrador	67%	67%	67%

Source: (CPIA, 2016)

While it is possible these rates have decreased over time, particularly due to the 2018 closure of Chinese markets for much of this material, extended producer responsibility (EPR) programs continue to include these materials in their scope, keeping them as a mandated commodity. The collection data on this material stream for the ICI sector are not as clear as in the residential sector, and the ICI sector is not mandated under EPR programs currently. As a result, most material is collected through curbside residential collections.

Figure 35. Other rigid plastics collected by pathway in Canada



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

Other Rigid Plastics Sorting

As mentioned in the section on PP rigid packaging, MRFs in Canada typically sort into rigid #3-7 bales if they are aiming to market the materials under this section. This material, however, is not as sought after by recyclers in the country. EFS does not produce a PVC or PS resin, and the only plastic in this group it considers a target in its bale specifications is LDPE rigids.

Additionally, Merlin Plastic does not sell PS or PVC specific resins; however, they do produce a "polyblend" pellet.

These weak end markets may help explain why the Calgary rigid #3-7 bale is only 3% LDPE and <1% PVC. There is also no PS rigid in their #3-7 bale. Provincial annual recycling reports do report that PS plastics and unmarked plastics are collected and marketed; however, so the material is finding a secondary outlet.

Eunomia estimates that 44,000 tonnes of this category of material is sorted/prepared for recycling, or 17% of the group's generation.

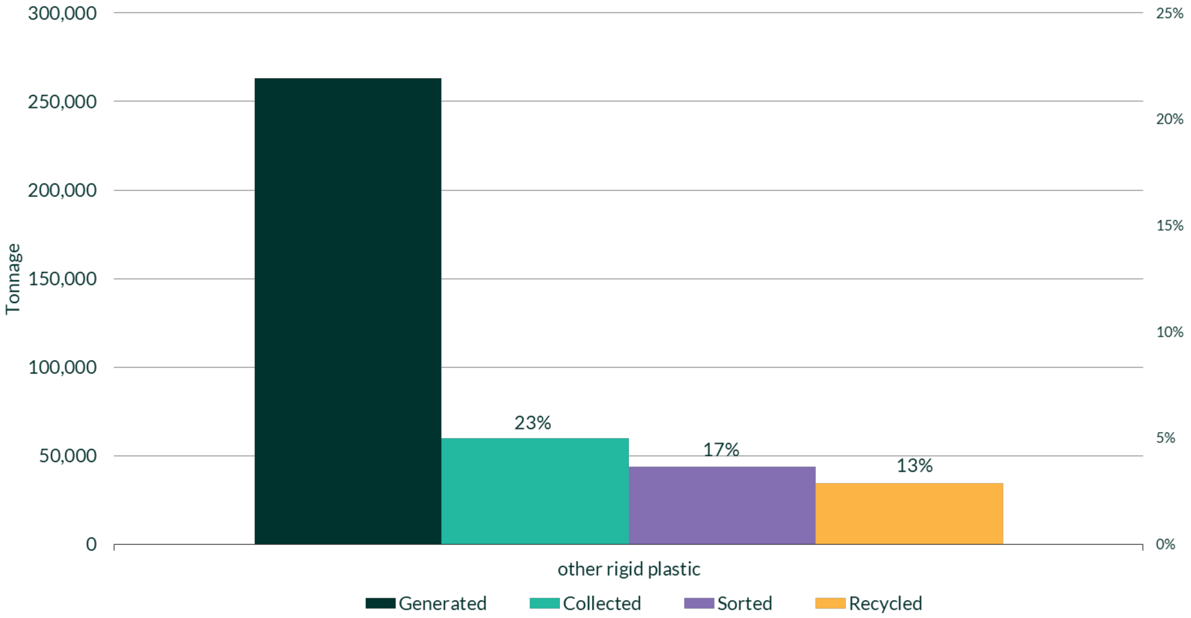
Other Rigid Plastics Recycling

End markets for these materials include durable goods, and other products that are not packaging related. Therefore, the potential for packaging circularity in this group of material is minimal. An estimated 34,000 tonnes of this material is recycled into new products. This relates to a recycling rate of 13%. This estimation, however, is difficult to verify, as the majority of this material is unmarked plastic.

Other Rigid Plastics Summary and Implication for Circularity

Due to the aforementioned challenges to the other rigid plastics market currently, there is less PCR potential for this group of materials. The figure below shows a summary of the material flows.

Figure 36. Summary of other rigid plastics recycling in Canada



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

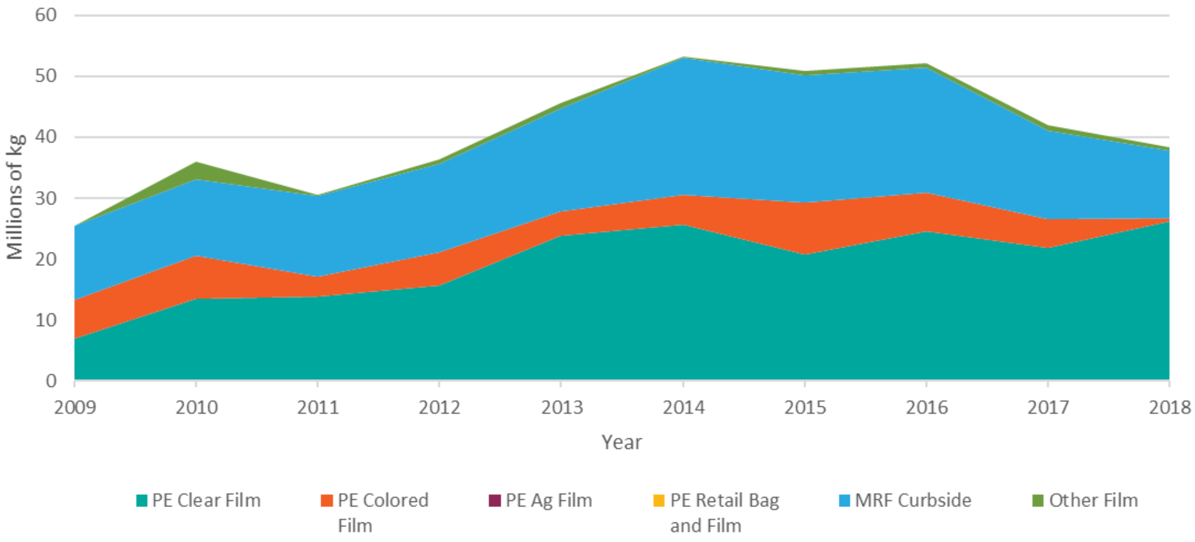
Plastic Film in Canada

An estimated 916,000 tonnes of plastic film is generated in Canada annually. Similar to in the US, plastic film generation is just about half of all plastic packaging generated in the country (49% for Canada). The material group is split again into PE films and laminated films, however there is less clarity in Canadian data on the resin composition of plastic films. EPR reports and the residential sector will breakout the two separately; however, the commercial sector has very little visibility into the composition of film generated.

Plastic Film Collection

Unlike in the US, plastic film collection for the residential sector is not limited to returning film to retailers. Instead, plastic film is collected in some curbside programs, as well as through drop-off-only collections. As seen below from MORE Recycling 2018 National Postconsumer Plastic Report, MRF curbside film was a non-trivial tonnage from 2009 to 2018.

Figure 37. Film collected in curbside programs



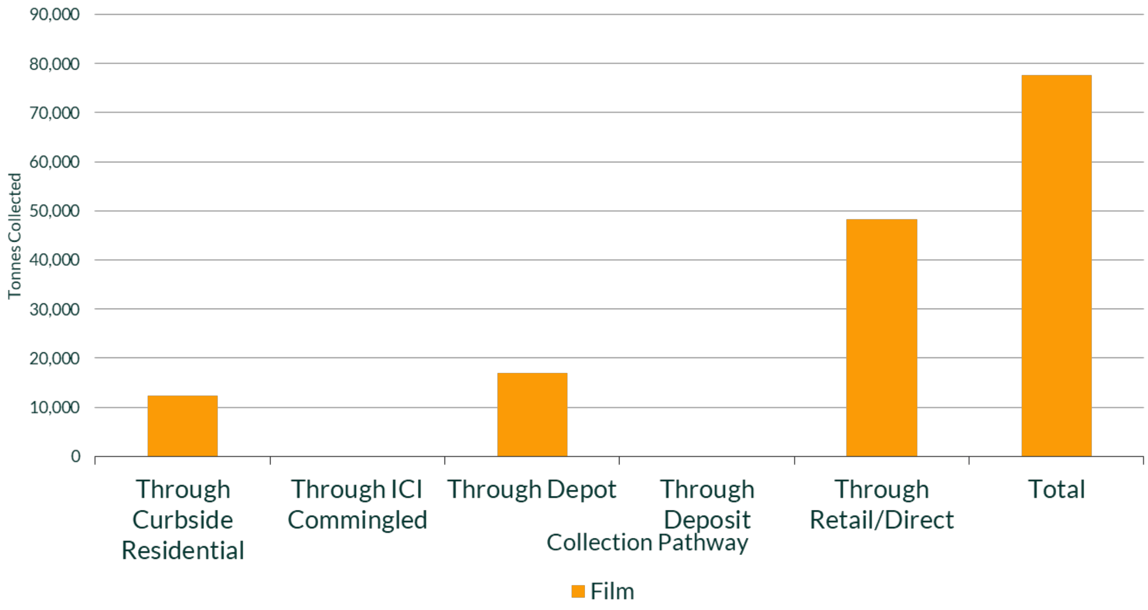
Source: (More Recycling, 2020)

Although MRF curbside film began to shrink from 2016 to 2018, it was still the second highest mode of collection for film in Canada, behind only source separated PE clear film. Noticeably when compared with the US, PE retail bag and film is only a small fraction at all points in the graph above.

In 2021, British Columbia reported a residential flexibles recovery rate of 28% (RecycleBC, 2022). B.C. uses a return to drop-off style collection. The first reported recovery rate for flexible packaging in B.C. was for 2017 (but was published in their 2018 report). The recovery rate at the time was 20%, and dropped slightly to 19% in 2018 (RecycleBC, 2018). The recovery rate would seem to have steadily increase since then. Additionally, through the B.C. EPR program's partnership with Merlin Plastics, drop-off centers in the province announced in January 2023 that they would begin accepting a range of multi-layer, multi-material flexibles in their collection systems (British Columbia, 2023). The additional materials include crinkly chip bags, candy wrappers, woven bags and protective envelope packaging. As in the US, monolayer PE film is only around half of film generation, meaning the remaining half must be addressed as well.

An estimated 79,000 tonnes of plastic film were estimated as collected for recycling. This relates to an 9% collection rate for plastic film. This is several percentage points higher than the collection rate of film in the US, despite Canada having seemingly increased access to film recycling. The 78,000 tonnes is 18% of all plastic packaging collected for recycling in Canada. The chart below shows the collection pathways for plastic film in Canada.

Figure 38. Collection of Plastic Film by Pathway in Canada



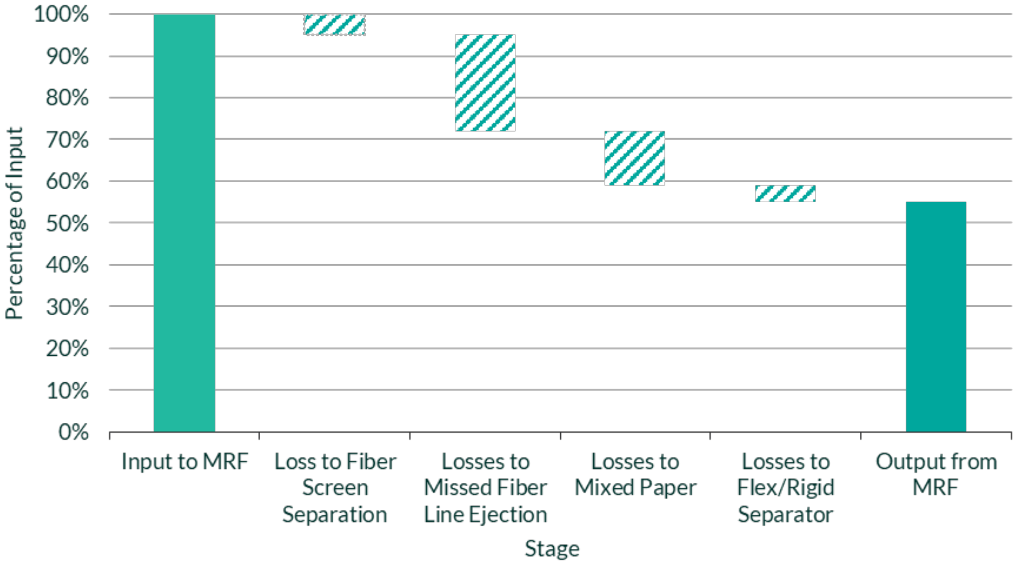
Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

Plastic Film Sorting

As plastic film is accepted in some curbside programs, film is sorted into its own bales at MRFs. The film is generally required by recyclers to be #4 LDPE film, rather than multi-layer or other film. Calgary's MRF reported that this commodity was only 0.22% of its output volume in 2020. Film may also end up in the rigids #3-7 bale as well. Calgary reported that 3% of its rigids #3-7 bale was #4 LDPE film.

Sorting films can be a challenge for MRFs due to its shape and ability to get caught in equipment. As a result, the yields on plastic film are relatively low from input to output in a MRF. In RRS's MRF of the Future study, the study found that the overall capture efficiency at the start of the pilot for plastic films was 55% (RRS 2020). While this study pertains to the US, it is one of the most detailed analyses of film capture at a MRF, and a similar analysis has not been undertaken in Canada. The study showed the following areas were losses at the MRF occurred:

Figure 39. Plastic film MRF losses



Source: (Eunomia Calculations), (MRFF, 2020)

The losses appear greatest at the missed fiber line ejection stage and the mixed paper stage.

In total, Eunomia estimates 59,000 tonnes of plastic film is sorted/prepared for recycling, this relates to a sorted rate of 6% of generation, and a 33% loss rate post-collection. This is lower than the 55% stated in the chart above, as there is a significant amount of plastic film collected through source separation, which doesn't need to be sorted at a commingled or dual-stream RMF.

Plastic Film Recycling

Both Merlin Plastics and EFS Plastics receive plastic film for recycling. EFS states that a plastic film bale delivered to them must contain at least 76% LDPE film and be relatively clean. Curbside film may have too many contaminants, such as labels and print coverage, that makes recycling the film difficult. Merlin Plastics does not publish a plastic film specification on its website. Both recyclers take in LDPE film and create pellets for use in new products. Merlin Plastics sells LDPE Natural and two separate LDPE mixed color pellets.

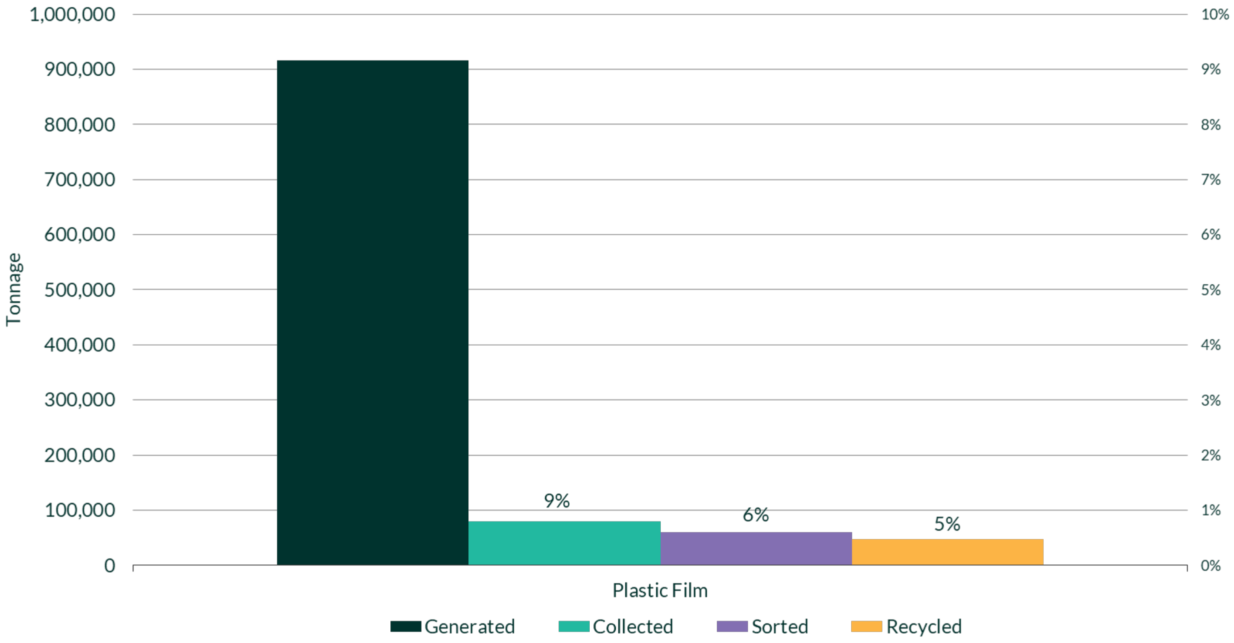
End markets for plastic film in Canada include non-food-grade packaging (e.g., new film and sheets) and drainpipes. Currently no food-to-food contact film is recycled in Canada.

In total, an estimate 47,000 tonnes of plastic film is recycled in Canada annually. This relates to 5% of generation.

Plastic Film Summary and Implications for Circularity

Plastic film is generally separated into PE films, which recyclers seek when it is clean enough, as well as composite/multi-laminated films, which have a smaller recycling market. Film generation is fairly even between these two categories, meaning only half of the film generated in Canada might be considered recyclable. In total, 9% of film is collected for recycling, 6% is sorted/prepared for recycling, and 5% is recycled. Because end markets include non-packaging applications, the current PCR content of plastic films for the Canada Plastic Pact is 1% for PE films, and 0% for multi-material flexibles (Canada Plastics Pact, 2020). Plastic film accounts for 49% of plastic generation in Canada—therefore increasing the use of PCR content to about 30% for both films specifically *and* plastic packaging at-large—which will require a significant increase in the tonnage recycled of plastic film. Below is a summary of the plastic film flows in Canada.

Figure 40. Summary of plastic film recycling in Canada



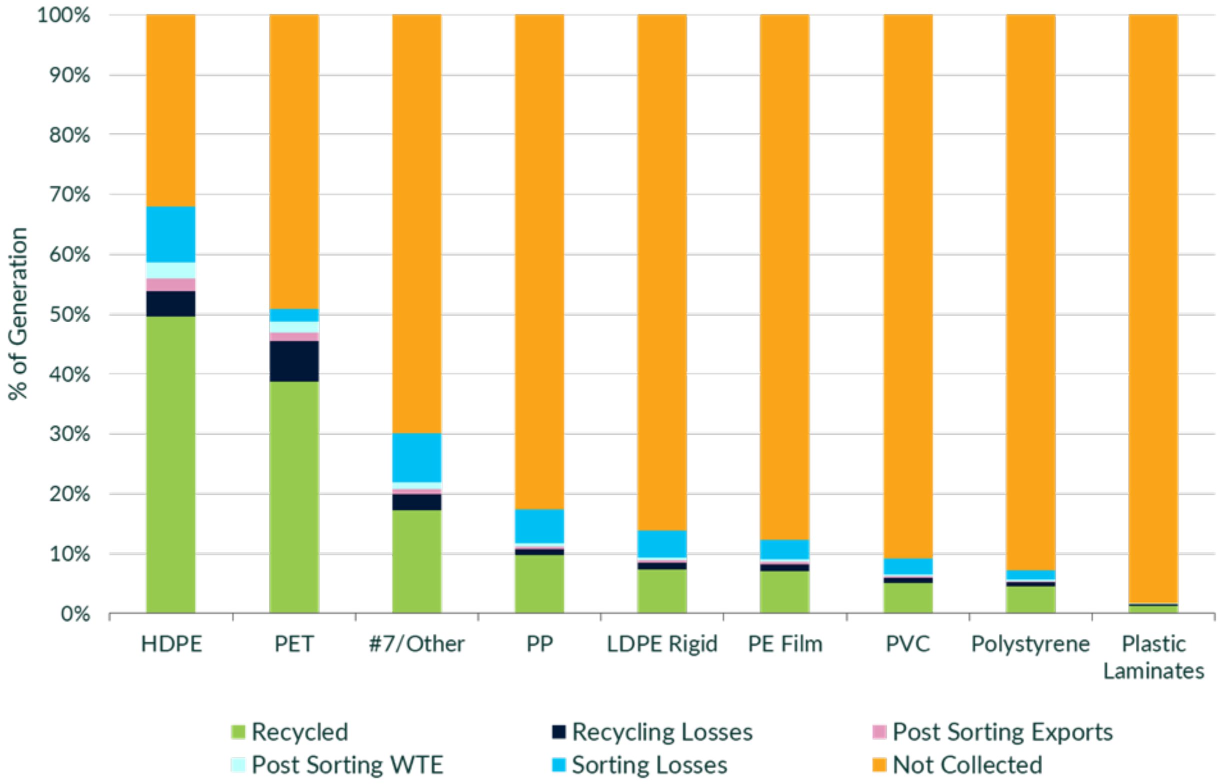
Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

Plastic Packaging Summary in Canada

Of the 440,000 tonnes plastic packaging collected for recycling in Canada, an estimated 345,000 tonnes (78%) are recycled in Canada and the US. An additional 13,000 tonnes are exported for recycling outside of North America. An estimated 16,000 tonnes are sent for energy recovery.

The figure below shows the end fate of generated plastic packaging waste, by resin. The chart shows the proportion of resins which are reprocessed into new material, as well as where unrecycled material is lost in the waste management chain (e.g., at the sorting, collection and disposal stages).

Figure 41. Recycling rates of plastic packaging in Canada (2020)



Source: (Eunomia Calculations), (StatCan Data, 2021) (Provincial Stewardship Reports), (Stina, 2018) (National Postconsumer Recycling Report)

HDPE has the highest proportion of tonnage that is recycled at over 45%. PET is next highest at just under 40%. The remaining plastics are all under 20% reprocessing rates. Multi-resin films/plastic laminates have the lowest proportion of material reprocessed, and nearly all of the material is not collected for recycling. The overall recycling rate of this group is estimated to be 16%. This is 14 percentage points below the Canada Plastic Pacts target of 30% PCR. Additionally, some of the 16% that is recycled is not suitable for new packaging applications, thus the PCR content of plastic packaging in Canada will be lower.

4.2 Material Flows and Recycling Performance: Plastics from Electronics

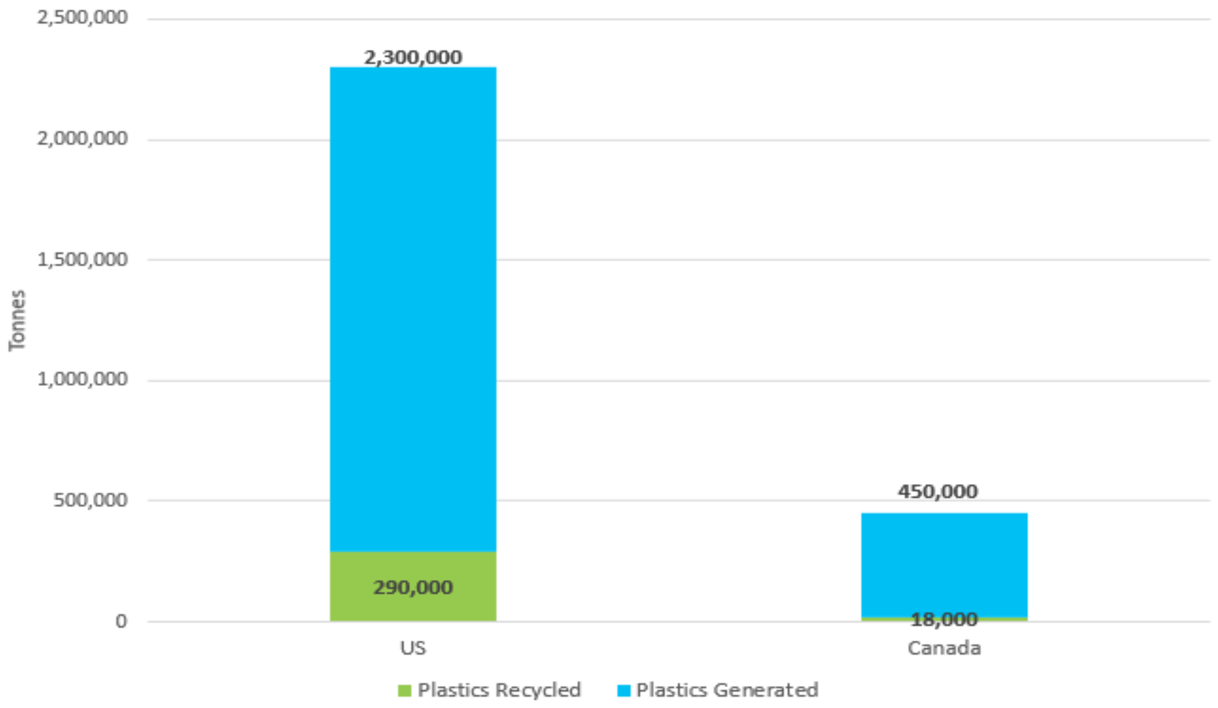
The following sections detail material flows and recycling performance for plastics from electronic waste in the US and Canada.

4.2.1 United States

The most comprehensive data on plastics waste material flows from scrap electronics is from the EPA in 2018. Their analysis was broken down into categories: major appliances, small appliances, selected consumer electronics, and lead acid batteries. Combining these generation values gives an overall estimated electronics waste generation of 11.8 million tonnes (US EPA, 2022). The quantity of plastics in electronics waste varies significantly depending on the type of product. The European Committee of Domestic Equipment Manufacturers commissioned the study "Material Flows of the Home Appliance Industry" which estimated a 20.2% contribution of plastics in major appliances and 24.5% in small appliances (CECED, n.d.). It was assumed that 38% of mobile phones were made with plastics, 10% of lead acid batteries (primarily from the casing), and 25% for other consumer electronics (Singh et al., 2018) (Achilias, 2015)., Based on these assumptions, the total plastic in generated electronic waste was estimated to be 2.3 million tonnes in 2018.

The presence of hazardous chemicals in the plastics from scrap electronics, particularly brominated flame retardants, poses significant limitations to the recyclability of these materials. Accurate detection of these hazardous materials is more successful under manual sortation; often under automatic sortation the recyclable and non-recyclable plastic resins are mixed and consequently, largely sent to landfills (Camec Technological Solutions, n.d.). Of the material that makes it to a manual sorter, roughly 290 thousand tonnes of plastics will be sent to a recycler (APR, n.d.).

Figure 42. Plastics waste in scrap electronics—the US and Canada



Source: (Singh et al., 2018) (Achilias, 2015)

4.2.2 Canada

The "Pilot physical flow account for plastic material, by product category" released by StatCan contains the most comprehensive national estimates of generated plastics in products produced for Canadian consumption. They estimated approximately 450 thousand tonnes of plastics in generated electronics in 2019 (Statistics Canada, 2023).

No comprehensive analysis of the plastics that were recycled from electronic waste was identified therefore the same assumptions for the US were used here. This approximated 18,000 tonnes of plastics from electronic waste being recycled in Canada. Most of the remaining material is landfilled with a smaller quantity (roughly 1%) being sent for waste-to-energy (Wisehart, 2021).

4.3 Material Flows and Recycling Performance: End-of-Life Vehicles

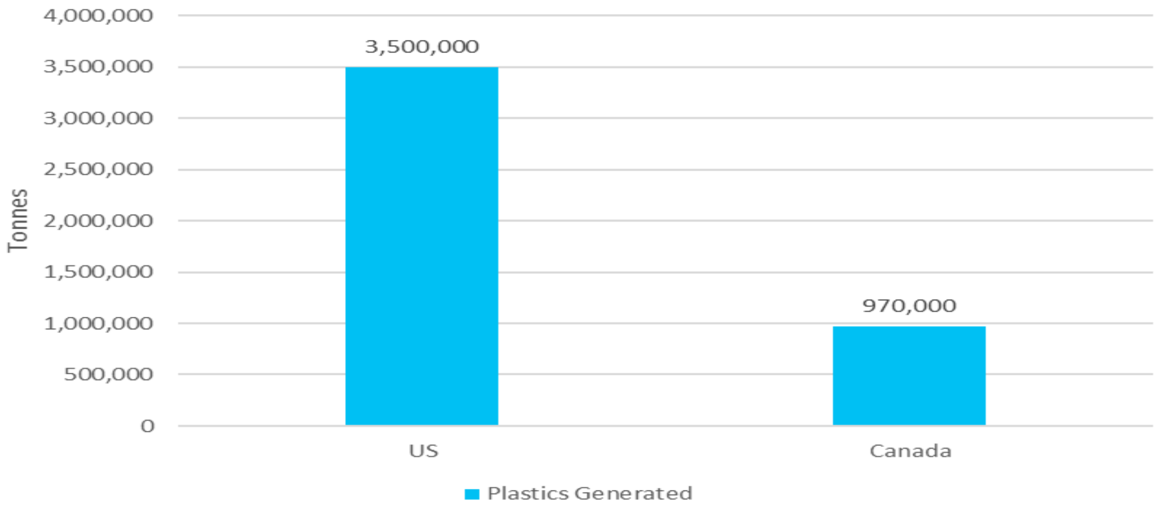
The following sections detail material flows and recycling performance for end-of-life vehicles in the US and Canada.

4.3.1 United States

The number of vehicles in the US has been increasing each year; with 289 million registered in 2020. However, limited data on the generation of plastics from end-of-life vehicles (ELVs) was available. The paper, "Sustainable end-of-life vehicle recycling: R&D collaboration between industry and the US DOE," estimated that the more than 200 shredders in the US shredded 10 to 15 million vehicles annually (Daniels, 2004). On average, the weight of a vehicle in 2010 was around 1.8 tonnes (Lowrey, 2011). Using the upper bound estimate of 15 million vehicles, there would be an estimated 27 million tonnes of ELVs waste generated annually. A publication by the European Commission in 2018 suggests that the plastic content of vehicles to be scrapped is around 13–14% (European Commission, 2018). Using the lower bound of their estimate, we can estimate that this would be equivalent to about 3.5 million tonnes of ELV plastic waste in the US.

These automotive scraps will most often be either landfilled or sent for waste-to-energy processes. Recycling of non-metallic residues has been limited, due to the presence of PCBs and other toxic substances such as mercury, lead, cadmium, chromium, arsenic, and polyvinyl chloride (Keller, n.d.).

Figure 43. Plastics waste in end-of-life vehicles—the US and Canada



Sources: (Daniels, 2004) (Lowrey, 2011) (European Commission, 2018) (Statistics Canada, 2023)

4.3.2 Canada

The "Pilot physical flow plastic material, by product category," released by StatCan, contains the most comprehensive national estimates of generated plastics in products produced for Canadian consumption: 970,000 tonnes of plastic generated for ELVs (Statistics Canada, 2023).

As in the US, automotive plastic waste is sent to a shredder, after which the plastic will end up in automotive shredder residue (ASR). There is currently no cost-effective method of recycling these plastics and thus they are sent to landfills to become cover material (Statistics Canada, 2020).

4.4 Material Flows and Recycling Performance—Construction and Demolition

The following sections detail material flows and recycling performance for construction/demolition (C&D) waste in the United States and Canada.

4.4.1 United States

Surprisingly little data are known about the C&D waste produced in the United States. The latest waste flow estimates available at the national level came from the EPA in 2018. They estimated that some 544 million tonnes of C&D debris were produced in the waste stream annually (US EPA, 2022). Of this generated waste, it has been further estimated that plastics contribute 1% to the total weight (Napier, 2016). CalRecycle also published estimates for the composition of C&D waste in California and attributed 0.8% to plastics; however, this study did not include carpet and carpet padding, which may account for the differences between these estimates (Cascadia Consulting Group, 2006). Using 1% as our plastics estimate, this would mean that about 5.4 million tonnes of plastic C&D waste are generated.

C&D Recycling Magazine estimated that there are 3,500 operating facilities processing C&D waste in the US (CDRA, 2023). Based on the EPA's suggested throughput capacity of 317 tonnes per day, 70% (3.8 million tonnes) of the total C&D waste generated will be sent to sorting facilities (Franklin Associates, 1998). The remaining 30% of the waste generated will be sent to a landfill.

A 2016 study of Massachusetts C&D debris management indicates that 3% of the total plastics generated in Massachusetts will be recovered after sorting (DSM Environmental Services, 2017). While this estimate is likely not indicative of C&D management nationwide, it is the best estimate available for gauging plastics recovered. It would indicate that 114,000 tonnes of plastic waste are being sent for recycling in the US.

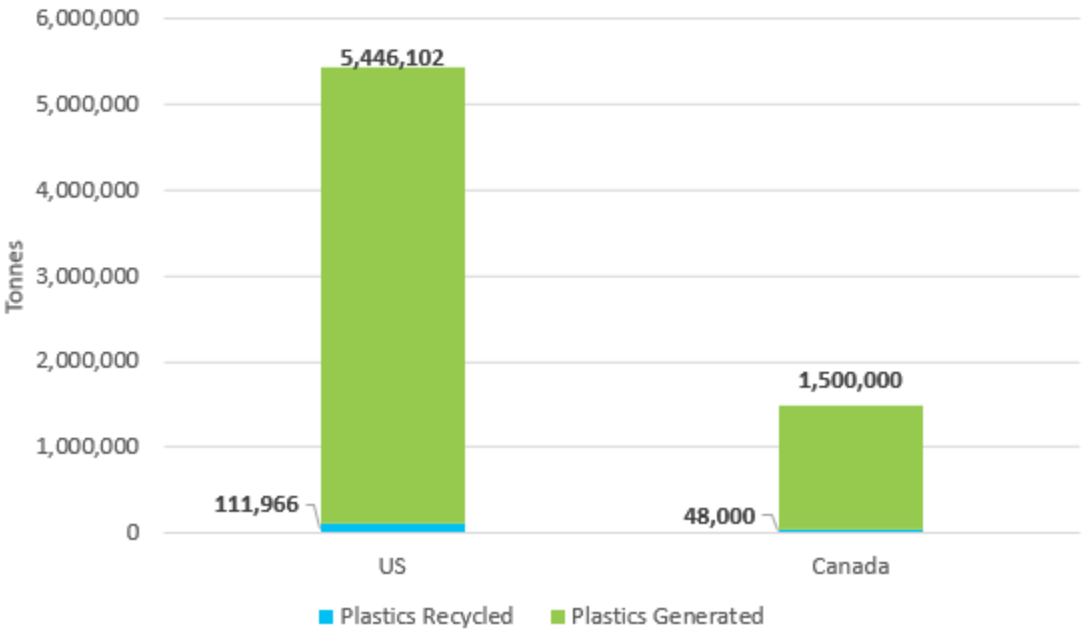
No compositional splits for plastic resins in generated waste were found for the United States; however, the C&D plastic waste splits from a 2018 report published by the European Commission can offer some insight into what the potential breakdown of resins might look like (see Table 34), below.

Table 34. C&D plastics waste splits in Europe

Polymer Type	Share
Polyvinyl chloride (PVC)	44.7%
Polyethylene (PE)	13.2%
Polystyrene (PS), Expanded polystyrene (EPS)	12.9%
Polyurethane (PUR)	8.8%
Polypropylene (PP)	5.1%
Other plastics	15.3%
Total	100.0%

Source: (European Commission, 2018)

Figure 44. Construction and demolition plastics waste in the US and Canada



Source: (US EPA, 2022) (Napier, 2016) (Cascadia Consulting Group, 2006) (Statistics Canada, 2023) (Light House, 2021)

4.4.2 Canada

The "Pilot physical flow account for plastic material, by product category" released by StatCan, contains the most comprehensive national estimates of generated plastics in products produced for Canadian consumption. Its estimate is that 1.5 million tonnes of plastic in C&D debris were generated in 2019 (Statistics Canada, 2023).

A report published by BC Housing estimated that 3.2% of C&D plastic will be recycled, similar to the estimate found for the US (Light House, 2021), which means that approximately 48,000 tonnes of plastic material will be sent for processing.

4.5 International Trade

A significant proportion of plastic waste is traded internationally. This waste is traded for several reasons, including, but not limited to, a lack of recycling capacity where the plastic waste is generated, increased demand for imports due to the economic value of plastic waste, and differences in legislative stringency. Using Harmonized System (HS) codes, with six-digit codes that enable product types to be uniquely identified, it is possible to track its trade. Table 35 highlights the HS codes relating to waste plastic products that can be identified in the United Nations' Comtrade database.

Table 35. Harmonized System (HS) codes related to plastics

HS Code	HS Product Description	Assumed product type
391510	Ethylene polymers; waste, parings and scrap	Polyethylene (PE)
391520	Styrene polymers; waste, parings and scrap	Polystyrene (PS)
391530	Vinyl chloride polymers; waste, parings and scrap	Polyvinyl chloride (PVC)
391590	Plastics, not elsewhere specified.	N/A

Further details on the quantity and value of each product type imported and exported by the US and Canada are provided below.

4.5.1 United States

In 2021, the United States was a net exporter of waste plastics, with a net trade balance of -87.07 kilotonnes. In 2021, out of the 557.1 kt of plastic waste that the US exported, 302.2 kt (54%) were exported outside North America. However, from a financial perspective, the US had a trade deficit of US$67.83 million, as shown in Table 36.

Table 36. US plastics waste imports and exports (2021)

HS Code	Imports				Exports			
	kt	%	Millions of US$	%	kt	%	Millions of US$	%
391510 (PE)	74.95	16.0	64.26	17.4	243.55	44.0	126.69	42.1
391520 (PS)	7.38	1.6	8.46	2.3	17.20	14.9	10.65	3.5
391530 (PVC)	28.72	6.1	26.48	7.2	23.64	21.1	10.09	3.4
391590 (Other)	358.99	76.4	269.54	73.1	272.72	20.0	153.46	51.0
Total	470.04		368.73		557.10		300.90	

Source: (UN Comtrade, 2021)

The majority of plastic waste imported into the US in 2021 was of the ‘Plastics, not elsewhere specified’ grade (HS code 391590), which accounted for 76.4% of the tonnage and 73.1% of the trade value. However, the export market is less dominated by a single grade, with ‘Ethylene polymers, waste, parings and scrap’ (HS code 391510) accounting for the greatest proportion of the tonnage exported, at 44.0%. Despite a more equally distributed split from a tonnage exported perspective, the trade values of the exported grades are dominated by ‘Plastics, not elsewhere specified’ (HS code 391590), and ‘Ethylene polymers, waste, parings and scrap’ (HS code 391510), which account for 51.0% and 42.1% of total exported trade value respectively. Table 36 shows that the US is a net exporter of ‘Ethylene polymers waste, parings and scrap’ (HS code 391510) and ‘Styrene polymers, waste, parings and scraps’ (HS code 391520) from both a tonnage and trade value perspective. This is likely driven by the limited recycling capacity in the US for these polymers.

Using UN Comtrade and the World Bank’s World Integrated Trade Solution, it is possible to identify the US’s largest trade partners which import waste plastics from the US, for each waste plastic grade. Table 37 shows the US’s largest trade partners for each waste plastics grade in 2021, by tonnes exported. The US’s largest export partner is Canada, with a total of 170.4 kilotonnes exported from the US to Canada in 2021. The majority of this (72.4%) consists of 'Plastics, not elsewhere specified’ (HS code 391590). The US’s second largest export market was Mexico, with 84.5 kilotonnes of plastic waste exported to Mexico in 2021.

Table 37. The US’s largest export trading partners by plastics waste grade (2021) (values in brackets indicate kilotonnes traded and value in US$, ranked by kilotonnes exported to these countries from the US)

Rank	391510 (PE)	391520 (PS)	391530 (PVC)	391590 (Other)
1	Malaysia (59.0, US$19.6m)	Canada (10.3, US$6.0m)	Malaysia (8.0, US$1.7m)	Canada (123.3, US$66.6m)
2	Canada (34.4, US$21.1m)	Mexico (2.2, US$1.4m)	Mexico (6.2, US$3.0m)	Mexico (64.4, US$39.4m)
3	India (31.1, US$16.1m)	Malaysia (0.9, US$0.4m)	Canada (2.4, US$1.1m)	Malaysia (13.5, US$3.1m)
4	Indonesia (27.1, US$12.3m)	Colombia (0.8, US$0.3m)	India (2.4, US$1.5)	Vietnam (10.4, US$3.8m)
5	Vietnam (25.5, US$8.3m)	Rep. of Korea (0.6, US$0.4m)	Spain (1.3, US$1.1m)	India (8.7, US$4.5m)

Source: UN Comtrade, 2021 and WITS, 2021

Table 45 shows the US’s largest import partners for plastic in 2021, by tonnage imported into the US. A total of 158.0 kilotonnes plastic was imported to the US from Canada in 2021, making Canada the US’s largest trade partner for plastic waste. The majority (64.5%) of this was 'Plastics, not elsewhere specified’ (HS code 391590). The second-largest import market for the US was Mexico, with 140.3 kilotonnes of plastic waste imported from Mexico in 2021.

Table 38. The US's largest import trading partners by plastics waste grade (2021) (values in brackets indicate millions of tonnes traded and value in US$, ranked by tonnes exported from these countries to the US)

Rank	391510 (PE)	391520 (PS)	391530 (PVC)	391590 (Other)
1	Canada (43.5, US$23.1m)	Mexico (6.1, US$7.5m)	Canada (11.6, US$6.5m)	Mexico (112.2, US$84.7m)
2	Mexico (19.0, US$23.1m)	Canada (1.1, US$1.0m)	Mexico (3.0, US$1.9m)	Canada (101.9, US$55.0m)
3	Australia (2.8, US$3.2m)	Australia	Czech Republic (2.6, US$4.8m)	Honduras (16.0, US$20.5m)
4	Ireland (2.4, US$4.5m)	Sweden	China (2.5, US$0.9m)	Germany (13.2, US$11.3m)
5	United Kingdom (1.8, US$3.1m)	New Zealand	Italy (2.5, US$3.3m)	Italy (11.6, US$10.0m)

Source: UN Comtrade, 2021

Overall, in terms of trade between the US and Canada, the US is a net exporter of waste plastics to Canada. The US exported a total of 170.4 kilotonnes of waste plastics and imported 158.0 kilotonnes of waste plastics in 2021, which nets to 12.4 kilotonnes. This is primarily due to Canada having a proportionally more developed waste processing infrastructure in place than the US, and therefore being in a better position to manage a greater amount of waste relative to the US. Based on the Comtrade data, it is not possible to determine whether waste is post-industrial or post-consumer. Additionally, there is no distinction for PE resins.

Overall, in terms of trade between the US and Mexico, the US is a net importer of plastic waste, importing 140.3 kilotonnes and exporting 84.5 kilotonnes. Again, this is primarily due to the US having a proportionally more developed waste processing infrastructure in place than Mexico.

4.5.2 Canada

In 2021 Canada was a net importer of plastic waste, with a net trade balance of 17.46 kilotonnes and -US$19.1 million, as shown in Table 39. Out of the 170.2 kt of plastic waste exported by Canada, only 12.2 kt (7%) were exported outside of North America. Across both imports and exports, by tonnage and value, the majority of trade was of the 'Plastics, not elsewhere specified' grade. For this grade, net imports totaled 29.1 kilotonnes and -US$24.8 million.

Table 39. Canada—waste imports and exports of plastics (2021)

HS Code	Imports				Exports			
	kt	%	Million US$	%	kt	%	Million US$	%
391510 (PE)	38.91	20.7	28.1	20.9	48.42	28.5	31.8	27.6
391520 (PS)	10.36	5.5	7.4	5.5	3.25	1.9	2.6	2.2

HS Code	Imports				Exports			
	kt	%	Million US$	%	kt	%	Million US$	%
391530 (PVC)	2.68	1.4	1.4	1.1	11.91	7.0	8.3	7.2
391590 (Other)	135.69	72.3	97.3	72.5	106.60	62.6	72.5	63.0
Total	187.64		134.2		170.18		115.1	

Source: (UN Comtrade, 2021)

The next largest grade of plastic waste imported and exported in Canada in 2021 was 'Ethylene polymers; waste, parings and scrap' (HS code 391510). Overall, in 2021 Canada was a net exporter of this plastic waste stream, with a trade balance of -9.5 kilotonnes and US$3.7 million.

Through Statistics Canada, it was possible to identify Canada's largest trade partners for each waste plastics grade in 2021. From the perspective of exports, the US was Canada's dominant trading partner in 2021, and ranked as the largest export partner for three of the four plastic waste streams in terms of tonnes exported. For the 'Styrene polymers, waste, parings and scrap' stream (HS code 391520) Canada exported more tonnes to Malaysia in 2021. In total, 157.9 kilotonnes of waste plastic was exported from Canada to the US in 2021. From a trade value perspective, this amounted to US$107.1 million.

Table 40. Canada's largest export trading partners by plastics waste grade (2021) (values in brackets indicate kilotonnes traded and value in US$, ranked by tonnes exported to these countries from Canada)

Rank	391510 (PE)	391520 (PS)	391530 (PVC)	391590 (Other)
1	United States (43.5, US$29.0m)	Malaysia (1.1, US$0.4m)	United States (11.6, US$8.1m)	United States (101.7, US$68.8m)
2	Malaysia (2.7, US$1.4m)	United States (1.1, US$1.3m)	Vietnam (0.2, US$0.1m)	Turkey (1.4, US$1.3m)
3	Vietnam (1.1, US$0.2m)	Spain (0.4, US$0.4m)	Pakistan	Thailand (0.9, US$0.5m)
4	India (0.4, US$0.3m)	Netherlands (0.3, US$0.3m)	Egypt	India (0.6, US$0.3m)
5	Turkey (0.1, US$0.1m)	Vietnam (0.1, US$0.1m)	Hong Kong	Bangladesh (0.4, US$0.3m)

Source: (UN Comtrade, 2021)

The US was Canada's largest import trading partner by tonnage for each plastics waste stream as shown in Table 41. In total, 171.6 kilotonnes of plastic waste was imported by Canada from the US in 2021. In terms of trade value, this equated to US$111.1 million.

Table 41. Canada's largest import trading partners by plastics waste grade (2021) (values in brackets indicate millions of tonnes traded and value in US$, ranked by tonnes exported from these countries to Canada)

Rank	391510 (PE)	391520 (PS)	391530 (PVC)	391590 (Other)
1	United States (36.52kt, US$25.69m)	United States (10.26kt, US$7.31m)	United States (2.50kt, US$1.35m)	United States (122.32kt, US$76.72m)
2	Ecuador (1.45kt, US$0.86m)	Slovakia (0.05kt, US$0.04m)	Italy (0.13kt, US$0.07m)	Netherlands (2.31kt, US$0.68m)
3	United Kingdom (0.45kt, US$0.78m)	Mexico (0.05kt, US$0.05m)	China (0.03kt, US$0.02m)	Ecuador (2.01 kt, US$3.26m)
4	India (0.13kt, US$0.06m)	Italy	Canada (0.02kt, -)	Canada (1.96 kt, US$0.60m)
5	Peru (0.09kt, US$0.06m)	Canada	Taiwan	Guatemala (1.20 kt, US$1.84m)

Source: (UN Comtrade, 2021)

Tables 40 and 41 highlight the plastic waste trade relationship between Canada and other countries. Overall, Canada is a net importer of waste plastics from the US. This is primarily due to Canada having proportionally more developed waste processing infrastructure in place than in the US.

5 Secondary Markets

Supply and demand for secondary plastics is tied to public and private sector Post-Consumer Recycled (PCR) content targets, facility capacity to process recycled materials, and other market drivers, as detailed in this section of the study.

5.1 Voluntary and Mandatory PCR Targets

Both voluntary commitments and mandatory requirements play a part in driving demand for secondary plastics. Voluntary commitments are typically made by individual companies as well as non-profit organizations. Mandatory requirements are typically established via local and national government legislation.

5.1.1 Voluntary PCR Targets

Many major consumer product companies operating in the US and Canada have made public commitments to produce new plastic products using PCR. They may also partner with various international NGOs promoting requirements for PCR use, such as the Alliance to End Plastic Waste, Plastic Waste Coalition of Action, and the Ellen MacArthur Foundation's New Plastic Economy Initiative which supports national Plastic Pacts. Both the U.S. Plastic Pact (USPP) and the Canada Plastic Pact (CPP) have set a target for their members to achieve an average of at least 30% recycled content across all plastic packaging by 2025. In general, it is unclear how members of these pacts will meet this goal—demand for PCR to meet this goal exceeds the current supply. In total, the US and Canadian Plastic Pacts require 1.4 million additional tonnes of plastic to be recycled to meet their target, which is double the quantity currently recycled (Canada Plastics Pact, 2020) (US Plastics Pact, 2021).

5.1.2 Mandatory PCR Targets

Neither the US nor Canada have set mandatory PCR targets. However, in late 2022, Canada announced plans to require at least 50% PCR in plastic packaging by 2030; the proposed regulations are expected to be published in Fall 2023 (ECCC, 2022). One goal of the proposed regulation is to strengthen market demand for recycled plastics which could drive increased collection, sorting, and recycling of plastic waste.

While the US does not have mandatory PCR targets, the US EPA Comprehensive Procurement Guideline program designates products that are or can be made with recycled materials. In some cases, state and local governments must comply with the guidelines when purchasing products using federal funds. The program lists 61 products designated in eight categories for which EPA has specified recommended PCR levels that cover a range of materials, including plastic (EPA, 2022).

Several US states have enacted recycled content laws associated with plastic beverage containers, rigid plastic containers, household cleaning and personal care products, and plastic bags. This is briefly summarized below. Additionally, in 2022, model legislation for minimum PCR in plastic products and packaging was developed by the Northeast Recycling Council and the Northeast

Waste Management Officials' Association (NERC, 2022). The purpose is to encourage states to integrate this language into legislation as well as to harmonize such legislation nationally.

- **California**.
    - California Beverage Container Recycling & Litter Reduction Act. Beverage containers. Containers subject to California Redemption Value law must contain no less than 15% PCR by 1/1/2022; 25% by 1/1/2025; and 50% by 1/1/2030. Wine and distilled spirits in a box must contain no less than 15% PCR by 1/1/2024; 25% by 1/1/2027; and 50% by 1/1/2032.
    - Rigid Plastic Packaging Containers Law. Containers must either use 25% PCR or reduce container weight; achieve at least a 10% product concentration or increase product concentration and reduce container weight; use reusable or refillable packaging; meet a 45% recycling rate.
    - Recycled Content Trash Bag Program. Must contain minimum aggregate of 10% Actual Postconsumer Material in trash bags sold in California or a minimum aggregate of 30% Actual Postconsumer Material in all plastic products sold in California.
    - Single-Use Carryout Bag Ban. Reusable plastic grocery bags must contain 40% PCR.
- **Maine**. An Act to Promote a Circular Economy. Plastic beverage containers. Must contain at least 25% PCR beginning 2026 and 30% beginning 2031.
- **New Jersey**. Recycled Content for Packaging.
    - Rigid plastic non-beverage containers must include an average of 10% PCR by 2024, increasing 10% every three years until reaching 50% by 2036.
    - Plastic beverage containers must include an average of 15% PCR by 2022, increasing 5% every three years until reaching 50% by 2045.
    - Plastic trash bags must contain an average of 10% PCR by 2024 and 20% by 2027.
- **Oregon**. Minimum Reuse or Recycled Content for Rigid Plastic Containers. Must meet one of three criteria: 25% recycling rate; 25% postconsumer recycled content; or be reused or refilled at least 5 times.
- **Washington**.
    - Recycling, waste, and litter reduction. Includes requirements for plastic beverage containers that must contain 15% PCR by 2023; 25% by 2026; 50% by 2031. Includes requirements for household cleaning and personal care products that must contain 15% PCR by 2-25; 25% by 2028; and 50%by 2031.
    - Minimum state standards for the use of bags at retail establishments. Must contain a minimum of 20% PCR until July 1, 2022, and thereafter a minimum of 40% PCR.
- **Wisconsin**. Recycled Content Plastic Containers. Must contain at least 10% recycled or remanufactured material.

5.2 Capacity for Generation of Secondary Materials

Most of the plastic collected for recycling in the US and Canada is purchased by reclaimers in North America. In 2020 in the US, a total of 2,003,900 tonnes (92%) was collected to be recycled. The remaining 8% of plastic material was exported (Stina Inc., 2020). In 2018 in Canada, the majority of plastic collected for recycling (282,400 tonnes, 92%) is purchased by reclaimers in North America, while 7% is exported (More Recycling, 2020).

The capacity and end uses of post-consumer plastics also varies by plastic type. The common end uses and reclaimer capacity in the US and Canada are shown in Table 42.

Table 42. Reclaimer capacity associated with post-consumer plastics in the US and Canada

Plastic Type	US Reclaimer Capacity (2020)	Canadian Reclaimer Capacity (2018)
PET Bottles	1,225,000 tonnes	116,000+ tonnes
HDPE Bottles	635,000 tonnes	100,000+ tonnes
PP and Other Bottles	Not available	Not available
Non-Bottle Rigid Plastic	544,000 tonnes	100,000+ tonnes
Film	499,000 tonnes	50,000+ tonnes

Source: (Stina Inc 2020) (More Recycling 2020)

In 2022, the US exported plastic scrap to Canada (143,335 tonnes) and Mexico (84,368 tonnes), which were the top two destinations for exported plastic scrap (Resource Recycling 2023). Overall, US plastic exports have declined by 20% between 2021 and 2022, continuing a decline that began in 2018 when China's National Sword campaign was implemented.

Canada has signed and ratified the Basel Convention, which restricts export of waste overseas, but the US has not. Furthermore, there are no requirements for companies to track what happens to plastic waste shipped between the two countries. Therefore, it is unclear how much of this traded waste is recycled versus landfilled or combusted.

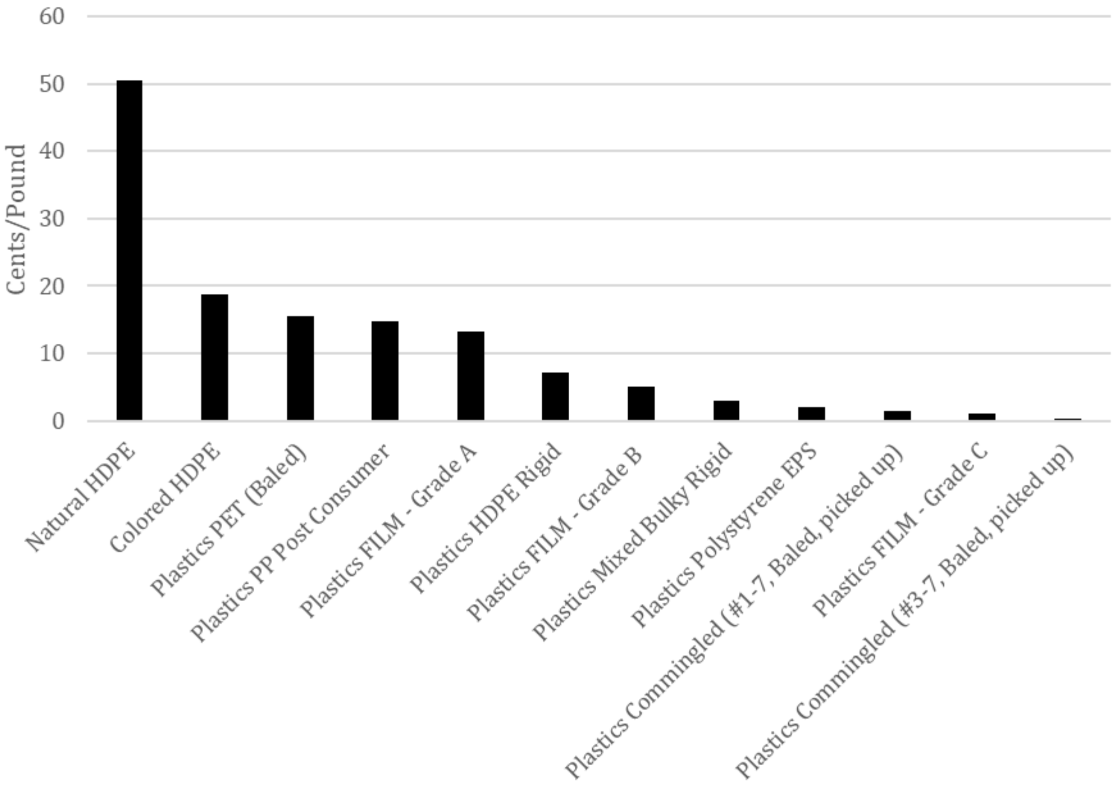
5.3 Price Variability

There is consistent week-to-week, month-to-month, and year-to-year variability in the cost of various commodity plastics, and many different drivers behind this variability, discussed in this section. More information on international trade of plastics is included in Section 4.5.

5.3.1 Factors Affecting Secondary Plastic Price

The current five-year average of different commodity prices is shown below. A number of factors influence the price of secondary material. Some are related to market forces such as supply and demand, however there are other characteristics of the material itself, geographic considerations and substitute material prices, which also play into the market price.

Figure 45. Highest to lowest five-year average plastic prices in the US and Canada (2018–2022)

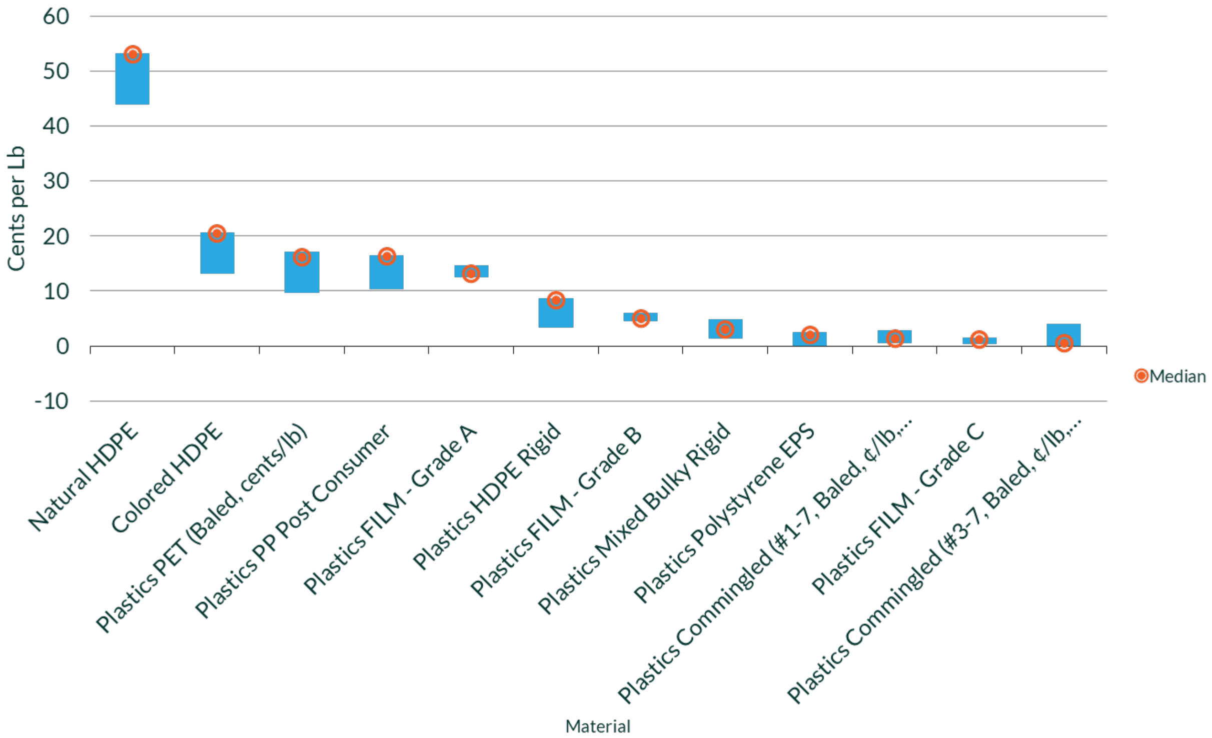


Source: (RecyclingMarkets, 2023)

Geography

The figure below shows the range of secondary material prices by plastics commodity, along with the median value across nine regions in the United States and Canada. It should be noted that this is material, which is collected through non-deposit streams. Deposit material often has a premium over the average value of its MRF stream counterpart.

Figure 46. Range of cost of various commodity plastics in the US and Canada, 2018–2022

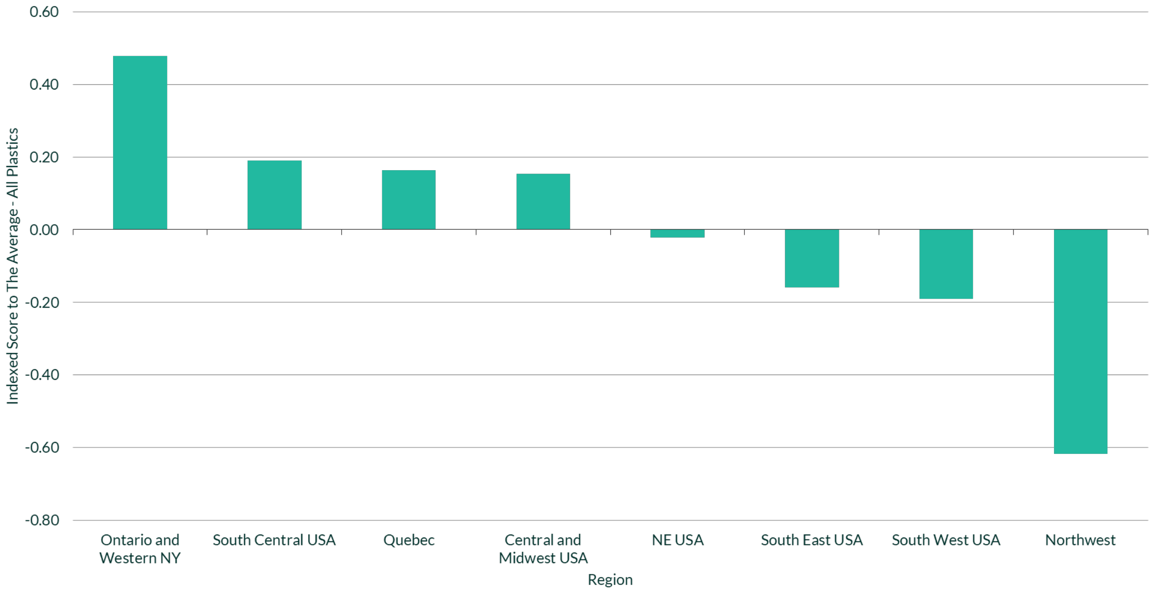


Source: (Eunomia Calculations) (RecyclingMarkets, 2023)

Natural HDPE has the highest median value over the past five years. It also has the highest absolute range at a range of US$199 per tonne, varying from US$970 per tonne (northwestern US) to US$1,169 per tonne (in the central US). Post-consumer PP and PET have each had similar five-year prices as well as similar ranges. Interestingly, PET has a recycling rate that is an estimated 13 percentage points higher than PP rigid packaging (see Section 4).

To assess all secondary plastics together, Eunomia indexed the price of each plastic commodity in each region to the average price of that plastic commodity in the US and Canada. Eunomia then took the average deviation of each plastic commodity in each region to the average of that commodity in the US and Canada. This allows us to standardize across each plastic type and show the overall trend in regions that are, on average, seeing higher commodity prices for plastic material. The results can be read such that if a region is given an average value of 0.20 across all plastics commodities, it yields prices that are 20% higher than the national average. The results are shown in Figure 47.

Figure 47. Average indexed values of plastic commodity prices to the US and Canada average



Source: (Eunomia Calculations) (RecyclingMarkets, 2023)

Across material types, the Province of Ontario in Canada and western New York State in the United States have the highest (above average) prices of all of the regions in the US and Canada. On average, the northwest region sees prices that are lowest across all markets. (Note that the northwest region includes areas such as British Columbia and is not restricted to the northwestern US.) The regions with the two lowest scores are the two regions on the West Coast of the US and Canada (northwestern and southwestern US). These two regions may still being impacted by the removal of China as a secondary market for plastics material, as they exported the most prior to the Chinese National Sword policy coming into play. British Columbia, which sits within the northwest category, has one of the largest plastic recyclers in the US and Canada (Merlin Plastics). Despite this, it still has the lowest score in the above chart.

Demand

Demand, driven in part by voluntary and mandatory PCR targets, can influence the price of material. Given that there is only a set amount of PCR currently available, unless recycling collections increase the supply of recycled plastic, additional demand for existing PCR may drive up the value of the material. In turn, this may drive investment in collection and sorting systems to meet the demand. An extended producer responsibility (EPR) system that has specific targets for different plastic types (flexible and rigids) or polymers will result in greater investment in the collection and sorting to meet demand. This could also result in prices dropping if there is more supply than demand.

Supply

The availability of recycled material can also influence the price of secondary commodities. Policies that incentivize recycling by consumers, such as deposits, can increase the amount of recycled material in a system. This increase in supply can lead to price decreases due to a lower scarcity of available recycled material.

Bale Quality

As discussed in Section 4, plastic recyclers have set specifications for their inputs. They demand that incoming material meet specifications on contamination, purity, composition of target commodities, as well as format. Recyclers may pay less for material that has higher levels of contamination or they may reject the bale completely (APR, 2023).

Virgin Material/Oil Prices

Secondary and virgin plastic material used in packaging perform essentially the same function. The difference and advantage for recycled material is generally related to either:

- A demand to use recycled content for either voluntary or mandatory reasons, or,
- A cost advantage in recycled material versus virgin material.

The cost advantage described in the second bullet above has not been the case in the recent past, as virgin plastic has seen lower prices per pound than secondary material (Resource Recycling, 2021). Lower oil prices lead to lower virgin plastic costs, which in turn lead to lower recycled plastic prices. As oil prices increase, the cost of virgin plastic increases, making secondary plastic more attractive from a cost perspective. This in turn raises the cost of secondary plastic material (Waste Dive, 2022). Higher oil prices would therefore increase the cost of secondary material, and thus potentially increase the supply of recycled material as the recycling industry sees an opportunity to make economic gains by increase the quantity of recycled material available.

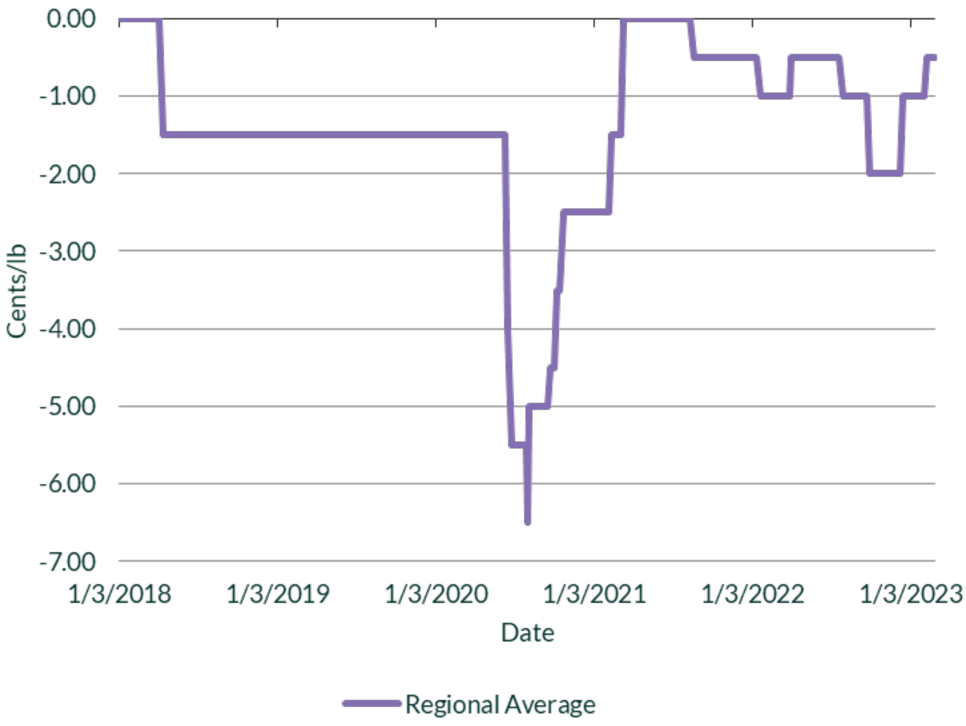
Transportation Costs

In addition to the low price of material, transportation costs can make hauling sorted plastics to a recycler cost-inefficient, particularly for lower value plastics. For example, rigid #3-7 plastics are priced at US$8.6 per tonne in their five-year average from the section above. Assuming a long-haul truck can haul 18.1 tonnes of plastic, a shipment of baled #3-7 would have a value of US$160. The cost to haul is about US$2.21 per mile (DAT Freight & Analytics, n.d.). Therefore, the breakeven point on hauling a truckload of rigids #3-7 is 72 miles. However, the net savings of hauling material to a processor rather than landfill would have to include savings on the tipping fee as well. Instead, a MRF may elect to not accept rigid #3-7 if the transport costs are too high, in this way they do not have to pay for the transportation or the landfill of material, as they would no longer receive it.

5.3.2 Rigids #3-7 Case Study on Variable Prices

Rigids #3-7 can have a positive or negative material value, depending on geography. Its low value is -1.4 cents per pound (also in the Northwest), while its high value is 2.6 cents per pound (Ontario, Canada and the western US). In a geographical area where rigid #3-7 has negative values, this means MRFs may have to pay secondary markets to take their material. This is further explored below as a case study in the variability and impacts of secondary plastic markets. The full five-year history of pricing of the Northwest's rigid #3-7 material is provided in Figure 48 below.

Figure 48. Northwest US secondary market pricing for rigid #3-7 bales (2018–2023)

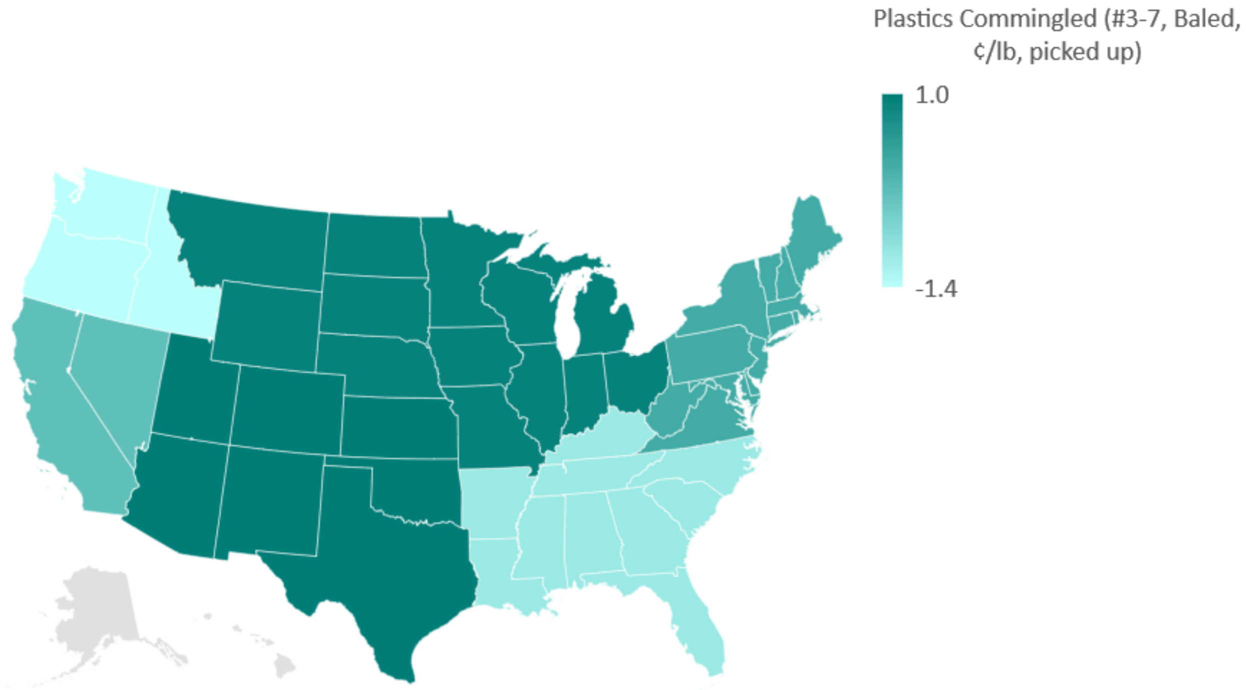


Source: (RecyclingMarkets, 2023)

Baled #3-7 material began having a negative value in the Northwest halfway through 2018, which is when China announced its National Sword policy, an import ban on certain secondary plastics (LORA, n.d.). The value dropped even further during the start of the Covid-19 pandemic and remains in negative territory today. In 2020, Eunomia calculated a 14% sorted rate for rigids #3-7 in the state of Washington using 2018 data (Cascadia Consulting Group, Eunomia Research and Consulting, 2020). In Eunomia's most recent report for Washington in 2021, the same group of materials had a sorted rate of 7% (Eunomia Research & Consulting, 2022).

The national variation in rigids #3-7 material can be seen in Figure 49 below.

Figure 49. Map of five-year average price of rigids #3-7 in the U.S.



Source: (RecyclingMarkets, 2023)

The prices of rigids #3-7 do not appear to be driven entirely by the availability of local recycling markets, although that may contribute to the pricing. Additionally, there are five states with mixed plastics processors: Louisiana, Missouri, North Carolina, Pennsylvania, and South Carolina. Although there are multiple mixed plastic processors in southeastern states, the prices in that region are relatively low. This would seem to indicate that the availability of mechanical recyclers is not the only factor in determining the regional value of a secondary material. Non-mechanical recycling outlets for mixed plastics, such as waste-to-energy or cogeneration at cement plants, may have an impact on the price of material as well.

6 Difficult to Recycle Plastics

In the following section, we define plastic's recyclability and emphasize recycling's dependency on the local waste management context, the ability to recycle plastics, and the demand for recycled resin. Difficult-to-recycle plastics are then characterized and listed, based on a combination of factors that considers plastic's manufacturing processes, product design and application, sorting and recycling processes, the availability and accessibility of local waste management infrastructure and collection programs as well as the market value of postconsumer plastics and recycled resin. We will also briefly explore product design across a range of applications (e.g., construction, packaging).

6.1 Characterization of Difficult to Recycle Plastic Packaging

The Ellen MacArthur Foundation (EMF) determines the recyclability of plastic packaging according to whether its successful collection, sorting and recycling are proven to work in practice and at scale, and whether the output is a commodity with suitable market value for its further used as feedstock in new plastic products (the same definition is employed by US and Canadian Plastics Pacts). The determination of what is ‘proof in practice and scale’ is subjective. EMF suggests using a threshold postconsumer recycling rate of 30% in multiple areas. For global recyclability, these areas should represent more than 400 million inhabitants (Ellen MacArthur Foundation and UN Environment Programme, 2020). The APR has a similar definition of recyclability though instead of providing recycling rate threshold, the APR definition sets out a criterion of at least 60% consumer accessibility to collection systems that accept the plastic item to demonstrate that the item is recyclable in practice and at scale (APR n.d.).

EMF assessed the global recyclability of plastic packaging in 2022 according to its definition of recyclability and using global survey data of recycling rates. Results from the survey demonstrated that flexible packaging is largely unrecyclable globally, except for larger than A4 mono-material PE flexibles in a B2B context (e.g., pallet wraps, large LDPE bags). Rigid plastic packaging that is unrecyclable globally includes PP non-bottle packaging (e.g., pots, tubs, trays), PET thermoforms (e.g., trays, cups, blisters) and any PVC, PS and EPS packaging (see Table 43, below) (The Ellen MacArthur Foundation, 2022). The US and Canada Plastics Pacts (USPP and CPP respectively) conduct country-specific assessments of recyclability according to EMF’s definition of recyclability and threshold of 30% postconsumer recycling rate in the respective Pacts’ market. According to Canada’s 2020 baseline report, Canada recycles PET thermoforms and other PET rigids, which are unrecyclable globally, at scale, as defined by the EMF (Canada Plastics Pact, 2020). EMF conveyed the same results for Canada in their 2022 global recyclability assessment (see Table 43, below) (The Ellen MacArthur Foundation, 2022). Conversely, though USPP identified HDPE bottles as the only recyclable packaging in practice and at scale in the US (US Plastics Pact, 2020), EMF’s global recyclability assessment (2022) demonstrated that no plastic packaging is recyclable in the US. The incongruence is due to mixed responses received from survey contributors on whether a plastic category met the 30% recycling rate threshold (The Ellen MacArthur Foundation, 2022).

Table 43. Global, Canada, an US recyclability (according to EMF's definition and threshold) of high-level plastic packaging categories

EMF Plastic Packaging Categories	Global Recyclability 2022*	Canada 2022*	US 2022**
PET Bottle	✓	✓	×
PET Thermoforms	×	✓	×
Other PET Rigid	×	✓	×
HDPE Bottle	✓	✓	✓***
HDPE Other Rigids	✓	✓	×
PP Bottle	✓	×	×
PP Other Rigid	×	×	×
PE Tubes	×	×	×
PS Rigid	×	×	×
PVC Rigid	×	×	×
>A4 mono-material PE flexibles in B2B context	✓	×	×
>A4 mono-material PE flexibles in business to consumer (B2C) context	×	×	×
Other >A4 flexibles	×	×	×
<A4 PE flexibles	×	×	×
<A4 PP flexibles	×	×	×
<A4 multi-material flexibles	×	×	×
Other <A4 mono-material flexibles	×	×	×

* According to the EMF's 2022 recyclability survey (The Ellen MacArthur Foundation, 2022).

** According to US Plastics Pact 2022 Baseline Report (US Plastics Pact, 2020).

*** Garnered mixed responses in EMF's 2022 recyclability survey (The Ellen MacArthur Foundation, 2022).

Table 43 provides a high-level breakdown of plastic packaging categories and their recyclability, based on resin, size and form. However, plastic products can be characterized as difficult to recycle due to a large combination of factors, including national and international context (e.g., availability of waste management infrastructure, collection system, market value of plastic); the plastic resin type, and the manufacturing processes involved (e.g., use of additives); and the product design and application (e.g., food applications). Plastic products can therefore be characterized as 'difficult to recycle' when product application, product design (i.e., resin, form, size, color) and their manufacturing processes (i.e., addition of additives, presence of contaminants):

- Reduce the likelihood of their correct disposal by consumers, such as multi-component packaging that require separation before disposal or small-format, 'on-the-go' products that are litter-prone and not captured by the collection system;
- Make the product disruptive to waste management infrastructure, namely sorting technology and recycling processes;
- Reduce the market value of the postconsumer product and recycled resin; and
- Generally, impede the collection and recycling of the product in practice and at scale according to the local waste management context.

A list of difficult to recycle plastic packaging and single-use items was collated based on the criteria above (see Table 44). This list of problematic packaging is not country specific, but applicable across the US and Canada. 'Problematic' plastic packaging identified by the USPP (US Plastics Pact, 2020) and CPP (Canada Plastics Pact, 2020) were included, as well as any additional products that satisfy the above criteria based on further research. Plastic packaging and single-use products were determined to be litter prone if the item was one of the top 10 most collected items from US or Canadian waterways in 2022, according to International Coastal Clean-up data (Ocean Conservancy, 2022). The criterion 'disruptive to waste management infrastructure' considered plastic that was difficult to sort or contaminated recycling streams, thereby reducing recycled plastic value. Products that were unrecyclable at scale in the US and Canada waste management contexts were defined as such according to EMF's definition and threshold of recyclability in practice and at scale for packaging types (as presented in Table 43). Rationale for classifying items as "difficult to recycle" are provided in Table 44.

Table 44. Difficult to recycle plastic packaging according to selection criteria

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
Single-use plastic straws, stirrers and cutlery	✓	✓	✓	Single-use and consumed "on the go" making the product difficult to collect and likely to be found as litter. Small format makes the product generally unrecyclable in practice, as identified by the USPP and CPP. Items smaller than 2 inches (5 cm) on at least one side are difficult to sort as they are smaller than the standard screen size in US and Canadian MRFs (APR, n.d.). Should the item be captured by the screen during sorting, optical sorters calibrated on items bigger than 2 inches will be unable to identify the plastic. Consequently, there are increasing legislative actions being taken to ban single-use items.
Bottle lids	✓	✓	✓	Small format and incorrect disposal make the packaging litter prone.

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
				Bottle lids may be disruptive to sorting technology because of their small format and because they may have seals which are difficult to separate. Bottle lids made of resins that make their separation from the bottle difficult in float-sink tanks (e.g., HDPE with PP) become contaminants in the recycling stream and may even render the bottle unrecyclable (e.g., trace amounts of PVC with PET) (APR, n.d.). Contaminants in the recycled output, for example blending PP (from lids) with HDPE (bottles), reduces the market value of the recycled output (APR n.d.). Lids are generally recyclable HDPE and PP however, recycling programs that accept bottle lids appear limited the US. A 2022 survey of 375 MRFs only identified 9 MRFs that explicitly accepted plastic lids (Last Beach Clean-up, 2022). In 2016, between 25% and 35% of the US population had automatic access to PP, PS and LDPE/LLDPE lids curbside recycling programs (Sustainable Packaging Coalition, 2016). As part of the Single-Use Directive in the EU, member states are starting to require single-use bottles to have tethered caps in order to combat some of these issues (European Parliament, 2019).
Single-use diapers			✓	On average, plastics make up over one-third of single-use diapers, by weight (Espinosa-Valdemar, 2015). However, in 2018, 4.1 million tonnes of disposable diapers were disposed of in the US alone, ~80% of which were landfilled while ~20% were incinerated with energy recovery (US EPA, 2022). Thus, diapers are substantial contributors to plastic waste and cannot be recycled by conventional methods (P. Notton et al., 2021).
Single-use checkout /grocery bags (LDPE)	✓	✓	✓	Single-use grocery bags are litter prone and not recyclable at scale in Canada and the US.
Films (including multi-layer) (PE, PP)		✓	✓	Multi-material and multi-layer films are undesirable, as the different resins cannot be separated. Resins do not melt at a uniform temperature, making them very difficult to process. Additionally, the film contains low value resins, which are likely to be disposed of rather than sent a secondary market. Mono-material films are recyclable in Canada (Canada Plastics Pact, 2020) and in the US (US
Multi-material films (both single and multi-layer)		✓	✓	

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
				Plastics Pact, 2020), though there are limited examples of this occurring at scale. PreZero in the US is accepting LDPE/LLDPE film that meet their specified requirements (PreZero, n.d.). Curbside collected film is usually collected in mixed waste and is thus susceptible to contamination. Additionally, product use and labeling increases contamination rates of film (Canada Plastics Pact, 2021). Recyclers are designed to process clear film from pre-consumer or commercial post-consumer sources. Sorting facilities are generally not designed to process flexible packaging, as they tend to be separated as 2D items, thus contaminating the paper and cardboard waste streams. Additionally, film can be disruptive to infrastructure by wrapping around sorting equipment and covering other materials on conveyors (Canada Plastics Pact, 2021). Films that are mono-material and multi-material are incompatible in recycling and need to be separated. Additionally, films (and other flexibles) are lightweight and require greater sorting effort to produce a bale of valuable material, thus increasing sorting costs. As such, MRFs in the US and Canada generally lack design and capacity to separate films economically.
Dark colored PET, PP and PE		✓	✓ (PP in Canada; PET and PP in the US)	Though PET and HDPE bottles, thermoforms, and rigids are considered recyclable at scale in Canada, dark colored PET, PP, and PE were identified by CPP as less easily recycled than unpigmented resins (Canada Plastics Pact, 2021). Only HDPE bottles are recyclable in practice and at scale in the US (US Plastics Pact, 2020) and the APR identified dark colored PP, (APR, n.d.) HDPE (APR n.d.), and PET (APR n.d.) resins as potentially detrimental to recyclability. They claim the "optical brighteners are not removed in the recycling process and can create an unacceptable fluorescence for any next uses of the recycled" material (APR, n.d.). Additionally, APR states that NIR sorting is sometimes unable to detect dark colored resins (PET, PP, HDPE), in particular, black. PE film is not separated by color, but dark colors are undesirable in the recycling stream (APR, 2022).
Opaque pigmented PET		✓	✓ (US)	The USPP identified opaque pigmented PET as problematic as it considers the current infrastructure in the US to be lacking at the scale

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
				necessary to recycle this waste stream, with projections to 2025 recycling management to continue to be open loop (US Plastics Pact, 2022). CPP on the other hand classified heavily pigmented PET as disruptive to sorting technology but not problematic (Canada Plastics Pact, 2021). The end-market for opaque PET is limited or zero, due to the use of mineral charges (e.g., TiO_2) and the range of pigments used, generating undesirable colors in recycled PET when mixed with clear PET (APR n.d.). PET is generally not recyclable at scale in the US (US Plastics Pact, 2020), and PET recyclers tend to reject the product in favor of clear PET or transparent blue/green PET.
Transparent pigmented PET (except for transparent blue and green)		✓	✓ (US)	Transparent pigmented PET is recyclable but requires separation from clear PET and pigmented recycled PET has lower market value (APR, n.d.). Transparent light blue and green are the exception as this can be recycled alongside clear PET. The USPP identified this material as problematic, and PET is not recyclable at scale in the US (US Plastics Pact, 2022).
Non-detectable carbon black pigmented plastics		✓		Identified as problematic by the USPP (US Plastics Pact, 2022) and CPP (Canada Plastics Pact, 2020), carbon-black pigment is not detectable by NIR sorters. Black absorbs light and therefore NIR sorters cannot identify the plastic resin based on the light reflectance.
Oxo-degradable plastics***	✓	✓	✓	Plastics containing oxo-degradable additives are detrimental to the environment, since they fragment rather than biodegrade, and generate microplastics; hence the categorization of these packaging items as litter-prone. Oxo-degradable plastics are not the same as compostable plastic and are not suitable for composting infrastructure. Additionally, oxo-degradable plastics are not designed for recycling since they contaminate recycling streams and reduce the market value of recycled content. Sorting technology generally cannot separate oxo-degradable plastics from common plastics (Ellen MacArthur Foundation, 2017). The fragmentation effect of oxo-degradable additives presents a risk to the performance of recycled content, potentially triggering degradation of recycled plastics in long-term applications (APR, n.d.). Both CPP and the USPP identified oxo-degradable plastics as problematic.

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
Plastics containing optical brighteners		✓		Optical brighteners are detrimental to recycling for several common polymers including PET, HDPE, PP and PS/EPS. Recycling facilities are unable to remove these additives from plastics and trace amounts can cause fluorescence in the recycled content, deeming it unacceptable for use. Moreover, this effect is not identifiable until much later in the recycling process, where low material value is only exposed after expenditures on several processing costs (APR, n.d.).
Multi-component and multi-material rigid plastics (including beverage cartons)	✓	✓		Correct disposal of multi-component products made of different materials can be confusing for consumers especially in the US and Canada where recycling confusion among consumers is already high (CBA, 2019) (Paben, "Survey finds lack of awareness for Canadian carton recycling," 2016). Product-specific labeling and provision of guidelines outlining which product component is recyclable and where it should be properly disposed of has not been legally enforced thus far. However, the Canadian government is developing labeling rules for recyclable packaging (see Section 7.2). Additionally, the EU is adopting a transition to harmonized labeling as part of their update to the packaging and packaging waste regulation that requires clear standardized labeling of plastic waste (European Parliament, 2019). Rigid plastic products with multiple components made of different materials (e.g., pumps, layers, dispensers, handles, seals, etc.) can be disruptive to the recycling process if the components cannot be separated from resin material through float-sink tanks (i.e., materials of similar density) or by other means. Multi-material components that are incompatible with base resins can also present contaminants in the recycling stream, degrading recycled content quality (e.g., aluminum composites, silicone, PVC). APR has detailed guidelines for preferred materials to be used in multi-component packaging according to base resin (APR, n.d.).
Products with problematic label constructions		✓		Packaging labels can be detrimental to sorting and recycling processes if they are not designed for sorting technology in mind. Certain label constructions can hinder sorting technology from accurately identifying resins and/or can enter as contaminants in the recycling stream due to difficulty in separation. A critical factor to consider for label materials is the density of the label, which may present challenges in float-sink tanks (meant

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
				to separate materials) should label and resin density be similar. Generally detrimental label constructions include: -Full sleeve labels and labels that cover large surface areas that hinder sorting; -Label materials that are incongruent with the product resin due to density similarities (in float-sink tanks) and become contaminants in the recycling stream, (e.g., paper, PVC and polylactic acid (PLA) labels which are detrimental across most common polymers); -Metallized labels, including metal foil and metallic printed labels, which lead to yield loss (inaccurate identification of plastic) or to contamination (if not identified); -Label adhesives resistant to washing and not removed, becoming contaminants; -Inks printed directly on products that bleed, discoloring recycled resins; and -Labels that either sink or float with the resin in float-sink tanks due to ink, coatings, decoration and other label constructions used, introducing a contaminant in the recycling stream. APR has more detailed packaging design guidelines, including label construction recommendations according to common packaging resins in the US and Canada (APR, n.d.). See Section 6.2 for a more detailed overview of recyclability due to product design.
PETG (Polyethylene Terephthalate Glycol) in rigid packaging		✓	✓	Since PETG is a copolymer (glycol-modified PET), it performs differently than PET in the recycling process. PETG is currently unrecyclable at scale and because there is very little legislation on accurate labeling of PETG to distinguish it from PET, it is often labeled with #1 (APR, 2018). If it is not separated properly, PETG contaminates PET recycling by forming clumps with the PET flakes (APR, 2018).
PS (Polystyrene) including EPS (Expanded Polystyrene)	✓	✓	✓	EPS is litter-prone as a lightweight and highly fragile material. Neither PS/EPS are recyclable at scale in the US and Canada, though EPS is considered a highly recyclable material by APR. There are limited curbside collection systems in the US and Canada for PS/EPS (APR, n.d.). In 2021, 45% of the US population had access to recycling programs that (explicitly and implicitly) accepted rigid PS packaging, the lowest accessibility rate of

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
				packaging material after aluminum foil (Sustainable Packaging Coalition, 2022). EPS is lightweight and bulky, making it costly to collect and transport. As such, EPS is normally densified (ground and compacted) to make material handling and processing more cost-effective, though not all facilities are equipped with the infrastructure (Recycling Partnership, 2019). Additionally, EPS is fragile and susceptible to contamination in mixed waste streams. Standard technologies remove contamination from densified EPS with a lot of difficulty, leading to high losses and lower recycled content quality. The high costs associated with EPS recovery and processing limits market demand for the postconsumer material. PS was also identified by CPP as having low market demand (Canada Plastics Pact, 2021).
PVC (Polyvinyl Chloride) including PVDC (Polyvinylidene Chloride)		✓	✓	PVC is currently not collected and is unrecyclable at scale in both the US and Canada and has been identified as problematic material by both the USPP (US Plastics Pact, 2022) and CPP (Canada Plastics Pact, 2020). PVC is primarily used in construction material and is highly durable, reducing postconsumer PVC available on the market. Lack of volume of postconsumer PVC limits its end-market capacity and value (Canada Plastics Pact, 2021). PVC is also used in packaging for shrink-sleeve applications on caps or in some metal closures' liners. PVC's low melting temperature and chemical composition makes it highly incompatible with several polymers. Processing PVC with other common polymers causes PVC to degrade into hydrochloric acid and chlorine. Therefore, even small amounts of PVC contaminating the stream can severely degrade recycled content quality for PET, PS, PP, HDPE and PE films. Additionally, PVC is extremely detrimental to PET and PS recycling and can render both resins unrecyclable. This is due to the added difficulty in separating PVC from the PET/PS stream due to similarity in density (APR, n.d.).
Biodegradable plastics		✓	✓	Biodegradable plastic, which degrades in different conditions and encompass a wide range of plastics (see Bioplastics Milestone Study for breakdown), is a detrimental contaminant in recycling streams for common polymers. Biodegradable plastics

Plastic Packaging/ Single-Use Item	Incorrect disposal/ litter prone?	Disruptive to sorting/ recycling?	Not recyclable in practice and at scale?	Rationale
				often refer to industrially compostable packaging that require specific industrial conditions to become compost. However, the timeframes for industrially compostable plastics to decompose are longer than for food waste (and some garden waste) typically sent to aerobic composting/anaerobic digestion systems. As such, biodegradable plastics are largely incompatible with (i.e., do not fully decompose within) the limited composting infrastructure currently available in the US and Canada (see Bioplastics Milestone Study). Bio-based non-biodegradable plastics such as bioPET or bioPE are made from renewable sources to produce a chemically identical material to their fossil counterparts. These materials are not a contaminant to recycling processes and are just as attractive as conventional equivalents to recyclers.

In addition to the difficult-to-recycle plastics identified in Table 44, there is also a question of recyclability based on human and environmental health impact. The EU coined the term NIAS in 2011 to refer to non-intentionally added substances in food contact materials (FCM) that are chemicals which are not purposely introduced during the production process (European Union, 2011). Often, these chemicals can transfer from the FCM into food, and thereby ingested by consumers (Geueke, 2018). As yet, this term (NIAS) is not used in the US and Canada, though the US has other requirements for any food contact substance that is expected to migrate into food (Geueke, 2018).

The USPP, in identifying 'problematic' plastics, uses a criterion based on the presence of hazardous chemical additives that pose an environmental or health risk during manufacturing, recycling, or composting. Though technically unproblematic to the recycling process, the USPP has identified intentionally added Per- and Polyfluoroalkyl Substances (PFAS) as problematic, due to the aforementioned criterion (US Plastics Pact, 2022). PFAS are chemicals added to multiple products and have demonstrated long-term health effects and the ability to bioaccumulate in organisms. PFAS may be intentionally added and therefore be treated as contaminants (rendering affected plastics unrecyclable), in order to eliminate the introduction of persistent and harmful chemicals in plastic recycling streams. This approach was taken by How2Recycle in their recyclable labeling program (How2Recycle, 2021). However, PFAS can be unintentionally added to plastics by applying fluorine gas on plastics, as was revealed in an investigation by the EPA in 2020 (US EPA, 2021).

Due to the significant impacts to health at all stages in the lifecycle, as identified by the European Commission, PVC as a packaging material is considered to be a hazardous material (Zero Waste

Europe, 2021). "The polyvinyl chloride debate: Why PVC remains problematic material" states that some of the health concerns in the production of PVC is its contamination of air and drinking water supplies, and the presence of carcinogenic vinyl chloride monomers and bio-accumulating toxics (e.g., mercury, dioxins, and furans). Given that PVC is one of the "most environmentally damaging types of plastic, and that safer alternatives are already available for virtually all uses of PVC," it is strongly recommended that the use of PVC in products be phased out and eliminated (Zero Waste Europe, 2021).

6.2 Product Design

Product design is imperative to reducing plastic waste and increasing circularity. Plastic products' sustainability performance can be improved upon by designing for reuse (see Section 8), improving recyclability or replacing plastics with suitable alternatives and more circular material (The Ellen MacArthur Foundation, 2016). The first route to consider in product design is merely eliminating unnecessary plastic altogether. For packaging this may include producing solid-form cosmetic products (e.g., shampoo bars), removing unnecessary plastic film from fresh produce, and removing multi-buy packaging for products such as canned foods (Ellen MacArthur Foundation, 2020). Additionally, there is increased interest in making design switches to more recyclable packaging such as using paper instead, as Nestlé has demonstrated (Nestle, 2020).

Designing for recyclability means abandoning problematic designs that generate recycling challenges (see Section 6.1) and decrease value of recycled output. Overall design changes that address difficult to recycle plastic products or components may include:

- Designing mono-material instead of multi-material plastic products;
- Designing for easy separation of multi-layer/multi-component plastic products;
- Avoiding labels, pigments, inks, adhesives and additives which complicate sorting and/or 'degrade' recycled content quality;
- Designing products with more easily recycled plastic resin and forms (Ellen MacArthur Foundation, 2016); and
- Reducing virgin plastic use by light-weighting and incorporating PCR (US Plastics Pact, 2021).

However, the light-weighting trend (particularly the evolution towards more complex, multi-material formats to reduce the overall weight of the packaging) can have undesirable consequences at a systems level. If the cost and difficulty of collecting and recycling the packaging becomes too high compared to the revenues achieved from recycling the packing, it might not be recycled or even collected, and overall system outcomes might be worse (Ellen MacArthur Foundation, 2020). Lightweighting of plastics also demonstrates the potential to decrease recovery in a single stream MRF due to losses to the paper streams (RRS, 2015).

Product design recommendations are highly dependent on plastic product type, application, form, resin and recovery and recycling context (e.g., policy, infrastructure, technology). In the textile sector, these aforementioned, general design principles may manifest by choosing monofibers over blended fibers, minimizing the amount of fiber types used, avoiding additives, dyestuffs and coatings (e.g., water-repellent coating) that might contaminate recycled content, minimizing the use of non-recyclable accessories, and providing accurate labeling to aid in manual sorting (Redress, 2022). Similarly, in electronics production, designing for recyclability includes enabling easy access and removal of hazardous and non-recyclable material (e.g., click/snap solutions for batteries), avoiding coatings that change plastic density (e.g., lacquer), avoiding unrecyclable thermosets, avoiding molding/blending polymers, and using commonly recycled plastics (e.g., PET) (PolyCE, 2021). Recycling construction plastic materials face technological and financial feasibility issues due to the longevity of plastics used, reducing the available volume of postconsumer plastics and difficulties in post-consumer waste separation, decontamination, and recycling (EEA, 2020). Designing modular plastic building components for disassembly and deconstruction, reducing types of material used, and using mechanical fasteners could improve construction plastic material recovery for recycling or reuse (US EPA, 2022).

Regarding plastic packaging, the APR provides comprehensive guides in (re)designing plastic packaging for recyclability in the US and Canada according to the material and packaging type (APR, n.d.). Specific examples of product design adaptations that can improve to plastic packaging recyclability include:

- Avoiding multi-material and multi-layer film, which produce a low-value, recycled content and, instead, using mono-material film;
- Using clear, unpigmented PET or transparent blue/green pigmented PET instead of opaque or dark-colored PET, which lower the value of recycled PET;
- Using the compatible resins for lids, caps and other product attachments and closures;
- Avoiding labels that use incongruent materials to packaging resins that can disrupt accurate sorting, effective separation and can introduce contaminants in the recycling stream (Table 45);
- In particular, removing PLA and PVC in packaging labels that severely degrade recycled content quality and are difficult to separate from most common resins due to similarities in density;
- Avoiding PVC, PS and EPS due to limited collection systems in the US and Canada and contamination with other common polymers;
- Removing oxo-degradable additives and optical brighteners since they degrade the quality of recycled content;
- Avoiding additives that interfere with plastic density, which could hinder accurate resin recognition and sorting in float-sink tanks (APR, n.d.);
- Avoid using labels that generally cover more than 50% of the surface of plastic packaging so as to not hinder sorting technology from identifying plastic material; and
- Avoiding labels that use non-recyclable materials such as mineral oil colors, heavy metal inks and hot-melt adhesives (Eunomia, 2022).

Alternative materials could be utilized in place of fossil-based plastic. Innovation to replace plastic packaging with compostable materials containing similar properties is growing. For example, the efficacy of (nano)cellulose as a replacement is being researched (US Plastics Pact, 2021) and business are using innovative, organic materials like seaweed (see Loliware, n.d.) and mycelium (see Ecovative Design, n.d.) for packaging. Plastics made from bio-based sources and/or compostable plastics (e.g., PLA, polyhydroxyalkanoate (PHA), polyethylene furanoate (PEF), starch-based plastics) are further material alternatives to fossil-based plastics (Ellen MacArthur Foundation, 2016). Bioplastics are explored in more detail in the CEC Bioplastics Waste Milestone Study that accompanies the present study.

Table 45. Incongruent and preferred label materials, according to packaging base resin, and based on APR Design Guidance

Base Resin	Incongruent Label Material	Preferred Label Alternatives
PET	• Paper • PLA and PVC (contaminant in any amount) • PS • PET-G • Metallized, metal foil and metallic printed labels	• Labels that float, namely PP and PE
HDPE	• Paper • PVC • Metallized, metal foil and metallic printed labels • PS and PLA when adhesives not released during wash	• PP and PE labels (little quality degradation regardless of detachment)
PP	• Paper • PVC • Metallized, metal foil and metallic printed labels • PS and PLA when adhesives not released during wash	• PP and PE labels (little quality degradation regardless of detachment)
PS	• Paper • PVC and PLA (contaminant in any small amount) • Metallized, metal foil and metallic printed labels	• Labels that float • PS • Labels with high-melting temperatures such as PET (remain solid in PS extruder)
EPS	• Paper • PP and PE labels • PVC (contaminant in any small amount) • Metal foil labels	• PS • Labels with high-melting temperatures such as PET (remain solid in PS extruder)
PVC	• Paper • PET and PETG • Metallized, metal foil and metallic printed labels	• Labels that float, namely PP and PE

Source: (APR, 2023)

7 Policy and Regulatory Frameworks

Government policies and regulations are put in place to mitigate the negative impact that the production and mismanagement of waste can have on the environment, human health, and the economy. Policy and regulation are key to changing waste and recycling practices in order to move waste up the waste hierarchy and to increase material circularity, as part of the transition to the circular economy.

All countries are using policy to address plastics waste to varying degrees. The United States has a decentralized approach, where each state is responsible for implementing its own laws, and while some US states have done so to improve waste management and increase recycling, others have taken little action. Some states were early adopters of deposit return systems (DRS, e.g., Oregon in 1971), but not all of these programs include a full range of beverages, which means they are not capturing large volumes of PET (for example, the policies of Vermont and Massachusetts do not include non-carbonated beverages—e.g., water bottles). Due to the design of most of these programs, unclaimed deposits are not available to support infrastructure development and, as such, their performance currently is not optimal. While extended producer responsibility (EPR) for packaging is emerging in the US, it is too early to assess the impact of such systems. Canada has the most developed policy to address plastics and has set country-wide, waste reduction and resource recovery targets that will accelerate the transition to a circular economy. The Canadian federal government also released the Single-use Plastics Prohibition Regulations in 2022 and is supporting implementation of extended producer responsibility (EPR) programs for packaging and partnering with provinces and territories to support waste management and improve recycling programs. All but one (Nunavut) of Canada's provinces and territories have implemented a DRS for beverages and many have EPR and stewardship programs for a range of materials, many containing plastic components. There is also recognition that DRS and EPR for packaging can work together. Key components of effective policies to improve circularity, such as EPR and DRS, are discussed in Section 8.2.

This section gives an overview of the different policies that the US and Canada have implemented to manage plastic waste. It is akin to the policy section in the CEC Paper Milestone Study that accompanies the present study, concentrates on the impact of policy on circularity. More detail can be found in the Appendix.

7.1 United States

Despite efforts to regulate plastic waste at the federal level, management of plastic waste has primarily been left to individual states and municipalities in the United States (Mull, 2021, Jebe, 2022).

7.1.1 Federal Policy

Federal waste policy in the US has historically focused on regulating the processing of waste. The Resource Conservation and Recovery Act (RCRA), passed in 1976 and amended in 1980 and 1984, is the federal law that created the framework for proper management of hazardous and non-hazardous solid waste (EPA, 2022, US Congress, 1984). RCRA prohibits open dumping, requires the use of engineered end of life management, and sets standards for the construction and operation of municipal solid waste landfills and incinerators. RCRA also requires development of comprehensive solid waste management plans at the state level. Each state is ultimately responsible for implementing the laws under RCRA and can implement more stringent requirements if desired (Sicotte, 2021).

Waste policy in the US has also historically aimed at regulating the discharge of pollutants and hazardous substances. However, existing legal and regulatory definitions do not list plastic as a pollutant or hazardous substance. Furthermore, no plastic effluent limits exist at the federal level for industrial wastewater, stormwater, and plastic production facilities (National Academies of Sciences, Engineering, and Medicine, 2021). The current federal regulatory framework thus prioritizes regulating manufacturing and waste disposal processes rather than regulating individual products (Sicotte, 2021). The only plastic product that has been subjected to regulation is plastic microbeads under 5 millimeters in personal care items, which was banned through the Microbead Free Waters Act of 2015. The EPA has recently published their *Draft National Strategy to Prevent Plastic Pollution* (EPA, 2023) which also included proposed regulations on PFAS as a chemical of concern.

While there is no federal policy requiring plastic waste recycling or reduction (Sicotte, 2021), there have been recent policy developments supporting management of plastic waste. For example, the 2021 Infrastructure Investment and Jobs Act offers grants to states and local governments to enhance recycling infrastructure, incentivizing action rather than enforcing it. Additionally, in April 2023, the US EPA released a Draft National Strategy to Prevent Plastic Pollution that aims to (1) reduce pollution during plastic production, (2) improve post-use materials management, and (3) prevent trash and micro/nanoplastics from entering wasteways and remove escaped trash from the environment (EPA, 2023).

Further, in March 2023, the Biden-Harris administration's White House Office of Science and Technology Policy (OSTP) announced goals to promote bio-based manufacturing. One goal aims to, in 20 years, "demonstrate and deploy cost-effective and sustainable routes to convert bio-based feedstocks into recyclable-by-design polymers that can displace >90% of today's plastics and other commercial polymers at scale" (The White House Office of Science and Technology Policy, 2023). The White House's goals to transition from fossil-fuel based to bio-based plastics is discussed in more detail in the Bioplastics Milestone Study.

Table 46 lists current federal policies and describes their regulatory impact on plastic waste management. A significant portion of federal waste policy comprises environmental statutes enacted more than 30 years ago.

Table 46. US Federal legislation impacting plastic waste management

Policy	Date enacted	Description of policy	Impact on Plastic
Infrastructure and Investment	2021	Provides new funding for infrastructure projects.	The Act directs the Environmental Protection Agency (EPA) to provide

Policy	Date enacted	Description of policy	Impact on Plastic
Act (US Congress, 2021)			grants to improve recycling, including US$275 million to invest in municipal recycling program and updates to improve waste management infrastructure, as well as US$75 million to enhance recycling education and outreach.
Microbead Free Waters Act	2015	Aims to reduce water pollution caused by plastic microbeads.	Ban on plastic microbeads <5mm in personal care products.
Marine Debris Act	2006 (amended 2012, 2018, 2020)	Determines the sources of, assesses, prevents, reduces, and removes marine debris and addresses the adverse impacts of marine debris.	Aims to reduce plastic pollution and improve waste management and recycling infrastructure. The 2020 Save Our Seas 2.0 Act which amends the Marine Debris Act, includes a requirement for the EPA to publish a series of reports identifying challenges and solutions for managing plastic waste.
Pollution Prevention Act	1990	Encourages pollution prevention and source reduction. Requires the EPA to produce recommendations to develop pollution prevention and source reduction strategies.	Encourages waste minimization through implementation of a waste hierarchy that favors recycling. Requires treatment and proper disposal if waste reduction and recycling are not possible.
Clean Air Act	1963 (amended 1967, 1970, 1977, 1990)	Regulates the discharge of pollutants and hazardous substances from facilities.	Impacts municipal solid waste combustion with and without energy recovery. Also applies to chemical recycling facilities that use pyrolysis.
Resource Conservation and Recovery Act (RCRA)	1976 (amended 1980, 1984)	Framework for the management of hazardous and non-hazardous waste.	Prohibits open dumping and requires the use of engineered end of life management (landfilling or incineration).

Many of the environmental statutes that make up the bulk of federal waste policy were passed over 30 years ago. More recent bills have been introduced in Congress to improve regulation of waste management and recycling. However, no major legislation focusing on plastic recycling and circularity has become law. Therefore, policy regulating and managing plastic waste in the United States has primarily been left to individual states and municipalities. Table 47 below enumerates recent bills introduced in the United States Congress that have yet to be passed. These bills serve to signpost the potential future direction of US policy with respect to increased material circularity.

Table 47. Recently introduced federal legislation related to plastic waste management in the US

Policy	Date Introduced	Description
Break Free from Plastic Pollution	2021	The bill creates a national DRS and a national extended producer responsibility program for plastic and paper packaging, mandates the phase-out of single-use products that are not recyclable, requires minimum recycled content for plastic beverage containers, establishes standardization of labels for disposal, and provides support for reuse and refill technology.
Recycling and Infrastructure Accessibility Act	2022	This law would create an EPA pilot program aimed at making recycling programs more accessible to rural and disadvantaged communities
Recycling and Composting Accountability Act	2022	The EPA creates an inventory of public and private MRFs, including details on materials each can process, and collect data on the count of community curbside or drop-off recycling programs, total inbound contamination, and capture rates for MRF and curbside programs, and the number of residents who face barriers to using recycling services.
REDUCE Act	2021	Set a fee of 10 cents per pound for the sale of most virgin plastics starting in 2022 and increase it to 20 cents per pound in 2024.
Ocean-Based Climate Solutions Act	2021	Set a fee of 5 cents per pound tax on virgin plastic used to make single-use products.
RECOVER Act	2021	Provides up to US$500 million in federal grants for improvements of MRFs, curbside collection, and education programs.
CLEAN Future Act	2021	Establishes recycled content targets for bottles and products, creates a task force to establish a national EPR system for covered products, produce a study on single-use products and product bans to determine any environmental, economic, or other effects of such bans.
Plastic Waste Reduction and Recycling Research Act	2020	Establishes plastic waste reduction and recycling research and requires the development of a strategic plan for waste reduction.

Non-Regulatory Federal Agency Action for Plastic Waste Management

Action at the federal level is not solely carried out by Congress. Federal agencies contribute strategic guidance, carry out scientific research, and provide funding to improve plastic waste management at home and abroad (US Department of State, 2022). The EPA is the federal agency tasked with implementing RCRA. It provides grants and funding to support plastic waste management and recycling in states, tribes, counties, and municipalities across the country. The 2021 Infrastructure Investment and Jobs Act directs the EPA to provide grants to improve recycling, including US$275 million to invest in municipal recycling program and updates to improve waste management infrastructure and US$75 million to enhance recycling education and outreach.

The EPA develops strategic objectives to improve plastic waste management. It released the first National Recycling Strategy in November 2021, reaffirming the goal of increasing the recycling rate to 50% by 2030. The strategy outlines five strategic objectives to improve recycling nationally, namely: (1) improve markets for recycling, (2) increase collection and improve infrastructure, (3) reduce contamination in the recycling stream, (4) enhance policies to support circularity, (5) and standardize measurement and increase data collection (EPA, 2021). The EPA has started releasing the drafts of a Circular Economy Strategy Series that will include a Plastics Strategy (EPA, 2022). The Circular Economy Strategy Series will build upon the National Recycling Strategy to identify action to reduce the impacts of material use, consumption, and disposal.

The Department of Energy (DOE) launched the Plastics Innovation Challenge in 2018 to coordinate initiatives on plastic recycling. The goals of the program include improving collection of plastics to reduce leakage into the environment, developing biological and chemical methods to deconstruct plastic waste, developing technologies to upcycle waste and increase recycling, manufacturing new plastics that are designed for recyclability, and supporting domestic supply chains by assisting manufacturers to scale and deploy new technologies (US Department of Energy, 2023).

The DOE built off this program to develop the Strategy for Plastics Innovation (SPI). The Department released the SPI report in January 2023, outlining its research and development strategy to improve domestic processing of plastic waste, reduce waste accumulation, and develop new plastic materials (US Department of Energy, 2023). The strategy addressed:

- Deconstruction (develop methods for selective and nonselective deconstruction, overcome challenges with plastic waste streams);
- Upcycling (identify and develop new strategies for converting waste plastic into valuable materials, develop markets for upcycled materials);
- Recyclable by Design (use advances in science and biology to design new plastic materials, co-design new materials for efficient deconstruction); and
- Scale and Deploy (improve collection and sorting technologies, assess energy and environmental impacts, demonstrate technologies at relevant scales).

The DOE also funds research and innovation through multiple research projects and laboratories, public-private partnerships, and industry partnerships. In 2021, the DOE announced a 14.5 million research and development fund to improve plastic recycling technology, specifically for single-use plastics and plastic film (Bioenergy Technologies Office, 2021).

The Food and Drug Administration (FDA) regulates the use of recycled resin in food-contact applications. The FDA considers the use of recycled plastic on a case-by-case base, issuing letters of no objection to manufacturers who satisfy safety standards for food-contact applications (FDA, 2020). To be approved to recycle plastic for use in food-contact applications, manufacturers must provide contaminant tests and a full description of their own recycling process, as well as proposed conditions for use of recycled plastic (temperature, type of food, duration of food-plastic contact, etc.).

The Federal Trade Commission (FTC) prohibits unfair and deceptive advertising or marketing claims, which applies to recyclability claims of plastic packaging (includes bottles and liquid containers). The FTC publishes “Green Guides” that are designed to aid marketers and prevent consumers from being misled about the sustainability and recyclability of a product. For example, the Green Guides recommend that a product or its packaging only be marketed as recyclable if recycling facilities are available for at least 60 percent of consumers or communities where that product is sold. The Green Guides also emphasize that the lower the levels of access to appropriate facilities, the more strongly the marketer should emphasize the limited availability of recycling for the product. While the Green Guides have not been integrated with any rulemaking and do not preempt state and local laws, they influence Unfair or Deceptive Acts or Practices (UDAP) laws and have been cited in litigation.

The National Oceanic and Atmospheric Agency (NOAA) Marine Debris program was authorized by Congress in 2006 to address marine debris and its adverse impact on the environment. The 2021—2025 Strategic Plan outlines six main goals: prevention, removal, research, response, coordination, and monitoring and detection. The program aims to support the blue economy by preventing marine debris from entering the environment and removing existing debris, benefiting fisheries, small businesses, and coastal communities (NOAA, 2022).

Federal Legislation Impacting Chemical Recycling

Currently, pyrolysis and gasification are regulated as solid waste incineration under Section 129 of the Clean Air Act, a federal law that imposes emissions guidelines and new source performance standards based on maximum achievable control technology (Ballingrud, 2021). However, the Clean Air Act does not directly regulate pyrolysis and gasification, but rather regulates chemical recycling as “solid waste incineration” and “institutional waste incineration.” In August 2020, the EPA under the Trump administration proposed a rule to exclude chemical recycling from incineration as a way to ease regulatory requirements. However, this rule never went into effect.

Recognizing that the industry has tried to use pyrolysis and gasification processes to treat plastic waste, the EPA released an advanced notice of proposed rulemaking related to regulation of pyrolysis and gasification in September 2021 (US Federal Register, 2021). Through this process, EPA gathered information and public comment to better understand the positions of industry and environmental groups. While the rulemaking process is ongoing, the EPA included a brief mention of chemical recycling in the National Recycling Strategy published in November 2021. The EPA stated in the report that “chemical recycling is part of the scope of this strategy and further discussion is welcome” (US Federal Register, 2021). The ambiguity of federal policy on chemical recycling leaves a void that states have filled by passing their own legislation.

7.1.2 State Policy

Given that each state develops their own waste management policies, they can vary significant across the US. Some states have implemented comprehensive laws to improve waste management and increase recycling while others have taken little action, resulting in a fragmented system of plastic waste regulation across the country. This section outlines the main policy levers states use to regulate plastic waste. These are material bans, DRS, EPR, and labeling. Additionally, some states have passed legislation facilitating chemical recycling for plastic waste. A list of policies in each state is included in the Appendix to this study.

Material Bans

Plastic bans often target single-use items that are not recyclable, such as plastic carrier bags, plastic cutlery, plastic straws, and expanded polystyrene.

Single-Use Plastic Bag Bans

Nine states have banned single-use plastic bags: California, Connecticut, Delaware, Hawaii, Maine, New Jersey, New York, Oregon, Vermont, and Washington (NCSL, 2021) (Department of Ecology, State of Washington, 2021). However, some of the first plastic bag bans lacked specificity, allowing plastic bags to be considered reusable based on the thickness of the plastic. Often the thickness was low, leading to bags being disposed or littered, instead of reused. To address this, bag bans increased the designated thickness or changed the definition of 'reusable bag', relying on indicators such as material type (fabric bags instead of plastic), a minimum lifetime (must withstand a certain number of uses carrying a determined weight load), or ability to be washed.

Restrictions on Single-Use Plastic Straws

States have also passed restrictions on single-use plastic straws. A strict material ban on single-use plastic straws can disproportionately impact and place undue burdens on certain communities, such as people with disabilities, whom it can hinder from being able to consume food or beverages. Common alternatives such as paper or biodegradable straws are poor substitutes since they disintegrate more easily. Reusable straws made of bamboo or metal are not bendable, which is necessary for people with mobility limitations. To prevent such adverse impacts, states such as Washington, Oregon, Rhode Island, New Jersey, and California have enforced bans while requiring businesses to provide straws when customers request them (imPASTA, 2022).

This approach has also been applied to single-use cutlery. The states of Vermont, Washington, and California have banned single-use cutlery, but require businesses to provide plastic cutlery when customers request it.

Expanded Polystyrene Bans

Several states have also passed bans on expanded polystyrene (EPS):

- Starting in June 2024 in Washington, the sale and distribution of EPS products such as portable containers for cold storage and food service products (excluding packaging for raw food) are prohibited (Washington State Legislature, 2021). The sale and distribution of EPS void filling packaging, also known as 'packing peanuts', is also prohibited.
- Vermont prohibits food service establishments from providing EPS items for sale or distribution in the state, except for certain healthcare dining facilities and packaging destined for out-of-state distribution (Vermont Legislature, 2019).
- In New Jersey, individuals and food service businesses are prohibited from selling polystyrene foam food service products (State of New Jersey, 2020). Some polystyrene products are exempt from the ban for a period of two years until May 2024, including disposable, long-handled polystyrene foam soda spoons when required and used for thick drinks, portion cups of two ounces or less if used for hot foods or foods requiring lids, meat and fish trays for raw or butchered meat, including poultry, or fish that is sold from a refrigerator or similar retail appliance, and any food product pre-packaged by the manufacturer with a polystyrene foam food service product.

- In Maine, covered establishments are prohibited from processing, preparing, selling or providing food or beverages in or on disposable food service containers made of polystyrene foam (State of Maine, 2022). Covered establishments include food establishments, eating establishments, agricultural fairs, farmers' markets, food pantries, churches, community organizations, boarding homes, retirement homes, independent living places, and nursing homes. However, hospitals and meals on wheels establishments funded by the Department of Health and Human Services are exempted from the definition of covered establishment.
- Starting in 2024 in Colorado, retail food establishments cannot distribute EPS products for use as containers for ready-to-eat food (Colorado State, 2021).
- In Virginia, food vendors and restaurants with 20 or more locations are prohibited from distributing EPS packaging food service containers. This prohibition will extend to all food vendors from 2025 (State of Virginia, 2022).
- New York banned the sale and distribution of EPS food service packaging and polystyrene loose fill packaging in 2022 (The New York State Senate, 2021).
- Maryland prohibits individuals and food services from selling or providing EPS food service items (Maryland General Assembly, n.d.).
- California's EPR law requires producers of EPS food service ware in the state to demonstrate that their products meet certain recycling rates (State of California 2022). The recycling rates increase over time, starting at 25% on January 1, 2025, and reaching 65% on January 1, 2032, and annually thereafter. This is considered a de facto ban due to the low recycling rates of EPS.

Deposit return Systems (DRS)

Ten US states have deposit return systems (DRS) for beverage containers (California, Connecticut, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Oregon, and Vermont), with all these DRS covering plastic containers.

Details of each state's DRS are included in the Appendix, while California and Maine's DRS, as examples of centralized and de-centralized DRS respectively, are discussed in Sections 8.2.1 and 8.2.2, along with a discussion of best practice when implementing DRS programs.

Extended Producer Responsibility (EPR)

Four states have passed EPR legislation for plastic consumer packaging: Oregon, Maine, Colorado, and California. As these bills passed in 2021 and 2022, the EPR programs have not yet been implemented and cannot be evaluated on their impact.

Full details of each of these four EPR programs are presented in the Appendix. Points of interest drawn from these programs include:

- All EPR programs cover the cost of collecting and recycling plastic.
    - In Oregon, the Department of Environmental Quality is developing a list of covered materials for which producers must provide collection and recycling. The rulemaking process is ongoing, and the proposed list is expected to be published in November 2023 (Oregon Department of Environmental Quality, 2023). This list will

inform which plastic products are covered, including materials such as multi-layered items such as films.

- Producers, importers, and distributors of covered products are required to join a Producer Responsibility Organization (PRO) that manages EPR programs on producer's behalf. In California, producers comply individually without joining a PRO if they have achieved a source reduction of at least 5% through changing to refill, reuse, or elimination and at least 8% source reduction through optimization, concentration, right-sizing, bulking, shifting to non-plastic packaging, lightweighting, or increasing the number of consumer uses between 2013 and 2022. Producers can also comply individually if 75% of covered products sold achieve a 30% recycling rate as of January 1, 2023.
- All EPR programs are expected to have modulation of fees based on environmental impacts.
    - In Maine, the Department of Environmental Protection will issue a rule regarding the payment calculation including modulation to incentivize recyclability.
    - In California, fees are modulated based on various factors, including recycled content, source reduction, standardization of packaging that simplifies processing, marketing, sorting, recycling, and composting, and on the acceleration of source reduction and investment in reuse/refill systems.
    - In Oregon, producer fees are modulated based on PCR content, product-to-package ratio, material type, life cycle environmental impact, and recycling rate, with the aim of incentivizing producers to make changes to their production, use, and marketing of covered products.
- The programs in California, Colorado and Oregon will also include recycling targets for plastic materials; Colorado's program will also include targets for the proportion of post-consumer recycled (PCR) content in covered products; and California's program will also require all covered products to be either recyclable or compostable by 2032, achieve a 65% recycling rate for plastic material by 2032, and achieve a 25% source reduction by weight and by plastic component by 2032.

In 2023, Maryland lawmakers passed a bill mandating a needs assessment for the state and the formation of an advisory council to report findings and recommendations regarding EPR. It is likely that more states will adopt EPR covering packaging and paper products over the next 5 years.

Post-Consumer Recycled Content Requirements

PCR content requirements aims to increase demand for recycled material by requiring products to have a minimum amount of recycled content. PCR content requirements have been adopted in legislation in three states (New jersey, Washington, California) and incorporated into many voluntary corporate targets.

New Jersey (State of New Jersey, 2020)

This bill sets requirements for postconsumer recycled content in certain products such as rigid plastic containers, glass containers, paper and plastic carryout bags, and plastic trash bags. It also prohibits the sale of polystyrene loose fill packaging. Trash bags must have PCR of 10–40% depending on thickness. Rigid plastic containers must increase PCR by 10% every three years until reaching 50%, while plastic beverage containers must reach 50% PCR in increments of 5% every three years. Plastic carryout bags must have at least 20% PCR in 2024 and 40% by 2027. The bill also establishes exemptions, such as dairy products, infant formula, food for special dietary use, and refillable containers, and it provides for waivers if the manufacturer cannot meet requirements. The bill directs the New Jersey Department of Environmental Protection to establish incentives and develop a recycling education program and gives it the authority to review and update requirements based on market conditions.

The bill also requires labeling of rigid plastic containers with the name of the manufacturer and location, or a URL to an Internet website that has the information. Certain exceptions apply to the requirements such as for products destined for shipment outside the State or for products regulated under federal laws.

Washington (Committee on Appropriations, 2021)

Washington has minimum postconsumer recycled content requirements for plastic beverage containers, plastic trash bags, household cleaning and personal care products, as well as wine in 187-milliliter containers and dairy milk. The minimum recycled content percentages increase over time, reaching 50% on and after January 1, 2031 (for beverages except wine and dairy milk), and on and after January 1, 2036 (for wine and dairy milk).

The bill also requires producers of plastic trash bags to label each package with the name of the producer and the location of the producer's headquarters, or with a URL or QR code to a website containing that information. This requirement does not apply to plastic bags designed to hold, store, or transport dangerous waste or biomedical waste.

Table 48. Washington PCR content requirements

Washington PCR content requirements					
Recycled content required	Beverage container producers	Household cleaner and personal care container producers	Plastic wine container (187 milliliters) producers	Dairy milk containers	Plastic trash bag producers
10 percent	–	–	–	–	1/1/2023
15 percent	1/1/2023	1/1/2025	1/1/2028	1/1/2028	1/1/2025
20 percent	–	–	–	–	1/1/2027
25 percent	1/1/2026	1/1/2028	1/1/2031	1/1/2031	–
50 percent	1/1/2031	1/1/2031	1/1/2036	1/1/2036	–

Source: (Committee on Appropriations, 2021)

California

California has minimum PCR content requirements for beverage containers subject to the California Beverage Container Recycling and Litter Reduction Act. From January 1, 2021, to December 31, 2024, beverage manufacturers subject to California Redemption Value must ensure that, on average, the plastic beverage containers they sell contain at least 10% postconsumer recycled plastic each year. From January 1, 2025, to December 31, 2029, the minimum requirement will be 25% postconsumer recycled plastic. Starting January 1, 2030, it must be at least 50% (State of California, 2019).

California's single-use plastic bag ban additionally requires reusable grocery bags made from plastic to contain a minimum of 40% PCR content since January 2020 (State of California, 2015).

Labeling

A clear labeling system ensures transparent and consistent approaches to advertising and marketing on recyclability claims. Labeling aims to reduce consumer confusion and increase awareness of what can and can't be recycled. One of the major challenges as highlighted in previous section is that there is significant variation on what can and cannot be recycled across different municipalities and jurisdictions. Examples of labeling requirements in California and Oregon are described below.

California

California's Truth in Labeling law (SB343) was passed in May 2021. The law prohibits the use of the chasing arrows symbol or any other suggestion that a product is recyclable unless it is collected for recycling by at least 60% of the population of the state or it is sorted for recycling by processing facilities that serve at least 60% of recycling services statewide (State of California, 2021).

The law requires a product container that is advertised or labeled as good for the environment (using terms such as "environmental choice," "ecologically friendly," "earth friendly," "environmentally friendly," "ecologically sound," "environmentally sound," "environmentally safe," "ecologically safe," "environmentally lite," "green product") or through a chasing arrows symbol must maintain records and documentation substantiating that claim (Section 1-17580).

Additionally, rigid plastic bottles and rigid plastic containers sold in California are required to have a code indicating the resin used to produce it inside of a triangle with the associated abbreviation of plastic. The bill prohibits the resin identification code from being placed inside a chasing arrows symbol unless the product meets the requirements for statewide recyclability (Section 3-18015). Plastic packaging, plastic products, and non-plastic products will not be considered recyclable if they are designed with any components, adhesives, inks, or labels that prevent such materials from being recycled.

Furthermore, California's EPR law incorporates labeling in the eco-modulation of fees for producers (State of California, 2022). EPR fees for a covered product are adjusted following a bonus/malus system. A product with clear and accurate instructions for disposal, recycling, composting, or reuse that improve consumer behavior are incentivized by lowering fees, and vice versa.

Oregon

The Plastic Pollution and Recycling Modernization Act is Oregon's EPR law, which creates a truth in labeling task force to evaluate misleading or confusing claims regarding the recyclability of products and packaging (OR Senate Bill 582, 2021). This work must include consideration of accessibility for diverse audiences. The EPR law also repealed the statute requiring all rigid plastic containers to have Resin Identification Codes (RICs) surrounded by a chasing arrow symbol. Despite this, 36 other states still have this labeling requirement, meaning many plastic packages in Oregon still have a RIC with a chasing arrow. Oregon currently has no labeling requirements. The Truth in Labeling Task Force evaluated a wide array of recycling labels and provided recommendations to the legislature in its final report submitted in June 2022 (Oregon Truth in Labeling Task Force, 2022). The task force defines a recyclability claim as a representation on a label or in advertising of a consumer good as recyclable. This includes text-based claims and symbols. Table 49, below, details packaging covered by statutes and whether recyclability claims are allowed or prohibited. The task force recommends mandating embedded consumer-facing recyclability labeling using smart-labeling technology and supporting labeling improvements at the federal level.

Table 49. Oregon labeling claims authorized per packaging category

Packaging	Recyclability Claim Authorization	Details
Beverage containers covered by Oregon's Deposit return Systems (DRS)	Allowed	Text and/or symbols allowed, including recycling instructions
Items on the Oregon local government collection list (this includes the state-wide collection list)	Allowed	Text and/or symbols allowed, including recycling instructions
Items exclusively on the Oregon drop-off center list	Allowed	Text and/or symbols allowed, instruction must say "drop-off recycling only", "recycle separately," or similar.
All other items	Prohibited	No recycling claims. Exemption for the recycling symbol surrounded by a circle with a 45-degree slash to indicate the item is not recyclable.

Source: (Oregon Truth In Labeling Task Force, 2022)

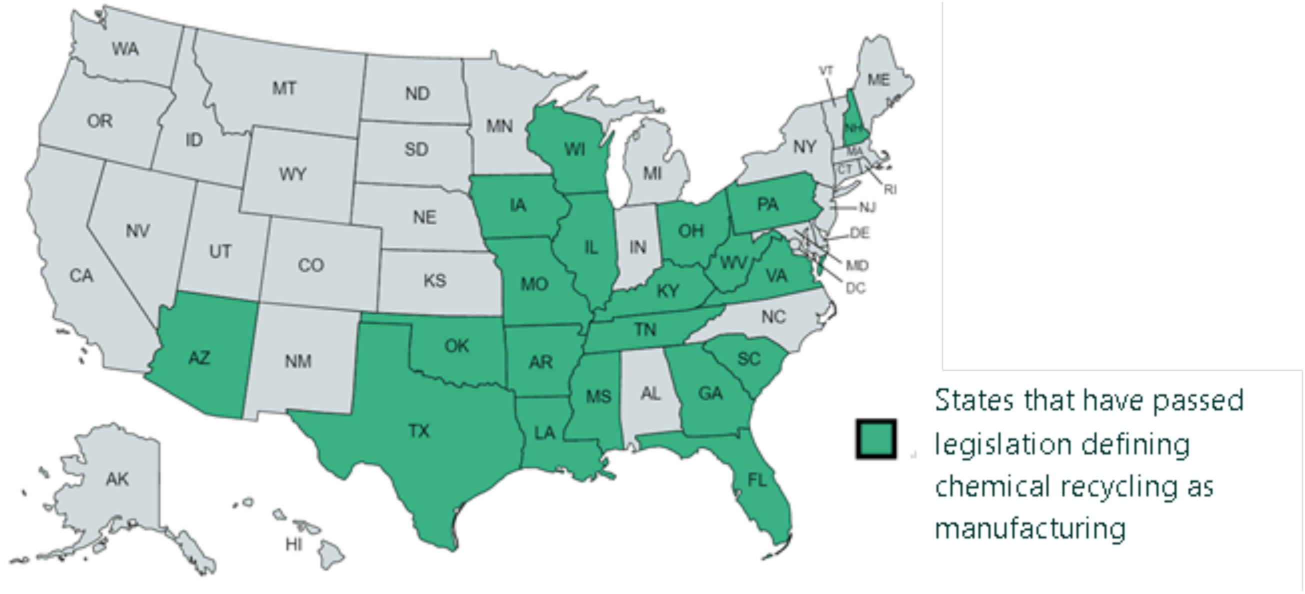
Chemical Recycling Legislation

Laws on chemical recycling in the US have been passed at the state level. Most of the laws classify advanced recyclers as manufacturers rather than waste treatment facilities. This classification gives advanced recyclers access to funding, alternative taxation structures, and/or less stringent environmental regulation requirements.

Being subject to less stringent environmental regulation requirements has the most significant impact, as it lifts the obligation for advanced recycling facilities to obtain a waste permit under a state's solid waste management laws, leading to much less regulatory oversight. It also means advanced recyclers do not have to obtain permits, meet site planning requirements and/or have wastewater management plans. While the specifics vary by state, all states reduce the planning or permitting requirements on advanced recyclers. This trend has become a cause for concern to environmental groups and legislators in the US Congress are taking note. In May 2022, 25 Democratic lawmakers sent a letter to the EPA seeking legislative language that would direct the EPA to maintain the current regulation of air emissions from chemical recycling plants (M. Quinn, 2022).

Many industry actors want to see pyrolysis and gasification regulated as manufacturing processes. In the EPA's advanced notice public comment period, many groups insisted that pyrolysis and gasification should not be considered combustion or incineration because the processes do not involve burning in an oxygenated space. This is supported by the American Chemistry Council, which defines advanced recycling as recycling and, as of August 2022, has supported 20 states (40% of US states) in passing laws to classify advanced recycling as manufacturing (ICIS, 2022). These states are listed in Table 65 of the Appendix and shown in Figure 50. While pyrolysis and gasification do not inherently combust or incinerate, they are nonetheless chemical processes that release increased toxins and emissions relative to mechanical recycling facilities. Consequently, while demonstrating promise as a recycling technology, it is still not fully endorsed as a recycling pathway by the EPA, other government agencies, and NGOs.

Figure 50. States with chemical recycling as manufacturing legislation



Source: Eunomia Research & Consulting

7.1.3 Local Policy

Local governments hold significant authority over the management of waste within their municipality or county. Local governments are often in charge of carrying out or contracting collection services, can set targets or goals to improve recycling, and implement bans designed to promote recycling. They exercise this power by establishing regulations for recycling and solid waste management through ordinances.

Collection Services

In the US, municipalities are generally responsible for the collection, recycling, and disposal of waste within their jurisdiction. This means that they have the power to determine how waste is collected and processed and can use that control to implement programs that encourage recycling and reduce waste to landfill. Municipalities usually either carry out waste collection or contract haulers to carry out collection services. Municipalities that contract haulers to collect waste and recyclables can use their bargaining power to negotiate for practices that can improve plastic waste collection and recycling. Additionally, municipalities can implement pay-as-you-throw programs, which charge residents based on the amount of waste they generate, encouraging them to reduce their overall waste and recycle more. More information on the collection systems in the US and Canada can be found in Section 3.1.

Targets and Goals

Local governments can set recycling goals, and a growing number of municipalities are implementing zero waste plans. Zero waste refers to a solid waste management strategy that aims to establish a circular material flow such that no material is wasted or underused. Zero waste strategies focus efforts on repair and reuse above recycling or resource recovery. This approach is being embraced by an increasing number of cities in the US, which are either incorporating zero waste principles into their existing waste management plans or developing their own dedicated zero waste plans. These plans outline a series of policy changes aimed at reducing overall waste, enhancing recycling efforts, and establishing systems that promote repair, reuse, and refurbishment.

Local Bans

Municipalities have the power to pass local landfill bans or material bans, which can be an effective way to improve plastic recycling.

Landfill bans, also known as disposal bans, aim to keep recyclables out of trash and subsequently out of landfills or waste-to-energy facilities. Landfill bans aim to improve source separation to maximize capture of recyclable material. A local landfill ban prohibits throwing recyclable products or packaging with municipal trash destined to landfill or waste-to-energy. Landfill bans can be general, targeting all materials that are recyclable based on that municipalities' recycling guidelines. Landfill bans can also be material specific or target specific types of packaging and products. Compliance with a landfill ban can fall on a variety of stakeholders, including residents, businesses, landfill operators, and waste haulers. For landfill bans to be effective, municipalities need to provide convenient and accessible recycling options for the targeted products. Moreover, appropriate penalties need to be in place to deter non-compliance, along with sufficient resources to ensure that the ban is enforced.

Material bans aim to eliminate the use of a material for a specific application or a specific item. This can be effective at reducing the overall amount of waste generated, or at reducing the amount of a material that contaminates the plastic recycling stream. For example, many municipalities have been implementing bans on expanded polystyrene foam in food packaging. This material is not easily recyclable and can contaminate the plastic recycling stream if it is not separated properly. By banning the use of polystyrene foam in food packaging, municipalities engage in a type of source reduction that can reduce the amount of contaminated plastic in the recycling stream, making it easier and more cost-effective to recycle plastic waste. Another example is bans on single-use carrier bags. Over 400 US cities have implemented policies to either ban or tax the use of plastic bags (Zeitlin, 2019). This encourages customers to bring their own bags and use reusable bags. Other local material bans include bans on single-use food service items such as plastic cutlery, straws, and takeout containers.

Reuse

Some jurisdictions have enacted law to impose reuse in certain applications. For example, Berkeley, CA, and Bellingham, WA, have enacted a requirement for reusables for on-site dining. Santa Cruz, CA, and Watsonville, CA, have introduced a disposable cup charge to encourage the use of reusable cup alternatives. Some municipalities have introduced organizations or partnerships to enable local reuse. For example, Seattle, WA launched a public-private partnership called Reuse Seattle among with partners including the city’s large sports and entertainment venues and small and medium-size restaurants and businesses to help standardize and increase access to reuse solutions (City of Seattle, n.d.).

State Pre-emption

The proliferation of ordinances on a local level can drive momentum for state legislation, which can enable greater legislative uniformity. However, some states have enacted pre-emption laws that restrict local governments from passing specific ordinances. For example, the uptick in local plastic bag bans has led some states to pass preemption laws, making it illegal for municipalities to pass any legislation that bans plastic bags or that places a fee on plastic bags and plastic packaging. So far pre-emption laws have been passed in twenty states.

7.1.4 Non-Packaging Plastics Policy

Policies related to the construction and demolition, automotive, and electronics sectors rarely focus on plastics and more commonly target the hazardous elements or contaminants that can be found within products in those sectors. Table 50 outlines the policies related to construction and demolition, automotive and electronics at a high level. More information on the non-packaging plastic markets and recycling systems is included in Section 3.2.

Table 50. Policies related to non-packaging plastics in the US

Sector	Policy Overview
Construction and demolition (C&D)	There are many policies that regulate the removal of potentially hazardous materials in C&D projects, such as asbestos or lead materials. Some states and municipalities also offer resources to encourage material reuse or the use of products with recycled content. For example, CalRecycle publishes a "Recycled Content Construction Products Catalogue," which includes some plastic items such as pipefittings with recycled content (CalRecycle, n.d.).
Electronics	There are no federal laws that require electronics recycling or target the plastics within WEEE specifically, but there are federal laws, such as the Resource Conservation and Recovery Act (RCRA) that covers the disposal of toxic elements found in electronics. Meanwhile, 23 states and the District of Columbia have EPR for WEEE or electronic devices. There are also states with polices that mandate manufacturers provide free and convenient recycling access for electronics wastes to consumers.
Automotive	Roughly 75% of most vehicles is metal, thus most recoverable material from vehicles is metal, not plastic (US Environmental Protection Agency, 2017). As such, there are no policies that directly target plastics found within automobiles. Most policy focuses on the special handling, transportation, and disposal of hazardous fluids and materials found in cars.

7.2 Canada

Overall, in Canada, regulation of waste falls under the remit of provincial and territorial governments, while management is overseen by municipal authorities. The Government of Canada has authority under the Canadian Environmental Protection Act (CEPA) of 1999 when there is the potential for toxic pollution from waste into the air, land, or water (L. Giroux, State of Waste Management in Canada, 2014). The federal Government is also responsible for waste management activities on federal land, as well as interprovincial and international movement of hazardous waste and hazardous recyclable materials. The following sections provide an overview of existing legislation that regulates plastic and proposed policies to address challenges and develop an integrated management approach to plastics at the federal, provincial, territorial, and municipal levels of government.

7.2.1 Federal Policy

The Government of Canada is working with industry to reduce plastic pollution and has set targets for 100% reusable, recyclable, or recoverable plastics by 2030; at least 50% recycled content in plastic products by 2030; and at least 55% reuse and/or recycling of plastic packaging by 2030, followed by 100% recovery of all plastics by 2040 (Government of Canada, 2021 and CCME, 2020).

In a discussion paper published in 2019, the Canadian Government underlined the key challenges Canada faces in its transition to a circular economy (ECCC, 2020). These include:

- Inconsistent feedstock composition and a labor-intensive cost structure for the recycling industry;
- Weak end-markets for recycled plastics due to inconsistent supply of quality feedstock at a competitive price;
- Low collection rates for plastics and only a fraction of collected plastics being recycled due to contamination;
- Infrastructure deficiencies;
- Lack of markets; and
- Competition from low-cost disposal alternatives such as landfills.

In Canada, waste management responsibility is shared across different levels of government, including the federal government, provinces, territories, and municipalities (Chhabra, 2019). An institution that facilitates such collaboration is the Canadian Council of Ministers of the Environment (CCME). The CCME brings together members of federal, provincial, and territorial environment departments and provides a forum for cooperation on environmental issues, including plastic waste management (Aldag, 2019). The CCME releases comprehensive reports and action plans that support improving plastic recycling across Canada, which are listed in Table 51 below. Two notable action plans adopted by the CCME are the 2009 strategy to develop a nationally harmonized approach to EPR and the 2018 strategy on zero waste to work towards waste reduction.

Table 51. Canadian Council of Ministers of the Environment (CCME) publications

Publication	Date	Summary
A Roadmap to Strengthen the Management of Single-use and Disposable Plastics	2022	A product of Phase 1 of the *Canada-wide Action Plan on Zero Plastic Waste*, this roadmap is aimed as policy makers to identify suitable instruments in the reduction of plastic waste and pollution from non-durable products (CCME, 2022).
Guidance to Facilitate Consistent Extended Producer Responsibility Policies and Programs for Plastics	2022	A product of Phase 1 of the *Canada-wide Action Plan on Zero Plastic Waste*, this publication aims to increase consistency in EPR policies between provinces and territories. A more uniform EPR framework across Canada would decrease friction within the system and increase efficiency (CCME, 2022).
Best Management Practices for Disposal Bans, Levies, and Incentives for End-of-Life Plastics	2021	Identifies the best management practices for using economic incentives to target end-of-life plastics as part of the *Canada-wide Action Plan on Zero Plastic Waste – Phase 1* (CCME, 2021).
Canada-wide Action Plan on Zero Plastic Waste – Phase 2	2020	The final phase of the *Strategy on Zero Plastic Waste* action plan targets actions that improve information exchange and awareness about plastic waste, manage the waste from aquatic activities, aquaculture and fishing industry, implement capture and clean up measures, invest in R&D to improve plastic waste value recovery (CCME, 2022).

Publication	Date	Summary
Canada-wide Action Plan on Zero Plastic Waste – Phase 1	2019	The first stage of implementing the *Strategy on Zero Plastic Waste* focuses on EPR implementation, non-durables, updating national standards for recycled content, developing economic incentives for a circular economy, and improving and investing in infrastructure and innovation (CCME, 2019).
Strategy on Zero Plastic Waste	2018	Presents strategies for plastic waste prevention, collection, and value recovery in the transition to a more circular plastics economy (CCME, 2019).
Canada-wide Action Plan on Extended Producer Responsibility	2009	Presents a harmonized approach to EPR implementation and policy for government action. This is used as guidance by jurisdictional authorities when developing their EPR frameworks (CCME, 2009).
A Canada-wide Strategy for Sustainable Packaging	2009	Building on the Canada-wide Action Plan on Extended Producer Responsibility, this publication addresses the need for packaging strategies and proposes measures that would improve sustainable packaging choices and systems in Canada (CCME, 2009).

With regard to plastics specifically, at a federal level, the Government of Canada released the Single-use Plastics Prohibition Regulations in June 2022, which place a ban on the manufacture, import, and sale of six categories of single-use plastics items (Government of Canada, 2022) (this is currently under litigation at the Federal Court). These are:

1. Checkout bags;
2. Cutlery;
3. Foodservice ware in the form of clamshell containers, lidded containers, cups, plates, and bowls containing expanded polystyrene foam, extruded polystyrene foam, polyvinyl chloride, carbon black, and oxo-degradable plastic;
4. Ring carriers for beverages;
5. Stir sticks;
6. Straws.

The scope of the regulation will expand to ban the export of the covered single-use plastic items starting in December 2025 (ECCC, 2022). To support businesses and organizations as they make this transition, the Government has prepared a set of guidelines on best practices and alternatives to single-use plastic items (ECCC, 2022).

Table 52. Coming into force of the prohibitions on the manufacture, import, and sale of six categories of single-use plastics items (ECCC, 2022)

Item	Manufacture and import for sale in Canada	Sale	Manufacture, import and sale for export
Checkout bags, cutlery, foodservice ware, stir sticks, straws	December 20, 2022	December 20, 2023	December 20, 2025
Ring Carriers	June 20, 2023	June 20, 2024	December 20, 2025
Flexible straws packaged with beverage containers	Not applicable	June 20, 2024	December 20, 2025

Upcoming Federal Rules for Plastics

The Government is proposing new rules for country-wide recycled content targets, labeling requirements for recyclable packaging, and a federal plastics registry to centralize data.

The federal government is in the process of developing minimum recycled content requirements for plastic items. Recycled content requirements can create a market demand for recycled plastics by setting a minimum percentage of recycled content that products must meet. This lessens the pressure for recyclers to compete with the cost of virgin resin and drives investments in recycling operations and material separation technologies. It also encourages companies to redesign their products to include recycled materials that have environmental benefits, such as reducing greenhouse gas emissions and supporting a circular economy (ECCC, 2020).

The Government published a notice of intent in February 2022 that proposed setting a goal of 50% recycled content by 2030. Plastic items considered in the scope of this requirement are beverage containers, non-food contact bottles, non-bottle rigid containers and trays not in food contact, foam packaging not in food contact, garbage bags, and waste bins. Proposed minimum recycled content regulations were to be published for public comment in the fall of 2023 (ECCC, 2022).

The Government of Canada is also developing rules to improve the accuracy of labeling for recyclable and compostable packaging and single-use items (ECCC, 2023). In a public consultation from July to October 2022, the Government proposed potential approaches to establish a labeling system for recyclable and compostable plastics (ECCC, 2022). These approaches include a rule prohibiting the use of the chasing-arrows symbol unless 80% of Canada's recycling facilities accept and have reliable end markets for the labeled product. The Government is also proposing to regulate the use of terms such as "compostable," "degradable," and "biodegradable" in the labeling of plastic packaging and single-use items.

In the proposed system, producers would be required to assess the recyclability of their packaging or single-use plastic items and apply a label reflecting the results of the assessment. They would have to select a compliance mechanism such as a calculator, guideline, or third-party labeling program that meets certain minimum standards and follows a systematic process. For the proposed compostability labeling rules, a producer would require third-party certification of the plastic packaging or single-use item to a specified standard. To promote and support compliance with labeling rules, the Government is also considering ways to include data collected from surveys of what is accepted in public recycling systems across Canada, a technical committee of experts to advise on implementation, and guidelines and other tools to facilitate recyclability assessments (ECCC, 2022).

Another consultation held concurrently with the labeling consultation sought feedback on developing a federal plastic registry that would require producers to report on the plastic they place on the market in Canada (ECCC, 2023). This registry would support provinces and territories that have extended producer responsibility (EPR) programs. EPR data requirements in Canada are currently inconsistent across different provinces and territories, with different requirements for measuring performance and inconsistent tracking and reporting processes. This makes it difficult to compare or verify EPR programs between jurisdictions or product categories, limiting the ability to measure the performance of EPR across the country (ECCC, 2019).

The proposed federal plastics registry would provide a single point of data collection, covering a broad range of categories of plastic products to resolve issues related to inconsistent data collection across Canada. The objectives of the registry include making data open and accessible to the public, providing comprehensive and comparable information across jurisdictions and product categories, providing baselines for future EPR work, supporting compliance with EPR policies, and informing and encouraging investment to improve the design, manufacture, collection, and management of plastics (ECCC, 2019).

Non-Regulatory Federal Agency Action for Plastic Waste Management

As seen in the United States, the Government of Canada funds plastic waste management innovation through their Sustainable Development Technology Canada (SDTC) program. The primary goal of the SDTC is to support Canadian pre-commercial SMEs that "demonstrate significant and quantifiable environmental and economic benefits" (Canada, 2022). Most notably, the SDTC has demonstrated financial investment in the advancement of the chemical recycling industry, with multiple investments into companies such as Polystyvert and Pyrowave (Government of Canada, 2021). The most recent grant was for C$3.5 million in 2021.

Federal Legislation Impacting Chemical Recycling

Canada currently has no federally mandated recycling targets or policies that specifically address chemical recycling. As of 2022, regulations governing chemical recycling were in place in Ontario, Quebec, British Columbia, and Alberta (these are summarized in the Appendix). On a national level, plastics regulations and the place of chemical recycling within the waste hierarchy will have larger repercussions for the future of the industry.

The Canadian government has been supporting this developing industry through investments into new technologies. Sustainable Development Technology Canada, a foundation created by the Government of Canada to fund new clean technologies, has been investing in Polystyvert, a Montreal-based chemical recycling company (Quebec). With the focus on funding startups and promising technologies, the regulatory environment is expected to encourage the development of chemical recycling technologies for the foreseeable future.

7.2.2 Provincial Policy

The regulation of plastic waste and recycling is carried out by provincial and territorial governments. This regulation takes the form of bans, deposit return systems, product stewardship programs, and EPR programs.

Bans

The Single-use Plastics Prohibition Regulations passed by the federal government in 2022 will impose bans on single-use items across all the provinces and territories. Some provincial and territorial governments already had their own materials bans, which are detailed in the Appendix to this study.

Deposit Return Systems

A deposit return system (DRS), also called a container deposit system, or bottle bill, is a legislatively designated system that places a monetary deposit on a product, paid by the consumer at the time of purchase, which is refunded when the consumer returns the product to a designated return location for reuse or recycling. Eleven of the 13 provinces and territories have deposit returns systems, averaging a return rate of 73.6% (Reloop, 2022).

Details of each province and territory's DRS program, in terms of the plastic containers they have accepted and the deposit redemption rates achieved (which serves as a proxy for the collection rate), where applicable, are provided in the Appendix.

EPR and Stewardship Programs

Canadian provinces have, in recent years, focused primarily on two types of waste diversion programs: EPR and product stewardship programs. Both programs shift responsibility for product waste onto producers and away from governments and consumers. However, EPR programs place full responsibility and costs on producers while stewardship programs are partially funded by the government or consumer fees (Youden, 2022).

Product stewardship programs are government-designed programs to centralize a recycling system for a specific material or product. Many product stewardship programs use eco-fees or advance disposal fees to finance their operations. These fees are added to the price of goods at the point-of-sale, which means that producers are not responsible for recycling costs (Arnold, 2019). Product stewardship programs aim to improve resource recovery outcomes, but they do not directly incentivize environmental performance and circularity. The responsibility for managing materials does not fall on producers, who do not participate financially or operationally in the program.

Stewardship programs are operated by regional, municipal, provincial governments, or can be operated by a Delegated Administrative Organization (DAO) such as a non-governmental organization (NGO). As the producer, importer, and businesses have no responsibility or relationship to the program or through the legislature, there is criticism that this model lacks the incentives needed for producers to innovate and improve their packaging and plastic products. Additionally, there is concern that consumers take on the burden in this model, as they are not at fault for the products on the market or the impact that economic fluctuations will have on the cost to support the system. Consequently, Canada has the long-term target to transition from this stewardship model into an EPR model. Table 61 in Appendix to this study describes the stage of transition towards EPR within each province.

To provide consistency, clarity, and better understanding across all stakeholders, the CCME has released guidance on implementation of EPR across provinces. Provinces and territories are encouraged to develop their EPR based on this guidance to reduce inconsistency between regions in Canada. The benefits of greater consistency among province EPR policies include:

- Cost savings and improved outcomes for producers who can achieve economies of scale by operating programs in larger markets that cross jurisdictional boundaries;
- Reduced administrative burdens for producers, including for data collection and reporting;
- Opportunities to collaborate between jurisdictions, offering advantages to jurisdictions that may not otherwise be able to achieve economies of scale;
- More effective and transparent tracking of performance measurement through comparable data; and
- Business service, manufacturing, and product innovations.

The guidance does not state all EPR programs need to be the same but rather encourages jurisdictions to adopt EPR policies that have similar objectives, aim for similar outcomes, treat producers similarly across jurisdictions, measure outcomes in a comparable way, and use consistent definitions (CCME, 2022). For example, consistent targets across EPR policies formalize the requirement that producers will contribute over time to achieving zero plastic waste, and allow them to plan accordingly (e.g., by investing in needed diversion infrastructure) (CCME, 2022).

As of November 2022, five provinces have implemented EPR for plastic products (British Columbia, Ontario, Manitoba, Quebec, Saskatchewan); two have enacted legislation and are in the process of setting up their respective programs (New Brunswick and Alberta); and a territory is currently consulting on its enactment (Yukon). The Appendix to this study provides the status of legislated EPR programs for packaging in Canada.

Summary of Policies by Province and Territory

Across Canada, policy approaches to tackle plastic waste vary greatly by province. If comparing provinces, generally, British Columbia and Quebec have arguably the most comprehensive plastic management policies, while the territory of Nunavut has minimal policy targeting plastic waste. Indeed, a 2010 study found that it would be cost-prohibitive to establish recycling programs in Nunavut citing high transportation costs to transport materials out of the territory for recycling (Dillon Consulting Limited, 2010). The Appendix to this study contains additional detail on the plastic-related policies for each province.

Reducing waste to landfill has been the main objective in most Canadian provinces largely due to increasingly high costs of and public opposition to building new landfills along with increasing tipping fees at privately owned landfills (I. Giroux, 2021). Nevertheless, provinces are starting to realize that waste management policy can go beyond simply diverting waste from landfills and can also facilitate circular practices that minimize greenhouse gas emissions. Most provinces have transitioned to or are in the process of transitioning to a system in which the private sector funds, develops, and manages the recycling system (i.e., EPR) (I. Giroux, 2021). Still among EPR policies, there is variation in the policy structure and implementation, with regards to multi-PRO or single PRO model, the level of transparency, and access and target requirements for example. This variation in EPR policy is also apparent in US states that are introducing EPR programs. More information on variation in EPR and best practices is included in Section 8.2.

Currently, EPR agencies establish their framework for determining reasonable access independently. Although there is some coordination between agencies such as through the Stewardship Agencies of British Columbia (SABC), the lack of alignment between agencies creates limitations in the system.

- **Various categories and definitions for community groups.** Different EPR agencies use various terms to determine community groupings while others with the same terms use different definitions. This creates challenges as a community may be categorized one way for one EPR agency and a different way for another, leading to the use of inconsistent standards.
- **Lack of granularity in community groups.** Most EPR agencies define communities as either urban or rural. By only having two categories for community groups and by setting a single province-wide target, EPR agencies can meet their targets without providing service to the most rural and remote communities.
- **Standards for reasonable access are inconsistent.** EPR agencies use a variety of factors for determining reasonable access. These include the drive time to the return location, total number of return locations, or distance to return locations. This lack of consistency makes it difficult to evaluate and compare reasonable access across programs.
- **Standards for reasonable access are limited and modest.** Most EPR agencies only use one standard for evaluating reasonable access. This evaluation with limited scope, does not consider many qualities that may impact an individual consumer's ability or likelihood to return a product. Additionally, the standards set are modest which in turn may lead to some communities not yet having reasonable access.

7.2.3 Local Policy

In Canada, municipal entities are required to provide waste management services to their residents as defined by Provincial "Municipalities Act" or similar legislation (I. Giroux, 2021). Municipalities are responsible for ensuring collection, separation, processing, and disposal are conducted in accordance with provincial and territorial legislation or their own municipal laws. This responsibility applies to cities, towns, counties, or regional collectives.

Local Disposal Bans

In many provinces, landfills are managed by regional district governments or municipal governments which can pass local disposal bans if recycling programs are available. Common disposal bans related to plastics focus on beverage containers, recyclable plastics, electronics, and tires. Some municipalities (e.g., Metro Vancouver, British Columbia, and the Region of Peel, Ontario) have banned the landfilling for items like textiles, requiring that they be recycled or donated for reuse.

Local Plastic Bans

Various types of plastics are regulated under local material bans, but the most commonly banned product types include single-use plastic bags, plastic straws, EPS (Styrofoam), and plastic cutlery. Section 6 discusses these product types and similar difficult to recycle materials and why material bans are effective policy mechanisms.

Reuse

Some jurisdictions have enacted laws to encourage reuse in certain applications. For example, the City of Vancouver, British Columbia adopted a “Single Use Item Reduction Strategy” targeting single-use foam containers, cups, straws, utensils, and shopping bags in 2019 (City of Vancouver, n.d.). However, in May 2023, beverage cups will become exempt from this law and there will no longer be a C$0.25 fee on single-use beverage cups. The Town of Banff, Alberta, passed a “Single Use Item Reduction Strategy” in 2022 that encourages the use of reusables over single-use items that goes into effect July 2023 (Town of Banff, n.d.). The strategy includes a requirement for businesses to provide reusable food ware for dine in services.

7.2.4 Non-Packaging Plastics Policy

Policies related to the construction and demolition, automotive and electronics sectors rarely focus on plastics and more commonly target the hazardous elements or contaminants that can be found within products in those sectors. Table 53 outlines the policies related to construction and demolition, automotive and electronics at a high level. Additional specificity on the policies across applications of plastics is included in the Appendix to this study. More information on the non-packaging plastic markets and recycling systems is included in Section 3.2.

Table 53. Policies related to non-packaging plastics in Canada

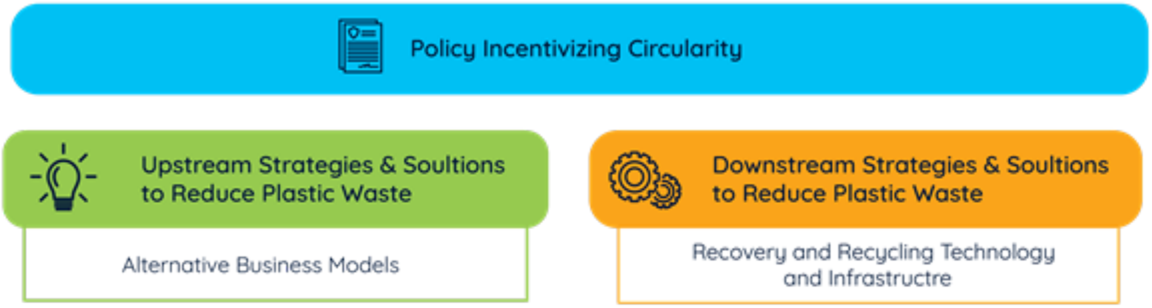
Sector	Policy Overview
Construction and demolition (C&D)	There are many policies that regulate the removal of potentially hazardous materials in C&D projects, such as asbestos or lead materials. Some provinces and municipalities also offer resources to encourage material reuse or the use of products. For example, Metro Vancouver has a sample bylaw to encourage reuse and recycling through a refundable fee applied to demolition permits, though it is not plastics-focused (British Columbia, n.d.). This sample bylaw is being adapted by municipalities to suit their local circumstances.
Electronics	There are no federal laws that require electronics recycling or target the plastics within WEEE specifically, but there are federal laws that regulate the disposal of toxic elements found in electronics. The CCME oversees the Electronics Product Stewardship Standards, which works with provinces to oversee their WEEE programs. Generally, electronics regulation takes the form of EPR or product stewardship policies at the province-level.

Sector	Policy Overview
Automotive	There is no regulation that requires recycling of end-of-life plastics for the automotive industry (I. Giroux, 2021). Most policy focuses on the special handling, transportation, and disposal of hazardous fluids and materials found in cars. There are provincial polices that target used tires, often in the form of EPR or product stewardship policies.

8 Best Practice – Alternative Models, Policy Options, and Emerging Technologies

In the following sections, we outline best practices for improving circularity and reducing plastic consumption. We briefly explore alternative business models that encourage plastic reuse in business-to-business and business to consumer applications. Then, we analyze policy options for improving circularity by examining US, Canadian, and European case studies where plastic recycling rates were particularly high due to multi-faceted measures such as EPR programs, Deposit return Systems (DRS), product bans, PCR content targets and statewide/national plastic recycling and waste reduction targets. Finally, we outline notable emerging technologies that would improve rates for recycling plastics, where US, Canadian and European initiatives and companies developing innovative solutions in sorting, chemical recycling and recycling for food-grade applications are explored. These strategies target plastics both upstream and downstream.

Figure 51. Methods to increase circularity and reduce plastic waste



Source: Eunomia Research & Consulting

8.1 Alternative Business Models

8.1.1 Reuse Systems

Redesigning plastic products for reuse and refill plays an important role in the circular economy. Reuse systems extend a product's lifetime, keeping it in use repeatedly and avoiding the emissions, waste, and costs associated with the extraction of new virgin materials or processing required to recycle materials. Reusable packaging options do exist at varying levels across the US and Canada. Some examples of the most common reuse practices include reusable shopping bags, water refilling systems [bring your own bottle (BYOB)], bulk stores, and returnable beer bottles (Canada Plastics Pact, 2023). Reusable packaging can be applicable to several industries, such as logistics and in B2B and business to consumer (B2C) applications (Ellen MacArthur Foundation, 2013).

Figure 52. Four reuse models

Source: Ellen MacArthur Foundation, Reuse – rethinking packaging (2019)

The Ellen MacArthur Foundation has established four reuse models in B2C applications where "responsibility" over packaging reuse differs and whether reuse happens at home or on the go (see figure above). Two examples of B2C reusable packaging are produced by DeliverZero and Clorox, both recently awarded the Sustainable Packaging Innovation Award from US Plastics Pact for reuse and refill, respectively. DeliverZero's containers can be reused up to 100 times and will reduce plastic packaging waste associated with takeout food. The containers have a 98% return rate and are returned by scheduling a pickup or dropping them off at return points, generally restaurants that use the containers ("Return on the go" and "Return from home" models) (US Plastics Pact, 2022). Clorox's Concentrated Refillable Cleaners use refillable spray bottles that are reusable, which the company claims will help to reduce plastic use by 80%.

The Ellen MacArthur Foundation reuse models in B2C applications also addresses refill in the same way as for reuse. The Clorox Concentrated Refillable Cleaners sell refill pods containing liquid concentrate that can be used to refill their spray bottles ("Refill at home" model). Other reuse and refill packaging finalists include IFCO (B2B reusable packaging containers), Pact Retail Accessories (B2B reusable shipper for fashion logistics), RePack (B2C reusable mailer) and TOMBag (B2B and B2C reusable trash bags) (US Plastics Pact, 2022).

Additional reuse model pilots include:

- Walmart+ InHome, which partnered with Loop to deliver select items in reusable packaging in select Arkansas locations (Walmart, n.d.);

- Topanga.io and Grubhub that have partnered to deliver meals on college campuses in reusable containers using Topanga.io's Reuse Pass program (Reusepass, n.d.); and
- in the NGO space, Perpetual is working on reusable food ware systems at the city level (Perpetual, n.d.).

As demonstrated, reverse logistics, typically used for non-plastic packaging through producer-funded deposit return systems (e.g., glass beverage bottles) can improve plastic packaging reusability, especially if businesses keep distances between their deposit and supply points short (Ellen MacArthur Foundation, 2013). Sorting and washing facilities also need to be put in place to complete the reverse logistics supply chain. Additionally, reusable containers should be recycled at end of life.

8.1.2 Repair Systems

Technological development has skyrocketed in the last decade and a half, increasing the level of consumption and consequently disposal with it. In 2022, it was estimated that roughly one-third of the 16 billion cell phones used globally were disposed or put away (Matteucci, 2022). Europe has the most comprehensive insights into their electronic consumptions patterns and has found that the average European family hoards approximately five kilograms of e-devices that are out of use (Matteucci, 2022). It has been proposed that the average life span of a cell phone is three years. If we were to extend this by one year (to four) the average person would decrease their lifespan electronic emissions by 25%, and overall, annually we would be reducing the same quantity of emissions as Ireland outputs (World Economic Forum, 2021). The repair system aims to prolong the longevity of these electronics so that we can aim to consume less in our lifetimes.

The US Government set an executive order on promoting competition in the American economy in July 2021, which encouraged the right to repair models (White House, 2021). Specifically, it encouraged the Federal Trade Commission to issue "rules against anticompetitive restrictions on using independent repair shops or doing DIY repairs of your own devices and equipment" (White House, 2021). Similarly, in March 2023, the Government of Canada introduced the plan to implement right to repair for electronic devices and home appliances in 2024 (Government of Canada, 2023). Additionally, the plan includes a five-year tax credit to encourage Canadian clean tech manufacturers, estimated to be worth US$4.5 billion as part of their budget (Government of Canada, 2023). These policy triggers would assist in reducing the cost of repairing electronics which is key given it is often considered cheaper to purchase than to repair (World Economic Forum, 2022). Thereby reducing the consumption of new electronic devices.

8.2 Policy Options

As outlined in Section 7, there is a range of policy options for reducing plastic landfilling and improving circularity and recycling rates. Federal policy regulating plastic waste remains relatively limited in the US and Canada, though states and provinces have enacted measures to tackle plastic waste. The following section examines best practice policy case studies from the US, Canada, and Europe that could be applicable to policymakers looking to emulate policies and improve plastics recycling rates. Plastic packaging makes up a significant proportion of waste plastics in the US and Canada (based on 2018 data). Case studies from the US and Canada were chosen based on whether states or provinces achieved a plastic packaging recycling rate >40% overall or for specific packaging types (e.g., PET bottles) and to highlight the variety of policies that could be emulated in the US and Canada. Case studies were also chosen where evidence demonstrated that plastic waste management policies led to an increase in plastic recovery and/or recycling for certain products.

European case studies were included to provide a broader understanding of successful policy options. In particular, we highlight:

- Norway's beverage container tax
- Belgium's EPR[+] system for packaging (Fost Plus)
- Germany's multi-PRO* EPR program for its packaging and de-centralized deposit return system (DRS)

[+]EPR=Extended Producer Responsibility
* PRO=Producer Responsibility Organization

Germany and Belgium have relatively high recycling rates following policy implementation, despite employing different methods to attain their targets. EU reported recycling rates are adjusted and only include plastic packaging waste that has been recycled back into plastic (Eurostat, 2022). According to Eurostat, Germany had the fourth-highest recycling rate (46.2%) for plastic packaging waste in 2020, followed by Belgium (44.7%) (Eurostat, 2023). Germany was also the first EU country to implement a nationwide EPR program and provides a good example of a uniform, nationwide single-use deposit-return system (DRS) with the highest reported return rate globally (98%) (Reloop, 2022) and a case study on the effects of transitioning from a single-PRO system to multiple, competitive PRO systems. On the other hand, Belgium has recycling rate of 44.7% (Eurostat, 2023), achieved using a single-PRO EPR system (Fost Plus) and without a DRS (though they will be introducing one in 2025). Finally, though Norway's recycling rate was 27.9% in 2020 (Eurostat, 2023), Norway's beverage tax led to the voluntary, industry-led establishment of an efficient DRS that has achieved high return rates of 92.3% in 2021 (Reloop, 2022).

The use of recovery rates, which includes energy recovery, recycling, and other plastics recovery options into 'useful' material (Eurostat, 2023), was avoided as a selection criterion for the examples below. Germany and Belgium maintain over 99% recovery for plastic packaging waste, largely due to their use of incineration for energy recovery. Approximately 53% and 55% of plastic packaging waste is incinerated in energy from waste (EfW) plants in Germany and Belgium, respectively (Eurostat, 2022). Though Norway had a reported recovery rate of approximately 69% in 2020, incineration at EfW plants still makes up a greater share compared to recycling (Eurostat, 2022). From a circularity viewpoint, 'recovering' plastic waste through EfW plants is not closed-loop and is considered a leakage, according to the Ellen MacArthur Foundation (Ellen MacArthur Foundation, n.d.). However, there is contention, from a climate view, over whether energy recovery is more beneficial than landfilling plastic. Burning plastic does not bring 'carbon benefits' unless it is replacing a more polluting source within the grid, which would be coal or oil.

This section is structured by the following policies:

- Reuse policies;
- Deposit return System (DRS), differentiating between centralized and de-centralized DRS;

- Extended producer responsibility (EPR), exploring single-PRO* and multi-PRO* programs;
- PCR content mandates; and
- Bans, fees, and other measures

* PRO=Producer Responsibility Organization

Research has demonstrated that DRS and EPR systems were more often linked with successful cases, indicating that adopting a 'producer pays' principle within the US and Canada may be worthwhile. In Canada, out of 13 provinces and territories, nine provinces and two territories have deposit return systems, averaging a return rate of 73.6% (Reloop, 2022) (see Section 7.2.2). Five provinces have an EPR system for packaging, four of which are transitioning to a full EPR system where industry contributes to 100% of the waste management costs. In the US, ten states have established a DRS that cover plastic material, averaging a return rate of 69.1% in 2019 (see Section 7.1.2). Four states enacted EPR systems for packaging, though their success cannot yet be determined since legislation passed in 2021 and 2022.

8.2.1 Reuse Policies

Reuse can be incentivized via many policies, often working in tandem to incentivize reuse and disincentivize single-use alternatives. France has a law that sets a reuse packaging target, requiring 5% of packaging placed on the market to be reusable by 2023 and 10% by 2027, and has recently introduced a 3R (Reduction, Reuse, and Recycling) decree (Prime Minister of France, 2020). The latter sets reduction and reuse targets until 2025, highlighting that 50% of the 20% reduction in single-use plastic packaging should be obtained through reuse. There is also set a ban of single-use items for take-away by the end of 2023.

In November 2021, Austria was the first European country to implement binding and enforceable reuse targets in their Waste Management Act, by mandating a beverage reuse quota of 25% by 2025 and 30% by 2030 (Zero Waste Europe, 2022). Austria now has a reuse rate of 19% for beverage bottles. Portugal is requiring that by 2030, 30% of all packaging put on the market, of any material, must be reusable (Assembleia da República, 2021). In Germany, the VerpackG law has established a 70% target for refillable beverage bottles (VerpackG, n.d.). Additionally, Germany requires restaurants and cafes selling food or drinks on the go, to offer their products in reusable packaging as of January 1, 2023, and that the reusable alternative must not be more expensive than the product packaged in disposable packaging.

Some EPR and DRS policies include reuse and refill targets or requirements or establish funds for the acceleration of source reduction and investment in reuse/refill systems. For example, in the US, recently passed EPR legislation includes reuse in varying ways:

- California: single-use plastic source reduction goals, with a target for reuse and refill.
- Colorado: incentives for reusable packaging.
- Maine: incentives for reusable packaging and reuse targets.
- Oregon: the creation of a state-run, producer funded Waste Prevention and Reuse Fund.

Reuse infrastructure can be supported through EPR and DRS alongside regulatory measures, financial incentives, and partnerships between government, private sector, and other stakeholders to create a sustainable funding mechanism for the development and operation of reuse systems.

8.2.2 Centralized DRS

A centralized DRS uses a centralized clearing system, where deposit return claims are managed by only one clearinghouse (Reloop, 2022).

California's case study demonstrates the effects of an insufficient deposit level and handling fee. California's rigid plastics packaging recycling rate in 2018 was around 30%, however, the recycling rate of PET bottles, which is included in the state's DRS, was 57% (Eunomia, 2021). California's DRS (the California Beverage Container Recycling and Litter Reduction Act) is overseen by the Department of Resources Recycling and Recovery (CalRecycle) and charges a redemption value (CRV), depending on container size: 5 cents for bottles of less than 24 oz. and 10 cents for bottles greater than or equal to 24 oz. The DRS includes plastic, metal and glass beverage containers but excludes such containers as those containing milk, wine, infant formula and juices (dependent on container size) (CalRecycle, n.d.).

Nevertheless, California's DRS return rate for beverage containers was 61% in 2021, lower than those reported in Oregon and Maine. California's DRS return rate has steadily declined over the past decade (from 74% in 2013), primarily due to the low deposit value of five cents and the closure of over 50% of redemption centers because of underpayments to compensate for their services (CRI 2022). Characteristics of successful DRS systems, explored below, include increasing the deposit value to incentivize consumers, requiring retailers to accept beverage containers and combining EPR and DRS programs to enforce targets and compensate redemption centers. The three characteristics were demonstrated in Oregon, British Columbia and Germany's DRS that have been successful (Eunomia, 2020).

Oregon has the second-highest overall recycling rates in the US for packaging, however their recycling rate for *rigid plastic* packaging in 2018 was approximately 26%. Nevertheless, due to Oregon's DRS for beverage containers, the state has been successful in recycling PET bottles (69% recycling rate in 2018) (Eunomia, 2021). Oregon increased the refundable deposit from US$0.05 to US$0.10 in 2018 and amended the legislation that mandated the increase of the deposit should container return rates fall below 80% for two consecutive years (State of Oregon, n.d.). The increase in the deposit led to an increase from 59% in 2017 (Oregon Beverage Recycling Cooperative, 2017) to an 83.9% overall return rate in 2021 (Oregon Beverage Recycling Cooperative, 2021). Return rate for plastic PET was 78.4% in 2021 (Reloop, 2022). The Oregon Beverage Recycling Cooperative (OBRC) owns bottle redemption centers and manages DRS operations. As a non-for-profit run by state beverage distributors, OBRC has increased DRS efficacy through their technological innovations, such as the BottleDrop program (Oregon Beverage Recycling Cooperative, 2021).

In 2018, Oregon increased its beverage container deposit **from $0.05 to $0.10**

Leading to a **25% increase in average return rate** between 2017 and 2021

Beverage Container Tax and DRS: Norway's Case

Norway's DRS is unique, as it was established voluntarily by industry after the nation implemented a tax for all beverage containers in 1993. The System Operator (now known as Infinitum) was founded by producers and retailers in 1996 and the DRS launched in 1999 (Infinitum, 2021).

The tax reduces as collection rates for post-consumer containers increases and a DRS was recognized by legislation as a cost-effective way to increase collection and reduce how much tax producers paid. The excise tax is charged to the producer per unit of beverage container placed on the Norwegian market. It is made up of two components, a Basic Fee on single-use containers (introduced 1994) and an Environmental Tax (introduced 1993), which producers pay in full when collection rates are less than 25%. When collection rates reach at least 95%, producers are exempt from paying the environmental tax (Lovdata, 2001). Collection rates differ from return rates (through DRS) in that they include containers collected through centralized sorting, slag sorting at source, and at energy recovery facilities (Infinitum, 2021).

The single-use container fee was introduced to encourage use of refillables, however, retailers preferred single-use containers that can be compacted to reduce storage space necessary during return (Infinitum, 2021). The Norwegian Environment Agency is responsible for approving the take-back system, determined by whether the Agency expects the system to achieve a minimum collection rate of 25%. The take-back system needs to demonstrate that it will recover the packaging in an environmentally-sound way. Consequently, the Environment Agency will only approve systems based on energy recovery if reuse and recycling are not technically, environmentally or financially feasible treatments (Lovdata, 2022). Norway's DRS is highly effective and recognized as a best-practice of DRS, achieving return rates of 92.8% for plastic containers in 2021 (92.3% overall). The DRS is non-profit, centralized and includes plastic bottles and cans but excludes glass bottles (Reloop, 2022). Since 2011, Infinitum's members have not had to pay the Environmental Tax component due to its high return rates (Infinitum, 2021). The voluntary and flexible nature of the system has been largely successful, as retailers and producers are incentivized to achieve cost-efficiencies with the DRS to reach collection rate targets.

While Infinitum largely decides how to run the system, the Ministry of Climate and Environment must approve deposit values based on Infinitum recommendations (Lovdata, 2022). Infinitum is owned by beverage producers and retailer organizations (50% each) and ownership is industry-determined rather than government appointed (Infinitum, 2021). Producers have the option to join the Green Dot EPR program (Gront Punkt Norge, n.d.) instead of the DRS; however, that system has a lower collection rate and members have to pay a higher tax (Eunomia, 2022). Additionally, the DRS performed better from a carbon perspective, having a climate impact 11% and 24% less compared to the Green Dot system, according to a NORSUS study (NORSUS, 2016).

The legislation requires all retailers selling beverages with a deposit to take back the used containers, which provides convenience and widespread access to return points for consumers. Retailers must thus register with Infinitum; however, they can decide how to organize the collection of used containers on their premises. Majority of Norway's collection is done automatically through reverse vending machines (approximately 93%). Infinitum pays retailers a handling fee per container based on whether their use of compacting RVMs or non-compacting RVMs/manual collection (Reloop, 2022).

Producers choosing to join Infinitum register all their eligible beverage products in the system and pay a one-time registration fee when they join. There are also monthly producer fees, which are calculated based on the number of containers they place in the Norwegian market. Producer fees are variable and eco-modulated and reflect the costs of containers by accounting for the material and product design (Infinitum, n.d.). This creates incentives for producers to design containers that are more efficiently recyclable and avoids the situation where aluminum container producers, due to the high value and low recycling costs of the containers, are effectively subsidizing the producer fees for plastic bottles (Eunomia, 2022).

Infinitum's request for an increase in deposit values to address concerns of falling return rates, was approved by the Ministry of Climate and Environment in 2018. Deposits increased from 1 to 2 Norwegian kronor (KOR), (equaling US$0.10 to US$0.20), and 2.5 to 3 NOK (US$0.25 to US$0.30) for containers (both plastic and metal) at most or greater than 500 mL, respectively. Since the change, the return rate increased from 88.6% in 2018 (Infinitum, 2018) to 92.8% in 2021 (Infinitum, 2021). Review of deposits, as seen in the Oregon case study, can be particularly beneficial for ensuring continuous improvement in plastic collection and recycling.

8.2.3 De-centralized DRS

De-centralized DRS have multiple clearinghouses to manage deposit returns. Germany has a successful de-centralized DRS that is combined with an EPR system for packaging under their VerpackG legislation (see Section 8.2.5).

8.2.4 Single-PRO EPR Programs

Extended producer responsibility (EPR) programs can have multiple configurations, although often they consist of a non-profit, single-PRO (Producer Responsibility Organization) that manages producer registration and funding for waste collection and recycling.

This year, California passed an EPR law for single-use and disposable plastic packaging producers. The bill contains clear targets for the PRO and CalRecycle will be reviewing and enforcing PRO performance. By 2032, 65% of plastic packaging covered must be recycled, all packaging must be recyclable or compostable and all packaging sold must be reduced by 25%. Increasing recycling rate targets are set out between 2024 to 2032 to ensure the PRO is on track. EPR fees are also eco-modulated to incentivize PCR use and improve recyclability and labeling (State of California, 2022).

Given that it passed recently, its success cannot be determined however continuously revising recycling targets and employing eco-modulation under a single-PRO EPR system has been successful in British Columbia and Belgium.

Maine also recently signed into law EPR legislation for packaging which covers paper and plastic packaging. Within the program, producers pay a fee into a fund based on the quantity, recyclability of and recycled content in their packaging. Through the fund, municipalities will be reimbursed for their waste management and recycling costs (including administration and enforcement), investments in infrastructure and educational programs. Beverage containers within the DRS are exempt from the EPR legislation. Other exemptions include small/low-volume packaging from local producers and some packaging associated with specific products (e.g., paint) (State of Maine, 2021). Benefits of the EPR program are to be seen since the bill was passed July 2021.

British Columbia has a comprehensive EPR programs for beverage containers (see Section 8.2.5) and for PPP. The Canadian province has reported recovery rates in 2021 of 67% for rigid plastics and 55% for plastics overall and has recycled approximately 86% of collected PPP (RecycleBC, 2022). The PPP EPR system legislation requires that all producers register with the Ministry of the Environment and Climate Change Strategy, where producers submit their annual plans and reports for revision, either individually or under the PRO, RecycleBC. Funded by producers, RecycleBC assumes all financial and operational responsibility for recovering and managing PPP waste in British Columbia. The PRO modulates producer fees according to material, charging higher fees for problematic materials. Furthermore, within the EPR system, municipalities can decide to: become contracted as a collector to RecycleBC, transfer the responsibility for cursbide and multi-family household collections to RecycleBC, or opt-out of the program (Eunomia, 2022). Thus far, RecycleBC has achieved several of their recovery rate targets, including achieving a 50% recovery rate for plastics by 2025, which they surpassed in 2020 with a recovery rate of 52%. In their draft proposal for their program plan, RecycleBC is proposing new plastic recovery targets based on revised methodology to improve reporting accuracy, namely reaching 56% plastics recovery by 2027 (RecycleBC, 2022).

Belgium has an EPR system, single-PRO and non-profit, for household packaging waste. Waste is a regional competence in Belgium and each region develops its own policy. Nevertheless, there is common agreement between Flanders, Wallonia and Brussels on packaging waste (Cooperation Agreement), which requires producers who place packaging on the Belgian market to take back and treat packaging waste. Producers can complete the requirement by setting up an individual take-back system (rare for household packaging) or joining a PRO. Additionally, producers had a reporting obligation and were required to submit waste prevention plans (IVCIE, n.d.). National recycling and recovery targets were set in 2009 within the agreement but have since been updated given that previous minimum recycling rates have been achieved. The 2020 update stipulates that:

- For household plastic packaging, a minimum recycling rate of 65% by weight must be achieved by 2023;
- For industrial and commercial packaging waste, the minimum recycling rate was updated to 55% for plastics by 2023; and
- By 2030, a minimum recycling rate of 70% and 65% by weight must be achieved for plastic household packaging and industrial packaging waste respectively (IVCIE, n.d.).

Introduced in 1994, Fost Plus is the PRO operationally and financially responsible for the collection, sorting, and recycling of household packaging waste, including glass, plastic, paper and cardboard and metal containers. Municipalities are responsible for collecting and sorting household waste but Fost Plus reimburses them for their activities. Fost Plus contracts recycling operators directly and reports tonnages to the Interregional Packaging Commission IPC, which is responsible for inspections, data collection, and giving permits to PROs (Bio Intelligence Service, 2014). In 2021, Fost Plus reported a recycling rate of 89.8% overall, 52% for plastic packaging, and 73% for drink cartons. The PRO has also reported that its 2021 operations yielded approximately 15 euros per person, demonstrating their cost-efficiency (Fostplus, 2021).

Fost Plus is seen as having best practice for granularity in producer fee structures (i.e., fee modulation) that are charged annually. These rates vary based on material, color, format, and valorization. For example, there are fee differences between PET transparent and colorless bottles versus opaque PET bottles. Fees are charged on a weight or unit basis and are updated yearly to reflect PRO costs for financing collection, sorting and recycling. The PRO also supplements this fee structure with eco-modulation criteria ('Obstructive Packaging' rates) that penalizes packaging formats that are currently not recyclable by charging higher rates (e.g., oxo-degradable packaging, full-sleeve labels on plastic bottles, laminated plastic packaging) (Fostplus, 2023).

8.2.5 Multi-PRO EPR Programs

Multi-PRO EPR programs, where producers have the choice to register with one of the multiple, likely competing PROs, are less commonly implemented. Purported benefits of implementing a multi-PRO program include driving competition, reducing producer fees, and allowing for producer flexibility, improving system performance through competition and generating an environment for innovation. Nevertheless, as Germany's case below demonstrates, a multi-PRO system can introduce non-transparency in the system and reduce pressures on producers to improve systems. For example, price competition may dampen differences within producer fee structures (i.e., for eco-modulation) leading to a lower likelihood of producers designing their products for recyclability.

Germany's Experience: Transitioning from a Single, non-Profit to for-Profit, Multi-PRO EPR Program

According to Eurostat, Germany has one of the highest plastic packaging recycling rates in the EU, 46.2% in 2020 (Eurostat, 2023). Germany implemented the first nationwide EPR program in the EU (Der Grüne Punkt) in 1991 (under the Packaging Ordinance) for paper, cardboard, glass, plastic and metal packaging from residential waste streams. Producers were made financially and operationally responsible for the recovery and recycling of residential packaging waste to meet recycling targets. The Packaging Ordinance created a "dual system" in which household packaging waste were made a separate collection stream from non-recyclable and food wastes, which remain under the responsibility of municipalities. All affected producers were required to comply with the EPR program through the only non-profit PRO, Duales System Deutschland GmbH DSD; however, the government opened the program to stimulate competition in 2001. As a result, twelve competing for-profit PROs are now operating in Germany (Verpackung Register, n.d.).

The introduction of multiple PROs generated producer flexibility in choosing desired EPR programs to comply with regulations. The PROs negotiate waste fees with producers individually and producers are provided with alternatives if the fee structure associated with one PRO seems too high (GIZ, 2018). Flexibility was also introduced at the waste management level. Collection and sorting contracts with PROs have a three-year duration and regular tenders for contracts are held so PROs can manage their registered waste volumes. Municipalities can participate in tenders, though they often must compete with private companies. The resulting contract costs are pooled and PROs pay contracts based on their market share. In Germany, PROs are required to cover a minimum of 50% of collection costs in the tendered area (Eunomia, 2020).

After the transition to a multi-PRO model, collection and recycling costs decreased while recovery and recycling rates generally improved. However, the system became difficult to monitor and manage, increasing instances of producer freeriding (NWRA, 2022). The Packaging Ordinance was replaced in 2019 by VerpackG (consistent with the EU Directive on Packaging and Packaging Waste), which contained stricter regulations and led to the creation of a central agency packaging register (ZSVR) for monitoring purposes to combat freeriding. Eco-modulation was not required until VerpackG was implemented, which aims to incentivize producers to increase recyclability, PCR content and the use of renewable raw materials (Prevent, 2020). Nevertheless, PROs are still responsible for setting their own eco-modulation fees, though fee discounts must meet the “minimum standard for recyclability” set by ZSVR annually in consultation with the German Environment Agency (Verpackung Register, 2022).

A 2021 amendment to VerpackG also enforces all stakeholders who commercially place packaging on the market to register with ZSVR (Landbell Deutschland, 2022). This includes packaging types that are not subject to system participation (i.e., registering with a PRO) such as reusable, transport, and industrial packaging. Additionally, service packaging and packaged goods sold through online sales platforms (Verpackung Register, n.d.), are now subject to system participation. Service packaging refers to packaging filled at the final distributor with consumer goods (e.g., takeaway containers, prescription bottles). Providers of service packaging can opt to exclusively buy ‘pre-participated’ packaging from suppliers that are registered. These suppliers have already paid for the recycling of the packaging (Verpackungsregister, n.d.). From 2023 forward, takeaway food service facilities will also need to offer their food in reusable packaging, which cannot be more expensive than the disposable packaging option (Bundesministerium der Justiz, 2017).

Despite not mandating producers of reusable packaging to register with a PRO, VerpackG does have a target of 70% of marketshare set for reusable bottles (VerpackG, n.d.). However, this is lower than the target of 80% set in the Packaging Ordinance and does not seem to be linked with any financial penalty. Overall, Germany’s EPR system is unlikely to encourage reusable packaging use by producers (see section below).

Results of the Packaging Act (VerpackG) are yet to be understood; however: (1) increasing recycling and PCR content targets, (2) introducing eco-modulation of producer fees, (3) mandating the participation of service packaging providers (e.g., food-service industry) and online retailers and (4) requiring **all** stakeholders to register with ZSVR, are all likely to improve plastic collection and recycling. The extent to which mandating eco-modulation will improve packaging recyclability, will be difficult to understand under Germany's competitive, multi-PRO model, since producer fees are not publicly available. In addition, flexibility in Germany's system allows producers to register with other PROs should they disagree with eco-modulated fees. Competition, therefore, may only lead to only slight modulation in fees across PROs, potentially dampening significant eco-modulation impacts realized in a single-PRO EPR system.

Table 54. Plastic packaging recycling and recovery rates over time in Germany

Year	1991	2000	2005	2010	2015	2020
Recovery Rate	11.7	53.7	47.8	96.7	99.5	99.7
Recycling Rate	11.7	52.7	39.3	49.4	48.8	60.5

Source: (GVM 2020)

8.2.6 Combined DRS and EPR Systems

While DRS minimizes recycling losses by claiming high quality material that would have been disposed at curbside, combining DRS with EPR can ensure collection and recycling systems for curbside materials not accepted within a DRS are also targeted and improved upon through producer investment. Additionally, implementing EPR alongside DRS can force continual recycling rate improvement by setting performance targets for producers across a range of materials, including those that are difficult to recycle.

British Columbia's EPR program funds a beverage container DRS which is operated by two industry-led PROs: Encorp Pacific and Brewers Recycled Container Collection Council (BRCCC). BRCCC primarily fund and operate collection of beverage containers from breweries and other alcohol manufacturers. The DRSs funded by each PRO have been largely successful, with BRCCC reporting an ~88% overall recovery rate (BC Brewers Recycled Container Collection Council 2021) and Encorp reporting a ~75% overall and ~70% recovery rate for plastics in 2021. All beverage containers have a C$0.10 deposit fee; however, Encorp also charges a separate container recycling fee for recycling operations (Encorp Pacific (Canada), 2021).

As part of their EPR system for packaging, Germany introduced a mandatory DRS for single-use beverage containers (plastic, glass, metal) in 2003. Since 2022, DRS is now mandatory for *all* disposable plastic beverage bottles, with some exceptions (e.g., milk jugs will have a transitional period until 2024) (Verbraucherzentrale, 2023). Germany requires all retailers to take back beverage containers within the deposit program if the material is supplied within a retailer's own product range. The DRS is decentralized, with several clearing service providers (CSPs). Every retailer and producer are (optionally though commonly) serviced by a particular CSP, which differs in their responsibilities depending on who they are servicing (retailers or producers) (DPG, n.d.). A retailer CSP (refund claimant service providers) will collate container return data and invoices from retailers and pass them onto the relevant beverage producer CSP (deposit account service providers) after validation. Deutsche Pfandgesellschaft is the standard-setting organization, overseeing the framework and central database for the multiple CSPs, and setting labeling standards for beverage containers to maintain a uniform, nationwide deposit system. Producer annual membership fees, which vary depending on production size, are paid to Deutsche Pfandgesellschaft and to the respective industry CSP. No handling fees exist as participating retailers own the collected containers and operational costs are covered by each individual participant (e.g. retailers paying for RVMs) (Reloop, 2022). A fixed-rate deposit of 25 cents is charged across all single-use beverage containers (DPG, 2022).

Since the implementation of the EPR and DRS systems in 1991 and 2003 respectively, German recovery and recycling rates have steadily increased (Table 54 above), demonstrating overall combined policy success. Regarding the DRS specifically, Germany has achieved a high plastic beverage container return rate of 98% in 2021 (Reloop, 2022). Though successful in increasing recovery of single-use plastic packaging, the DRS under the Packaging Ordinance had another effect: increasing the market share of single-use plastic bottles. In 2018, before the implementation of VerpackG, one-way plastic bottles made up 52.2% of the market share while reusable bottles (glass and plastic) made up 41.2% (Umweltbundesamt, 2018). Under VerpackG, DRS for reusable packaging is not mandatory. However, when registering with ZSVR, the central agency in Germany's EPR system, producers must indicate what type of packaging they are placing on the market. To register reusable packaging, adequate return logistics and an incentive system for the return of packaging must be in place. Deposits for reusable bottles are therefore common and typically range between 8 and 15 cents (Verpackungsregister n.d.), which is lower than the 25-cent deposit for all single-use packaging. Germany's DRS, despite demonstrating success, remains limited in incentivizing the production, use, and return of reusable packaging.

Thus, should jurisdictions within the US and Canada decide to emulate Germany's EPR system, DRS design should be completed with circularity and reuse in mind, where the program can accept and successfully redistribute reusable packaging to producers. Mandating producers to use and recover standardized reusable packaging through an EPR system (e.g., eco-modulation for reusable packaging) and setting strict and specific reusability targets—both of which Germany generally lacks—would improve circularity. Furthermore, reuse infrastructure can be supported through EPR and DRS alongside regulatory measures, financial incentives, and partnerships between government, private sector, and other stakeholders to create a sustainable funding mechanism for the development and operation of reuse systems.

8.2.7 PCR Content Mandates

Establishing PCR content requirements for plastic products aims to reduce the use and demand for virgin plastic. However, PCR content mandates are more effectively combined with EPR and DRS systems. Since there must be enough capacity for recycling plastics to meet increasing demand for recycled resin, EPR/DRS systems combined with PCR content requirements incentivizes producers to improve collection and invest in recycling infrastructure.

California's minimum recycled content mandates for rigid plastic packaging, plastic trash bags, beverage containers in the DRS and reusable grocery bags have been highly influential across state borders. These mandates, especially the Rigid Plastic Packaging Container law (RPPC) and Recycled Content Trash Bag program, have influenced demand for recycled HDPE, PET and LDPE across the US. For example, the demand for recycled unpigmented HDPE created by the RPPC law is estimated to be responsible for approximately two thirds of all recycled unpigmented HDPE in the US (Ocean Conservancy, 2022). Nevertheless, plastic recycling rates in the US are relatively low, demonstrating that the success of a PCR content mandate is dependent on there being sufficient supply of recycled content (European Commission, n.d.).

Table 55. PCR content mandates in California

Legislation	Requirements
RPPC Law	Producers selling products in rigid plastic packaging must meet one of the following: Use 25% PCR content, Source reduction targets, Be reusable/refillable, or Reach a 45% recycling rate (California Code of Regulations, 2023).
Recycled Content Trash Bag Program	Producers of plastic trash bags must annually certify that the weight of the annual aggregate of regulated bags intended for sale in California are at least 10% PCR content or the weight of the annual aggregate of all plastic products are at least 30% PCR content (CalRecycle, n.d.).
Single-use Carryout Bag Ban	Reusable plastic grocery bags must contain 40% PCR content (State of California, 2014).
Plastic Minimum Content Standards	Beverage containers under the DRS must meet the following PCR content standards: 15% by 2022, 25% by 2025 and 50% by 2030 (CalRecycle, 2022).

8.2.8 Bans, Fees and Other Measures

California banned single-use carryout plastic bags (CalRecycle, 2016) and has a landfill fee (Integrated Waste Management Fee), although the success of this fee in increasing recycling rates is contestable, given its low cost (US$1.40 per ton of solid waste) (CDTFA, n.d.) and that the overall plastic recycling rate in 2018 was 30%. Maine also banned single-use plastic bags (Maine Department of Environmental Protection, 2022) and EPS containers in food service ware (Maine Department of Environmental Protection, n.d.).

Germany banned single-use plastic items under the Single Use Plastics (SUP) Directive since 2021 (Blank, 2021). Furthermore, Germany recently approved draft legislation (EWKFondG) that will require manufacturers of single-use plastics outlined in the SUP Directive that are sold on the German market to pay a central fund (from 2025) for the cost of waste collection and treatment, litter clean-up and public awareness-raising (Ottinger, 2022). The fund is separate from Germany's packaging EPR program, will be managed by Germany's Environment Agency (UBA) and is expected to generate 450 million euros in its first year (Deutsche Welle, 2022). UBA estimates that costs of single-use plastic litter clean-up and disposal in Germany averages approximately 434 million euros annually (Umweltbundesamt, 2022) (Larissa Copello, Single-Use Plastics Directive Implementation Assessment Report 2022). Although the single-use plastic levy has not yet been established, it will be calculated according to mass of waste and levy rate for each single-use plastic product (kg/euros) and will be every five years at minimum (Ottinger, 2022).

Under a separate EU Directive (Plastic Bags Directive), Germany has also banned lightweight, single-use carrier bags since January 2022 as of its first amendment of VerpackG (Blank, 2021).

Given the recent introduction of the bans and the recent drafting of a single-use plastic EPR program, the outcomes of the legislations are not yet understood. However, it is expected to reduce single-use plastic production, consumption and litter, incentivizing producers to manage waste effectively and invest in innovative and environmentally favorable product designs through the 'polluter pays principle'. Nevertheless, Germany's draft legislation for the single-use plastics fund does not seem to encourage the manufacture of reusable products over single-use and may lead to producers swapping single-use plastics with other single-use materials (Larissa Copello, Single-use Plastics Directive Implementation Assessment Report, 2022). As discussed in Section 6.1, the US Plastics Pact developed a list of problematic and unnecessary materials they suggest should be phased out. Though the list itself is not a ban, it can help to inform policymaking to determine which plastic types might be most appropriate to include in bans.

The UK, Spain, and Italy have all implemented taxes on plastic products sold in the country, both manufactured domestically and imported. While all three taxes aim to discourage the use of plastic and promote more sustainable alternatives, they differ in their specific targets and rates. Spain and Italy's plastic taxes focus on non-recyclable and single-use plastic packaging, with a rate of €450 (US$495) per tonne of plastic. The UK's plastic tax applies to plastic packaging with less than 30% recycled content, with a rate of £200 (US$250) per tonne of plastic. The taxes on plastic have only come into effect in 2022 and 2023 so the precise impact of these policies is not yet measurable.

8.3 Recovery and Recycling Technology and Infrastructure

8.3.1 Sorting Technology: Artificial Intelligence (AI) Robotics, Near-infrared (NIR) Optical Sorters and Markers

NIR sorters are programmed to sort plastics by resin types using NIR wavelength signatures. After plastic material identification, nozzles direct streams of air at plastics to separate them into their respective streams. TOMRA developed several optical sorters with NIR sensors for plastic sorting. Additional sensors have been included in many products to increase bale quality and separate "difficult-to-sort" plastic, such as black plastic (see AUTOSORT™ line), Machinex developed MACH Hyspec® which uses short wave infrared hyperspectral detection for sorting (Machinex, n.d.). NIR sorting technology is continually evolving and overcoming obstacles for plastics separation. CEFLEX (A Circular Economy for Flexible Packaging) have been engaging in an experimental study to test the performance of NIR sorting for flexible packaging, including multi-layered packages, with public results expected in the coming months (CEFLEX, 2022).

Innovations improving sorting efficiency, bale quality and high-value material recovery include AI robotics, NIR optical sorting and marking. AI robotics can identify plastics by resin type and other specifications (e.g. shape, color) in real time through machine learning (AI) and multiple sensors, such as advanced camera systems. Using automated arms, AI robots then sort the plastics and other waste, into their respective bins. They are attractive to facilities, as they have demonstrated to be twice as efficient and more accurate in sorting waste than human-powered sorting. Currently, providers of innovative AI robotic sorters supporting multiple plastic resin types and forms include AMP Robotics (AMP Cortex^{TM}) (AMP Robotics, n.d.) and Machinex (SamurAI$^{®}$) (Machinex, n.d.). TOMRA pioneered GAIN^{TM} as an add-on technology for their optical, automated sorters (AUTOSORT^{TM}) to purify PE streams and sort wood chips (Tomra, n.d.). UK-based Grey Parrot developed an AI sorting technology to characterize waste streams in real time according to packaging type, material and brand. Their AI monitoring unit can be integrated onto sorting conveyor belts and linked with existing robotic sorters (Grey Parrot, n.d.).

Marking uses imperceptible digital watermarks or UV markers on plastic packaging to improve plastics identification and separation during sorting. Holy Grail 2.0, a multi-stakeholder, EU-based pilot project, is testing the technical and economic viability of its digital watermarks at semi-industrial and industrial scales. Holy Grail watermarks store information on the packaging material, though they can potentially store information on manufacturer, food compliance and composition of the plastic packaging. Digital markers have potential beyond sorting facilities and could help improve consumer engagement in recycling and transparency in supply chains (Digital Watermarks n.d.). UV markers used on multi-layered packaging to differentiate polymers during sorting. Each polymer is associated with a unique fluorescent marker, visible under UV light. Market-ready markers include those developed by ErgisGroup (ErgisMark$^{®}$) (Ergis Group, n.d.) and Nextek's NEXTLOOPP (also includes a recycling process), which is a UK multi-client project (PolyPRISM). The PolyPRISM by NEXTLOOPP, the current market leader in UV identification, is a marker that separates plastics by application type, namely food grade from non-food grade PP. The marker is adaptable to existing sorting equipment and sorting trials using the marker have achieved over 99% sorting purity for food-grade PP (Packaging Europe, 2021) (Philip Woolsey, 2021).

8.3.2 Chemical Recycling Technology: Chemolysis and Dissolution Recycling

Chemical recycling can effectively complement mechanical recycling in plastic waste management by converting mixed, contaminated and/or difficult to recycle plastic (e.g., multi-material plastics, flexible packaging) into high-quality products. As explained in Section 3, **pyrolysis** and **gasification** involve heating plastic waste at high temperatures with little to no oxygen to produce hydrocarbon fuels (pyrolysis oil and syngas). Plastic-to-fuel conversion is not considered part of the circular economy, partially because the process to purify and convert fuel into plastic monomers are energy intensive and generate yield losses (Eunomia, 2020). Nevertheless, both forms of thermal depolymerization dominate the chemical recycling industry in the US and Canada (Eunomia, 2020) and might be advantageous for more heterogenous streams of polyolefins (HDPE, LDPE, PP), though at the expense of output quality. Moreover, pyrolysis can deal with mechanically difficult to recycle waste including polystyrene (PS) and expanded PS, multi-layer plastic waste (e.g., PE/PP film), and some contaminated plastics (e.g., adhesives, pigments, other additives) (Eunomia, 2022). Though pyrolysis and gasification utilize high temperatures that can decontaminate plastic waste, facilities still have contaminant thresholds/limits (e.g., PVC, nylon, EVOH) and feedstock quality specifications in order to produce high quality output (Eunomia, 2022). Consequently, pyrolysis and gasification technologies can only effectively complement mechanical recycling in treating difficult to recycle plastics if accompanied by improved collection and sorting processes that provide reliable and relatively clean streams of plastic, as is the case for mechanical recycling. Additionally, both thermal depolymerization techniques are high energy and carbon intensive, though some companies are attempting to reduce energy usage while improving yields (Eunomia, 2020). Pyrowave, based in Canada, uses a patented microwave catalytic depolymerization (pyrolysis) technology in its pilot plant to recycle PS into PS monomers for food grade packaging, which the company claims to be less energy and carbon intensive and claims to have a 98% liquid yield (Pyrowave, n.d.). Notable, chemical recycling technologies for circularity include chemical depolymerization (chemolysis) which breaks down plastic polymers into monomers, through the addition of a chemical agent, that can then be used as plastic feedstock (Eunomia, 2020). Chemolysis generates polymers identical to virgin plastics and thus aids in recycling plastic products with strict safety and regulatory standards (e.g., food grade packaging). However, the quality of the output is dependent on homogenous streams of plastic resin, thus requiring highly effective sorting processes. Though chemolysis is less commercially mature, it is more circular, less energy intensive and generates lower rates of yield loss than thermal depolymerization techniques (Eunomia, 2020). With headquarters based in Canada, Loop Industries uses their patented depolymerization technology to recycle PET and polyester fibers and convert them into virgin-quality plastics. Their branded recycled PET has been approved for food grade applications (Loop Industries, 2023). Loop Industries are expanding their operations in Canada and France and partnered with Indorama Ventures to retrofit Loop technology at their South Carolina plant (Loop Industries, n.d.). Ambercycle, based in Los Angeles, uses chemical depolymerization technology to recycle polyester fibers from textile waste into cycora®. The company has received significant funding (US$21.6 million) to scale their operations commercially (Ambercycle, 2022).

Another form of physical recycling, solvent purification (dissolution recycling), is still in developmental stages but has potential for selectively separating plastic polymers from contaminants (e.g., adhesives, inks, additives) (Eunomia, 2020). Polystyvert in Canada is using its dissolution technology to dissolve PS waste in essential oils and separate it from contaminants (Polystyvert, 2023). MultiCycle, an EU based project, recycles multilayer plastics (including flexible packaging) as well as fiber reinforced thermoplastic composites using the CreaSolv® process (Cordis, 2022). Purecycle in the US is another solvent purification technology that focuses on polypropylene waste (see Section 8.3.4).

8.3.3 Mechanical Recycling Changes

There is also a focus on improving current mechanical recycling infrastructure to increase both scope of acceptable materials and by increasing the yield from materials being processed. CEFLEX in Europe have curated the Quality Recycling Process (QRP) which “enables a much greater percentage of flexible packaging to be returned to the economy—and in the quantities and the qualities needed to meet the requirements of new end markets” (CEFLEX, 2021). The process utilizes the following steps in order to increase the proportion of flexible packaging that can be mechanically recycled:

1. Advanced sorting techniques: such as using NIR technology at the pre-treatment stage would improve separation of target and non-target polymers to improve recycled content quality.
2. Hot washing: some recyclers currently wash ≤ 40 °C. An increase in temperature to > 60 °C could enable the removal of organic contaminants, some inks and pressure sensitive labels including laminates and adhesives label. Additional size reduction prior to washing could

also be beneficial. It should be noted however that elevated washing temperatures may result in polymer degradation (Plastic Recycling Machines, n.d.).

3. Extrusion with extra filtration: would facilitate the removal of contaminants (such as labels) that may pass through a single mesh sideways.
4. Deodorization: aims to reduce the scent memory of recycled plastic to produce higher quality recycled resin. Plastic has the ability to hold onto odors from products they came into contact with in their original form (Gerlat, 2018).

There is still yet to be a facility that has all of these steps in utilization at present.

A Note on Chemical Recycling and the Mass Balance Approach

An increasingly important measurement is that of recycled content in plastic products. Traceability of recycled material is important to maintain in the chemical recycling industry since recycled inputs are often produced into products alongside virgin feedstock. Mass balance is a proposed method for accounting for recycled content, where mass allocation of recycled input must equal the mass of product output. Several methodologies for mass balance have been proposed, some more flexible than others (Eunomia, 2020). Using group-level mass balance approaches, arbitrarily allocating recycled content to products and using a recycled feedstock credit system, means companies can claim a higher recycled content within individual products containing low actual recycled content (Zero Waste Europe, 2021). Group-level mass balance is based on allocating recycled feedstock for groups of products rather than at the process/batch-level or at the site-level (Eunomia, 2020). A more transparent and accurate approach would be applying mass-balance at the batch-level and allocating recycled content evenly, which takes the average of all inputs into the process as the recycled content, leading to lower recycled content claims due to even distribution of recycled material across products Zero Waste Europe, 2021).

8.3.4 Food Grade Recycled Packaging

Food grade packaging refers to packaging that is safe to be in contact with food, and is absent of harmful chemicals, as determined by the governing food safety agency such as the FDA in the US and Health Canada in Canada. However, as mentioned in Section 6.1, there are instances where chemicals are unintentionally added to food packaging during the production process (NIAS) (European Union, 2011). In order to combat these contaminants entering the market, manufacturers can apply for a Letter of No Objection (LNO) by governing bodies, which assure customers that the products have been evaluated and determined to be free of harmful chemicals (Government of Canada, 2023). Given the stringent regulatory environment surrounding food contact packaging and the difficult to recycle nature of films, it is a key plastic waste stream that needs to be addressed.

Achieving circularity requires closed-loop recycling technology and strategies, where plastic products are continually recycled into the same grade of product. PureCycle by P&G is a dissolution recycling process where PP products by P&G are recovered from waste streams and recycled into pure PP resin approved food contact. PureCycle recovers PP from waste by establishing partnerships with stakeholders in the plastic supply chain, such as brands (Pure Cycle, 2023). A commercial plant in Ohio is planning to begin operations in 2023. A facility in Georgia is also under development (M. Quinn, 2022). Other US and Canada based mechanical and chemical recyclers who have achieved FDA approval or non-objection letters for food grade applications include, but are not limited to, Loop Industries, Fraser Plastics, Merlin Plastics Supply (FDA, 2023) and Berry Global (CleanStream®) (Berry, 2022).

8.3.5 Organic Recycling

A controversial area of development for certain ‘bioplastics’ is organic recycling, also known as composting. Though often used interchangeably, compostable plastics are biodegradable only in certified (often industrial) environments whereas biodegradable plastics can generally degrade in “natural” conditions. There are both bio-based and fossil-fuel based biodegradable plastics. The nuances of each, along with the general state of bioplastics waste management in the US and Canada is outlined in detail in the Bioplastics Milestone Study.

8.3.6 Managing Plastic Packaging: Blockchain

Blockchain, a supply chain technology, can support policy approaches for managing plastic packaging. When applied to supply chains – or reverse supply chains, such as for waste management – blockchain is used to create an immutable ledger, a complete record of the movement of goods that has been verified at every transfer point. It can be used in combination with RFID or QR code technology to coordinate with physical products, such as recyclable packaging. While the use of blockchain for recycling collection is still very immature, in theory, it can be used in concert with programs such as EPR to ensure compliance within the waste management process, allowing governments and producers to better track their products at end-of-life. The tracked materials must still go on to either a mechanical or chemical recycling facility for processing (Eunomia, 2020).

While blockchain technology has the potential to improve plastic waste management, there are several barriers and potential issues that may reduce the technology's impact. These issues include:

- Lack of Standardization: The differences in collection and recycling processes, policies and regulations, and plastic waste types, make it challenging to develop a standardized and interoperable blockchain solution that can be universally adopted.
- Limited Traceability: Tracking plastic waste throughout its lifecycle will likely require multiple actors to input data at various stages along the value chain. Ensuring accurate and reliable data input can be challenging, as it relies on the cooperation of all participants in the supply chain.
- Scalability and Carbon Impact: Given the large quantity of plastic waste generated in the US and Canada, managing and recording all the data on the blockchain will likely require significant computational power, storage capacity, and network bandwidth. This can increase costs, reduce efficiency, and have a significant environmental impact (namely carbon emissions) due to the high computational power required for mining and validating transactions.
- Governance and Regulatory Challenges: Implementing a blockchain-based system for plastic waste management may face regulatory challenges. This includes determining roles and responsibilities of different stakeholders in the blockchain network, defining rules for data management and access, addressing privacy concerns, and ensuring compliance with relevant regulations and laws.

- Technological Maturity and Adoption: While blockchain technology has gained significant attention, it is still relatively new and may not yet be mature enough for widespread adoption in the waste management industry. Adoption of blockchain may require significant investments in infrastructure, education, and training for stakeholders, which may pose barriers to entry for smaller or less technologically advanced entities.
- Cost and Economic Viability: Implementing a blockchain-based system for plastic waste management may involve initial setup costs, ongoing maintenance costs, and potential transaction fees for using the blockchain network. These costs may impact the economic viability and feasibility of such a system, especially for small-scale waste management operations or economically disadvantaged regions.

In summary, while blockchain technology offers potential benefits for managing plastic waste, there are several challenges that need to be addressed, including standardization, traceability, scalability, governance, technological maturity, environmental impact, and cost considerations. Careful consideration of these challenges is necessary to ensure that blockchain-based solutions for plastic waste management are effective, efficient, and sustainable.

9 Findings and Recommendations

Based on the analysis of the plastics value chain, policy and regulatory landscapes, and best practices for improving circularity across the US and Canada given above, this section sets out, in table form, the key barriers to circularity and their possible causes, and provides recommendations for solutions, with these translated into concrete actions for policy makers.

Barriers to circularity are grouped by use application of plastics: packaging, construction & demolition, automobiles, and electronics. For some barriers there are multiple possible causes, with their own corresponding suggested solutions and policy recommendations; in such cases, the following tables are structured using separate cells and color coding for clarity. The color coding is simply red for the left two columns that outline the challenges and barriers to circularity; green for the right two columns that outline the suggested solutions. At the top of each table, the US and Canadian flags are used to indicate which nation the table applies to.

It should be noted that there is some repetition in the tables below. This is because barriers to circularity exist for multiple reasons, and policy actions can serve as solutions for overcoming more than one barrier. The most commonly featured policy recommendations include:

- **Extended producer responsibility** (EPR) is an environmental policy approach in which producers bear the financial responsibility for managing the packaging they place on the market at end-of-life. It can be leveraged to promote circularity in a number of ways, including introducing collection and recycling targets, modulating EPR product fees to incentivize the inclusion of recycled content and design for recycling, and using funds from EPR to finance investments into infrastructure and education and outreach.
- A **deposit return system** (DRS), also called a ‘container deposit system’ or ‘bottle bill’, places a monetary deposit on a product, paid by the consumer at the time of purchase, which is refunded when the consumer returns the product to a designated location for reuse and/or recycling. Passing DRS in jurisdictions in which these are not currently in place can help to increase the volume of plastic bottles collected domestically and thereby improve high quality recycling feedstock availability. DRS also typically leads to better data due to increased tracking of products placed on the market.
- **Recycled content targets** could help to reorientate the plastics value chain away from its historical dependance on virgin plastics towards using more recycled material. They would provide a clear market signal for recyclers by creating stable demand and prices for recycled plastic. They can also be used to drive innovation in overcoming the challenges associated with some difficult to recycle plastics, such as flexible films. As such, a first step would be to assess to what extent recycled content could be applied to different packaging materials, then develop ambitious but feasible targets and legislate for minimum recycled content requirements to increase demand for recycled plastics.
- There are **other kinds of targets**, beyond recycled content goals, that can help move the plastic packaging industry towards circularity. This includes targets for plastic source reduction, reuse for single-use plastic packaging, and reduction in virgin fossil-based plastics in packaging. Almost all targets could be a part of EPR or introduced as separate policies, as suits the legislative context.

9.1 Packaging

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
High disposal of plastic packaging compared to recycling: Across the US and Canada, due to low recycling rates, approximately 20.6 million tonnes of plastic packaging material are disposed of rather than being recycled.	**Design for single-use:** Most plastic packaging is currently designed for single-use applications. The resulting plastic waste often ends up in linear pathways (not recycled or reused). This issue is augmented by improper disposal by consumers and mismanaged landfill.	Replace single-use packaging with reusable where possible in order to reduce the need for single-use packaging waste management.	Carry out a study to identify in what locations and in what contexts (e.g., food and beverage, online shopping delivery packaging) reuse and refill is being used and/or trialed. Where suitable, set up public – private sector partnerships to invest in reuse infrastructure (e.g., washing facilities, collection systems, etc.), zero waste packaging shops, and pilot projects.
			Investigate suitable targets for plastic source reduction and reuse for single-use plastic packaging and foodservice ware. Where relevant, set these targets.
			Integrate reuse requirements and funding into state-level EPR and DRS legislation.
			Identify packaging types for which bans or taxes would be appropriate measures (making sure to consider the impact of substitute materials).

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			Identify packaging types that would benefit from grant programs for reuse/refill projects.
			Carry out a study to review and evaluate existing reuse standards. Then, following this, identify needs and recommend or develop standards where suitable.
			Develop regulation that encourages reuse by protecting liability (similar to Good Samaritan Act which provides liability protection for food donations).
Limited availability of recycled plastic: Insufficient quality and quantity of recycled plastic to make back into packaging means reliance on virgin plastic is still high. There is greater demand for this material than supply.	**Insufficient quality and quantity of recyclable material and a volatile market can hinder the recycling industry and limit production of recycled plastic:** Issues with collecting clean, recyclable plastics lead to insufficient quality and quantity.	Increase the volume and quality of recycled plastic to make back into packaging.	Develop policies to incentivize and enable increased recycling activities, including improved collecting and sorting.
			Consider investment and pilot projects to accelerate technology for chemical recycling to address plastic waste not suited for physical recycling.
			Assess where, and to what extent, recycled content could be applied to different packaging materials, then develop targets and legislate for minimum recycled content requirements

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			to increase demand for recycled plastics.
		Decouple price of recycled plastic from virgin plastic.	Consider implementing virgin plastic taxes. Review and evaluate the success of virgin taxes in other jurisdictions and assess suitability of virgin plastic taxes.
			Implement minimum recycled content requirements to increase demand for recycled plastics.
			Support proposed EPR bills that include recycled content targets and include recycled content targets in any new EPR legislation proposals.
			If possible, consider applying import tariffs to virgin fossil-based materials to improve the economic viability of national recycled materials.
Limited use of recycled plastic relative to high use of virgin plastic: There are negative environmental and social impacts associated with the use of virgin material, which is used in increasing quantities for packaging. Recycled content use is limited to a small number of applications and is	**Recycled plastic poses more challenges compared to inexpensive virgin plastic:** Virgin plastics are a relatively inexpensive and lightweight material that is widely used in packaging. Volatile markets make the recycling industry less appealing to potential investors.	Optimize packaging design to remove unnecessary volume in plastic packaging types.	Investigate and pass legislation requiring headspace reduction (i.e., reduce empty space within packaging) and right-sizing for all packaging.
			Pass legislation to reduce plastic overwraps (i.e., the plastic film that covers products like produce, meat, or flats of soft drinks for example) by requiring them to be

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
being used in relatively small quantities.	When oil prices are high, so are virgin plastic prices, and recycled plastic can be more competitive. But when virgin plastic prices drop, they can out compete recycled plastic on price. This in turn can force down the price of secondary plastic material, making the recycling industry less profitable.		used only when "necessary" and down-gauged wherever possible.
		Increase the volume and quality of recycled plastics.	Develop policies to incentivize and enable increased recycling activities, including improved collecting and sorting.
			Consider investment and pilot projects to accelerate technology for chemical recycling to address plastic waste not suited for physical recycling.
			Review and evaluate the success of virgin taxes in other jurisdictions and assess suitability of virgin plastic taxes.
			Assess where and to what extent recycled content could be applied to different packaging materials, then develop targets and legislate for minimum recycled content requirements to increase demand for recycled plastics.
			Develop a US and Canadian standard to measure recycled content to enable cross-jurisdictional alignment on recycled content measurement.
			Set targets and transition packaging to increase recycled

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			content use. This could be supported by supporting industry standardization of recyclate specifications (e.g., those currently being developed by the Alliance to End Plastic Waste) and liaising with the European Committee for Standardization (CEN) on the standards they are revising and developing in Europe to support the European Strategy for Plastics in the Circular Economy.
		Decouple price of recycled plastic from virgin plastic.	Consider implementing virgin plastic taxes. Review and evaluate the success of virgin taxes in other jurisdictions and assess suitability of virgin plastic taxes.
			Implement minimum recycled content requirements to increase demand for recycled plastics.
			Support proposed EPR bills that include recycled content targets and include recycled content targets in any new EPR legislation proposals.
			If possible, consider applying import tariffs to virgin fossil-based materials to improve the economic viability of national recycled materials.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
		Increase the use of sustainably sourced, recyclable, bio-based, non-biodegradable packaging.	Investigate and set targets for reduction in virgin fossil-based plastics in packaging. This could be a part of EPR or separate legislation, as suits the legislative context, and done in tandem with recommendations in the CEC Bioplastics Waste and Paper Waste Milestone Studies.
			Review and evaluate the success of virgin taxes in other jurisdictions and assess suitability of virgin plastic taxes.
Low quality of plastics collected for recycling due to contamination.	**Mixed collection streams:** Across the US and Canada, plastics are often mixed with other recyclables (glass, paper) or with general waste (organic, non-recyclable) when collected. These are contaminants that must be sorted out for plastic to be recycled, which requires investment in sorting infrastructure and still leads to losses if contaminants cannot fully be separated.	Encourage accurate source separation and mitigate contamination that happens during collection. Adopt dual stream or multi stream collection systems where glass is separated from paper/plastic, etc.	Support dual or multi-stream collection through grants pilot programs, etc. In rural areas, support the development of depots for packaging.
			Pass Deposit Return System (DRS)/bottle bills in jurisdictions without it to cover beverage containers.
		Improve consumer recycling behavior via better education.	Develop policies to incentivize and improve collection rates and reduce contamination.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	Inconsistent recycling requirements across different jurisdictions: Inconsistent recycling requirements across different jurisdictions (including sub-nationally) have resulted in consumer confusion regarding what items are recyclable. This inconsistency also poses challenges for creating uniform messaging or labeling either on product packaging or waste containers to educate consumers about correct disposal options and recycling practices.	Create accurate / consistent labeling. Harmonize/standardize materials that can be recycled in a region or jurisdiction to mitigate consumer confusion.	Invest in and conduct pilot projects to develop collection systems for flexible films and other plastic wastes that are not historically targeted by physical recyclers but are a growing feedstock for chemical recycling.
			Begin collaborative discussions around labeling consistency with stakeholders.
			Pass a federal law requiring accurate, transparent recyclability claims on product labels (e.g., updates to FTC Green Guides).
			R&D into improving resin identification codes (RICs) labeling to prevent confusion.
			Increase enforcement to incentivize correct recycling (e.g., fines for improper disposal).
Limited data availability: There is limited data availability around end-of-life treatment of plastics and processing capacities of facilities, meaning that we lack detailed insight into tonnages of different materials in circulation, entering the waste stream versus escaping	**Lack of standardized waste reporting requirements:** In both the US and Canada there is a lack of standardized, minimal waste reporting requirements. Additionally, there is a lack of incentives to report data. Furthermore, data	Implement waste characterization standards across both countries.	Develop guidance and potential incentives for waste reporting and guidance on performing waste characterizations.
		Implement extended producer responsibility.	Encourage extended producer responsibility, under which producers would be required to report sales and performance data.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
to the environment, and flows of material within waste streams, including how they are ultimately processed.	availability is often poor in the informal sector, which is especially active in parts of the US.	Implement DRS in more areas.	Support DRS to be enacted in more states/provinces, or across the entire nation. DRS typically leads to better data due to increased tracking of products placed on the market, throughout the waste value chain. Additionally, need to ensure that the DRS operate according to the same fundamental material list in order to increase standardization of waste management.
Minimal recycling of multi-material flexible plastics: There is currently a near negligible recycling rate of multi-material flexible plastics.	**Lack of infrastructure to sort and process multi-material flexibles:** There is a severe lack of infrastructure to sort and process multi-material flexibles, specifically infrastructure that is able to process these materials without struggling with contamination problems.	Encourage source reduction via implementing a ban on multi-material flexibles for packaging where there is a more circular alternative.	Carry out a study into which multi-material flexibles are most problematic and what alternatives could be used if a ban was implemented.
		Improve product design for ease of recycling.	Set design requirements for flexible films that enable easier sorting and recycling (e.g., mono-material flexibles).
			Support and increase grants for R&D into improved packaging design for recyclability.
		Increase infrastructure than can sort and process multi-material flexibles.	Invest in technology R&D and pilot facilities.
			Encourage federal leadership to define chemical recycling in order to standardize the industry.

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Low recycled content in food grade packaging: Relative to other packaging, there is especially low recycled content usage in food grade packaging.	**Lack of suitable feedstock:** There is a lack of infrastructure which can produce food grade recycled resin outside of PET bottles as quality of material feeding into these processors is not pure enough.	Guide industry on what technology or production methods can achieve food grade recycled content.	Work with industry to align on requirements needed for food grade recycled content (in conjunction with bioplastics).
		Increase infrastructure that can create food grade recycled resin.	Encourage investment, pilot studies in food-grade recycling technologies.
Unreliable comparisons across jurisdictions: Lack of clarity on how recycling rates compare across jurisdictions.	**Lack of consistent methodology for measuring recycling rates or recycled content:** There is no consistent methodology for measuring recycling rates or recycled content across the US and Canada.	Publish standard guidance on how recycling rates and recycled content should be calculated across NA.	Begin collaborative discussions around calculation methods for recycling rates and recycled content with stakeholders.

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Relatively low beverage container recycling rate: There is a low recycling rate of beverage containers relative to other countries with DRS programs.	**Limited use of DRS:** DRS is not implemented in 40/50 states in the US. The ten states with DRS in the US are not consistent and do not cover all beverage containers.	Implement DRS in more areas.	Provide guidance for DRS legislation to enable policymakers and to improve consistency across states.
			Provide incentives to strengthen the program for rural areas. Acknowledge the current efforts to demonstrate corporate responsibility and sustainable practices.

9.2 C&D

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Increasing virgin plastic use in construction: There are increasing quantities of fossil fuel plastics being used in construction materials.	**Plastics are often lower cost than alternative construction materials:** Plastics are a relatively inexpensive and lightweight material that are increasingly being used in construction.	Increase the use of recycled content plastics instead of virgin fossil fuel plastics.	Invest in R&D and pilot projects focused on increasing the use of recycled-content plastics in construction.
		Increase the use of sustainably sourced, recyclable, bio-based, non-biodegradable replacements.	Invest in R&D and pilot projects focused on increasing the use of bio-based plastics in construction.
Minimal reuse of C&D plastic waste: There is a low reuse of C&D plastic waste relative to other types of plastic waste.	**Difficult to separate** the plastic in C&D waste from other mixed materials.	Encourage design for disassembly.	Incentivize (e.g., tax breaks) construction plans that incorporate EOL considerations into their plans.
			R&D into construction methods that allow for easy EOL sorting, including for plastic components. Engage value chain stakeholders in pre-competitive collaboration to understand use needs and EOL options.
		Require source separation on site.	Set requirements source separation of materials for reuse and recycling on C&D sites.
	Difficult to store used building materials for long periods of time due to large size.	Increase construction material storage.	Offer grants for local building resources reuse centers that store and sell used building materials to allow for storage and reuse.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	Difficult to access used materials from other construction projects due to size, project timelines, and a lack of awareness about what materials are available.	Facilitate connection/accessibility to reusable plastic materials in order to encourage adaptive reuse.	Support and invest in reuse networks that provide a centralized online database of what materials are available, their condition, and location.
	Potential concerns about liability or material condition in relation to structural integrity which increase friction to reuse plastic materials in construction.	Create a verification standard/system which would provide industry with confidence in the reuse plastic material.	Clarify (1) material testing standards for reuse and (2) liability around the use of secondhand materials in construction.
Low recycling rate of plastics from C&D waste compared to other plastic waste categories.	**Difficult to separate for recycling:** The plastic in C&D waste is often difficult to separate from mixed materials.	Encourage design for disassembly which would make it easier to separate waste into material-specific streams.	Incentivize (e.g., tax breaks) construction plans that incorporate EOL considerations into their plans.
			Offer grants for R&D into construction methods that allow for easy EOL sorting, including for plastic components.
	Lower value of plastic materials: Plastic is of low value compared to other materials such as metals. Further reducing their value, some plastics used in construction release dioxins or are deteriorated from use by end of life.	Require source separation on site of materials which reduces sorting loss rates and increases quality of the waste stream i.e., less material is lost to contamination.	Set requirements for source separation of materials for reuse and recycling on C&D sites.
		Increase demand/price of recycled plastic in construction.	Implement taxes on using virgin plastic for construction, where possible. Specifically for parts that do not require bespoke structural specifications for the plastic.

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			Implement minimum recycled content requirements to increase demand for recycled plastics.
			Carry out a study to examine alternatives to toxins used in construction that reduce the value of the EOL plastic used in C&D.

9.3 Automobiles

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Increasing use of virgin fossil fuel plastics in automotive sector.	**Plastics are lightweight, improving fuel efficiency:** Substituting plastics for other heavier materials such as metal can reduce the weight of vehicles, thus improving fuel efficiency and reducing emissions.	Increase the use of recycled content plastics instead of virgin fossil fuel plastics.	Incentivize (e.g., tax breaks) auto design that meet recycled content requirements.
			Offer grants for R&D into design using recycled plastics in automobile manufacturing.
		Increase the use of sustainably sourced, recyclable, bio-based, non-biodegradable replacements.	Incentivize (e.g., tax breaks) auto design that meet bio-based targets.
			Offer grants for R&D into using bio-based plastics in automobile manufacturing.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	Rising individual car ownership: A secondary concern is the number of vehicles in the US and Canada which is increasing due to private car ownership being on the rise.	Improve public transport in order to reduce dependence on private car ownership and production, thereby reducing materials (including plastic) used upstream in the automotive industry.	Invest in expanding and improving public transport systems.
		Support sharing economy for vehicles in order to reduce dependence on private car ownership and production, thereby reducing materials (including plastic) used upstream in the automotive industry	Pass policies (e.g., tax breaks) that support car sharing, ride sharing, etc. (e.g., taxis, Uber, Lyft, Turo).
Low recycling rate of plastics in automotive sector.	**Difficult to separate** some of the plastic within vehicles from mixed materials.	Design for deconstruction.	Incentivize (e.g., tax breaks) for auto design that incorporate EOL considerations.
			Offer grants for R&D into design for deconstruction improvements.
	Costs associated with deconstruction: Not all vehicles are deconstructed before being shredded as it is often more cost-effective and less labor-intensive to crush and shred vehicles rather than to dismantle parts.	Increase access to deconstructing locations prior to shredding.	Investigate capacity and needs for deconstruction facilities and infrastructure for EOL vehicles.

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	Sorting is minimal – mostly becomes automotive shredder residue (ASR).	Improve plastic recovery from ASR.	Investigate (e.g., possible use of existing technology or development of new technology / trials) how to improve recovery of plastics from ASR.

9.4 Electronics

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Increasing use of virgin fossil fuel based plastics in electronics.	**Plastics are relatively inexpensive and lightweight:** Plastics are a relatively inexpensive and lightweight material that are used in many kinds of electronics.	Increase the use of recycled content plastics instead of virgin fossil fuel plastics.	Incentivize (e.g., tax breaks) electronics that meet recycled content requirements.
			Offer grants for R&D into design using recycled plastics in electronics manufacturing.
		Increase the use of sustainably sourced, recyclable, bio-based, non-biodegradable replacements.	Incentivize (e.g., tax breaks) electronics that meet bio-based targets.
			Offer grants for R&D into using bio-based plastics in electronics.
Increasing consumption frequency of select electronics.	**Short product lifespans:** Some electronics are not designed for longevity but are instead designed to be	Design products with longer lifetimes, enabling reuse and refurbishment.	Offer grants for R&D into electronics design for extended lifetime length and repairability.
			Implement a ban on designed obsolescence for certain products.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	replaced every 2-3 years. For some products, such as cell phones, annual upgrades are incentivized (e.g., discounts, promos, etc.,) by producers.	Limit unnecessary upgrades and similar promos.	Perform or commission a study on impacts of promotions and incentivization around unnecessary upgrades to electronics.
	Barriers to repair: Inaccessible repair due to proprietary parts, tools, etc. that limit who or what organizations can repair.	Increase convenient, affordable access to repair.	Pass/support right to repair legislation (establishes that consumers and independent repair providers have a right to obtain manuals, diagrams, diagnostics, and parts from original equipment manufacturers (OEMs) in order to repair their own devices).
Difficult to separate parts, including plastics, for many electronics.	**Not designed for recycling:** Many electronics are not designed to enable easy/efficient dismantling, sorting, and recycling or reuse of parts.	Increase sorting efficiency of e-waste.	Offer grants for R&D into sorting technology to improve sorting speed/efficacy and repairability/reusability.
			Incentivize (e.g., tax breaks) electronics that incorporate EOL considerations.
			Carry out a study to identify incentives and policies to increase the reuse of secondhand parts of materials in refurbished equipment.

Appendix

10 Circular Economy Definitions

Currently, there is no standard, internationally recognized definition of the "circular economy." Below are several definitions that were used to provide guidance and reference for carrying out this study.

10.1 Governments and Institutions

The Government of Canada:

The circular economy is a different way of doing business. The way our economies extract, use, then dispose of resources is putting pressure on our natural systems, communities, and public health. This is a linear economy—it moves in a straight line from resource extraction to waste disposal. In a circular economy, nothing is waste. The circular economy retains and recovers as much value as possible from resources by reusing, repairing, refurbishing, remanufacturing, repurposing, or recycling products and materials. It's about using valuable resources wisely, thinking about waste as a resource instead of a cost, and finding innovative ways to better the environment and the economy.

Source: https://www.canada.ca/en/services/environment/conservation/sustainability/circular-economy.html

The Government of the United States:

The term "circular economy" means: an economy that uses a systems-focused approach and involves industrial processes and economic activities that; are restorative or regenerative by design; enable resources used in such processes and activities to maintain their highest values for as long as possible; and aim for the elimination of waste through the superior design of materials, products, and systems (including business models).

Source: Save Our Seas 2.0 Act – United States law enacted on December 18, 2020

The European Commission:

The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended.

In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible thanks to recycling. These can be productively used again and again, thereby creating further value.

This is a departure from the traditional, linear economic model, which is based on a take-make-consume-throw away pattern. This model relies on large quantities of cheap, easily accessible materials and energy.

Source: https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits#:~:text=The%20circular%20economy%20is%20a,reducing%20waste%20to%20a%20minimum

10.2 Reports/Studies

Closed Loop Partners Report (2020)

Put simply, the circular economy eliminates the concept of waste and makes the most of materials that are already in play, much like natural systems in which nutrients are continually cycled. Resource efficiency, and the resulting opportunities for savings and profit, is at its core.

Source: The Circular Shift: Four Key Drivers of Circularity in North America Report

McCarthy et al. (part of OECD Environment Working Papers series):

There is no single commonly accepted definition of the term “circular economy”, but different definitions share the basic concept of decoupling of natural resource extraction and use from economic output, i.e. increased resource efficiency as outcome. One core view of the circular economy is that it can be defined relative to a traditional linear economic system, i.e. one that focuses on closing resource loops. A second, slightly broader, view of the circular economy stresses the importance of slower material flows, either within an economy with some degree of material circularity, or within one that is more linear. The third, and broadest, view of the circular economy is that it involves a more efficient use of natural resources, materials, and products within an existing linear system. This broad view of the circular economy affects potentially all economic activities, not only those that have a high material use profile, and is the one applied in most modelling assessments and in this review.

Source: McCarthy, A., Dellink, R. and Bibas, R., 2018. The macroeconomics of the circular economy transition: A critical review of modelling approaches.

Circle Economy – Circularity Gap Report (2018):

At the heart of the circular economy is the idea of moving away from linear value chains that we have had in place for more than 200 years. It means breaking with the ‘take-make-waste’ tradition and transitioning towards a circular approach that is much less heavily reliant on raw material extraction and much more focused on minimizing and eliminating waste. The broader benefit of this circular model is to separate things we do want from our economic system – such as equally distributed prosperity and a bright future for the next generations – from those we do not want – like wasteful use of scarce natural resources and adverse effects on our environment and society. A circular economy is thereby a decoupling strategy aimed at growing prosperity, whilst intelligently managing resources within the boundaries of our planet.

Source: https://www.circularity-gap.world/

Circle Economy – Circularity Gap Report (2023):

This reduction [of material extraction] is rooted in the circular economy principles of using less for longer, using regenerative materials and cycling materials at their end-of-life. At this moment in time, we've never needed a circular economy more.

Source: https://www.circularity-gap.world/2024

10.3 Organizations

Ellen MacArthur Foundation:

Systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature. It is underpinned by a transition to renewable energy and materials. Transitioning to a circular economy entails decoupling economic activity from the consumption of finite resources. This represents a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides environmental and societal benefits.

Source: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/glossary

International Resource Panel (IRP) & United Nations Environment Programme (UNEP):

The circular economy is one in which the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimized. This is in contrast to a 'linear economy', which is based on the "extract, make and dispose" model of production and consumption.

Source: https://www.resourcepanel.org/glossary

United Nations:

Whilst there is no universally agreed definition of a circular economy, the 2019 United Nations Environment Assembly, the UN's flagship environment conference, described it as a model in which products and materials are "designed in such a way that they can be reused, remanufactured, recycled or recovered and thus maintained in the economy for as long as possible".

Source: https://news.un.org/en/story/2021/06/1093802

10.4 Events and related communications

Sitra / World Circular Economy Forum 2021, Toronto (Canada) (WCEF2021):

The circular economy is not a new idea. Indigenous communities across North America and beyond have been practicing principles of circularity, including regeneration and reciprocity, since time immemorial.

Source: https://www.sitra.fi/en/publications/wcef2021-summary-report/

An economic model which does not focus on producing more and more goods, but in which consumption is based on using services – sharing, renting and recycling – instead of owning. Materials are not destroyed in the end, but are used to make new products over and over again.

Source: https://www.sitra.fi/en/dictionary/the-circular-economy/

The circular economy is part of the glue that binds together the need to tackle climate change, the loss of biodiversity and the overconsumption of natural resources with an inclusive democracy, economic growth and increasing social well-being.

Source: https://www.sitra.fi/en/blogs/circular-economy-makes-business-sense-and-can-help-tackle-globalcrises/

Sitra / World Circular Economy Forum 2021, Brussels (Belgium) (WCEF2024):

Lack of funding has slowed down the development of the circular economy, but the barriers are coming down.

Source: https://wcef2023.com/blog/2023/06/01/leading-multilateral-development-banks-tighten-their-collaboration/

Circular North America – Discussion Paper and Event Summary (May 2021)

The circular economy has come to the forefront as a solution for moving away from today's linear 'take-make-waste' society, addressing growing environmental and social challenges and risks while generating significant economic benefits. Defining the opportunities for North America requires an understanding of where things are today, what the end goal is, and how to get there – identifying relevant natural resource industry strengths while leveraging service-based sectors and the broader innovation ecosystem.

Source: https://www.canada.ca/content/dam/eccc/documents/pdf/circular-economy/north-americapaper/WCEF-Circular-North-America_Report_2021_EN.pdf and https://circulareconomyleaders.ca/circularnorth-america/

11 Market Overview Appendix

11.1 Collection

Table 56. Estimated access rates in Canadian provinces and territories

Province/Territory	% of Households with Curbside Collection
Alberta	77%
British Columbia	72%
Manitoba	86%
New Brunswick	67%
Newfoundland and Labrador	82%
Northwest Territories	N/A (no curbside collection)
Nova Scotia	81%
Nunavut	N/A (no curbside collection)
Ontario	87%
Prince Edward Island	N/A*
Quebec	99%
Saskatchewan	84%
Yukon	4%

*Prince Edward Island reported ~30 tonnes of recycling collected 2021-2022, roughly 0.5lb/person. This tonnage is significantly lower than every other province and as such as was treated as 0% in the modelling for this study.

11.2 Sorting

Table 57. North America's 75 largest MRFs (2020)

#	Plant Operator	MRF Address	Country	Total Tonnage Shipped 2020
1	Sims Municipal Recycling	472 2nd Ave., Brooklyn, New York 11232	U.S.	230,600
2	GFL Environmental	124 Arrow Rd., Toronto, Ontario M9M 1M6, Canada	U.S.	218,850*
3	Waste Management Inc.	6120 River Rd., Hodgkins, Illinois 60525-4278	U.S.	215,445
4	Republic Services	360 W Cheyenne Ave., North Las Vegas, Nevada 89030	U.S.	208,000*

#	Plant Operator	MRF Address	Country	Total Tonnage Shipped 2020
5	Waste Management Inc.	8000 Powell Rd., Hopkins, Minnesota 55343-8580	U.S.	184,102
6	Waste Management Inc.	7175 Kit Kat Rd., Elkridge, Maryland 21075-6419	U.S.	180,183
7	RWS of Southern California (Republic)	2775 E Gretta Lane, Anaheim, California 92806	U.S.	178,000*
8	S.W. Authority of Palm Beach County	5860 45th St., West Palm Beach, Florida33412	U.S.	169,400*
9	Waste Management Inc.	20701 Pembroke Rd., Pembroke Pines, Florida 33029-2005	U.S.	167,666
10	Rumpke Recycling	5535 Vine St., Cincinnati, Ohio 45217	U.S.	163,404
11	Republic Services	1601 Dixon Landing Rd., Milpitas, California 95035	U.S.	162,500*
12	Republic Services	7911 Notes Dr., Manassas, Virginia 20109	U.S.	162,000*
13	Potential Industries	922 E E St., Wilmington, California 90744	U.S.	161,500
14	Republic Services – Rabanco Recycling	2733 3rd Ave. S, Seattle, Washington 98134	U.S.	155,000*
15	Waste Management Inc.	150 Saint Charles St., Newark, New Jersey 07105-3946	U.S.	154,448
16	Waste Management Inc.	W132 N10487 Grant Dr., Germantown, Wisconsin 53022-4445	U.S.	154,389
17	GFL Environmental	645 W 53rd Pl., Denver, Colorado 80216	U.S.	153,000*
18	Cascades Recovery	8325 Main St., Vancouver, British Columbia V5X 3M3,	Canada	149,827
19	Casella Recycling	24 Bunker Hill Industrial Pk., Charlestown, Massachusetts 02129	U.S.	147,834
20	Waste Management Inc.	1440 Port of Tacoma Rd., Tacoma, Washington 98421-3704	U.S.	147,370
21	Waste Management Inc.	6211 234th St. SE, Woodinville, Washington 98072-8658	U.S.	140,304
22	Cascades Recovery	1845 Emerson St., Rochester, New York 14606	U.S.	139,723
23	Penn Waste	85 Brick Yard Rd., Manchester, Pennsylvania 17345	U.S.	135,185
24	Waste Management Inc.	5201 Bleigh Ave., Philadelphia, Pennsylvania 19136-4225	U.S.	134,915

#	Plant Operator	MRF Address	Country	Total Tonnage Shipped 2020
25	Homewood Disposal/Diversified Recycling	17415 S Ashland, East Hazel Crest, Illinois 60429	U.S.	133,000*
26	WestRock Atlanta West	1775 County Services Pkwy., Marietta, Georgia 30008	U.S.	132,000
27	Rumpke Recycling	1191 Fields Ave., Columbus, Ohio 43201	U.S.	131,964
28	Republic Services	30205 N Black Canyon Hwy., Phoenix, Arizona 85085	U.S.	129,360*
29	Waste Management Inc.	2050 N Glassell St., Orange, California 92865-3306	U.S.	127,788
30	Balcones Resources	9301 Johnny Morris Rd., Austin, Texas 78724	U.S.	127,762
31	California Waste Solutions	1005 Timothy Dr., San Jose, California 95133	U.S.	127,300*
32	Cascades Recovery	10351 46th St. SE, Calgary, AB T2C 2X9, Canada	U.S.	126,572
33	Western Placer Waste Management Authority	3195 Athens Ave., Lincoln, California 95648	U.S.	121,330*
34	Waste Management Inc.	40 Ledin Dr., Avon, Massachusetts 02322-1129	U.S.	118,653
35	Waste Management Inc.	4300 E 51st Ave., Denver, Colorado 80216-3145	U.S.	116,866
36	Mazza Recycling	3230 Shafto Rd., Tinton Falls, New Jersey 07753	U.S.	115,000
37	J.P. Mascaro & Sons	1270 Lincoln Rd., Birdsboro, Pennsylvania 19508	U.S.	114,750*
38	GFL Environmental	7795 Torbram Rd., Brampton, Ontario L6T 0B6,	Canada	114,100*
39	Waste Management Inc.	1501 W. Gladstone Ave., Azusa, California 91702-3219	U.S.	112,857
40	Eureka Recycling	2828 Kennedy St. NE, Minneapolis, Minnesota55413	U.S.	110,607
41	Friedman Recycling	3640 W Lincoln St., Phoenix, Arizona 85009	U.S.	110,273
42	Recology	1000 Amador St., San Francisco, California 94124	U.S.	109,000
43	Waste Management Inc.	8491 Fruitridge Rd., Sacramento, California 95826-4807	U.S.	105,380
44	Cascades Recovery	2811 Sheffield Rd., Ottawa, Ontario K1B 3V8,	Canada	104,457

#	Plant Operator	MRF Address	Country	Total Tonnage Shipped 2020
45	Willimantic Waste Paper Co. Inc. (acquired by Casella earlier this year)	1590 W Main St., Willimantic, Connecticut 06226	U.S.	104,312*
46	Republic Services	6100 Elliott Reeder Rd., Fort Worth, Texas 76117	U.S.	100,000*
47	Groot Industries	1759 Elmhurst Rd., Elk Grove Village, Illinois 60007	U.S.	99,675
48	Outagamie County	1419 Holland Rd., Appleton, Wisconsin 54911	U.S.	95,609
49	Republic Services	6025 Byassee Dr., Bridgeton-Hazelton, Missouri 63042	U.S.	95,000*
50	Sierra Processing (a subsidiary of Waste Connections)	865 South Pearl St., Albany, New York 12202	U.S.	92,000
51	Dem-Con Cos.	13020 Dem-Con Dr., Shakopee, Minnesota 55379	U.S.	90,000
52	Ricova RSC	2240 Rue Michel-Jurdant, Montréal, QC H1Z 4N7,	Canada	87,907
53	Waste Management Inc.	3518 4th Ave. N, Tampa, Florida 33605-5816	U.S.	87,146
54	Waste Management Inc.	5610 FM 1346, San Antonio, Texas 78220	U.S.	85,166
55	Republic Services Delaware	1101 Lambsons Lane, New Castle, DE 19720	U.S.	85,000*
56	Waste Management Inc.	72 Salem Rd., North Billerica, Massachusetts 01862-2707	U.S.	84,002
57	LRS	6201 W Canal Bank Rd., Forest View, Illinois 60402	U.S.	82,690
58	Single Stream Recyclers, a Balcones Co.	3901 N Orange Ave., Sarasota, Florida 34234	U.S.	82,141
59	Casella Recycling	15 Hardscrabble Rd., Auburn, Massachusetts 01501	U.S.	81,798
60	Emterra Environmental	6362 – 148th St., Surrey, BC V3S 3C4,	Canada	81,750*
61	Friedman Recycling	5021 Edith NE, Albuquerque, New Mexico 87107	U.S.	81,600
62	Sims Municipal Recycling	1 Linden Ave. E, Jersey City, New Jersey 07305	U.S.	81,000
63	Waste Management Inc.	650 Townsend Rd., Cocoa, Florida 32926	U.S.	80,412
64	Republic Services	725 44th Ave. N, Minneapolis, Minnesota 55412	U.S.	80,000*

#	Plant Operator	MRF Address	Country	Total Tonnage Shipped 2020
65	LRS	111 N 22nd Ave., Minneapolis, Minnesota 55411	U.S.	79,045
66	TFC Recycling	1958 Diamond Hill Rd., Chesapeake, Virginia 23324	U.S.	78,750*
67	American Disposal Services (purchased by Waste Connections)	10370 Central Park Dr., Manassas, Virginia 20110	U.S.	77,300*
68	GreenWaste Recovery	625 Charles St., San Jose, California 95112	U.S.	77,000*
69	Republic Services	1949 Hormel Dr., San Antonio, Texas 78219	U.S.	76,850*
70	Montgomery County, Maryland	16105 Frederick Rd., Derwood, Maryland 20855	U.S.	76,680*
71	Rhode Island Resource Recovery Corp.	65 Shun Pike, Johnston, Rhode Island 02919	U.S.	76,430
72	Waste Management Inc.	2404 S 88th Ave., Kansas City, Kansas 66111	U.S.	75,878
73	FCC Environmental Services	5200 Simpson Stuart Rd., Dallas, Texas 75241	U.S.	75,000
74	Republic Services	1007 Amble Dr., Charlotte, North Carolina 28206	U.S.	74,500*
75	Republic Services	10550 Buckingham Rd., Fort Myers, Florida 33905	U.S.	73,000*

Source: (Recycling Today 2021)

11.3 Recycling Claims and Standards

Table 58. Major recycling standards applicable in North America and Globally

Name	Jurisdiction	Description
ISO 22095 Chain of Custody – General Terminology and Models	Global	Provides unambiguous definitions of the different CoC models and the corresponding requirements, which are independent of sectors, materials, products, and issues addressed. Can be used by any organization operating at any step in a supply chain, as well as by standard setting organizations as a reference point for specific CoC standards.
International Sustainability and Carbon Certification (ISCC) Plus	Global	A global voluntary certification system that certifies sustainable, deforestation-free, and traceable supply chains for materials from agriculture, forestry as well as waste and residue raw materials, non-bio renewables and recycled carbon materials and fuels. The standard can be applied to all markets including chemical and energy markets, as well as food and animal feed.

Name	Jurisdiction	Description
UL 2809 Environmental Claim Validation Procedure (ECVP) for Recycled Content	Global	Authenticates the post-consumer, pre-consumer (post-industrial), closed-loop or total recycled content of products, providing third-party validation. Also includes Ocean Bound Plastic and Ocean Plastic in the source materials. In addition, the program can certify any material or industry and has completed projects in glass, gold, copper, tantalum and cobalt at all stages in the supply chain. Industries served include electronics, jewelry, and batteries. Any material or industry is eligible for certification.
SCS Recycled Content Standard	Global	Voluntary standard that evaluates products made from pre-consumer or post-consumer material diverted from the waste stream. Certification measures the percentage of recycled content for the purpose of making an accurate claim in the marketplace.
Association of Plastic Recyclers (APR) Postconsumer Resin (PCR) Certification	USA	Provides converters and brand owners certainty that the material they are buying and incorporating into their packaging is PCR.
GreenBlue Recycled Material Standard (RMS)	North America	Voluntary, market-based framework that enables consistent labelling of products and packaging that contain or support verified recycled material, either through a certified CoC or via the Attributes of Recycled Content (ARC) certificate trading system.
Recycled Claim Standard (RCS)	Global	Voluntary standard that sets requirements for third-party certification of recycled input and CoC. The goal of the standard is to increase the use of recycled materials. The affiliated standard, Content Claim Standard (CCS), ensures the accuracy of content claims. The CCS accomplishes this goal by verifying the presence and amount of a given raw material in a final product.
RSB Standard for Advanced Products	Global	The program aims to certify all sectors. Certification applies to non-energy products such as plastics, textiles, pharmaceuticals, packaging, tableware, cosmetics, nutritional supplements, food, feed, pulp, paper, etc. One uniform standard for bio-based, recycled content, and attributed systems.
QA-CER Recycled Content Certification System	Global	Voluntary independent, third-party system certification based on ISO 9001 principles including CoC.

12 Policy Appendix

12.1 Canadian Policy at the Province Level

British Columbia

The Government of British Columbia regulates waste management through the Environmental Management Act. The Recycling Regulation, established in 2004 and amended in 2020, establishes an EPR program with the goal of reducing the overall volume of waste and diverting 75% away from landfills (British Columbia, 2022). The Recycling Regulation outlines products that are covered under EPR, including electronic and electrical products, packaging and paper products for residential, institutional, commercial, and industrial waste, and some residual products categories such as pesticides containers, paint containers, and automotive antifreeze containers (British Columbia, 2022).

RecycleBC operates EPR in British Columbia for packaging and paper products (PPP). RecycleBC provides recycling services covering 99.3% of residents in urban, rural, remote, and First Nations communities and works with 181 collection partners to provide curbside, multi-family, and drop-off center collection (RecycleBC, 2022).

Additionally, British Columbia has a DRS that covers all sealed and ready-to-drink containers made of plastic, including pouches, bag-in-box, and polystyrene cups. Encorp Pacific and Brewers Recycled Container Collection Council are the stewardship organizations that operate the DRS system for beverage containers (Encorp Pacific (Canada), 2021) (BC Brewers Recycled Container Collection Council, 2021).

The following table lists the material specific EPR programs that are currently active in British Columbia.

Table 59. Non-packaging EPR programs in British Columbia, Canada

EPR Program	Covered Materials in BC
PCA	Paint, Pesticides, and Flammable Liquids
BCUOMA	Used Motor Oil, Filters, Containers and Antifreeze
CBA	Auto Batteries/Lead Acid Batteries
EPRA	Electronics
CESA	Small Appliances
PCA	Light bulbs and light fixtures
PCA	Smoke Alarms, Carbon Monoxide Detectors
Call2Recycle	Alkaline and Rechargeable Batteries
Telus	Telecommunication Equipment
HSPA	Medications
HRAI	Thermostats

EPR Program	Covered Materials in BC
CWTA	Cell Phones
OPEIC	Outdoor Power Equipment
TSBC	Tires
MARR	Large Appliances

Alberta

The Alberta Environmental Protection and Enhancement Act (2000, updated 2020) requires recycling programs for materials, including beverage containers, but does not impose requirements on collection and processing at recycling facilities. Consumer packaging and paper, cellophane wrap, chip or snack bags, and wraps, and outer protective wrap for food are not required to be recycled province wide.

Alberta currently has a stewardship program, where recycling programs are government-operated and managed by three DAOs. In October 2022, the province passed an EPR program, which will be operational in 2025 (Province of Alberta, 2022). The EPR program will cover single-use products and packaging, including flexible and rigid plastics, and printed paper such as newspapers, packaging, cardboard, printed paper, and magazines.

Additionally, Alberta has a container deposit system for all sealed containers, including PET, HDPE, other plastics, bag-in-box, and pouches, as well as paper aseptic containers, gable top, and tetra pak.

Saskatchewan

Saskatchewan's Environmental Management and Protection Act (2010, updated 2022) requires the recycling of packaging and paper products through a stewardship program for residential waste (The Statutes of Saskatchewan 2010). Under the current system, producers are responsible for 75% of the cost of recycling while municipalities retain operational control and pay for the remaining 25% (Saskatchewan 2023). The province is planning on transitioning its stewardship program for packaging and paper products towards a full EPR model where producers are responsible for 100% of costs. Additionally, the province has DRS for beverage containers, plastic and multi-material containers, as well as paper containers like gable top and aseptic.

Manitoba

In 2022, the province announced plans to implement a full EPR program for household packaging and printed paper, which will be managed by Multi-Material Stewardship Manitoba Inc. (MMSM). The program is set to be fully operational by 2025. Additionally, Manitoba has a deposit return system for certain sealed beverage containers, including plastic and glass bottles and aluminum cans.

Ontario

The Resource Recovery and Circular Economy Act of 2016 in Ontario requires the recycling of materials in the blue box, including plastic. The province is transitioning to a full extended producer responsibility model for paper and plastic packaging and single-use foodservice items starting in 2023. Ontario also has a deposit return system for all alcoholic beverage containers, including PET bottles and bag-in-box containers, as well as paper gable top and tetra pak containers.

Quebec

Pursuant to the Environmental Quality Act, the Government of Quebec published its Residual Materials Management Policy which aims to promote better residual materials management and consumption practices to create a zero-waste society in Quebec (Québec, 2023). It addresses three main challenges: ending resource waste, promoting the goals of the Climate Change Action Plan and the Quebec Energy Strategy, and making all stakeholders responsible for residual materials management. The policy aims to reduce the volume of residual materials sent to disposal sites and to recover and reuse resources by prioritizing source reduction, increase fees for disposal, place a landfill ban on organic material, implement full EPR, promote the recycling of residual materials generated by the industrial, commercial, and institutional sectors, as well as improve knowledge of residual materials management and raise awareness to educate the public about the impacts of residual materials on the environment (Québec, 2011).

The government of Quebec is implementing EPR policies for packaging, printed paper, single-use products, electronics, paints and their containers, oils and antifreeze, and agricultural plastics (Gazette Officielle du Québec, 2022). Producers will be required to meet performance targets for collection and recycling and may face penalties or be required to invest in system improvement if they do not meet these targets. The new system will be managed by an organization approved by RECYC-QUÉBEC and will be in effect by fall 2022 with full implementation by summer 2025 (Québec, 2022).

RECYC-QUÉBEC operates the DRS for beverage containers. DRS in Québec use to cover soft drinks under eight liters and beer containers. Beginning in 2023, DRS will cover all containers from 100 ml to 2 L ready-to-drink beverage containers, excluding bag-in-a-box containers. The deposit amount will rise to C$0.10 for most containers covered and C$0.25 for containers over 500 mL (Québec, 2023).

Québec has a government-operated program that diverts used tires from landfills and is financed through a fee on the sale of new tires. This fee is mandated by the Act Respecting the Québec Sales Tax and goes towards recycling or energy recovery using tires in cement kilns, through RECYC-QUÉBEC (Québec, 2023).

New Brunswick

Each region in New Brunswick has their own recycling services and material acceptance, as it is governed by 12 regional commissions. New Brunswick is currently drafting legislation to implement an extended producer responsibility system for residential packaging and printed paper. The province has EPR for paint and stewardship programs for tires, milk packaging, and electronics. New Brunswick has a DRS for all sealed containers, including plastic bottles, cans, and plastic cups with foil lids, pouches, and bag-in-box, excluding milk and containers under 5L.

Nova Scotia

Solid Waste-Resource Management Regulations under the Environment Act (Nova Scotia 2018) and Activities Designation Regulations under the Environment Act (Nova Scotia, 2022).

Nova Scotia has DRS for plastic, gable top, and tetra pak containers.

Nova Scotia has province-wide landfill bans on all recyclable materials, including plastic packaging, beverage containers, plastic bags, paint, used oil and glycol, tires, and electronics (Nova Scotia n.d.).

Nova Scotia has several stewardship programs in place for various materials, including electronics, paint, used tires, used oil, milk packaging, and newspapers (Nova Scotia n.d.). Milk producers voluntarily take responsibility for the end-of-life management of milk packaging through a stewardship agreement with NS Environment and the Atlantic Dairy Council. The newspaper industry has an industry stewardship agreement with Nova Scotia Environment to address objectives of waste reduction, newsprint recovery, and public education for recycling. Two approved electronic stewardship programs exist: “Recycle My Cell” for cellular phones and “EPRA Nova Scotia” for TVs, computers, monitors, printers, scanners, audio/video systems, and telephones. The Resource Recovery Fund Board (RRFB) operates the consumer paint product stewardship program and used tire program, and an environmental fee is applied to on-road passenger tires at the point of purchase.

Prince Edward Island

The government established the Island Waste Management Corporation (IWMC) as a crown corporation under the Environmental Protection Act (1988, amended in 2019) to manage and oversee the provincial recycling program for packaging and paper materials. Prince Edward Island has stewardship programs for electronic products, paint products, glycol, and oil containers. Prince Edward Island also has EPR for agricultural plastics, which covers containers of pesticides, fertilizers, seed, silage plastics, bale wraps, and grain bags (Legislative Counsel Office 2022).

The province also has DRS for plastic beverage containers, bag-in-box, and drink pouches. Businesses in Prince Edward Island are prohibited from selling or distributing single-use plastic bags (Legislative Counsel Office 2022). They can, however, sell paper bags for C$0.15 and reusable bags for C$1.

The Waste Resource Management Regulations of 2019 prohibit the disposal of recyclable materials in landfills in the province.

Newfoundland and Labrador

Environmental Protection Act (2004, amended 2019). Waste Management Regulations outline the requirements governing the implementation and operation of waste diversion programs.

Recycling programs for tires, beverage containers, and packaging and paper materials are government-operated and managed by the Multi-Materials Stewardship Board (MMSB), a crown agency responsible for developing, implementing, and overseeing waste diversion and recycling programs throughout the province.

DRS covers all sealed, ready-to-drink containers including plastic, pouches, and bag-in-box.

Yukon

The Yukon territorial government subsidizes the recycling of non-designated materials such as packaging and paper in some municipalities, but these programs are not regulated territory-wide. All recovered materials are shipped out of the territory for recycling.

The Beverage Container Regulations establish DRS for plastic, aluminum, bimetal, glass, gable top, and tetra pak beverage containers (Statutes of Yukon 2002). Covered containers over 750mL have a deposit of C$0.35, with a C$0.25 refundable portion, while containers between 30mL and 750mL have a deposit of C$0.10 with a C$0.05 refundable portion (Bottle Bill Resource Guide, 2022).

The Yukon government has put in place a ban on businesses distributing single-use plastic bags, with the ban extending to single-use paper bags in 2023 (Yukon, 2021).

Northwest Territories

The Waste Reduction and Recovery Act (WRRA) (2004, amended 2017) provides the overall legislative framework for waste reduction, reuse, and recycling in the Northwest Territories (Government of Northwest Territories, 2003).

DRS in the Northwest Territories covers beverage containers, including bottles, cans, plastic cups, paperboard cartons, and packages made of metal, plastic, paper, glass, or any other material that contains or contained a beverage ready for consumption, including milk and liquid milk products (Government of Northwest Territories, 2016). This excludes infant formula container, a container with a capacity less than 30ml, an empty container intended for retail sale without being filled.

The Electronics Recycling Regulations authorize fees to be charged at point of sale to fund program recycling operations for electronics. The regulations prohibit the distribution or sale of new electronics in the territory without being registered as a distributor and no electronics can be distributed or sold without paying the surcharge to the environment fund (Government of Northwest Territories, 2016).

The single-use retail bag regulations prohibit the distribution or sale of single-use retail bags in the Northwest Territories (Government of Northwest Territories, 2011). All paper, plastic and biodegradable bags sold in stores must be sold at a cost of C$0.25. This fee is passed onto the Environment Fund, which uses the revenue to cover program expenses and fund new waste reduction and recovery programs (Government of Northwest Territories, n.d.).

Nunavut

Nunavut does not have relevant legislation or a defined waste management strategy pertaining to plastics.

Figure 53. Provincial policies for sectors and materials consisting of or containing plastics in Canada

Province	EPR or Stewardship Program	DRS	Material Ban	Other policy mechanism
British Columbia	🧴 🔌 🌾 🪣 🚗 🛞	🥤	🛍	Disposal/recycling requirements vehicles C&D waste)
Alberta	🧴 🛞	🥤		Disposal/recycling requirements vehicles C&D waste)
Saskatchewan	🧴 🔌	🥤		Disposal/recycling requirements vehicles C&D waste)
Ontario	🧴 🔌 🛞	🍾		Disposal/recycling requirements vehicles C&D waste)
Quebec	🧴 🔌 🌾 🪣 🚗 🛞	🥤		Disposal/recycling requirements vehicles C&D waste)
New Brunswick	🧴 🔌 🪣 🛞	🥤		
Nova Scotia	🔌 🪣 🥛 🛞	🥤	🛍	Fee on tires Landfill ban (plastic packaging, beverage containers, tires, electronics)
Prince Edward Island	🌾 🔌 🪣	🥤	🛍	
Newfoundland and Labrador	🔌	🥤	🛍	
Yukon		🥤	🛍	
Northwest Territories		🥤	🛍	Fee on electronics
Nunavut				
Manitoba	🧴 🔌	🥤		

Key	
🧴	Packaging
🔌	Electronics
🌾	Ag Plastics
🪣	Paint containers
🚗	Auto containers
🛞	Tires
🥛	Milk containers
🥤	Beverage containers
🍾	Alcoholic beverage containers
🛍	Single use plastic bags

Table 60. Canadian regulations related to chemical recycling at the province level

Province/Territory	Law	Year Passed	Main Components
Ontario	O. Reg. 101/07	2022	Requires facilities to undertake an Environmental Assessment (EA)
Quebec	Environmental Quality Act Q-2, r. 35.1	2022	No current Environmental Assessment requirements. Requires permits/approvals for air emissions, waste, water discharged, as relevant. Considers alternative fuels from conversion as recovery/reclamation
British Columbia	Environmental Management Act SBC, 2003	2003	No explicit requirements for chemical recycling facilities. Considers alternative fuels from conversion as recovery.
Alberta	Environmental Protection and Enhancement Act	2021	No current environmental assessment requirements. The Director has discretion to require an EA for the activity. Requires permits/approvals for air emissions, waste, water discharged, as relevant. Facilities where >10 tonnes waste/month are processed to produce fuel, or treated by physical, chemical, thermal biological process, are required to obtain environmental approvals. Considers alternative fuels from conversion as recovery

Table 61. Progress Transitioning to Full EPR for Consumer Packaging by Province in Canada

	Ontario	Quebec	Manitoba	British Columbia	Saskatchewan	New-Brunswick	Alberta
Year of program start	2003	2005	2010	2014	2016	TBD 2023 (6 months following plan approval)	Spring 2025
Producer Responsibility Organization (PRO)	Stewardship Ontario (SO)	Eco Entreprises Quebec (EEQ)	Multi-Material Stewardship Manitoba (MMSM)	RecycleBC	Multi-Material Stewardship Western (MMSW)	TBD	TBD
Service provider to the PRO	Circular Materials (CM)	none	Circular Materials (CM)	Circular Materials (CM)	Circular Materials (CM)	Circular Materials (CM)	TBD
Share of Industry Contribution	Current: 50% Future (2023 onwards): 100%	Current: 100% of eligible costs Future (2025 onwards): 100%	Current: 80% Future: 100%	100%	Current: 75% Future: 100% (TBC)	Full, based on defined service standards	Full

	Ontario	Quebec	Manitoba	British Columbia	Saskatchewan	New-Brunswick	Alberta
Responsibility for recycling service delivery	Current: local gov't Future: producers	Current: local gov't Future: local gov't resp. for collection; producers resp. for post-collection	Current: local gov't Future: producers	Producers	Local gov't	Collection: Local gov'ts will be given right of first refusal Post-Collection: producers	Producers
Targeted Materials	Current: packaging and printed paper Future: packaging; paper product; packaging-like product	Packaging; Printed paper; Single-use products	Packaging; printed paper	Packaging; Single-use products; Packaging-like product; Paper	-packaging -paper	Paper (printed and unprinted) Packaging and Packaging-Like Products	Single-use Products Packaging Paper Products
Program Scope	Current: municipal Future: Residential (single-family (SF)+multi-family (MF)) Retirement & long-term care homes Public spaces Schools	Current: municipal Future: Municipal + Industrial, Commercial, and Institutional (ICI) (phased implementation over 9 yrs)	- residential (SF & MF)	-residential (SF & MF) -streetscape	-residential (SF & MF)	Residential (SF & MF) Schools Public space	Residential (SF & MF)

12.2 Canadian DRS Programs

Table 62. Deposit return systems by province/territory that include plastic containers (Canada)

Province / Territory	Containers Covered by DRS	Redemption Rate for Covered Containers (2021)
British Columbia	All container types of any size excluding infant formula, meal replacements, and dietary supplements. Includes polystyrene (PS) cups.	Plastic: 72.7% Pouches: 23.5%
Alberta	All sealed containers under 50L	Plastic: 81.3% Pouches: 78.3%
Saskatchewan	All beverage containers under 5L, except bag-in-box, juice concentrates, nutritional supplements.	Plastic: 76.9%

Province / Territory	Containers Covered by DRS	Redemption Rate for Covered Containers (2021)
Ontario	All alcoholic beverage containers	PET: 46.1%
Quebec	Starting in 2023, all drinks and container types in plastic (Governement du Québec, 2022)	Plastic: 65.6 % *This rate does not capture the expansion of covered containers in 2023
New Brunswick	All containers under 5L except milk, milk products, and unpasteurized cider.	PET: 73.4% *This is data from 2019–2020 as more recent figures are not available at time of writing.
Nova Scotia	All sealed beverage containers under 5L except milk, milk products, concentrates, and nutritional supplements.	PET/High density polyethylene (HDPE): 80.5%
Prince Edward Island	All sealed beverage containers under 5L except milk, concentrates, and nutritional supplements.	PET: 87.7% Other Plastic: 37.6% Pouches and aseptic: 62.2%
Newfoundland and Labrador	All sealed drinks under 5L, excluding milk, infant formula, concentrates, and nutritional supplements.	PET Plastic: 77.1% Other Plastic: 21.17%*
Yukon	All sealed drinks over 30 mL, except juice concentrate, infant formula, meal replacements.	Total: 65% (includes all materials)
Northwest Territories	All sealed drink except infant formula and milk.	Plastic: 60.7% Pouches: 23.4%
Nunavut	No DRS	
Manitoba	No DRS for plastic containers	

Source: (Reloop, 2022), (Bottle Bill, n.d.)

12.3 US Policy at the State Level

Table 63. US plastic recycling policy summary by state

State	Policy	Description
Alabama	Overview	Alabama does not have comprehensive statewide legislation regarding the management of plastic waste and recycling beyond a non-binding statutory waste reduction goal of 25% set through its 2008 Solid Wastes and Recyclable Materials Management Act (ADEM n.d.). Cities have their own plastic recycling programs and regulations.
Alaska	Overview	The Alaska Department of Environmental Conservation oversee waste management rules and regulations. Recycling in Alaska faces unique challenges due to the small population, distance to markets and transportation costs. The state has no overarching legislation

State	Policy	Description
		regarding the management of waste. Some local governments have targeted programs such as WEEE collection.
Arizona	Overview	ADEQ oversees solid waste management in the state. Arizona does not have comprehensive statewide legislation regulating plastic waste management and recycling. Municipalities have their own plastic recycling programs.
	Chemical Recycling	SB 1156 defines chemical recycling as a manufacturing process
	Preemption law	HB 2131 prohibits municipalities and counties from regulating the sale, use, or disposal of disposable and reusable bags, boxes, beverage cans, bottles, cups, and containers made of cloth, plastic, polystyrene, glass, aluminum, cardboard, and other food-contact materials.
Arkansas	Overview	The Arkansas Division of Environmental Quality oversees solid waste management in the state. Arkansas does not have comprehensive statewide legislation regulating plastic waste management and recycling. Municipalities have their own plastic recycling programs.
	Chemical Recycling	HB1944 defines chemical recycling as a manufacturing process
	Preemption law	H1704 prohibits municipalities and counties from taxing, regulating, or prohibiting the sale, use, or disposal of plastic grocery bags or disposable containers
California	Overview	California has numerous laws regulating plastic waste management and recycling. The California Department of Resources Recycling and Recovery (CalRecycle) oversees the collection of recycling within the state
	EPR	SB 54 establishes EPR for single-use packaging and food service ware. The Electronic Waste Recycling Act requires electronics manufacturers to fund and manage the collection and recycling of electronic waste in the state.
	PCR	AB793 establishes minimum recycled content standards for plastic beverage containers subject to the state's DRS. The law requires a postconsumer plastic recycled content standard of 15 percent beginning in 2022, increasing to 25% in 2025 and 50% in 2030. SB54 requires producers of expanded polystyrene food service ware to achieve a 25% recycling rate in 2025, 30% in 2028, 50% in 2030, and 60% in 2032. California's single-use plastic bag ban requires reusable grocery bags made from plastic to contain a minimum of 40% PCR content.
	DRS	California has a deposit return program for beverage containers.
	Bans	Stores are prohibited from providing single-use plastic carryout bags.
	Labeling	SB343 prohibits the use of the chasing arrows symbol or any other suggestion that a product is recyclable unless it is collected for recycling by at least 60% of the population of the state or it is sorted

State	Policy	Description
		for recycling by processing facilities that serve at least 60% of recycling services statewide.
Colorado	Overview	The Colorado Department of Public Health and Environment has oversight of all waste management and recycling activities in Colorado.
	EPR	HB22-1355 establishes EPR in Colorado (State of Colorado, 2022).
	Bans	Starting in 2024, retail food establishments in Colorado are prohibited from distributing expanded polystyrene products for use as containers for ready-to-eat food (State of Colorado 2021).
Connecticut	Overview	Connecticut's Department of Energy and Environmental Protection oversees waste management and recycling in the state.
	DRS	Connecticut has a DRS for beverage containers Connecticut 2015). The deposit value will increase from US$0.05 to US$0.10 in 2024.
	Bans	HB 7424 prohibits single-use plastic bags provided at the point of sale
	EPR	Connecticut has EPR for electronic devices which requires manufacturers pay for the collection, transportation, and recycling of residentially generated covered devices (Connecticut n.d.).
Delaware	Overview	The Department of Natural Resources and Environmental Control works with local governments in Delaware to manage solid waste and encourage recycling. Delaware has a universal recycling law which requires all waste haulers providing residential trash collections to also include recycling collection. The law also requires businesses, non-profits, and institutions to participate in a recycling program (Delaware General Assembly, 2010).
	Bans	HB212 prohibits store from providing or selling a plastic carryout bag to customers (Delaware General Assembly, 2022). Stores can provide paper carryout bags or reusable bags.
Florida	Overview	Counties in Florida are required to implement a recycling program for solid waste and must be designed to recover and recycle a significant portion of at least four of the following materials: newspaper, aluminum cans, steel cans, glass, plastic bottles, cardboard, office paper and yard trash.
	Chemical Recycling	HB335 defines chemical recycling as a manufacturing process (Florida Senate, 2017)
Georgia	Overview	The state has no overarching legislation regarding the management of waste and recycling
	Chemical Recycling	HB785 defines chemical recycling as a manufacturing process (Georgia General Assembly, 2018)
Hawaii	Overview	The Hawaii Department of Health is responsible for waste management programs in the state. Each county must have an integrated solid waste management plan approved by the department.

State	Policy	Description
	DRS	The Hawaii Solid Waste Management Deposit Beverage Container covers plastic (PET, HDPE), aluminum and bi-metal, and glass beverages under two liters (State of Hawaii, 2004).
	EPR	The state requires manufacturers to fund and manage the collection and recycling of covered electronic devices in the state (State of Hawaii, 2022).
Idaho	Overview	The state has no mandated waste diversion goal. Both recycling and garbage collection are optional services provided at the discretion of local governments or by private recycling companies.
	Preemption	2016 HB 372 regulation regarding the use, disposition or sale of plastic bags or other “auxiliary containers” shall be imposed only by a statute enacted by the legislature.
Illinois	Overview	The Illinois Environmental Protection Agency is responsible for waste management in the state. The state faces a unique risk of running out of landfill space; recycling and waste reduction solutions are becoming increasingly important.
	EPR	Electronic Products Recycling and Reuse Act, 2008
	Chemical Recycling	HB2491 defines chemical recycling as a manufacturing process (Illinois General Assembly, 2020)
Indiana	Overview	Recycle Indiana is a division of the Department of Environmental Management that works with partners to promote and provide technical assistance on recycling. The department also administers a Recycling Market Development Program that grants funding to develop recycling markets in the state.
	Recycling Rate	In 2014, the state passed recycling legislation that requires annual reporting of recycling rates and sets a goal to achieve and maintain a 50% recycling rate.
	EPR	E-Waste Recycling (2009)
Iowa	Overview	Iowa cities and counties are responsible for developing solid waste reduction programs in collaboration with their waste facilities, but there are no statewide targets to guide these plans.
	DRS	Iowa's DRS covers beer, carbonated soft drinks, mineral water, wine coolers, wine, and liquor in sealed glass, plastic, or metal bottles, cans, jars, or cartons (State of Iowa, 2022).
	Chemical Recycling	SF534 defines chemical recycling as a manufacturing process
Kansas	Overview	The state has no overarching legislation regarding the management of waste and recycling. Recycling is not mandated in state law.
Kentucky	Overview	The state has no overarching legislation regarding the management of waste and recycling
	Chemical Recycling	HB45 defines chemical recycling as a manufacturing process (State of Kentucky, 2022)
Louisiana	Overview	The state has no overarching legislation regarding the management of waste and recycling

State	Policy	Description
	Chemical Recycling	SB97 defines chemical recycling as a manufacturing process (State of Louisiana, 2021)
Maine	Overview	The Department of Environmental Protection administers various recycling programs. Maine is a leader in the county in adopting laws for recycling, being the first state to pass EPR for packaging.
	DRS	Maine's DRS covers all beverages in containers of 4 liters or less (Statutes of Maine, 2022).
	EPR	HB1541 establishes EPR for paper and plastic packaging (State of Maine, 2021) Maine has an WEEE law requiring manufacturers to pay for the collection and recycling of electronic waste generated in the state (State of Maine, 2017)
	Bans	2019 HB 1115 prohibits a retail establishment from providing single-use carryout bags at the point of sale or otherwise making the bags available to customers, with exemptions for certain types and uses of plastic and paper bags.
Maryland	Overview	Waste management is overseen by the Maryland Department of the Environment (MDE).
	Recycling rate	Maryland has a 30% recycling rate mandate under the Maryland Recycling Act of 1988. The law was updated in 2012 to include a recycling plan for state agencies, with failure to meet targets resulting in penalties in the form of denials of construction permits. Jurisdictions with populations greater than 150,000 are mandated to reach 35% recycling targets.
	EPR	Maryland passed an EPR law for packaging in 2023. Statewide Computer Recycling Pilot Program (2005)
Massachusetts	Overview	The Massachusetts Department of Environmental Protection oversees waste-related services in the state and has established reuse and repair programs to move materials up the waste hierarchy.
	Bans	The state has a landfill ban covering mono-material plastic containers, white goods, and tires.
	DRS	The Beverage Container Recovery Law in Massachusetts covers sealable containers made of glass, metal, plastic, or a combination of these materials
Michigan	Overview	Michigan's Department of Environment, Great Lakes, and Energy oversees state solid waste and recycling policy.
	DRS	Michigan Beverage Container Act covers airtight metal, glass, paper, or plastic container, or a combination, under 1 gallon (Michigan Department of Treasury, n.d.).
	Bans	Landfill ban on tires
	EPR	Electronics Recycling (2008)
Minnesota	Overview	The Minnesota Pollution Control Agency supports local efforts and provides information on recycling, composting, and solid waste management. Counties in Minnesota have control of solid waste

State	Policy	Description
		management and produce solid waste plans, which are updated every 6 or 10 years, depending on their location.
	EPR	Electronics Recycling (2007)
	Recycling Rate	In 1989, the Minnesota Legislature set a goal for Greater Minnesota counties to recycle a minimum of 35% of total solid waste by 2030, while the 2014 Legislature increased the recycling goal for the seven-county metro area to 75% by 2030.
Mississippi	Overview	The Mississippi Department of Environmental Quality oversees solid waste facilities statewide, while the Office of Pollution Control manages recycling and waste reduction in the state. Around 46% of counties in Mississippi currently do not have access to community recycling programs.
	Preemption	2018 SB 2570
	Chemical Recycling	HB1135 defines chemical recycling as a manufacturing process
Missouri	Overview	The Missouri Department of Natural Resources oversees waste management in the state.
	Preemption	2015 HB 722 prevents localities from imposing a ban, fee, or tax upon the use of either paper or plastic bags.
	EPR	Computer Equipment Recovery (2008)
	Chemical Recycling	HB2485 defines chemical recycling as a manufacturing process
Montana	Overview	The Montana Department of Environmental Quality manages the state's solid waste facilities and programs.
Nebraska	Overview	The Nebraska Department of Environment and Energy manages solid waste facilities in the state.
Nevada	Overview	The Nevada Division of Environmental Protection's Bureau of Sustainable Materials manages waste permitting and compliance programs in the state.
	Collection requirements	Counties in Nevada are required to provide specific recycling programs based on their population. Those with populations over 100,000 must have source separation, recycling centers, and household hazardous waste collection programs. Counties with populations between 45,000 and 100,000 are required to establish recycling centers and handle HHW. However, counties with populations under 45,000 are not required to create recycling programs.
New Hampshire	Overview	New Hampshire has no major statewide programs to enable recycling or waste diversion
	Chemical Recycling	SB367 defines chemical recycling as a manufacturing process
New Jersey	Overview	The New Jersey Department of Environmental Protection (DEP) oversees waste and plastic management in New Jersey. The New Jersey Statewide Mandatory Source Separation and Recycling Act of 1987 required counties to develop recycling plans mandating the recycling of designated materials

State	Policy	Description
	PCR	Recycled content requirement for plastic carryout bags, trash bags, rigid plastic containers, and beverage plastic containers
	EPR	Electronic Waste Recycling Act (2009)
	Bans	Ban on single-use plastic bags and expanded polystyrene foam food packaging.
New Mexico	Overview	The Solid Waste Bureau of the New Mexico Environment Department regulates solid waste facilities and operations in the state.
New York	Overview	Waste and plastic management is overseen by the New York State Department of Environmental Conservation (DEC).
	DRS	The New York State Returnable Container Act covers individual, separate, sealed glass, metal, aluminum, steel, or plastic bottles.
	Bans	Single-use plastic bags and polystyrene foam food packaging.
	EPR	Electronic Equipment Reuse and Recycling Act (2010)
North Carolina	Overview	The North Carolina Department of Environmental Quality's Waste Management Division is responsible for implementing solid waste programs.
	EPR	Discarded Computer Equipment Management (2007)
North Dakota	Overview	The North Dakota Department of Environmental Quality's (DEQ) Division of Waste Management oversees waste management in North Dakota. The state has no overarching legislation regarding the management of waste and recycling.
	Preemption	2019 HB 1200 prohibits a political subdivision from regulating an auxiliary container.
Ohio	Overview	The Ohio Environmental Protection Agency and individual Solid Waste Management Districts are responsible for implementing waste reduction and recycling programs in Ohio. The state does not have does not have comprehensive statewide legislation regarding the management of plastic waste.
	Chemical Recycling	HB166 defines chemical recycling as a manufacturing process
Oklahoma	Overview	The Land Protection Division of the Oklahoma Department of Environmental Quality oversees solid waste permitting and ensures compliance with solid waste regulations. The state does not have does not have comprehensive statewide legislation regarding the management of plastic waste.
	Preemption	2019 SB 1001 Preempts local governments from regulating, taxing, or restricting the sale or use of an "auxiliary container," such as plastic bags, plastic water bottles, or disposable food containers.
	Chemical Recycling	SB448 defines chemical recycling as a manufacturing process
	EPR	Computer Equipment Recovery Act (2008)

State	Policy	Description
Oregon	Overview	The Oregon Department of Environmental Quality (DEQ) oversees waste management in the state. Oregon has multiple policies for the management of plastic waste, including a bottle bill, EPR, bans, and labelling requirements.
	EPR	The Plastic Pollution and Recycling Modernization Act establishes EPR for packaging, paper, and food service ware. Chapter 459A of the Oregon Revised Statutes establishes EPR for electronic devices including computer monitors, desktops, televisions, printers, as well as computer keyboards or mouses (Oregon Laws 2023).
	DRS	The Beverage Container Act covers individual, separate, sealed glass, metal, or plastic bottles containing a covered beverage and less than 3 liters in volume.
	Bans	Ban on expanded polystyrene food packaging and single-use plastic bags.
	Labeling	Oregon's EPR law, the Plastic Pollution and Recycling Modernization Act, has a truth-in-labeling section.
Pennsylvania	Overview	The Pennsylvania Department of Environmental Protection (DEP) oversees waste management in the state. The Pennsylvania Act 101, also known as the Municipal Waste Planning, Recycling and Waste Reduction Act, mandates that all municipalities in the state develop and implement a comprehensive solid waste management plan.
	EPR	Covered Device Recycling Act (2010)
	Chemical Recycling	HB1808 defines chemical recycling as a manufacturing process
Rhode Island	Overview	The state set recycling targets and requires consumer access to recycling. All solid waste generated from residential and commercial facilities must be separated into recyclable and non-recyclable.
	EPR	Electronic Waste Prevention, Reuse and Recycling Act (2008)
	Bans	Ban on single-use plastic bags
South Carolina	Overview	South Carolina has no overarching legislation regarding the management of waste and recycling.
	EPR	Manufacturer Responsibility for Electronics (2010)
	Chemical Recycling	S525 defines chemical recycling as a manufacturing process
South Dakota	Overview	South Dakota has no overarching legislation regarding the management of waste and recycling.

State	Policy	Description
Tennessee	Overview	The Division of Solid Waste Management (DSWM) oversees waste management activities in Tennessee.
	Preemption	2019 HB 1021 Prohibits local governments from regulating in various ways auxiliary containers, a term that includes plastic bags along with many other products.
	Chemical Recycling	SB0923 defines chemical recycling as a manufacturing process
Texas	Overview	The Texas Commission on Environmental Quality (TCEQ) oversees solid waste management in Texas
	EPR	Computer Equipment Recycling Program (2007)
	Preemption	A 2018 ruling by the Texas Supreme Court (16-0748 prohibits local governments from banning or regulating the sale or use of container packages.
	Chemical Recycling	HB1953 defines chemical recycling as a manufacturing process
Utah	Overview	Utah has no overarching legislation regarding the management of waste and recycling. Regulations are set at a county level.
Vermont	Overview	Vermont has multiple laws regulating plastic waste across the state and has waste reduction and recycling goals.
	EPR	An Act Relating to the Recycling and Disposal of Electronic Waste (2010)
	DRS	The bill covers beer, carbonated soft drinks, and mixed wine drinks, and liquor (Bottle Bill Resource Guide 2023)
	Bans	The state has a Universal Recycling Law that prohibits curbside recyclables from being disposed in waste bins.
Virginia	Overview	Waste management is overseen by the Virginia Department of Environmental Quality (DEQ).
	EPR	Computer Recovery and Recycling Act (2008)
	Chemical Recycling	SB1164 defines chemical recycling as a manufacturing process
Washington	Overview	The Department of Ecology (DEC) supports recycling programs across the state. Washington has introduced policy to support recycling and has been active in supporting municipalities to reduce plastic waste.
	Bans	Ban on single-use plastic food service ware items such as plastic utensils, condiments, cup lids for cold beverages. Ban on expanded polystyrene packing peanuts and food service products.
	PCR	PCR content requirement for plastic trash bags, plastic beverage bottles, household cleaner and personal care plastic containers, as well as plastic dairy milk and plastic wine containers.
	EPR	Electronic Product Recycling (2006)

State	Policy	Description
West Virginia	Overview	West Virginia has no overarching legislation regarding the management of waste and recycling.
	EPR	Takeback Program for Electronic Devices (2008)
	Chemical Recycling	HB4084 defines chemical recycling as a manufacturing process
Wisconsin	Overview	The Wisconsin Department of Natural Resources manages solid waste facilities in the state. The state of Wisconsin has a solid waste reduction, recovery and recycling law that was enacted in 1990 to promote waste management and encourage reduction, reuse, and recycling.
	EPR	Electronic Waste Recycling (2009)
	Chemical Recycling	AB789 defines chemical recycling as a manufacturing process
Wyoming	Overview	Wyoming has no overarching legislation regarding the management of waste and recycling.

12.4 US DRS Programs

Table 64. Summary of US state DRS programs

DRS States	Return Rate (2019)	Materials Covered	Deposit Amount
California	67%	Plastic, aluminum and bi-metal, and glass beverages such as soft drinks, water, juices, coffee, and tea, as well as beer, malt, wine coolers, wine, and distilled spirits (excludes milk and infant formula)	5 cents for containers under 24 oz 10 cents for containers 24 oz or larger
Connecticut	50%	Sealed glass, metal or plastic bottle, can, jar or carton including beer, malt beverages, and carbonated beverages, non-carbonated water, sports drinks, energy drinks, and juices	5 cents before January 1, 2024 10 cents after January 1, 2024
Hawaii	62.7%	Plastic (PET, HDPE), aluminum and bi-metal, and glass beverages under 2L including beer, malt beverages, and all non-alcoholic beverages except milk and dairy products	5 cents for all containers
Iowa	64%	Plastic, glass, metal beverages including beer, wine, liquor, carbonated soft drinks and mineral water	5 cents for all containers
Maine	84%	Glass, plastic, metal beverages under 4L except dairy and unprocessed ciders	15 cents for liquor bottles above 50mL 5 cents for all other beverages

DRS States	Return Rate (2019)	Materials Covered	Deposit Amount
Massachusetts	50%	Plastic, aluminum and tinplate, and glass beverages including beer, malt, carbonated soft drinks, mineral water	5 cents for all containers
Michigan	88.7%	Plastic, aluminum and tinplate, glass, and liquid paperboard beverages under 1 gallon including beer and ale, carbonated and mineral water, wine coolers, malt drinks (excludes juice, coffee, milk, sport drinks, wine, liquor, foil pouches)	10 cents for all containers
New York	64%	Plastic, aluminum and tinplate, and glass beverages under 1 gallon including carbonated soft drinks, soda water, beer and other malt beverages, wine products and water which does not contain sugar (excludes milk, wine and liquor, tea, sports drinks, juice)	5 cents for all containers
Oregon	85.8%	Plastic, aluminum and tinplate, and glass beverages such as juices, coffee/tea, energy drinks, and sports drinks between 4oz and 1.5L and carbonated drinks, water, and beer under 3L	10 cents for all containers
Vermont	75%	Plastic, aluminum and tinplate, and glass beverages including liquor and spirits, wine coolers, malt beverages, soft drinks, carbonated drinks (excludes wine, hard cider, water, milk, juices, sports drinks, other non-carbonated beverages)	15 cents for liquor 5 cents for all other containers

12.5 US EPR Programs

California (State of California, 2022)

California's EPR law covers single-use packaging and single-use food service ware. Exempted products include medical products and foods, packaging for products regulated by the Federal Insecticide, Fungicide, and Rodenticide Act, packaging containers for hazardous materials and flammable products, beverage containers subject to bottle deposit, and packaging for long-term storage of a product.

The Department of Public Health and Environment and the PRO will contract an independent third-party to prepare a needs assessment, which will be updated every five years and funded by the PRO. An initial needs assessment for specific covered materials will also be completed before any PRO plan that includes such material is approved.

Within 12 months of the effective date of the bill, producers of covered materials must form and join a PRO. A producer cannot sell, distribute, or import a covered material unless the producer is approved to participate in the plan of a PRO, or by January 2027. However, a producer can comply individually without joining a PRO if they achieved a source reduction of at least 5% of covered materials through shifting to refill, reuse, or elimination and at least 8% source reduction of covered materials through optimization, concentration, right-sizing, bulking, shifting to non-plastic packaging, lightweighting, or increasing the number of consumer uses between 2013 and 2022.

The PRO determines the fee structure and schedule for producers based on the cost of implementing the plan, operating costs, completing the needs assessment, mitigation requirements, and the California circular economy fee. The fee structure for covered materials is based on factors such as the cost to develop and sustain end markets, the cost to collect, sort, avoid or remove contamination, aggregate and transport materials into defined streams to support end markets for recycling, and costs incurred by local jurisdictions or recycling service providers. Fees will be modulated for covered materials that have adverse environmental or public health impacts. They will be modulated based post-consumer recycled (PCR) content, source reduction, standardization of packaging that simplifies processing, marketing, sorting, recycling, and composting, presence of hazardous materials and toxic additives, clear and accurate labeling instructions that improve consumer behavior to sort and dispose products, and the acceleration of source reduction and investment in reuse/refill systems.

The program aims are to ensure that covered plastic products distributed in the state are recyclable or compostable by January 1, 2032, and subsequently meet the following recycling rates: 30% by January 1, 2028, 40% by January 1, 2030, and 65% by January 1, 2032. Additionally, the program aims to achieve a 25% source reduction by weight and by plastic component by January 1, 2032.

Colorado (State of Colorado, 2022)

Colorado's EPR program law is established to increase recycling rates and improve access to recycling services. The program will be operated by a PRO overseen by the Colorado Department of Public Health and Environment with input from an advisory board of recycling stakeholders. Producers joining the PRO will fund the program through responsibility dues.

The PRO will develop a minimum recyclable list based on the availability of recycling services, recycling collection and processing infrastructure, and recycling end markets. There are exemptions to materials covered such as packaging for long-term storage, beverage containers subject to a deposit system, packaging used in industrial or manufacturing processes, and packaging of regulated products such as drugs and infant formula.

The PRO will hire an independent third party to conduct a needs assessment by September 1, 2023, to evaluate the state's current recycling services and identify needed improvements. The results of the needs assessment will be reported by April 1, 2024.

The funding mechanism for the EPR program will include costs for providing recycling services, conducting the needs assessment, education, and outreach, and reimbursing administrative and implementation costs. Any surpluses generated by the program will be placed back into the program to fund improvements or reduce PRO dues. The PRO will calculate membership dues using an objective formula that considers factors such as the results of the needs assessment, regional recycling costs, population density, number and types of households served, collection method, revenue generated from collected materials, and contamination rates. Dues will be modulated to discourage practices that increase the costs of recycling or disrupt the recycling of other materials, and to discourage the use of materials not on the minimum recyclable list. The Executive Director of the department will develop the eco-modulation bonus schedule in consultation with the PRO.

The PRO will set minimum collection rates, recycling rates, and PCR content rates for covered materials. Targets will be set to be reached by January 1, 2030, and January 1, 2035, and the minimum rates will be increased thereafter.

Maine (State of Maine, 2021)

Maine's EPR law requires producers to be responsible for the end-of-life management of the packaging they produce. The materials covered by the law include paper and plastic packaging. Exemptions are given to packaging for long-term storage, beverage containers subject to a deposit system, paint cans, federally regulated perishable foods, and small local producers/low-volume packaging producers.

Before the EPR program is implemented, a needs assessment must be carried out by the PRO. The assessment will evaluate funding needs for recycling, collection and transportation capacity and costs, market conditions and opportunities, and consumer education needs. The state will select a PRO via a competitive bid process and enter into a contract with the organization to coordinate the packaging stewardship program. Producers will be individually responsible for compliance.

Producers are required to pay a fee into a program fund that will reimburse local governments for the operation costs of collection, transportation, and sorting. These fees also cover the costs of administration and enforcement, investments in infrastructure, and improving recycling education.

Oregon (State of Oregon, 2021)

Oregon's EPR law covers packaging, paper, and food service ware. It excludes beverage containers subject to a deposit system. The Department of Environmental Quality will conduct multiple needs assessments to evaluate the costs of collection expansion, multi-family services, and litter management. The needs assessment will also provide a process for local governments to request services and survey interest in expanding collection options and recycling drop-off centers in areas without these services. The first needs assessment must be complete by July 1, 2023, with additional assessments required at least once every four years.

Under the law, a PRO must provide for the collection and responsible recycling of a specified list of covered products not collected in municipal programs and must fund or reimburse local governments for the costs of transportation, contamination reduction, education and outreach, recycling expansion and improvements, market development/end markets, and infrastructure improvements. Producer fees for PRO membership are adjusted based on environmental impacts such as PCR content, product-to-package ratio, material type, life cycle environmental impact, and recycling rate, with the aim of incentivizing producers to make changes to their production, use, and marketing of covered products. Recycling goals for plastics and plastic food service ware have been set at a minimum of 25% by 2028, 50% by 2040, and 70% by 2050.

Three states have introduced EPR legislation covering plastic products in 2023 (Washington, New Jersey, and Tennessee) and nine states have indicated they will be introducing EPR bills in the coming months (Minnesota, Illinois, New York, Pennsylvania, Virginia, Connecticut, Maryland, Rhode Island, Vermont).

12.6 US Chemical Recycling Policy

Table 65. US states with laws classifying chemical recycling as manufacturing

State	Law	Year Passed	Main Components
Florida	HB335	2017	Adds post-use polymers and pyrolysis facilities to those materials and facilities that are exempt from solid waste regulations
Wisconsin	AB789	2018	Removes regulatory barriers to implementing pyrolysis and gasification
Georgia	HB785	2018	Redefines post-use plastics as valuable raw materials for manufacturing and not as waste. Facilities which convert post-use plastics into liquid fuels, chemical, waxes and lubricants are correctly regulated as manufacturing operations.
Tennessee	SB0923	2019	Specifies that post-use polymers or recoverable feedstocks processed through pyrolysis or gasification are not solid waste. This bill also specifies that pyrolysis and gasification are not methods of solid waste processing
Illinois	HB2491	2019	Uncontaminated plastics that meet feedstock specifications for a gasification or pyrolysis facility and that are further processed and returned to the economic mainstream are considered recycling and are not subject to regulation as waste.
Iowa	SF534	2019	Defines pyrolysis and pyrolysis facilities as being separate from solid waste disposal facilities
Texas	HB1953	2019	Prohibits the Texas commission on Environmental Quality from considering postconsumer polymers or feedstocks as solid waste if converted, using pyrolysis or gasification
Ohio	HB166	2019	Defines manufacturing as mechanical, physical, or chemical transformation of materials, substances, or components into new products
Pennsylvania	HB1808	2020	Defines advanced recycling as a conversion process, including pyrolysis and gasification, for manufacturing and post-use polymers that are not considered waste.
Arizona	SB1156	2021	Subjects an advanced recycling facility to the Arizona Department of Environmental Quality (ADEQ) routing inspection.

State	Law	Year Passed	Main Components
Oklahoma	SB448	2021	Advanced recycling shall not be considered disposal, incineration, or a solid waste management system. Sites are subject to inspections by the Department of Environmental Quality.
Arkansas	HB1944	2021	To facilitate the conversion of plastics and other recovered materials through advanced recycling processes. Recycling in all forms plays a pivotal role in combating issue of plastic waste.
Louisiana	SB97	2021	The bill allows companies to use pyrolysis, depolymerization, solvolysis or gasification to break down plastics. Addresses how to manage post-use polymers. Exempts chemical recycling from regulations placed on solid waste disposal facilities. It also excludes energy recovery or the conversion of polymers into fuel from the definition of recycling.
Virginia	SB1164	2021	Defines advanced recycling as a manufacturing process for the conversion of post-use polymers and recovered feedstocks into basic hydrocarbon raw materials and other materials. The bill provides that advanced recycling shall not be considered solid waste management.
Kentucky	HB45	2022	Standard – redefines the key terms: advanced recycling, gasification, pyrolysis etc.
Mississippi	HB1135	2022	Standard – redefines the key terms: advanced recycling, gasification, pyrolysis etc.
South Carolina	S525	2022	Standard – redefines the key terms: advanced recycling, gasification, pyrolysis etc.
West Virginia	HB4084	2022	amending the definition of solid waste to except out post-use polymers and recovered feedstocks which are converted or held for conversion at an advanced recycling facility. Facilitating the conversion and use of plastics and other recovered materials through advanced recycling.
Missouri	HB2485	2022	Standard – redefines the key terms: advanced recycling, gasification, pyrolysis etc.
New Hampshire	SB367	2022	Redefines the Solid Waste Management laws to include definitions for advanced recycling, advanced recycling facility, and waste-derived products.

13 Best Practice – Alternative Models, Policy Options, and Emerging Technologies Appendix

Only the batch level mass balance approach can generate a recycled content claim that more accurately matches the actual recycled content of the product. The mass balances approaches are shown in Figure 54.

Figure 54. Mass-balance approaches at the group, batch and site level

Figure 4: Group Level Mass Balance

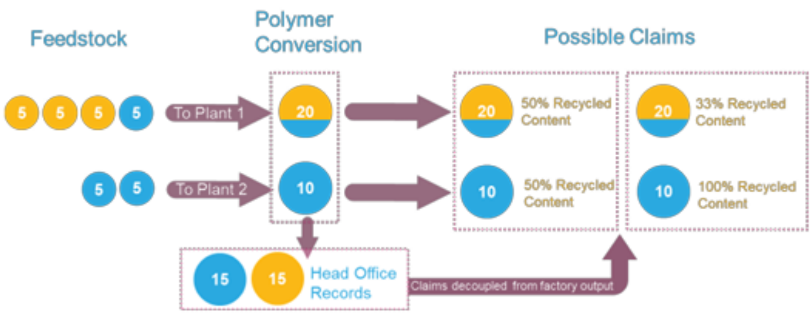


Figure 5: Batch Level Mass Balance

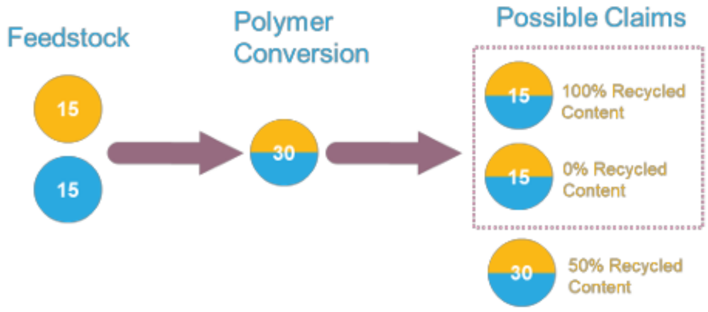
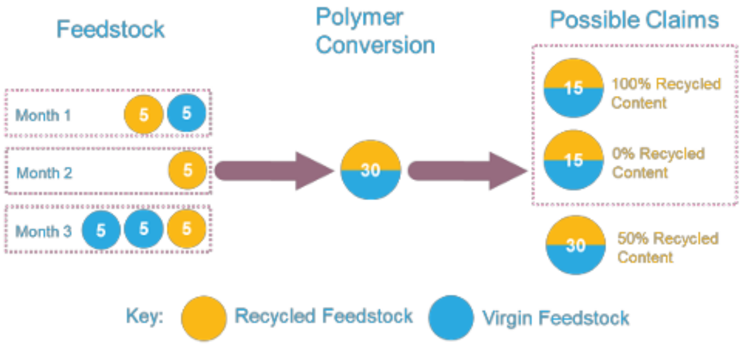


Figure 6: Site Level Mass Balance



Source: Eunomia Research & Consulting

14 Material Flows Technical Appendix

14.1 Introduction

This chapter details the data used to calculate the estimated tonnages of plastics generated, collected, sorted and recycling in the US and Canada.

Using available data, a methodology was developed to generate a material flow for plastic products in US and Canada. The methodology enables paper waste to be traced throughout the supply chain, from the production and consumption of paper products through to the collection, sorting and reprocessing of plastic waste. At each stage of the process, the losses from the system are quantified. This chapter details the approach taken to calculate the tonnage of paper generated, disposed, and recycled in each of these countries.

The purpose of this analysis is to establish a baseline from which policy makers, service providers, operators, and investors can make informed strategic decisions on what measures are needed in the short-, medium-, and long-term to support a circular economy, replace virgin material consumption in production with secondary materials, and reduce greenhouse gas (GHG) emissions.

This appendix section is organized as follows:

1. **Data Sources –** This section has a table of the main data sources used for each of the plastic types described in the plastics report.
2. **General methodology for data collection and quality assessment** – A high-level description of how the material flow figures were derived.
3. **Detailed data tables (United States and Canada)**– This section lists the detailed data tables which are used for the charts, statistics, and descriptions in the Material Flows section of the main body. The tables are the raw output from Eunomia's modelling to determine the flow of plastic material in the US and Canada.
4. **Conventional Plastic Methodology (United States and Canada)** – This section lays out the methodology for calculating the flow of plastic material with respect to the conventional plastic stream. This section covers both the United States and Canada.
5. **E-Waste, C&D, End of Life Vehicles Methodology United States (United States)** – This section covers the calculations and assumptions used for e-waste, C&D and ELV plastic flows in the Material Flows section of the main report for the United States. The section describes the methodology for the stream, above, on a product-by-product basis, as tonnages for the sectors are often reported as such, rather than by resin or stream.

6. **E-Waste, C&D, End of Life Vehicles Methodology (Canada)** – This section covers the calculations and assumptions used for the e-waste, C&D and ELV plastic flows in the Material Flows section of the main report for Canada. It describes the methodology for the stream, above, on a product-by-product basis, as tonnages for the sectors are often reported as such, rather than by resin or stream.

14.2 Data Sources

The below tables detail the data sources used to quantify the flows of plastic in the United States and Canada. A wide range of sources were used to develop the material flows, ranging from national sources such as the United States Environmental Protection Agency (EPA) to state- and provincial-level responses to freedom of information (FOI) requests. Some of the data used was also provided by sub-contractors, such as Ambiens, who provided the necessary detail and nuance in specific markets.

14.2.1 United States

Table 66 below highlights the key data sources used to develop the material flow for paper in the United States for 2021.

Table 66. Data sources used for United States Plastic Material Flow

Point of Measurement	Data Source	Year	Description
Recycling and generation tonnages for packaging	Eunomia 50 States of Recycling Data (Eunomia Research & Consulting Inc., 2021)	2018	The Eunomia 50 States of Recycling data includes state by state plastic packaging recycling figures by resin. The data includes recycling tonnages for PET, HDPE, PP and #3-7 packaging. The data does not include plastic film or non-packaging materials. The data also provides estimates of tonnage collected through bottle bills.
	STINA Recycling Reports (STINA Inc., 2021)	2021	Annual tonnages recycled of all post-consumer plastic resin. Data are national and includes separate collections of ICI plastic film.
	EPA Advancing Sustainable Materials Report (US EPA, 2020)	2018	Until 2018, tonnages generated and recycled by resin type.
	Access to Information and Privacy Requests	Various until 2021	Provincial recycling and disposal data
	American Chemistry Council Chemistry and	2012	Provides plastic compositional breakdowns

Point of Measurement	Data Source	Year	Description
ELV composition and tonnage	Light Vehicles (American Chemistry Council, 2012)		by polymer for end of live vehicles
	Statista Vehicle Sales Data (Statista, 2023)	2021	Provides sales of new vehicles annually up until 2021
Electronics tonnage	EPA Facts and Figures About Material Waste and Recycling – Product Specific Data (US EPA, 2022)	2018	Provides generation of different electronics types annually until 2018, as well as the tonnage recycled annually.
C&D tonnages	EPA Facts and Figures About Material Waste and Recycling – Product Specific Data (US EPA, 2022)	2018	Provides generation of different C&D types

14.2.2 Canada

Table 67 below highlights the key data sources used to develop the material flow for plastics in Canada for 2021.

Table 67. Data sources used for Canada Plastic Material Flow

Point of Measurement	Data Source	Year	Description
Residential material generated and recovered	Annual Provincial EPR Reports for 2021 (RecycleBC, 2022), (Stewardship Ontario, 2022), (Multi-Material Stewardship Manitoba (MMSM), 2022), (RECYC-QUÉBEC)	2021	These reports provide data on the tonnages of marketed plastic waste for the residential sector in Canada.
Material generated and recovered	Access to Information and Privacy Requests	Various until 2021	Provincial recycling and disposal data
Tonnage recovered of high-level plastic categories (e.g., plastic packaging, ELVs)	Statistics Canada Data (Statistics Canada, 2022)	2019, 2020	The database provides high-level recycling tonnages for the commercial and residential sectors in Canada by province and nationally.

Point of Measurement	Data Source	Year	Description
ICI tonnage recycled in Canada.	STINA (formerly MORE Recycling) Recycling's 2018 National Postconsumer Recycling Report (MORE Recycling, 2020)	2018	Provides insight into the tonnage of postconsumer plastic waste collected by each sector

14.3 General Methodology for Data Collection and Quality Assessment

There are different approaches that can be used to calculate the recycling rate of plastics:

1. Placed on market data reported by packaging producers to ascertain the quantity of paper generated along with consistent reporting of paper recycled at the point of measurement when the material can be used in a new product, the output from the processor.
2. Top down, using data provided by the plastics industry in each of the three countries.
3. Bottom up, using data on disposed and recycled tonnage data and waste characterizations with assessment of material loss through the recycling process to ascertain generation and recycling rates for different packaging materials.

Due to the lack of published and openly available information on the market, and to ensure a consistent approach across all packaging materials included in the study, the assessment approach used in this report is a combination of approaches 2 and 3, above. We recognize that using this approach is not ideal and depends on the data availability, quality and systems within each geographical area.

14.4 Detailed Data Tables

Below are the detailed data tables for the conventional plastics in the US and Canada. These relate to the summary tables for the United States and Canada conventional plastic material flows in chapter 4 of this study.

Table 68. United States Conventional Plastic Detailed Waste Flow

	Generated	Collected	Sorted	Recycled
PET	3,780,000	890,000	840,000	720,000
HDPE	2,610,000	760,000	650,000	600,000
PE Film	4,830,000	410,000	410,000	350,000
Plastic Laminates	5,670,000	16,100	16,100	13,800

	Generated	Collected	Sorted	Recycled
Polystyrene	1,130,000	10,200	7,100	6,100
LDPE Rigid	880,000	3,700	2,600	2,200
PP	1,200,000	110,000	80,000	70,000
PVC	320,000	4,900	3,400	2,900
#7/Other	370,000	28,000	19,000	16,000
Total	**20,790,000**	**2,232,900**	**2,028,200**	**1,781,000**

Table 69. Canada Conventional Plastic Detailed Resin Flows

	Generated	Collected	Sorted	Recycled
PET	327,000	162,000	155,000	123,000
HDPE	162,000	106,000	91,000	77,000
PE Film	585,000	73,000	53,000	42,000
Plastic Laminates	331,000	6,000	6,000	5,000
Polystyrene	63,000	6,000	4,000	3,000
LDPE Rigid	1,000	130	90	70
PP	200,000	35,000	24,000	19,000
PVC	21,000	1,800	1,300	1,000
#7/Other	178,000	52,000	38,000	30,000
Total	**1,868,000**	**441,930**	**372,390**	**300,070**

14.5 Conventional Plastic Material Flow Methodology

Data for the plastics waste flows for US and Canada were taken from a variety of sources. Data are pulled from government reports and third party-research. The high-level data processing steps taken are as follows:

1. Compile waste flow tonnages at best granularity possible (e.g., by resin)
2. Split material into commercial versus residential sectors
3. Calculate recycled and collected tonnages using MRF and mechanical recycling loss rates

14.5.1 United States

Data Processing Method

This section details how the data were taken from their raw data form into the tonnages presented in this study. To illustrate the process, PET bottles have been taken as an example calculation for each calculation step.

Residential versus Commercial Sources

The point of measurement for the 50 States of Recycling Data used for this report, as well as the STINA annual plastic recycling reports, are tonnages delivered to a plastic recycler. A sample of how the 50 States of Recycling Data are organized is shown below:

Table 70. Sample of 50 States of Recycling Data

	PET Bottles, in lbs. input to recycler (national)	PET other rigid lbs. input to recycler (national)	HDPE Bottles, in lbs. input to recycler (national)
All Sorted, lbs.	1,769,678,832	148,082,584	1,090,047,084

The tonnage above is reported as a total of what is sorted for recycling and input into a recycler. This tonnage needs to be split into residential versus commercial sectors. A combination of two sources were used to estimate the split of residential versus commercial sources of material:

- STINA recycling reports, which give estimates of tonnages collected through ICI collections (listed in Table 1), and;
- Eunomia's 2021 Consumer Packaging and Paper Products report for Washington State, which gives splits for generated and recycled plastic packaging from both the residential and commercial sectors (Eunomia Research & Consulting Inc., 2023)

The tonnages from the 50 States of Recycling were therefore subtracted from STINA data, using the splits from the two data sources above to estimate the tonnages allocated to the residential and commercial sector, respectively. A third category, a deposit return system (DRS) with collected tonnages, were already calculated in the 50 States of Recycling data. A walkthrough for PET bottles is shown below:

Table 71. Residential vs Commercial Calculation

Data Point	Description	Value	Source
a)	Total PET Bottles input to recyclers	800,000 tonnes	STINA and 50 States of Recycling Report
b)	Total PET Bottles collected via deposit	383,000 tonnes	50 States of Recycling Report
c)	**PET collected through non-deposit**	**417,000 tonnes**	**a – b**
d)	Commercial Percentage of PET Bottles Input to Recycling	46%	Eunomia CPPP Report for Washington
e)	**Non-deposit commercial tonnes of PET Bottles input to recycling**	**192,000 tonnes**	**c x d**
f)	**Non-deposit residential tonnes of PET Bottles input to recycling**	**225,000 tonnes**	**c – e**

Conducting the above analysis produces the following summary of PET bottles input to recycling:

Table 72. Summary of PET Bottles Input into Recycled Tonnages

Pathway	Tonnes	Percentage of Recycled Tonnes
PET Bottles input into recycling via DRS	383,000	48%
PET Bottles input to recycling via commercial collections	192,000	24%
PET Bottles input to recycling via residential collections	225,000	28%
Total PET Bottles input to recycling	800,000	100%

This process was repeated for each plastic packaging resin, including plastic films. Where possible, Eunomia applied a resin-specific breakdown of the plastic to apportion them into residential and commercial tonnages. The proportions were taken primarily from two sources:

1. The 2021 Washington Consumer Packaging and Paper Products Study (Eunomia Research & Consulting Inc., 2023) and;
2. 2021 Association of Plastic Recyclers Annual Recycling Report (STINA Inc., 2021)

Table 73, below, shows the assumed residential proportions of generated plastic packaging used to calculate the residential tonnage of material generated. The residential tonnage generated is then subtracted from the total tonnage generated to calculate the commercial generation of material as well.

Table 73. Residential Proportion of Plastics

	Generated Residential Percentage	Sorted for Recycling Residential Percentage
PET Bottles	61%	54%
PET Non-Bottle	64%	36%
HDPE Bottles	50%	50%
Other HDPE	38%	36%
PVC	37%	36%
LDPE Rigid	84%	36%
PP	58%	36%
PS	62%	36%
PE Film	46%	N/A

After applying these proportions to the overall post-consumer tonnages generated and recycled, Eunomia calculates total tonnages of material sorted for recycling and generated for each sector.

Calculating collected tonnages and post-sorting tonnages

As the input data sources used for the plastics analysis had a measurement point of "input to recycler," collected and recycled tonnages had to be back-calculated, using sorting and mechanical recycling efficiencies. These efficiencies were on a resin-by-resin basis.

The sources used for MRF and post-sorting losses were taken from:

1. RRS's MRF Material Flow Study (RRS, 2015)
2. King County's 2020 Material Recovery Facility Assessment (Cascadia Consulting, 2020)
3. Industry data on bale purities
4. Interviews with mechanical recyclers

To calculate tonnages collected, the data from the 50 States of Recycling were divided by sorting efficiencies. An example of calculating the residential collected tonnage of PET bottles is shown below:

Table 74. Calculating "Collected" and "Post-Recycling" Tonnage

Data Node	Data Node Description	Value	Source
a)	PET bottles Input to recycling via residential collections	225,000 tonnes	Table 4
b)	MRF sorting efficiency of PET bottles (percentage of bottles lost to residue or other bales at a sorting facility)	13%	Eunomia 50 States of Recycling Study, RRS MRF Material Flow Study
c)	PET Bottles collected for recycling	258,000	a / (1-b)

The process above was repeated for all resins and formats. The formats were then added together to reach a total collected tonnage by resin (e.g., PET bottles were combined with PET thermoforms).

To calculate post-recycling tonnages, mechanical recycling loss rates were applied to the tonnages input into recycling compiled in Section 4.1.2. Mechanical recycling loss rates were taken from the interviews Eunomia conducted with mechanical recyclers, as well as 50 States of Recycling data. Multiplying the tonnages input to recycling by the mechanical recycling efficiencies produces a figure for the tonnage of material that leaves mechanical recyclers and is ready to be put into manufacturing of new goods.

A work through of calculating PET bottles recycled is shown below:

Table 75. Calculating Tonnage of Recycled PET Bottles

Data Point	Description	Value	Source
a)	Total Deposit PET Bottles Input to Recycling	383,000 tonnes	Table 8

Data Point	Description	Value	Source
b)	Total Non-Deposit PET Bottles Input to Recycling	417,000 tonnes	Table 8
c)	Deposit Processor-Loss Rates	12%	Interviews with mechanical recyclers and 50 States of Recycling Data
d)	Non-Deposit Processor-Loss Rates	16%	Interviews with mechanical recyclers and 50 States of Recycling Data
e)	**Total Deposit PET Bottles Available for Manufacturing**	**337,040 tonnes**	**a x (1 – c)**
f)	**Total Non-Deposit PET Bottles Available for Manufacturing**	**350,280 tonnes**	**b x (1 – d)**

The process above was repeated for all resins and formats. The formats were then added together to reach a total recycled tonnage by resin (e.g., PET bottles were combined with PET thermoforms).

To estimate the tonnage of material collected via curbside collections versus depot-based collections, Eunomia used data from Stewardship Ontario's datacall. The datacall lists the relative yields per household of recycling collections for households with curbside versus depot collection (Stewardship Ontario, 2022).

14.5.2 Canada

Residential versus Commercial Sources

The plastics reported as recycled from Canadian stewardship programs are restricted to the residential sector. The point of measurement for the provincial EPR reports, as well as the Statscan data, are tonnages that were input to a plastics recycler.

For commercial tonnages, data was taken from:

1. Statistics Canada recycling tonnages (Statistics Canada, 2022)
2. STINA [at the time known as "MORE Recycling"] Recycling's 2018 national postconsumer recycling report for Canada (MORE Recycling, 2020)
3. ECCC's national waste characterization report (Environment and Climate Change Canada, 2020)

Tonnages from the STINA report were already broken down by resin; therefore, more data processing was necessary for the residential data than for the ICI data.

A sample of how the EPR data for the residential sector is organized is shown below. In the report, the term "supplied" is used for the tonnage of material sold into the residential sector. Elsewhere in this study, Eunomia uses the term "generated" rather than "supplied." "Supplied" is used in the table below as it is meant to be an exact example of how the stewardship report data are displayed:

Table 76. Sample of Stewardship Report Recycling Data

	Tonnes Collected 2021	Tonnes Supplied 2021
PET Containers and Bottles	3,632	5,659
HDPE Containers and Bottles	2,558	3,666

Source: (Multi-Material Stewardship Manitoba (MMSM), 2022)

Breakdown of Higher-Level Residential Plastics into Resin Type for Residential Sector

Although the STINA data used for the commercial sector is already broken down nationally by resin, some of the provincial stewardship reports for the residential sector only have high-level categories for recycled material, such as:

1. Rigid plastics
2. Plastic packaging
3. Flexible plastics

These high-level categories for the residential sector required a composition to be applied to the tonnages to estimate the resin-by-resin tonnages. A composition of non-deposit recycled plastics was compiled by finding the average composition of plastics sorted for recycling in provinces with resin-by-resin data. The compositions of resin-by-resin household data used were:

1. RECYC-QUÉBEC's Characterization of Residual Materials in the Residential Sector 2015–2017 final report (Eco Entrpesises Quebec, 2021)
2. Stewardship Ontario's 2021 SO Four Step Fee Model (Stewardship Ontario, 2021)
3. Multi Material Stewardship Manitoba's 2021 Annual Report (Multi-Material Stewardship Manitoba (MMSM), 2022)
4. Continuous Improvement Fund's Residential Waste Characterization Studies (Continuous Improvement Fund, 2021)

These studies were used to find an average split of plastics sorted for recycling, and then applied as needed to provincial data to break down high-level plastic categories. The following average split was used for non-deposit collected residential material, compared with the Canada Plastic Pact's (CPP) Foundational Study average of PET, HDPE and film's proportion of the non-deposit sorted plastics stream (Canada Plastic Pact, 2021). The Foundational Study only includes resin specific plastic for PET, HDPE, and PE Film, while the rest of the plastic in the study is classified as "other" or "unclassified". Table 77 below compares the collected rates for plastic packaging of the Eunomia calculated values for this CEC study with values calculated by the CPP.

Table 77. Average Calculated Non-Deposit Collection of Plastics

Plastic Material	% of Residential Plastic Collected – Non-Deposit (Eunomia Calculations)	% of Residential Plastic Collected – Non-Deposit (Canada Plastic Pact Foundational Study)
PET Containers	40%	46%

Plastic Material	% of Residential Plastic Collected – Non-Deposit (Eunomia Calculations)	% of Residential Plastic Collected – Non-Deposit (Canada Plastic Pact Foundational Study)
HDPE Containers	24%	22%
PE Film	11%	7%
Plastic Laminates	3%	N/A
Polystyrene	2%	N/A
Other Plastics	0%	N/A
PP	6%	N/A
PVC Plastics	0%	N/A
Total	100%	N/A

Eunomia found slightly less PET in the recycling stream when compared to the CPP foundational study, and slightly higher HDPE and PE Film. This could be due to a general shift towards flexibles since 2019 (the year of the CPP study), however the difference in PET could warrant further investigation.

Calculating Collected Tonnages and Post-Recycling Tonnages

The approach to calculate collected tonnages and post-recycling tonnages was the same as the United States.

14.6 United States E-Waste, Vehicles, and C&D Material Flow Methodology

End of life vehicles (ELVs), e-waste and C&D plastics had very different methodologies compared to the conventional plastics calculations.

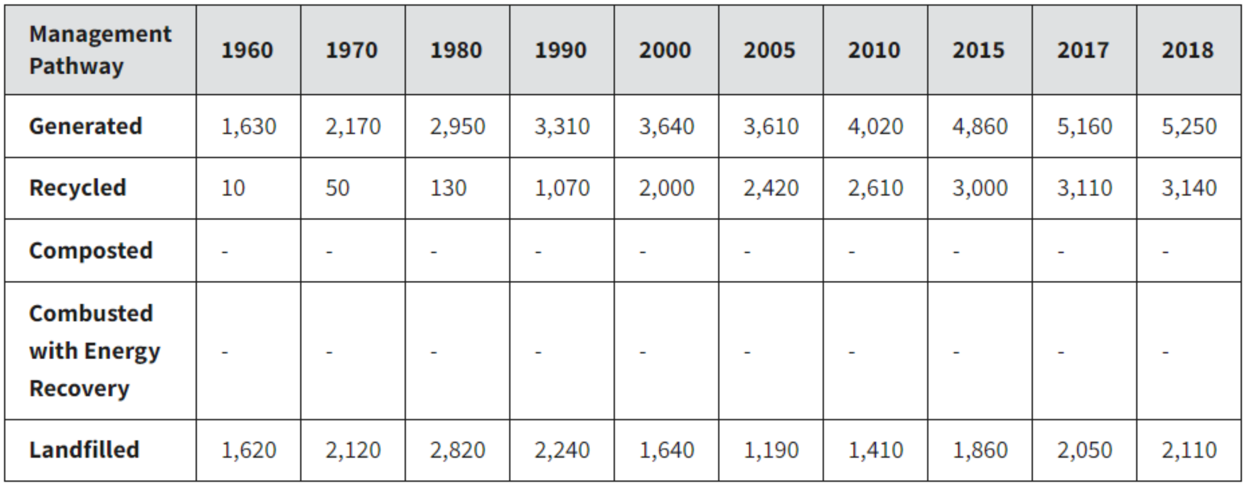
14.6.1 E-Waste

Generation

The EPA produces national data on generation of different electronics categories. This data was supplemented with data from other research reports on specific electronic products such as computers and monitors.

Firstly, the EPA include includes data on major appliances, which include items such as refrigerators, washing machines and water heaters (US EPA, 2022). Table 78 below shows these data.

Table 78. 1960–2018 Data on Major Appliances in MSW by Weight (in thousands of U.S. tons)

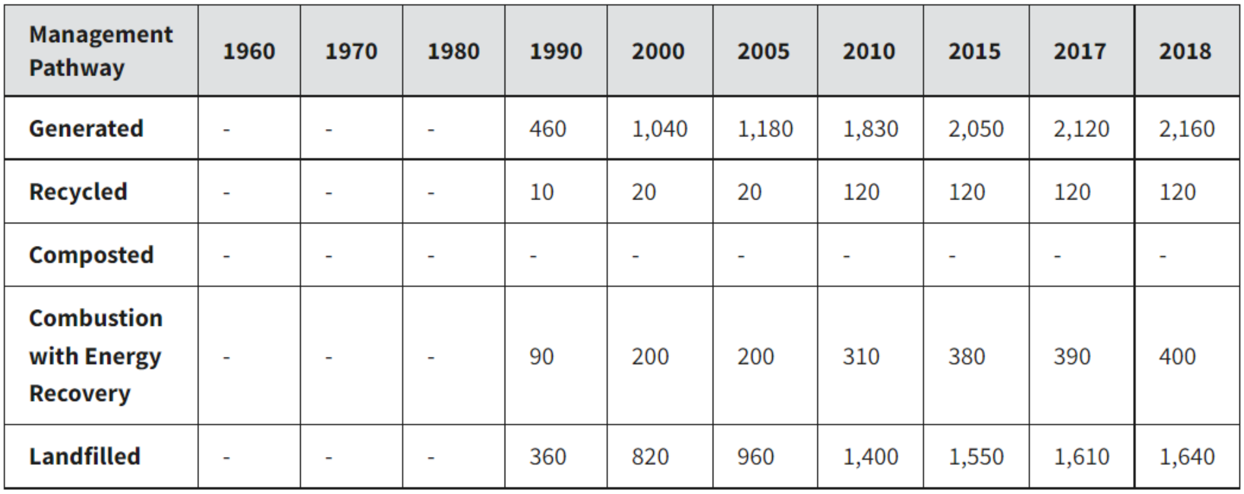


Management Pathway	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generated	1,630	2,170	2,950	3,310	3,640	3,610	4,020	4,860	5,160	5,250
Recycled	10	50	130	1,070	2,000	2,420	2,610	3,000	3,110	3,140
Composted	-	-	-	-	-	-	-	-	-	-
Combusted with Energy Recovery	-	-	-	-	-	-	-	-	-	-
Landfilled	1,620	2,120	2,820	2,240	1,640	1,190	1,410	1,860	2,050	2,110

Using regression analysis based on a linear trend to 2021, the estimated amount of major appliances becoming e-waste in 2022 is around 5,440 thousand tons.

Next, the EPA also includes data on small appliances such as toasters, hair dryers and electric coffee pots. The table (79) below shows these data.

Table 79. 1960–1980 Data on Small Appliances in MSW by Weight (in thousands of U.S. tons)



Management Pathway	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generated	-	-	-	460	1,040	1,180	1,830	2,050	2,120	2,160
Recycled	-	-	-	10	20	20	120	120	120	120
Composted	-	-	-	-	-	-	-	-	-	-
Combustion with Energy Recovery	-	-	-	90	200	200	310	380	390	400
Landfilled	-	-	-	360	820	960	1,400	1,550	1,610	1,640

Using regression analysis based on a linear trend to 2021, the estimated amount of small appliances becoming e-waste in 2021 is around 2,410 thousand tons.

The next category related to WEEE from the EPA is electronics, which includes products such as TVs, VCRs, DVD players, video cameras, stereo systems, telephones and computer equipment. Table 80 below shows the data as is presented by the US EPA.

Table 80. 1960–2018 Data on Selected Consumer Electronics in MSW by Weight (in thousands of U.S. tons)

Management Pathway	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generation	-	-	-	-	1,900	2,630	3,120	3,100	2,840	2,700
Recycled	-	-	-	-	190	360	650	1,230	1,020	1,040
Composted	-	-	-	-	-	-	-	-	-	-
Combusted with Energy Recovery	-	-	-	-	-	-	-	-	-	-
Landfilled	-	-	-	-	-	-	-	-	-	-

Using regression analysis, the estimated amount of consumer electronics becoming e-waste in 2021 is around 2,650 thousand tons.

A 2015 CEC report 'Quantitative Characterization of Domestic and Transboundary Flows of Used Electronic Products' focused on used computers and monitors as a case study (CEC, 2016). In addition, a 2013 report 'Quantitative Characterization of Domestic and Transboundary Flows of Used Electronics Analysis of Generation, Collection, and Export in the United States' also included separate flows for mobile phones (Huabo Duan, 2013). Therefore, these three categories are separated from total electronics to include the following categories:

- Computers
- Monitors
- Mobile phones
- Other electronics

The total generation of used computers and monitors in 2015 was around 260 thousand tonnes and 250 thousand tonnes, respectively.

Cell Phones

Smart Phones: Plastics contribute around 38% to total material usage in Smartphones (the predominant type on the market), of which the most common is polycarbonate (PC) (Narendra Singh, 2018). No further breakdown was obtained so it was assumed that 100% of the plastic is PC.

Lead Acid Batteries

No data regarding the material composition of lead acid batteries could be found. However, the majority of the weight will be lead and acid, and it was assumed that around 10% of the total weight of the battery is the plastic casing. The EPA website indicates that the plastic polymer is polypropylene (PP).

Computers, Monitors, and Other electronics

An article with an average composition of plastic polymers in e-waste was used for the remaining categories (Dimitris S. Achilias, 2015). This is given below.

Table 81. Polymer Breakdown for Other Consumer Electronics

Plastic polymer	Share
Acrylonitrile-butadiene-styrene (ABS) 30%	7.5%
High impact polystyrene (HIPS) 25%	6.3%
Polycarbonate (PC) 10%	2.5%
PC/ABS 9%	2.3%
Polypropylene (PP) 8%	2.0%
Poly(phenylene ether) (PPE)/HIPS 7%	1.8%
Poly(vinyl chloride) (PVC) 3%	0.8%
Polystyrene (PS) 3%	0.8%
Polyamide (PA) 3%	0.8%
Poly(butylene terephthalate) (PBT) 2%	0.5%
Total	25%

Electronics Management

There are several steps involved in the recovery of plastics from electronics:

1. Electronics are separately collected mainly through stewardship/EPR programs, and sent to an electronics treatment plant where some manual disassembly occurs; for plastics, these would generally be the larger higher value components;
2. The electronics may then be shredded;
3. The recovered mixed plastic fraction from the shredder can then be sent to thermal energy recovery or a plastics recycler; and
4. The plastics recycler processes the waste to produce a secondary raw material.

Alternatively, the electronics item or the recovered plastics fraction, can be exported outside of the country for further processing and recycling.

Major Appliances

Data on electronics processing in the US was very limited. A Canadian study from an electronics EPR schemes suggested that for the whole electronics fraction around 86% was recovered from what was collected (Wisehart, Electronic Products Recycling Association Annual Report to the Director, 2022). The total recycled in 2021 was estimated as 3,350 thousand tons, using regression analysis on the EPA data (see above). This implies that around 3,900 thousand tons of major appliances were collected in the US. This yields an overall collection rate of approximately 62%. Manual disassembly of plastics at electronics processors can occur but the amounts are not reported. It is assumed that a nominal amount is manually removed (2%) and sent to a recycler within the US, but the remainder is sent through an electronics shredder.

The shredder recovery rate was assumed to be 85%, which leads to approximately 86% overall recovered, and this is assumed to be what is sent to recyclers—but not what is ultimately recycled, which would be lower.

Most plastic in large appliances is assumed to be more of the type that can be recycled, and it comes from larger panels, so particle size is not too small. We thus assumed that 50% of what is sent to preprocessors is converted to a secondary raw material.

Small Appliances

The total recycled in 2021 was estimated as being around 150 thousand tons. Using regression analysis assumed a linear trend on the EPA data (see above). However, since significant amounts of small appliances were reported as 'Combustion with Energy Recovery'; it is not as clear for major appliances how to impute a collection rate. The collection of small appliances is likely to be less than for major appliances, which cannot be easily placed in the garbage. Thus a lower collection rate of 50% was used for small appliances.

Lead Acid Batteries

The EPA report that 99% of lead acid batteries are recycled. No collection rate is given, but it is assumed the collection rate is 99% and 100% of the lead is recycled. There is no recycling efficiency for the PP outer casing, but it is assumed to be highly recycled also. A figure of 95% has been used for modeling.

A significant proportion of the collected lead acid batteries are exported from the US. Reviewing a 2011 CEC study on lead acid battery exported from the U.S., although now relatively outdated, still provides some useful information. The following export figures were taken from the study and used in the modeling:

- Mexico – 15%
- Canada – 5%

Monitors

The 2015 CEC report 'Quantitative Characterization of Domestic and Transboundary Flows of Used Electronic Products' included estimated collection and export rates, as well as the top export destinations for computers and monitors (CEC, 2016). While the report is several years old, no updated information could be found but we believe the data still provide a useful benchmark: just under 80% in 2012.

However, the collection rate for monitors has been increased from the published figure to take into account more recent developments. The figure used in the model is thus 85%.

Computers

The same CEC study was used for computers. The assumed collection rate was 80% and the export rate around 6%. The destination countries, and shares, are the same for Monitors, above.

Mobile Phones

The 2013 report, 'Quantitative Characterization of Domestic and Transboundary Flows of Used Electronics Analysis of Generation, Collection, and Export in the United States,' also included separate flows for mobile phones (Narendra Singh, 2018). As above, the collection rate given in the report was increased to consider more recent developments. The collection figure used in the model was 75%.

Total Electronics

In summary, the overall recycling rate for all electronics, calculated using the assumptions shown above for the electronics category, is 18% (excluding lead acid batteries) and 27%, including lead acid batteries. These figures are a little lower than the overall electronics recycling rates in Europe, which is realistic as there are electronics EPR regulations in all countries there, whereas there are differing systems and incentives across the US states.

14.6.2 ELV Plastic Waste in the US

Generation of ELV Plastics

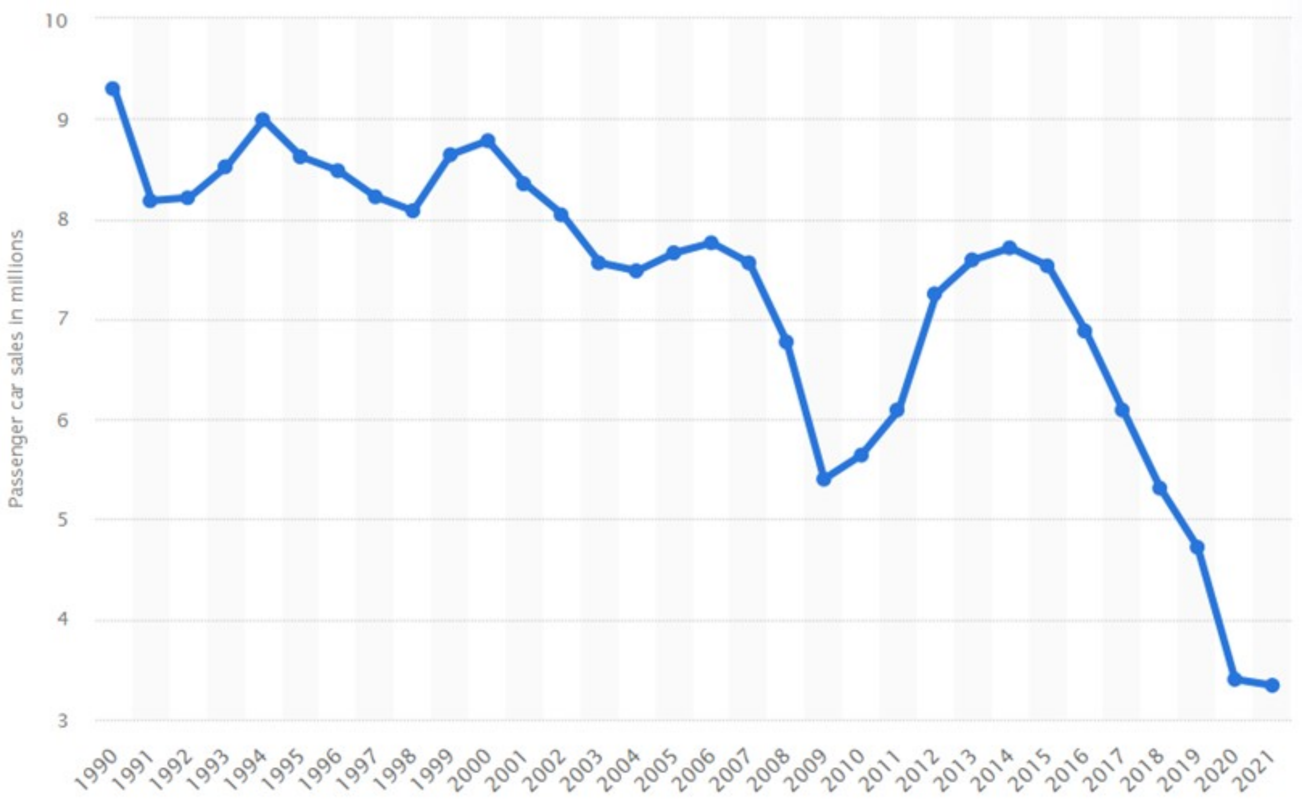
Only limited data could be found on the generation of plastics from ELVs. Thus an estimation methodology was used, based on historic vehicle sales and average vehicle compositions.

A few sources were found that included estimates of the number of ELVs generated, but these were more historic, and thus unlikely to reflect current trends:

- 12 million ELVs generated in 2010 (Argonne National Laboratory, 2011).
- 10 million cars scrapped in 2005 (End of Life Vehicle Solutions Corporation)
- In the United States 10–11 million vehicles reach the end of their lives and are taken off the road every year (Green Vehicle Disposal).

For the historic vehicle sales in the US used—see Figure 55.

Figure 55. Screenshot of US auto sales from 1990 to 2021 (in millions) from Statista



The data indicate a downward trend over the last 30 years. Taking an average vehicle life of around 15 years, perhaps about 7.5 million vehicles are likely to be scrapped in 2022. On average, these vehicles were produced in 2010, when an average vehicle weight was around 4,000 lbs (Lowrey, Your Big Car is Killing Me, 2011). Therefore, the total weight of ELVs generated in 2022 was estimated as 15 million tons.

According to the Institute of Scrap Recycling Industries (ISRI), 1 to 2 million tons of plastic are generated in shredder residue each year, most of which could be separated and recycled, rather than landfilled (Cooper, 2014). This article was for 2013 and would equate to around 12% of the total vehicle weight. Reports from an EU estimate that around 13–14% of scrapped vehicles are plastic (European Commision, Directorate-General for Environment, 2018). The estimate used for the modeling was 13%.

The polymer breakdown was taken from an American Chemistry Council report, and is given below (American Chemistry Council, 2012)

Table 82. ELV Plastics Waste by Polymer

Polymer Type	Share
Polypropylene (PP)	22%
Polyethylene (PE)	4%

Polymer Type	Share
Polyurethane (PUR)	20%
Polyamide (PA)	12%
Polycarbonate (PC)	4%
Polyvinyl chloride (PVC)	8%
ABS	7%
HIPS	11%
Other	12%
Total	**100%**

The data above for ELVs generated and proportion of plastics by polymer were combined to derive the total generation of each polymer from ELVs.

Table 83. Total ELV Plastics Waste by Polymer

Polymer Type	Thousand Tons
Polypropylene (PP)	429
Polyethylene (PE)	78
Polyurethane (PUR)	390
Polyamide (PA)	234
Polycarbonate (PC)	78
Polyvinyl chloride (PVC)	156
ABS	137
HIPS	215
Other	234
Total	**1,950**

Management of Plastics from ELVs

It is assumed that all ELVs are collected by scrap yards across the country. Of these, it is assumed that 100% are processed through automotive shredders, and all plastics remain in the automotive shredder residue (ASR).

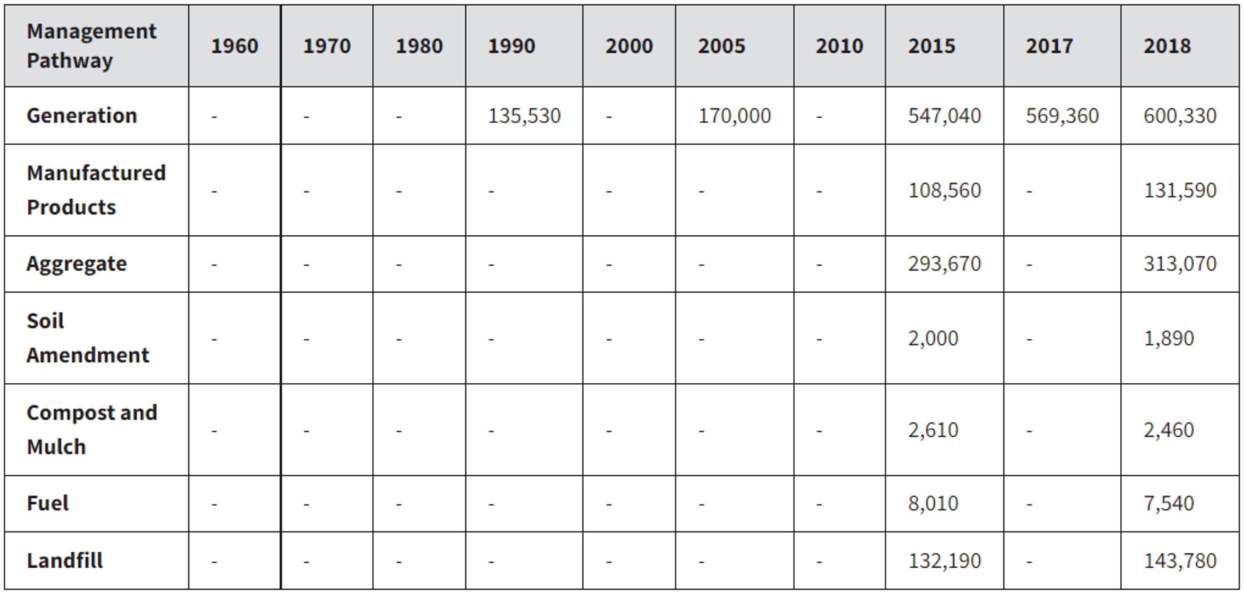
Some bumpers or other items may be removed for reuse, but the amounts are thought to be negligible, so no deduction in total waste generated was made.

14.6.3 C&D Plastic Waste in the US

C&D Waste Generation

There are very limited data available for C&D waste in the US. However, the EPA provides a facts and figures webpage that indicates the latest available data (US EPA, 2022).

Table 84. 1960–2018 Data on Construction and Demolition Debris by Weight (in thousands of US tons)—from EPA



Management Pathway	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generation	-	-	-	135,530	-	170,000	-	547,040	569,360	600,330
Manufactured Products	-	-	-	-	-	-	-	108,560	-	131,590
Aggregate	-	-	-	-	-	-	-	293,670	-	313,070
Soil Amendment	-	-	-	-	-	-	-	2,000	-	1,890
Compost and Mulch	-	-	-	-	-	-	-	2,610	-	2,460
Fuel	-	-	-	-	-	-	-	8,010	-	7,540
Landfill	-	-	-	-	-	-	-	132,190	-	143,780

Using regression analysis, total C&D waste generation in 2022 was estimated to be around 620,000,000 US tons.

C&D Waste Composition

An article by Whole Building Design Guide provides the composition of 20,000 tons of construction and demolition waste generated in an urban area in the US in 2010 for some materials—the plastic composition and description are given below (Napier, Construction Waste Management, 2016). Plastic is estimated to contribute 1% of total C&D waste generation.

> **Plastic—1%**: Post-consumer plastics 1 (PET) & 2 (HDPE) are valuable commodities. Plastics 3 through 7 are generally recyclable but have less value. Generally, plastics are not recycled into material of the same type and grade, but rather are downcycled. PET is readily converted into a wide variety of products. HDPE is downcycled into plastic lumber, trash receptacles, etc. Plastic film is a nuisance material that impedes efficient picking and sorting of all other materials. When prices of the recycled commodities are low, plastic materials may be exported and or combusted for their energy-producing potential. Plastic may be granulated or chopped into flakes and placed in industrial tote bags for transport.

A detailed waste composition study from CalRecycle reports the composition of plastic in total C&D waste generated to be 0.8%, approximately like the 1% reported above (Cascadia Consulting

Group, 2006). However, carpet and carpet padding were not included in the 'Plastics' category. Carpet is often made of polyester and the padding predominantly out of bonded urethane foam (What is Your Carpet Pad Made From?, 2016). Although the waste generated at the time of the study (2006) was likely manufactured and installed in the 1970's and 80's, and carpets then were usually wool-based shag pile and the padding was often made from rubber or recycled hessian bags. However, there is likely to be some plastic-based carpet and padding within those categories, so the total proportion of plastic could be a little higher than 0.8% if this were taken into account.

The study also included a detailed breakdown of types of plastic waste, as shown below.

Table 85. Detailed Composition of Plastic Wastes

Plastic waste type	Composition
PETE Containers	1%
HDPE Containers	5%
Misc. Plastic Containers	1%
Trash Bags	4%
Grocery/ Merch. Bags	0%
Non-Bag Comm./Ind. Packaging Film	9%
Film Products	11%
Other Film	2%
Durable Plastic Items	30%
Expnd. Polystyr. Packaging/Insulation	8%
Remainder/Composite Plastic	29%
Total	**100%**

However, for the most significant waste types, 'Durable Plastic Items' and 'Remainder/Composite Plastic,' it is not immediately clear what exactly these items would be, and therefore what the polymer breakdown would be.

A more recent Construction and Demolition Materials Composition Study from Minnesota included a breakdown for plastics (MSW Consultants, 2020). The total was only 0.3% of C&D generation; however, there were also plastic items in other categories, like General Construction and Demolition. Categories which included composite materials could also have included plastic, but without further information clear conclusions cannot be drawn. Pulling together the different plastic related categories, and assuming half of the insulation category is expanded foam boarding—as opposed to glass wool insulation—the following could represent the total plastic fraction (again potentially omitting some plastic from the carpet and padding categories). The total plastic composition is then calculated at 0.8%.

Table 86. Plastic Composition of C&D Waste from Minnesota

Plastics	% of total C&D	% of plastic items
Durable Plastic Items	0.1%	12.2%
Film Plastic (Comm./Indus.)	0.1%	12.2%
HDPE Buckets	0.0%	1.2%
Plastic Furniture	0.0%	1.2%
R/C and Other Plastic	0.1%	12.2%
Insulation	0.2%	24.4%
Plastic Piping	0.1%	12.2%
Plastic Siding/Decking	0.2%	24.4%
Total	**0.8%**	**100.0%**

Another study from Connecticut carried out a waste compositional analysis and found the share of plastic in total C&D waste was 1.1% (Green Seal Environmental, 2015). Of this, 0.4% was reported as Plastic Pipe, 0.3% Vinyl Siding and 0.4% Other Plastics.

A 2016 waste characterization report from Delaware indicated a slightly higher proportion of plastic in the C&D waste stream, at 2.6% (which included HDPE buckets 0.3%, clean recoverable film 0.2%, foamed insulation <0.0%, R/C and Other Plastic 1.4%, vinyl siding 0.4% and ceiling tiles 0.2%) (DSM Environmental, MSW Consultants, Cascadia Consulting Group, 2017).

In summary, several C&D waste compositions suggest around 1% of total Construction and Demolition waste is plastics. This is the figure used for modeling. However, none of the compositions allow for a polymer breakdown. To create polymer level figures, a waste composition from the study underpinning the European Plastics Strategy has been used—see the table below (European Commision, Directorate-General for Environment, 2018). While different products and construction methods are used in North America and Europe, this composition still seems representative of the North American waste stream. The most significant fractions—pipes, siding, insulation, durable items—as most likely manufactured from PVC, PE and EPS.

This aligns well with the top three polymer categories from the EU composition. While a North American polymer composition would be ideal, this approach is considered appropriate, given the lack of available data and the need to create polymer-level flows for the main report.

Table 87. Total Plastics C&D Waste by Polymer in EU27+2 (2010)

Polymer Type	Share
Polyvinyl chloride (PVC)	44.7%
Polyethylene (PE)	13.2%
Polystyrene (PS), Expanded Polystyrene (EPS)	12.9%

Polymer Type	Share
Polyurethane (PUR)	8.8%
Polypropylene (PP)	5.1%
Other plastics	15.3%
Total	**100.0%**

C&D Waste Management

The EPA estimated in 1988 there are about 3,500 operating facilities that process C&D debris materials in the United States (Franklin Associates, 1998).

The EPA suggests an average throughput of 350 tons per day (Franklin Associates, 1998). This equals around 130,000 tons per year. In total this would amount to an average annual throughput of 455 million tons, or around 70% of the total C&D waste generated. The target amount collected and sent to sorting centers was assumed to be about 70%, similar to the 75% estimate of C&D waste sent to sorting centers in the US, with the remaining 25% going directly to landfills.

Of waste sent to sorting centers, a 2016 study on C&D debris management indicated that only 3% of plastics were recovered (DSM Environmental, 2017). This figure represents the recovery of all plastics fractions. Some fractions managed at sorting centers, such as EPS and PE films, are not currently recycled to any extent, so recovery rates have been adjusted per polymer (figures estimated by project team experts). This is shown in the table below. The total recovery figure is very similar to the figure reported in Canada of 3.2%.

Table 88. Detailed Plastic Composition of C&D Plastic Waste

Polymer Type	Proportion of Total Recovered
Polyvinyl chloride (PVC)	50%
Polyethylene (PE)	25%
Polystyrene (PS), Expanded Polystyrene (EPS)	10%
Polyurethane (PUR)	0%
Polypropylene (PP)	15%
Other plastics	0%
Total	**100%**

Despite the recovery rate being from only one state and now seven years old, no additional data were available. This figure is likely to underrepresent the recovery of plastics, and efforts have increased in recent years along with new automated sorting technologies—such as density separation—have increased in use.

14.7 Canada E-Waste, Vehicles, and C&D Material Flow Methodology

14.7.1 E-Waste

This section will describe the calculations and sources used to estimate the electronic waste plastic flows in the main report.

Generation

A study published in January 2023 provides an up-to-date assessment of WEEE waste generation in Canada (Komal Habib, 2023). The study indicated that 975,000 tonnes of WEEE were generated in 2021. The 2020 national waste characterization report included a category for electronics. While the actual data were from 2016, and so not exactly comparable, some cross-checks could be made. However, the 'Bulky Objects' category also includes footnotes in some provinces that included white goods. We consider that minimal white goods are likely to be disposed of, so summing the entirety of the diverted category only of 'Bulky Objects' gives an estimate of 770 kt of WEEE generated in 2016, compared to 850 kt from the abovementioned 2023 study, thus giving a 10% variation in the figures. However, only a small proportion of the diverted category of 'Bulky Objects' may be white goods, in which case the total generated figure could be reduced to about 450 to 500 kt—significantly lower than the recently reported figures. While the 975 kt of WEEE generated could be on the high side, there is no conclusive evidence to suggest an alternative, so this figure (975 kt) was used for the model. Moreover, a check of WEEE generation between Canada and the US shows comparable figures (26 kgs per capita and 32 kgs per capita, respectively), providing some validation for the 975 kt figure.

The composition by WEEE category was reported as follows in Table 89, below.

Table 89. Composition of WEEE by Electronics Categories

Category	Proportion
Large household appliances	36%
Small household appliances	10%
IT and telecommunications equipment	14%
Consumer equipment	17%
Lighting equipment	7%
Electrical and electronic tools	5%
Toys, leisure and sports equipment	11%
Medical devices	0.1%
Monitoring and control instruments	1%
Automatic dispensers	0.28%

A 2015 CEC report, 'Quantitative Characterization of Domestic and Transboundary Flows of Used Electronic Products,' also included estimates for computers and monitors (CEC, 2016). The generated figures were around 14,000 MT and 18,000 MT, respectively. These items were separated from the ‘IT and telecommunications equipment’ group and modeled separately as some data on exports were available.

No detailed breakdown of polymers in WEEE from Canadian sources were found. The following tables from a report in the Nordic region show the plastic content of each WEEE category and a breakdown by polymer (Baxter, 2014).

Collection

Data for each province were not available, but using stewardship reports from Alberta, British Columbia, New Brunswick[8] and aggregated with regression analysis based upon population, a total WEEE collection amount for 2021 of around 106,000 MT was derived. A figure of 105,000 MT in 2018 for WEEE diverted (from landfill and incineration) was given in a 2022 article on EEE waste (Statistics Canada, 2022). National figures on diverted white goods and electronics from Statistics Canada were also taken, and for 2020 show a diversion of around 160,000 MT (Statistics Canada, 2022).

Table 90. Total Diverted Electronics in Canada (2020)

Category	Total Diverted, tonnes
White goods	63,119
Electronics	95,176
Total	**158,295**

All the figures obtained are different. Differences may be a result of differing scopes of material within the reports.

Assuming diverted waste means waste that is recovered, a greater proportion of WEEE would be collected. Taking the figure from the British Columbia annual report, of 86% of collected waste that is recovered, and assuming the Statistics Canada figure is the most accurate, around 185,000 MT of WEEE was collected in 2020, so an estimate of around 200,000 MT in 2021 was made.

As the total generation is around 975 kt, this equates to a collection rate of around 20%. This could be low when examining the findings from a 2019 survey suggesting that of WEEE that enters the waste stream[9] consumers are primarily reporting they “Took or sent them to a depot or drop-off center” or “Returned them to a supplier/retailer” (Statistics Canada, 2022).

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[8] Sources for the WEEE collection data were: Alberta Recycling Management Authority, 2022; Wisehart, Electronic Products Recycling Association Annual Report to the Director, 2022; RecycleNB.

[9] i.e., garbage or taken to a depot or retail outlet (the other options – such as donated, resale or keep hold off – would not define the EEE as waste at those points).

Table 91. Garbage and Depot Calculations

	Garbage (a)	Depot (b)	Supplier/retailer (c)	% Returned (b + c) / (a + b +c)
Computers	3	63	9	96%
TVs or monitors	4	65	6	95%
Cellphones	3	33	15	94%
Gaming equipment	1	49	7	98%
Printers and fax machines	5	65	7	94%
Audio/visual equipment	3	65	6	96%
Landline phones	8	50	7	88%
Microwave ovens	10	53	3	85%

It may be that consumers do not truthfully report disposing of WEEE and may underplay what they report as being placed in the garbage. Nevertheless, the data sources seem quite inconsistent. Either the total WEEE generated is too high; or amounts collected are too low; or proportion recovered is too low.

One article on WEEE management in Ontario suggested the diversion rate is 38%, but no source information could be found to support this figure (Thompson, 2020). The Alberta EPR report also suggested a recovery rate of around 38% (Alberta Recycling Management Authority, 2022). This suggests the 20% figure maybe be low, but corroborations cannot be made due to data limitations.

Monitors and Computers

For monitors and computers rates were taken from the CEC report 'Quantitative Characterization of Domestic and Transboundary Flows of Used Electronic Products' (CEC, 2016). Collection rates of 80% and 85%, respectively, were used in the model. For export rates, the following were used – 30% and 12% respectively. In terms of export destinations, the following were taken from the report:

- United States – 32%
- Mexico – 1%
- Rest of World – 67%

Treatment & Recycling of E-waste

Of the WEEE collected and processed in Canada, a nominal amount of some of the main polymers was assumed to be removed through manual separation and sent for recycling (e.g. 5%). The remainder was assumed to be treated via WEEE shredders with the plastic containing residual fraction being sent to energy recovery and landfill.

This assessment of end-of-life treatment of WEEE plastics is corroborated through recent Government initiatives focused on increasing the recycling of plastics from e-waste in Canada (Shared Services Canada, 2020). They state:

> E-Waste recyclers in Canada currently lack the technologies to decontaminate plastics removed from e-waste at the dismantling stage. Such technologies would divert e-waste plastics from landfills without exporting and recycling it outside of Canada. These technologies would also enable the conversion of e-waste plastics into valuable materials or molecules.

14.7.2 ELV Plastic Waste in Canada

A study from the Automotive Recyclers of Canada suggests that around 300kt of automotive plastic waste is generated annually (Government of Canada, 2021). The polymer composition of ELVs was assumed the same as in the United States.

That same source states:

> After drainage of operating fluids and dismantling of reusable parts, ELVs are compressed and shredded. Most of the valuable ferrous and non-ferrous metals are recovered using established separation technologies. The non-metallic components, known as [Automotive Shredder Residue] ASR, consist of a mix of plastics, rubbers, textiles and other fibrous materials, glass and metal fragments. As it is a complex feedstock, in terms of composition and as it contains several contaminants and toxic substances, there is currently no cost-effective method to valorize ASR. Therefore, most of the ASR is currently sent to landfills, where it is used as a cover material.

Therefore, it is assumed that all ELVs are shredded and 100% of the plastic in ASR is diverted to landfill cover. Some bumpers or other items may be removed for reuse, but the amounts are thought to be negligible and so no deduction in total waste generated was made.

14.7.3 C&D Plastic Waste in Canada

This section describes the process for calculating C&D waste flows for Canada.

C&D Generation in Canada

Only limited, federal level data for Canada could be found. One research report from 2013 indicated that 27% of MSW landfilled was from the C&D sector (Muluken Yeheyis, 2012). It also reported that an estimated 9 million tons of C&D waste is generated in Canada annually.

Waste Composition of C&D in Canada

A 2021 report on residential C&D waste indicated that Plastics accounted for 0.6% of the total (Light House, 2021). However, some EPS will be present in a separate category Foam/Insulation, along with glass wool insulation (0.9%). So the total plastic fraction, including foam, could be around 1% in total if a quarter of the separate category were foam insulation (reflecting C&D waste includes waste from construction materials installed 30+ years ago when more glass wool insulation was being installed. This would be around 20% of the total plastic waste generated, which is higher than the 13% suggested for the US, however the Canadian climate is colder overall so a higher proportion of insulation in the C&D waste stream would be expected.

A 2012 research report included waste compositions separately for construction and demolition wastes (though those were sourced from a 1992 Canadian Construction Association report) (Muluken Yeheyis, 2012). For construction wastes the figure was 3.0% plastic and for demolition 0.7%. The total amount of demolition waste is much larger than the amount of construction waste generated, so an average figure would be more around 1.0% than 3.0%.

A waste compositional analysis for the Vancouver Metro area was also found, but the figure for plastic was much higher at 11.5% (Metro Vancouver, 2020). Suggesting C&D debris in metro areas is not representative of the national average.

A national waste characterization report for Canada from 2020 (using 2016 data) found that the contribution of plastic in total residual Demolition, Land-Clearing and Construction (DLC) and Drop-off (DO) waste was around 5% (Environment and Climate Change Canada, 2020).

Overall, it was assumed that the proportion of C&D waste that is plastic is 1%.

Waste Management

There is limited data on the current level of C&D plastics recycling in Canada. A 2021 report by Light House reports a plastic recovery rate of 3.2% (Light House, 2021). This is similar to the 3% figure used for the United States. This figure was used with relative adjustments made to vary by resin, based on the increased recovery rates of certain resins at sorting centers.

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