EXPLORING CANADA'S CIRCULAR EXPORT POTENTIAL

AUGUST 2022

Smart Prosperity Institute
DELPHI GROUP
CIRCULAR ECONOMY LEADERSHIP CANADA

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Circular Economy Leadership Canada (CELC) was launched in 2018 at the G7 Oceans Summit in Halifax as a network of corporate leaders, non profit think tanks, and academic researchers. An initiative of The Natural Step Canada, CELC is working to connect Canada's circular economy community and serves as a bridge to similar networks around the world. We provide thought leadership, technical expertise, and collaborative platforms for accelerating systems change and the transition to a low carbon, circular economy in Canada.

Acknowledgements

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EXECUTIVE SUMMARY

To counteract the emerging global challenges of waste, pollution, biodiversity loss, and climate change, an alternative circular economy model is emerging in business, policy, and civil society discussions. This model promotes three main principles:

- designing out the concept of waste and pollution from all products and services;
- keeping products and materials in use for as long as possible; and
- regenerating natural systems.

At its ideal, a circular economy is a productive economic model that is financially, environmentally, and socially sustainable.

Given the highly globalized nature of the world economy, trade can play an important role in driving the circular economy transition. This is particularly important for a natural resource producing and exporting nation like Canada. To date, Canada's core competitive advantages have been in clean energy and natural resources, a strong business environment, and an educated labour force. However, with emerging international policies on the circular economy such as the EU's Circular Economy Action Plan and the forthcoming global plastic pollution treaty, many of Canada's major trading partners and competitors are beginning to position themselves for a future which embraces circularity, decarbonization and resource efficiency. Therefore, in the coming years, demands from Canada's international trading partners likely to start shifting towards more sustainable goods and services. It follows that Canada risks falling behind in global market share and innovation if it does not make strides in developing its circular export offerings. A circular economy may also present opportunities to diversify trading relationships with countries that are not currently engaged in trade with Canada but are seeking more sustainable trading partners.

> To date, there has been no analysis done on the scale or scope of the trade opportunity the global circular economy transition offers Canada. There is also a dearth of research on how well positioned Canada might be to capitalise on the opportunity.

In addition, the GHG emissions reduction potential of circular solutions offers an opportunity for Canada to advance not only its domestic net-zero ambitions, but also contribute to global mitigation efforts by exporting low-carbon circular goods, services, and technologies. Recent international studies have found

that the circular economy transition could deliver 20-40% global emission cuts and help keep temperature rise below 2 degrees.

To date, there has been no analysis done on the scale or scope of the trade opportunity the global circular economy transition offers Canada. There is also a dearth of research on how well positioned Canada might be to capitalise on the opportunity. This report is intended to be a first step towards filling that gap.

It does this by first providing an overview of what circular solutions may look like in five selected sectors: mining, plastics, construction, the bioeconomy, and crosscutting enabling technologies. This is summarized in Tables 1 and 2, below. It then offers a high-level scan of policy, business, and consumer trends that are spurring the demand for such circular solutions and identifies existing or emerging Canadian industry solutions that could be leveraged to meet this demand. This is summarized in Table 3.

Table 1: Circular business models

	Circular inputs	Life extension	Product service systems	Resource recovery	Sharing
Mining	• Renewable energy • Eco-friendly chemical inputs	• Repair and maintenance • Refurbished equipment	• Renting, leasing equipment	• Utilization of low-grade ores, tailings	• Equipment sharing
Plastics	• Renewable energy • PCR Plastic	• Repair, maintenance, refurbished equipment • Self-healing plastics • Reusing plastics products	• Renting, leasing equipment	• Plastic recycling	• Product sharing
Bioeconomy	• Bioenergy, bioproducts, biomaterials from forest and agriculture by-products	• Repair, maintenance, refurbished equipment and products (e.g., furniture)	• Renting, leasing equipment	• Nutrient recovery • Energy recovery	• Equipment sharing
Construction	• Bio-based building materials • Recyclable building materials	• Disassembly and reassembly • Repair and maintenance • Refurbished equipment	• Renting, leasing equipment	• Recycling C&D waste	• Equipment and infrastructure use sharing

Table 2: Enabling technologies and relevance to circular business models

Technology	Value driver	Relevant business model	Illustrative application
Artificial intelligence	Enables process to become more efficient over time	• Circular inputs • Product life extension • Resource recovery	Categorisation of waste streams through AI-based robots
Big Data	Enables descriptive and predictive analytics	All	Design and material selection in certain industries through rapid prototyping
Machine learning	Enables predictive analytics through algorithms and optimization	All	Optimization of routing in reversed logistics based on historic patterns
Internet of Things	Enables exchange of data generated from sensors and smart assets	• Circular inputs • Product use extension	User customized "pay-per-use" models for services
Blockchain	Enables transparency and traceability in supply chain	• Sharing platform • Product use extension • Resource recovery • Product as a service	Materials origin tracing via material passports and provenance tools

Table 3: Summary of findings

	Global trends	Canadian strengths
Mining	• Electrification of mining equipment • Increasing production efficiencies • Higher utilization of low-grade ores • Efforts to reduce mine tailings	• Electrified mining equipment • Process optimization technologies • Value recovery technologies (from low-grade ores, tailings, EoL products) • Equipment maintenance, sharing
Plastics	• Increasing regulations and bans on plastic waste • Increasing demand for post-consumer recycled plastics • Innovation in mechanical and chemical plastic recycling technologies • International collaboration on plastic waste reduction	• Chemical recycling technologies
Bioeconomy	• Growing demand for replacing fossil-fuel based products and energy with biomass sources • Innovation in biofuels, biochemicals, bioplastics and other biomaterials	• Value-added wood products • Advanced renewable and low-carbon fuels and energy • Agricultural technologies • Biochemicals
Construction	• Increasing energy efficiency and sustainable building regulations • Increasing demand for lower-carbon and renewable building materials • Innovation in business models that design for disassembly and adaptability, modular construction, durability, and deconstruction • Growing water recovery, recycling, and efficiency practices	• Value-added wood products • Circular design and architectural practices • Upcycled building materials • Living walls and green roofs • Utilization of Building Information Modelling platforms • Modular construction practices
Enabling technologies	• Increasing applications of Artificial intelligence, big data analytics, machine learning, and IoT and blockchain-based tools	• Artificial Intelligence technologies • Sensor technologies • Automation & robotics technologies • Quantum computing

Key findings of the kinds of circular export solutions Canadian companies can already offer include:

- In the mining sector: Companies are developing leading solutions for waste and mining by-product management, as well as deploying innovative technologies such as electrified mining equipment to reduce the overall environmental footprint stemming from mining operations.
- In the plastics sector: Companies are leveraging expertise in petrochemical engineering to create solutions for chemical plastics recycling, subsequently enabling a true circular outlook for end-of-life (EoL) plastics management.
- In the bioeconomy sector: Companies are leveraging existing strengths in torrefaction, pyrolysis, and gasification technologies to convert by-products from various sectors into bioenergy with low lifecycle greenhouse gas intensity.
- In the construction sector: Companies are leveraging existing technological strengths to reduce embodied carbon emissions in the built environment, divert difficult-to-recycle materials from landfill, and produce high performance low-carbon building material alternatives.
- Companies are also leveraging technological strengths in the form of artificial intelligence, Internet of Things (IoT), and smart imaging technologies amongst others to enable and accelerate the application of circular economy principles across all sectors.

The findings of this report suggest areas where Canada currently has or could further develop capabilities to play a significant role in furthering the circular economy transition globally through the export of products, services, technologies, and knowledge. However, to determine the how best to capitalize on the export opportunity the transition presents, further research and analysis is required. This includes studies that:

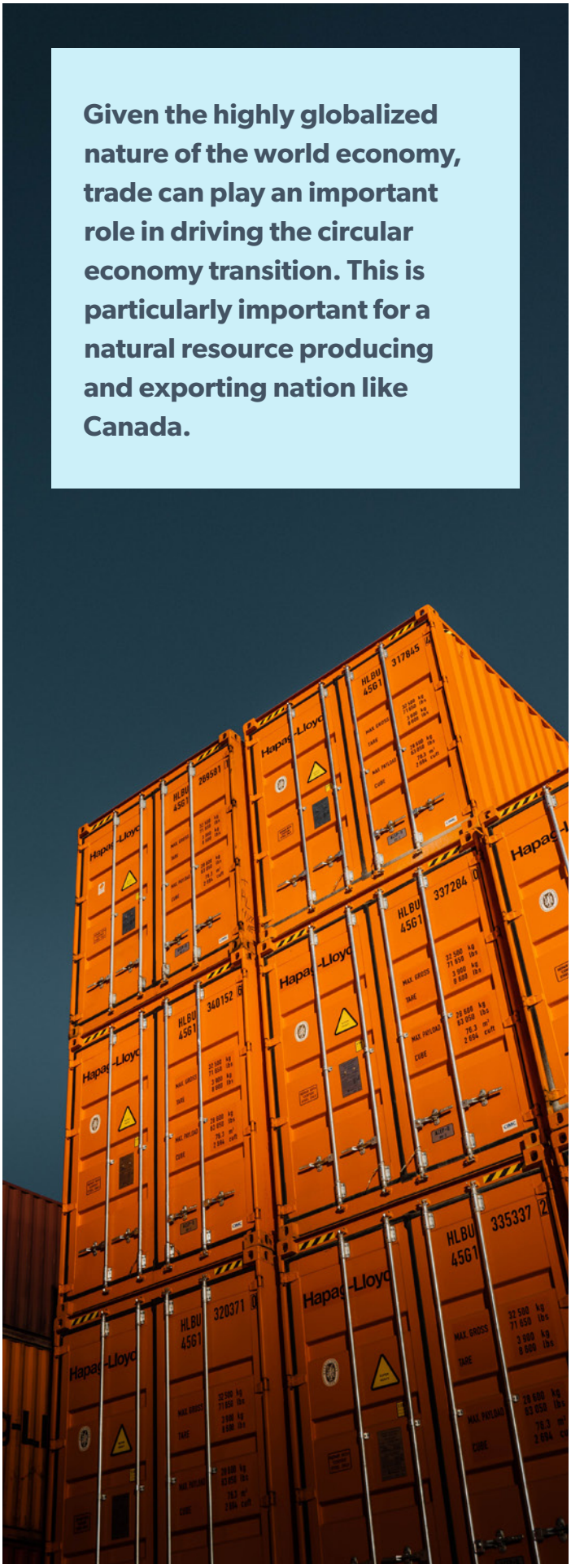
- Conduct deeper sector analysis and market assessments through comprehensive business and industry association engagement, as well as an understanding of the emerging demand for circular solutions across sectors and value chains by market/region.
- Identify financial, regulatory, and technical barriers for growing circular trade and how existing trade agreements as well as new policies and programs can be designed to overcome these.

- Understand how emerging geopolitical trends are likely to impact circular economy related trade flows including: (a) the global low carbon transition, (b) growing economic nationalism and deglobalization, (c) increasing plurality of geopolitical alliances, and (d) growing South-South economic integration.
- Further validate the true 'circularity' of the industry capabilities identified. While the solutions surveyed in this report meet popular conceptions of what circularity entails, further work to validate and quantify their full material, waste, and life cycle benefits should be undertaken.

Based on the high-level study conducted, some initial recommendations to government are as follows:

- Build circular economy capacities across federal departments, including Global Affairs Canada and the Trade Commissioners Service, to socialize the circular economy as an emerging model and create a working knowledge of circular economy strategies, practices, and business models.
- Track nascent clusters of circular business solutions emerging across Canada, with emerging companies advancing circular solutions in a rapidly evolving space that can help meet growing net-zero and ESG goals.
- Build partnerships across North America to create a supporting regional ecosystem for circular innovation, investment attraction, and trade, taking inspiration from the Nordic regional cooperation model.
- Explore opportunities to participate in and lead multilateral efforts to push the circular economy transition through multilateral efforts, such as the WTO's Trade and Environmental Sustainability Structured Dialogues and the Global Alliance on Circular Economy and Resource Efficiency.

Given the highly globalized nature of the world economy, trade can play an important role in driving the circular economy transition. This is particularly important for a natural resource producing and exporting nation like Canada.



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ABBREVIATIONS

4IR	Fourth Industrial Revolution
AI	Artificial intelligence
BIM	Building information modelling
C&D	Construction and demolition
CAP	Canada-wide Action Plan for EPR
CaPSA	Canadian Plastic Science Agenda
CE	Circular economy
CLT	Cross-laminated timber
CPIA	Canadian Plastic Industry Association
CPP	Canada Plastics Pact
CSM	Critical and strategic minerals
DMT	Dimethyl terephthalate
EoL	End-of-life
EPR	Extended producer responsibility
FMCG	Fast-moving consumer goods
GDP	Gross domestic product
GHG	Greenhouse gases
ICT	Information and communication technologies
IoT	Internet of Things
LCA	Life cycle accounting
MEG	Monoethylene glycol
MTA	Metal Tech Alley
REEs	Rare earth elements
WTO	World Trade Organization

1 INTRODUCTION

To counteract the emerging global challenges of waste, pollution, biodiversity loss, and climate change, an alternative circular economy model is emerging in business, policy, and civil society discussions. This model promotes three main principles:

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At its ideal, a circular economy is a productive economic model that is financially, environmentally, and socially sustainable.

Given the highly globalized nature of the world economy, trade can play an important role in driving the circular economy transition. This is particularly important for a natural resource producing and exporting nation like Canada. To date, Canada's core competitive advantages have been in clean energy and natural resources, a strong business environment, and an educated labour force.[1] However, with emerging international policies on the circular economy such as the EU's Circular Economy Action Plan and the forthcoming global plastic pollution treaty, many of Canada's major trading partners and competitors are beginning to position themselves for a future which embraces circularity, decarbonization, and resource efficiency. Therefore, in the coming years, demands from Canada's international trading partners likely to start shifting towards more sustainable goods and services. It follows that Canada risks falling behind in global market share and innovation if it does not make strides in developing its circular export offerings. A circular economy may also present opportunities to diversify trading relationships with countries that are not currently engaged in trade with Canada but are seeking more sustainable trading partners.

In addition, the GHG emissions reduction potential of circular solutions offers an opportunity for Canada to advance not only its domestic net-zero ambitions, but also contribute to global mitigation efforts by exporting low-carbon circular goods, services, and technologies. Recent international studies have found that the circular economy transition could deliver 20-40% global emission cuts and help keep temperature rise below 2 degrees.[2,3]

To date, there has been no analysis done on the scale or scope of the trade opportunity the global circular economy transition offers Canada. There is also a dearth of research on how well positioned Canada might be to capitalise on the opportunity. This report is intended to be a first step towards filling that gap.

It does this by first providing an overview of what circular solutions may look like in five selected sectors: mining, plastics, construction, the bioeconomy, and crosscutting enabling technologies. It then offers a high-level scan of policy, business and consumer trends that are spurring the demand for such circular solutions. Finally, it identifies some existing or emerging Canadian industry solutions that are already responding to this demand and industry strengths that could be leveraged to further develop these offerings.

The findings of this report suggest that Canada currently has or could further develop capabilities to play a significant role in furthering the circular economy transition globally through the export of products, services, technologies, and knowledge. Based on these findings, some initial recommendations for Canadian policy makers and for future research are also provided.

To inform these findings, research for this report included a literature review of trends, Canadian industry capabilities and exports in the sectors of focus, an internet scan of innovative, export-ready circular solutions, and interviews with selected sector experts. The approach and outcomes are presented in the following sections:

Section 2 provides a primer of the circular economy concept and highlights its interlinkages with international trade.

Section 3 highlights the level of circularity in Canada and the importance of developing domestic circular solutions that can be exported.

Section 4 provides an overview of how circular business models apply in the five selected sectors, highlights emerging trends in these sectors, and identifies current or emerging Canadian industry solutions in relation to circular export capabilities.

Section 5 concludes the report with recommendations for government and future research.

The findings of this report suggest that Canada currently has or could further develop capabilities to play a significant role in furthering the circular economy transition globally through the export of products, services, technologies, and knowledge.

2 CIRCULAR ECONOMY PRIMER

2.1 What is the circular economy?

The circular economy is a conceptual model that has begun to emerge in business, policy, and civil society discussions as a potential response to emerging global challenges of unsustainable resource use and the environmental impacts (including greenhouse gas [GHG] emissions and other environmental degradation) that this causes.

The Expert Panel on the Circular Economy in Canada of the Council of Canadian Academies defines the circular economy as:

A systemic approach to production and consumption for living within planetary boundaries that conserves material resources, reduces energy and water use, and generates less waste and pollution.[4]

The circular economy is based on three principles driven by design[5]:

1. Eliminating waste and pollution
2. Circulating products and materials (at their highest value)
3. Regenerating natural systems

It is underpinned by a transition towards the adoption of more renewable energy and regenerative materials. A circular economy decouples economic activity from the consumption of finite resources. It is a resilient system that is good for business, people, and the environment.

The circular economy can be implemented through a variety of strategies, each of which focuses on changing the way materials flow within the economy. These strategies, organized in line with the objectives they meet, include:

Objective 1: Reduce resource consumption and promote cleaner production

Using fewer materials: reducing resource and energy consumption through demand-side management of materials (e.g., by eliminating overspecification of materials in the built environment, vehicle light-weighting, and product eco-design); and preventing waste along the whole value chain.

Cleaner production: regenerative land management, substituting lower-carbon materials (e.g., timber for steel and cement, dietary shifts), energy efficiency, fuel switching, and lower-GHG process changes.

Objective 2: Intensify product use

Using assets more intensively: to derive more utility from every given investment in infrastructure, building, equipment, or goods.

Objective 3: Extend the life of products and components

Using assets longer: extending the lifetime of assets such as buildings, vehicles, and products through thoughtful design and value-retention approaches such as re-use, repair, refurbishment, and remanufacturing.

Objective 4: Give resources new life

Using resources again: industrial ecology, composting, nutrient recovery, recycling, and energy recovery.

Circular economy strategies and practices to achieve these objectives can be implemented through loops of various scales at one or more points in the value chain, as illustrated in Figure 1, below.

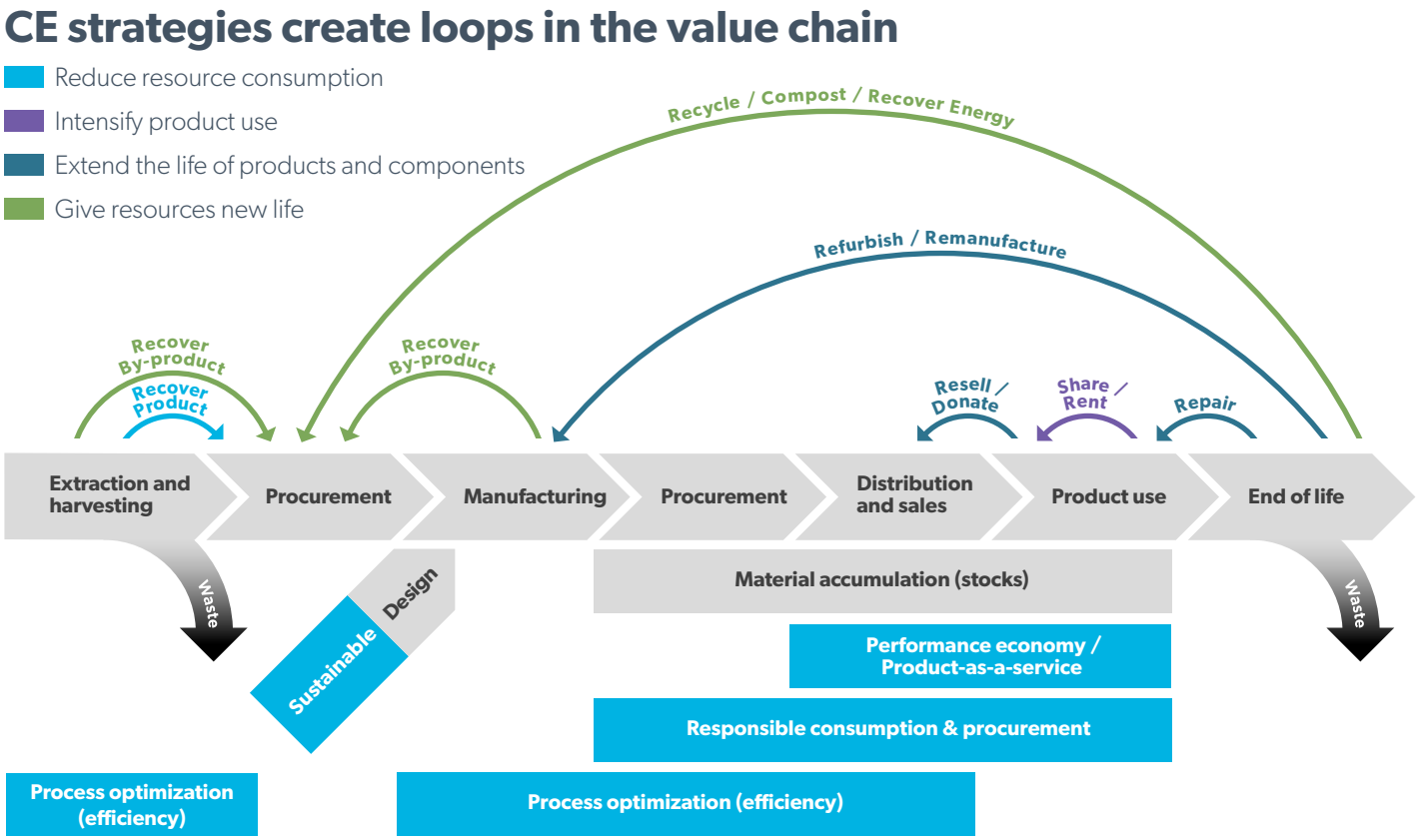


Figure 1: Strategies and Approaches for a Circular Economy.[6]
Adapted from Council of Canadian Academies. (2021) Turning Point: The Expert Panel on the Circular Economy in Canada. Council of Canadian Academies.

Circular strategies can also be framed as the following business models, which can help highlight the business value of these practices[7] (See Figure 2):

- **Circular inputs into supply chains:** involve the replacement of traditional production inputs with bio-based, renewable, or recovered materials.
- **Product service systems (PSS) models:** involve combining a physical product with a service component. This model has three variants:
  - Product-oriented product service system: manufacturing firms continue to produce and sell products in a conventional way but include additional after-sales service in the value proposition.
  - User-oriented product service system models: provide access to the services associated with a particular good without ownership of the good itself.
  - Result-oriented product service models: instead of marketing manufactured assets or goods in a traditional way, adopting firms market the services or outcomes provided by these goods.
- **Sharing models:** involve using under-utilized consumer assets more intensively, either through lending or pooling. This model has two variants:
  - Co-ownership: involves the lending of physical goods.
  - Co-access: involves allowing others to take part in an activity that would have taken place anyway.
- **Product life extension models:** involve extending the life of products. This model has three variants:
  - Classic long life: involves designing products with longer service lives.
  - Direct reuse: involves the redistribution of used products to new owners.
  - Maintenance and repair: involves fixing or replacing defective components.
  - Refurbishments and remanufacturing: involves the restoration of degraded products, either for a fee, or for subsequent resale to original or new owners.
- **Resource recovery models:** involve the production of secondary raw materials from waste streams. This model has three variants:
  - Downcycling: involves the transformation of waste into inferior quality secondary raw materials.
  - Upcycling: involves the transformation of waste into high quality secondary raw materials.
  - Industrial symbiosis: involves the use of production by-products from one firm as production inputs by another.

Figure 2: Circular Business Models.[8]

Adapted from Council of Canadian Academies. (2021) Turning Point: The Expert Panel on the Circular Economy in Canada. Council of Canadian Academies.

2.2 Trade linkages

Given the highly globalized nature of the world economy, trade plays an important role in the transition towards a circular economy both domestically and globally. While circular economy practices largely take place within national boundaries, they could have interlinkages with three specific trade flows: supply chains, end-of-life value chains, and services.[9] These are summarised below and denoted in Figure 3.

1. **Supply Chains:** The circular economy encourages more environmentally sustainable and resource-efficient supply chains. The production stage of the global supply chains impacts the circularity of the economy where it takes place. Production of circular products can be highly impacted by the cross-border trade of raw materials, intermediate goods, and final products that feed into the production process. If circular products produced are exported, trade can also impact the circularity of the importing nations since the environmental impacts of consumption will occur in different jurisdictions from where production occurs.
2. **End-of-life value chains:** End of life products can cross borders in various forms including:
    - **Waste and scrap:** trade in waste and scrap can provide potential economic opportunities to transform waste into resources. This has two advantages. For one, it can help achieve economies of scale in collecting waste destined for recycling and (material and energy) recovery operations. Second, trade can channel waste and scrap to countries with comparative advantage in sorting and processing them into valuable materials. Current restrictions on trade in waste and scrap are thought to be more significant for exports than for imports.[10]
    - **Secondary raw materials:** trade in secondary raw materials could potentially encourage decoupling by decreasing demand for primary materials in the importing nation. Since natural resources are geographically unequally concentrated, trade implications are significant in the worldwide distribution of primary raw materials. Currently, export restrictions are frequently applied to secondary raw materials.[11]
    - **Second-hand goods:** trade in second-hand goods can help keep materials in use for longer before these products reach their end-of-life. However, despite potential benefits of second-hand goods trade, there could be potential drawbacks. For instance, this could lock importing economies into old and inefficient technologies. There could also be issues related to potential downcycling of end-of-life products depending on the level of recycling, recovery, and waste management technologies available at their destination. Second-hand goods trade is also a concern for some importing countries as they can be a potential loophole for illegal trade in hazardous or contaminated waste. Second-hand goods can also raise potential issues with the right-to-repair and their relationship with protecting Intellectual Property Rights in certain trade agreements.[12]
    - **Goods for refurbishment and remanufacturing:** trade of refurbished and remanufactured goods can reduce the cost of inputs compared to new manufactured goods and enable the use of materials more efficiently for exporting nations. It also provides opportunities for importing foreign markets that require lower prices for products.[13]
3. **Services:** The transition to a more circular economy has the potential to grow the service sector relative to the manufacturing sector. The growth in service-intensive sectors such as waste management, recycling, refurbishment and remanufacturing, reuse, and repair are expected to grow as manufacturers substitute secondary raw materials for primary raw materials and consumers substitute services for goods through product service systems. These new business models (e.g., product as a service and sharing models) may provide new opportunities for international trade. Furthermore, digital technologies and innovation play an important role in enabling trade in circular services by 'dematerializing' the need for certain products and goods.[14]

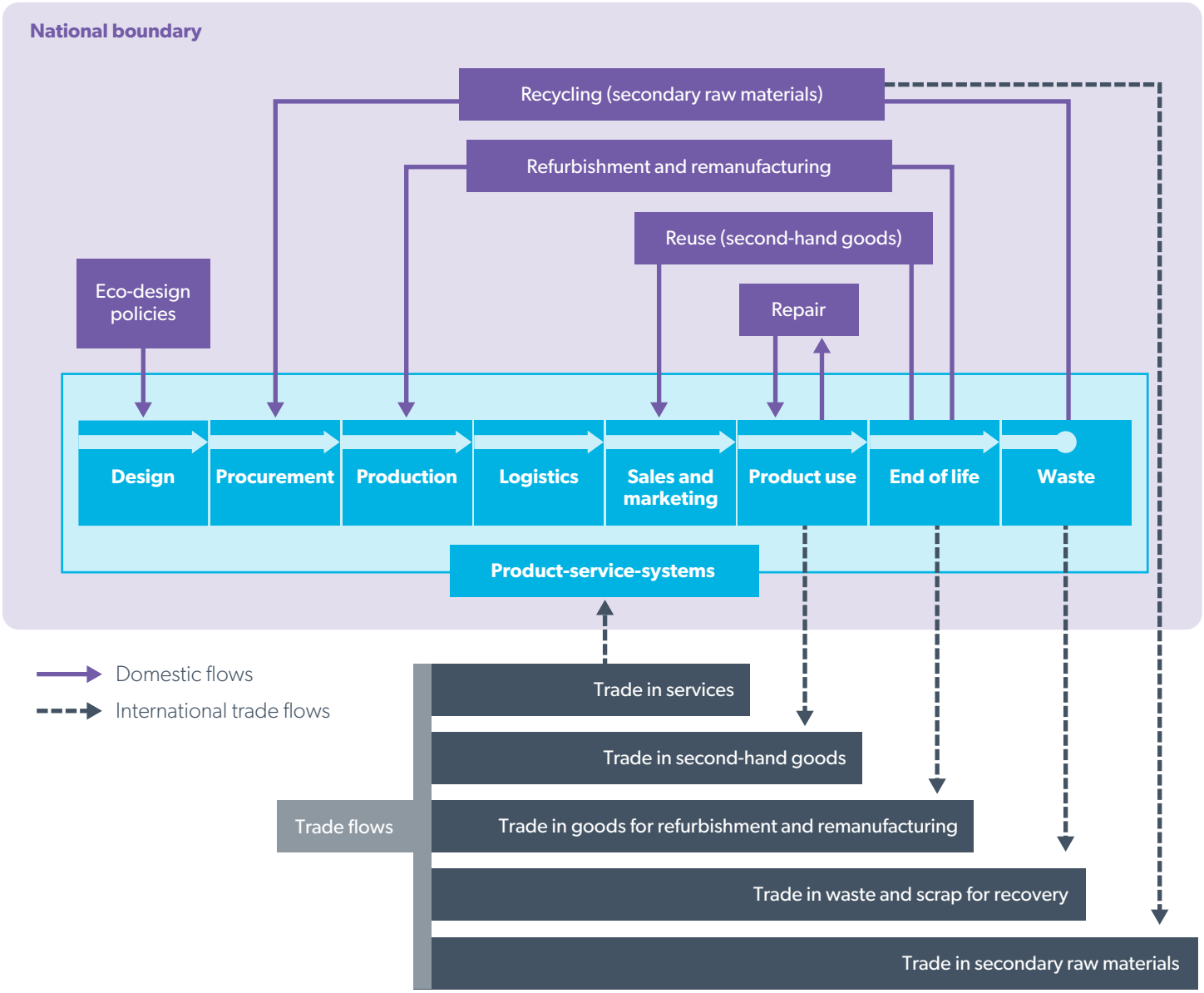


Figure 3: Linkages between international trade and circular economy.
Adapted from OECD (2021). International trade and circular economy - Policy alignment. Paris, France: OECD.

3 AN OPPORTUNITY FOR CANADA

In November 2021, the Council of Canadian Academies' Expert Panel on Circular Economy released a report that presented the first estimation of Canada's level of circularity. For this, the Panel created a material flow model using the Canadian material flow database and taking into account recycling and backfilling*; the material intensity of products determined by design; and product functionality, durability, reuse, reparability, and sharing. It estimated that, currently, the circularity rate[15] for Canada is 6.1%.[16] This is visualized in the form of a Sankey diagram in Figure 4.

While the circularity rate in Canada is relatively low, the concept is quickly picking up in Canada. Over the past few years, Canada has seen fragmented policy developments and pockets of interest among businesses. Much of the circular initiatives in Canada are being driven by partnerships and collaborations among NGOs, research institutes, and municipalities. These initiatives are being seen across sectors, notably in mining and minerals, forestry, fossil fuels, construction, food, plastics, electronics, and textiles.[17]

Being a natural resource producing and exporting country, Canada's motivation for becoming more circular may be different from other jurisdictions where circular action is being driven largely by scarcity concerns and the rising prices of primary natural resources. Canada's motivation for moving towards a circular economy lies more in reducing the environmental impacts of its natural resource sector and increasing competitiveness in a global economy that is increasingly prioritizing sustainable products and practices. For instance, innovation and growth opportunities in areas such as the circular bioeconomy (i.e., enhanced use of forestry and agricultural feedstock, both domestically and for export) and mineral and metal recycling and secondary manufacturing could present significant opportunities for Canada.[18]

* Backfilling is a recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a substitute for non-waste materials (Eurostat, 2015).

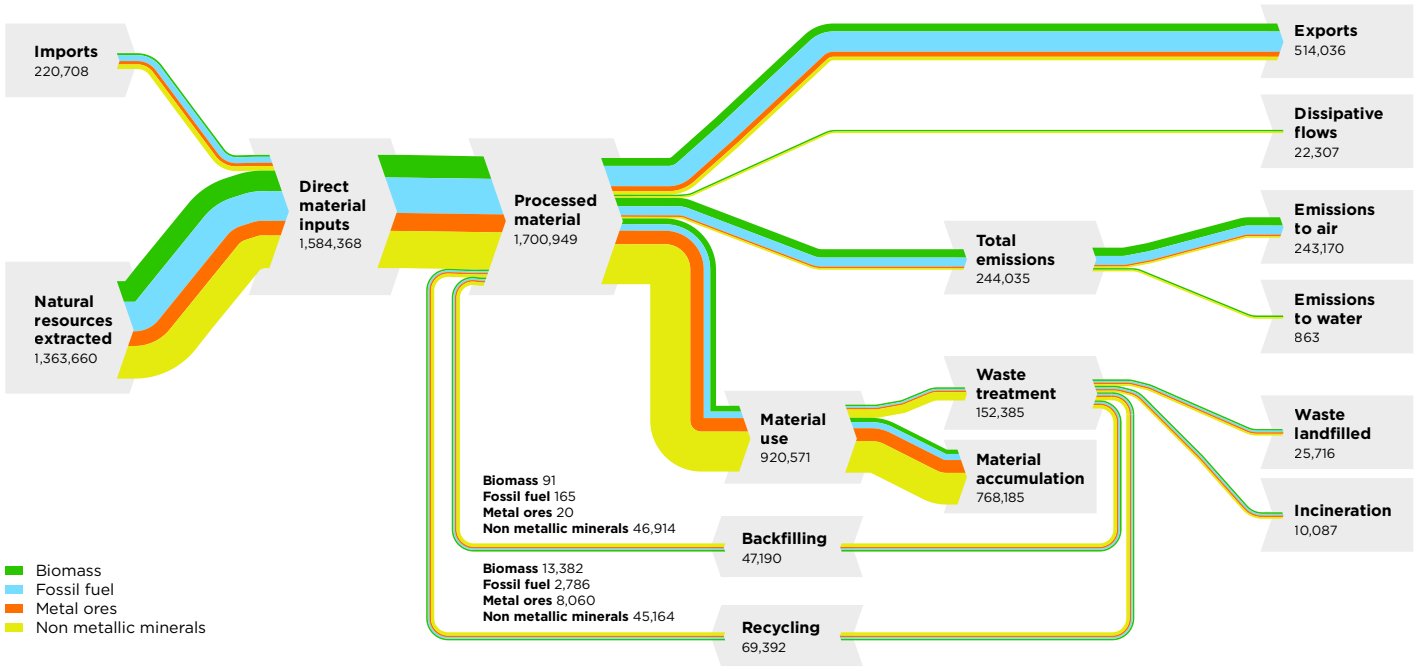


Figure 4: Sankey Diagram of estimated material flows in Canada, 2021 (Thousand Tonnes).
Adapted from Council of Canadian Academies. (2021) Turning Point: The Expert Panel on the Circular Economy in Canada. Council of Canadian Academies.

As demands from Canada's international trading partners are shifting, for both environmental and economic reasons, Canada risks falling behind in global market share and innovation if it does not make strides in developing its circular export offerings. In addition to staying competitive, the early adoption of circular practices would also provide opportunities to capture greater value from the natural resource sector. Finally, a circular economy may also present opportunities to diversify trading relationships with countries currently not engaged in trade with Canada but that are seeking more sustainable trading partners.[19] Therefore, it is worth exploring whether the global circular economy transition could provide an export growth opportunity for Canada. The main areas of Canada's international trade that would likely be impacted by the transition towards a circular economy include natural resources, recyclable waste, cleantech, and service exports.[20]

Canada–United States Trade Relationship

Trade between countries can help grow the circular economy, and Canadian trade with the United States has been suggested as a valuable opportunity to advance the circular economy in North America.[21] This is because the Canadian economy is heavily dependent on its trade relationship with the United States. This relationship is characterized not just by high volume but also high levels of supply chain integration.

Current Canada–US trade already involves important commodities in the context of the circular economy. For example:

- The US is the largest importer of Canada's plastic waste[22]
- The US is a major importer of Canada's e-waste[23]
- Canada is the largest market for US exports of remanufactured goods across a variety of sectors[24]

4 EXPLORING CANADA'S CIRCULAR ECONOMY EXPORT POTENTIAL

Sectors of focus for this report were selected based on previous work by the Smart Prosperity Institute that identified high potential industries in Canada and its territories and provinces based on popular ongoing circular economy initiatives worldwide.[25] That report built on the quantitative methodology initially developed by Yves Richelle for L'Institut EDDEC[26] which found that industries with the highest potential to benefit from circularity are construction, food manufacturing, and primary metal manufacturing and fabricated metal manufacturing (taken together). As such, these sectors have socio-economic-environmental incentives to transition from a linear to a circular model and have seen ongoing development of circular initiatives in Canada. Figure 5 illustrates these priority sectors of circular focus.

Based on this study, and considering global circularity trends, the export opportunities these trends generate for particular industries, and the capacity of Canadian companies to respond to such opportunities, the following sectors were chosen for deeper study:

- Mining
- Plastics
- Bioeconomy
- Construction
- Enabling Technologies

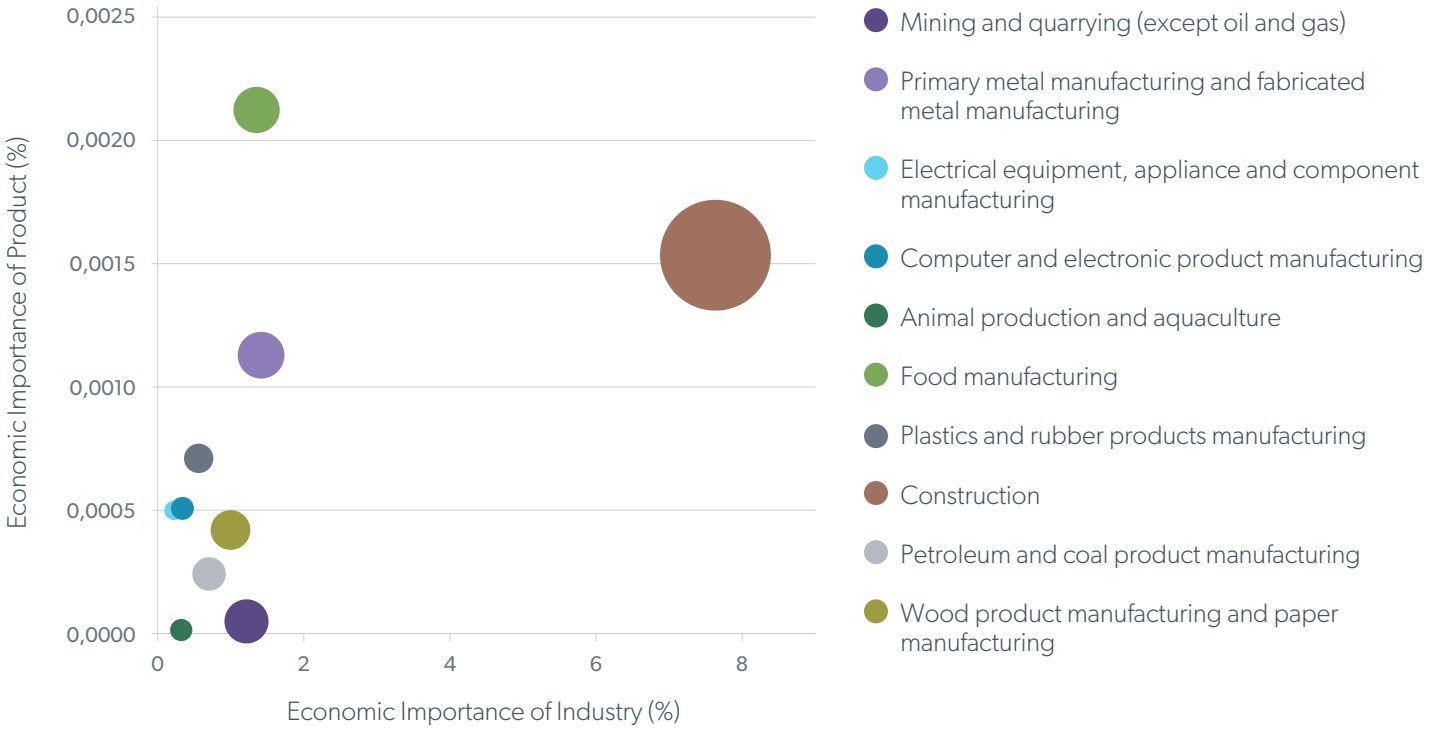


Figure 5: Priority Industries for a Circular Economy in Canada.
Adapted from Patel, Sonia and Donin, Genevieve. (2020). Priority Industries for A Circular Economy In Canada. Smart Prosperity Institute.

4.1 Mining

In 2020, the mining sector contributed to roughly 5% of Canadas nominal GDP.[27] The mining sector contributes significantly to both local and global economies and is responsible for the supply of several essential metals and minerals, including critical minerals that are essential for the low-carbon transition. As national and international efforts to tackle GHG emissions intensify, the demand for critical minerals including rare earth elements (REEs) is expected to grow exponentially. And with nations worldwide seeking to diversify supply chains away from China, Canada is expected to play a major role in enabling not only domestic but also international low-carbon transitions as a key supplier of sustainable metals, minerals, and technologies.

4.1.1 Circular mining solutions

Circular business models described in Section 2.1 can be applied to the mining sector in the following ways:

1. **Circular inputs into supply chain models:** using of renewable energy, electrifying mining equipment, switching to eco-friendly chemical inputs.
2. **Product life extension models:** prolonging mining and extraction equipment use through repair, maintenance, upgrading, and resale.
3. **Product as a service model:** reducing overall demand for mining equipment by leasing equipment as a service instead of selling equipment.
4. **Sharing models:** increasing overall usage rates of assets such as extraction equipment via collaborative models for sharing, access, and ownership.
5. **Resource recovery models:** recovering valuable minerals and metals from end-of-life technologies, extracting value from low-grade ores, and tailings as a product.

4.1.2 Emerging trends

There is increasing recognition worldwide of the mining sectors environmental footprint. Globally, the mining sector generates approximately 100 billion tonnes of solid waste per year[28] and the liability for managing tailing and other mining waste exceeds $50 billion in Canada and the United States alone.[29]

In the wake of the global climate crisis, there is growing pressure on mining companies from shareholders, workers, consumers, governments, and local mining communities to reduce their GHG emissions, enable the energy transition away from fossil-based fuels to low carbon alternatives, and more broadly, to address their overall impact on the natural environment.[30]

As such, several companies in the mining and metals value chain are innovating and using a circular lens to address concerns over their environmental footprints and lead the mining sector towards the impending technological revolution. The electrification of mining equipment,[31] increasing efficiency of resource production,[32] reducing mining waste and by-products, extracting value from low-grade ores,[33] and minimizing impacts of mine tailings[34] are some of the broader sustainability trends emerging in the mining and metals sector.

The lack of reliable open-source data makes it difficult to estimate the gross economic value of mining-related circular economy business models. There is a lack of standard definitions, and the mining supply and services activities do not readily correspond to traditional industry classifications[35]; however, some data exists for specific circular economy practices. To illustrate:

- The market for electric mining equipment is projected to grow at a CAGR of 19.6% and reach $11.7 billion USD by 2030.[36] North America is projected to account for the largest market share for electric mining equipment.
- It is estimated that there is about $10 billion CAD in total metal value in Canadian gold mine waste alone, according to conservative estimates.[37]
- The market size for heavy equipment rental industry in 2021 was $9 billion CAD. This includes the renting or leasing of heavy construction, transportation, mining, forestry, and commercial equipment such as earthmovers, aircraft, and drills to a variety of industries.[38] CRA forecasts continual growth for the sub-sector.[39]
- Size of the metals recycling market is projected to grow from $277 billion USD in 2015 to $406 billion USD by 2020[40]; however, the strategic value of critical and strategic minerals (CSM) far exceeds their economic value.
- "Smart Mining" market is expected to grow to $13-38 billion USD by 2027 at a CAGR of between 8-20%.[41]

4.1.3 Canadian Strengths

Canada is recognized globally as a leading mining nation[42] and is home to approximately 50% of the world's publicly listed mining and exploration companies.[43] The Canadian mining sector possess several unique strengths that place it amongst the best in the world in terms of quality of goods and services. These strengths include:

- **Electrified mining equipment:** The Canadian mining sector is the global leader in testing innovative technologies at the mine site.[44] This includes deploying novel mining equipment and vehicle fleets running on electricity as well as the development and deployment of new clean technologies. This is in part driven by access to several clean energy sources, including hydroelectricity, resulting in a high Environmental Performance Index relative to other mining nations.[45]

FVT Research Inc.

FVT Research Inc. designs, builds, and installs Battery Electric Vehicles (BEVs) that support the electrification of mines. Its systems power underground equipment, for which it offers a Batteries as a Service (BaaS) option as well as mining vehicles, which are clean, efficient, and more powerful than diesel engines.

FVT is currently exporting to countries like England and Sweden and looking to further expand its exports in the future.

Click here for more details.

- **Established markets for equipment maintenance, sharing, and rentals:** Several Canadian companies offers services that extend the utilization and lifetime of mining equipment such as maintenance, repair, and rentals.
- **Technologies to improve production efficiency:** Canadian mines have high production efficiencies, with even off-grid Canadian mines being more energy efficient than mines in other sites abroad.[46] Supported by world-class enabling technologies such as imaging systems, inversion technologies and the use of artificial intelligence, Canadian mining companies have demonstrated experience in reducing the exploration drilling activity ten-fold and identifying exploration targets with 95% or higher certainty.
- **Technologies to capture value from by-products:** Canadian companies are adopting novel and innovative technologies that allow for recovering value from low-grade ores, tailings, and end-of-life products. Adoption of these technologies not only creates an untapped revenue stream from the sale of secondary materials but also eliminates contaminants which would otherwise be released into the environment.

EnviroGold Global Inc.

EnviroGold Global is a clean technology company that is capitalizing environmental stewardship and sustainably supplying the world's increasing demand for precious, critical and strategic metals by profitably reclaiming unrecovered value from mine tailings and resource development waste streams.

Using cutting edge Electrochemical Separation Technologies (EST), EnviroGold's patent-pending processes use a unique application of advanced electrochemical and surface probe techniques to recover up to 98% of residual gold from mine tailings on a commercial scale. Its processes also recover over 95% of other precious, critical, and strategic metals, including platinum, lithium, cobalt, germanium, and titanium. Strategically positioned for sustainable, data-driven development of high-margin assets, EnviroGold provides a scalable solution for a virtually untapped global market. In addition, its processes are eco-friendly and remove contaminants like chlorides, nitrates, arsenic and mercury from mine waste. Treated process water is clean and suitable for reuse in agriculture, storage, or release to the environment.

EnviroGold has several projects at different stages of execution in Australia, Mexico, and Ghana and has a target to have seven major projects in production by 2025.

Click here for more details.

The continued innovation of circular practices in the mining sector has been driven by both government policy direction and industry leadership. Some relevant in initiatives are noted below:

- Canadian Minerals and Metals Plan (CMMP): a culmination of over two years of dialogue and engagement between the Canadian federal, provincial, and territorial governments, the CMMP provides a framework to guide a competitive minerals and metals industry. The primary aim of the plan is to minimize the environmental footprint of the mining sector and enable the sectors CE transition.[47]
- Towards Zero Waste Mining Innovation Strategy: developed by The Canadian Mining Innovation Council, this plan aims to minimize waste stemming from mining and support activities by closing loops and subsequently improving water quality, increasing energy efficiency, and reducing GHG emissions across the value-chain.[48]
- CanmetMINING Project: a mining value-from-waste pilot project launched by the Green Mining Innovation Intergovernmental Working Group at NRCan in 2017 to close mining loops such as tailing waste and to reduce the socio-economic-environmental impacts of mining waste and by-products.[49]
- Quebec Critical & Strategic Minerals Strategy: a comprehensive circular economy roadmap that enables circular economy business models across the metals and minerals value-chain, the Quebec CSM strategy seeks to promote circularity within the mining industry as part of their broader plan to sustainably develop critical and strategic metal and mineral supply chains.[50]
- Metal Tech Alley (MTA): a first-of-its-kind initiative, this organization aims to advance a regional movement towards a circular economy for long-term stability and environmental sustainability. MTA is composed of a group of academics, government, local mining businesses, and non-profits based in Trail, B.C. who share a mutual goal of stimulating local growth while minimizing regional waste.[51] This is achieved by making environmental protection profitable and developing a roadmap to support local communities and businesses.

4.2 Plastics

In 2020, the Canadian plastic recycling market stood at 3.08 million tonnes and is projected to grow at a CAGR of 3.15% to reach 4.38 million tonnes by 2030.[52] Growing awareness of plastic pollution coupled with policies such as bans on single use plastic and green procurement are expected to increase the demand for recycled goods and promote recycling. The plastic recycling sector is expected to see increased revenue with expected investments between $4.3 billion USD and $8.6 billion USD driving 167 new sorting and recycling facilities to come online.[53]

4.2.1 Circular plastics solutions

Circular business models described in Section 2.1 can be applied to the plastics sector in the following ways:

1. **Circular inputs into supply chain models:** use of recycled plastic, carbon capture-sourced plastics, and closed loop manufacturing.
2. **Product life extension models:** prolonging plastic lifetime via repair, maintenance, and refurbishment and through designing self-healing plastics.

3. **Product as a service model** – N/A
4. **Sharing models:** increasing overall usage rates of plastics via collaborative models for sharing, access, and ownership.
5. **Resource recovery models:** recovery of plastics from end-of-life products via recycling and transforming plastic waste that cannot otherwise be reused, recycled, or composted into energy with minimal environmental impact.

4.2.2 Emerging global trends

The past few decades have seen increasing concerns about the enormous impact that plastic waste has on the natural environment. More than 400 million tonnes of plastic are produced annually worldwide,[54] and the majority of end-of-life plastic is grossly mismanaged. Recycling rates for plastics are extremely low (between 14-18% as the global average) and approximately 25% of plastic waste is incinerated and 56% is landfilled.[55]

End-of-life landfill rates for plastic are even higher in Canada, with 87% of plastic waste ending up in landfills or the environment.[56] A recent study estimates the lost value from plastic material not being recovered at end-of-life to be $7.8 billion CAD, based on the value of the virgin resin material.[57]

Recent pressure on fast-moving consumer goods (FMCG) companies to address plastic pollution has led to an increase in demand for recycled plastics and FMCG companies are taking up voluntary commitments to use recycled plastic in their packaging.[58] Beyond FMCG companies, other segments of the plastics value chain are also facing increased scrutiny for enabling plastic pollution. This includes petrochemical plastic resin producers, as well as financial institutions who have historically turned a blind eye to the negative externalities of their business-as-usual approach to managing plastics and their contributions to plastic pollution. Subsequently, these players are seeking opportunities to address plastic pollution using circular practices.[59]

Government regulations banning single-use plastics such as drinking straws, coffee stirrers, plastic bottles, cups, plates, and shopping bags have increased in several countries.[60] Polyethylene bags have been banned in many parts of the world and consumer interest surrounding the impact of plastic waste on the environment has risen to an all-time high.[61]

On the demand side, companies are innovating to increase efficiency and reduce primary plastic consumption during production. Finally, mechanical, and chemical plastic recycling technologies are emerging to recirculate end-of-life plastic into other raw materials for further use.[62] The market for plastic recycling is projected to grow at a CAGR of 7.19% and reach $67.32 billion USD by 2030.[63]

The past few years have also seen growing international collaboration to address plastic pollution. This is evident from the various Plastics Pacts in Europe, Africa, North America (including Canada), and Latin America that form a network of regional initiatives working towards a shared vision for a circular plastics economy.[64] Moreover, the United Nations recently approved a landmark resolution to develop a treaty aiming to address global plastic pollution.[65] The first-of-its-kind treaty will provide a legally binding pathway to reduce plastic pollution by placing restrictions on plastic production, use, and design.[66] The idea of a United Nations treaty on plastic pollution has received enormous public support.[67]

4.2.3 Canadian Strengths

A recent report by The Canadian Plastic Industry Association (CPIA) highlighted the resiliency of the Canadian recycling infrastructure over the past few years as it weathered market challenges.[68] In 2017, despite the cost of recycled plastic resin being competitive with virgin resin, major plastic and recyclables import markets in Asia, including China, employed 'National Sword' policies that blocked plastic waste from entering their countries. This subsequently led to a 5% reduction in overall plastic recycling, with plastic film recycling rates being the most profoundly affected.

These actions drove Canadian plastic recyclers to innovate, leading to additional Canadian recycling processing capacity. This additional capacity includes traditional mechanical recycling, as well as novel 'resource recovery' technologies like chemical recycling, which aims to recover value from plastic material.[69] Canada's plastic recycling industry has evolved from and benefited from its mature petrochemical industry. In many cases, legacy technologies from petrochemical manufacturing that transform oil and natural gas into polymers, monomers, and plastic resins have been leveraged and adapted for chemical recycling. Chemical recycling allows for plastics to be recycled infinitely and is therefore a sustainable solution for managing end-of-life plastics.[70]

Plastics recycling is a growing industry in Canada and is supported by several government and private initiatives including:

- Advancing Science: in 2019, the Government of Canada released Canada's Plastic Science Agenda (CaPSA). CaPSA is a framework that aims to inform future science and research investments and to fill knowledge gaps, including advancing plastic recycling and recovery.[71]
- Strategic Investments into Plastics Innovation: in 2020, the Government of Canada launched two initiatives to fund priority research areas. The Increasing Knowledge on Plastics Pollution Initiative provides funding for 16 research projects and the Plastics Science for a Cleaner Future initiative will fund projects up to $1 million CAD over four years. Moreover, the Canadian Plastics Innovation Challenges provide funding to small and medium-sized enterprises engaged in finding innovative solutions to manage plastic waste. Through the program, the Government of Canada is investing approximately $19 million CAD to support Canadian innovators.[72]
- Canada-wide strategy on Zero Plastic Waste: implemented by the Canadian Council for Ministers of the Environment, the plan aims to cut per capita plastic waste in Canada by

30% from 2014 levels by 2030. The plan takes a circular approach to reducing plastic waste and targets improved collection and recovery rates for end-of-life plastic in Canada.[73]

- Extended Producer Responsibility (EPR): currently, five Canadian provinces (British Columbia, Saskatchewan, Manitoba, Ontario, and Québec) have EPR strategies implemented for plastic packaging. EPR strategies allow local jurisdictions to gain greater control over their waste streams[74] and are observed as key drivers for innovation amongst companies involved in the management of plastics.[75]
- Canada Plastic Pact (CPP): launched in early 2021, the Pact is an industry-led group of key plastics stakeholders that seeks to enable cross-sectoral collaborations to uniformly reduce plastic waste and pollution.[76] In October of 2021, the CPP released a roadmap for a circular plastic packaging economy.[77] The three key focus areas of the roadmap are (a) reducing plastic packaging at source, (b) recirculating end-of-life plastic packaging, and (c) increasing demand for circular plastics packaging.[78]
- Plastics Alliance of Alberta: a multi-stakeholder collaboration involving industry, government, and academia, the aim of this effort is to support the development of a circular roadmap for plastics in Alberta.[79]

Loop Industries Inc.

Loop Industries is a chemical recycling company that has developed a patented technology to supply CPG brand companies around the world with PET plastic and polyester fiber made from 100% recycled content.

Loop's Infinite Loop™ facilities provides an end-to-end industrial solution to supply the global demand for Loop™ PET resin made from 100% recycled content. Loop's proprietary depolymerization technology breaks down traditionally hard to recycle waste PET into its base chemical building blocks, or monomers: dimethyl terephthalate (DMT) and monoethylene glycol (MEG) using low heat and no added pressure. The monomers are purified and then recombined into Loop™ branded PET plastic and polyester fiber. This high purity, virgin-quality plastic is infinitely recyclable and suitable for use in food-grade packaging.

Loop Industries currently exports Loop™ PET plastic and polyester products and has made partnerships to set up Infinite Loop™ facilities in Europe, U.S.A and Asia. It has a goal to construct 10 Infinite Loop™ facilities by 2030, thereby diverting 1 million tonnes of waste from landfills and oceans annually.

Click here for more details.

- Industrial partnerships:
  - HP & Lavergne Group: HP Canada and the Lavergne Group are partnering to manufacture new HP printer cartridges from recycled plastics.[80]
  - Circular Plastics Taskforce: the aim of this partnership between the Canadian Plastics Industry Association, CTTÉI and five companies in Canada's packaging, food, and beverage sectors is to find concrete solutions to improve the management of post-consumer plastics.[81]

4.3 Bioeconomy

The Canadian bioeconomy sector includes several sub-sectors engaged in the production, processing, and management of biological materials. These sub-sectors produce food, materials and energy using renewable resources such as crops, fish, animals, forests, and organic waste. In 2015, Canadian industries transformed 21 million metric tonnes of raw biomass into bioproducts with forestry being the largest source of biomass at 12.3 million metric tonnes.[82] This was followed by the agriculture sector which produced 8.8 million metric tonnes. Together, forestry and agriculture accounted for approximately $4.27 billion CAD in revenue.[83]

The 'Circular Bioeconomy' is an emerging concept that involves the use and subsequent conversion of bio-based materials from traditional sectors such as agriculture, forestry, and marine ecosystems, as well as the use and conversion of by-products from industrial streams and organic waste. These sustainably sourced by-products can be utilized to produce bioproducts, biochemicals, bioenergy, and biomaterials such as bioplastics, cellulose nanofiber, and engineered wood products.[84]

The circular bioeconomy is estimated to present a $7.7 trillion USD opportunity by 2030 and coupled with soil and forest carbon cycling and storage capabilities, re-integration of biomaterials into the biosphere, and carbon storage in products creates tremendous value.[85]

4.3.1 Circular Bioeconomy Solutions

Circular business models described in Section 2.1 can be applied to the bioeconomy sector in the following ways:

1. **Circular inputs into supply chain models:** Use of bio-sourced plastics, materials, fuels, and products, and closed-loop water consumption. This includes re-thinking supply chains based on bio-sourced platform chemicals, and recovery of energy from high-organics wastewater.
2. **Product life extension models:** prolonging bioproduct lifetime via repair, maintenance, and refurbishment activities such as wood-based furniture refurbishment, production of longer-lived engineered wood products, increasing stability and shelf-life of products, and through the re-appropriation of food by-products, surplus, and waste.
3. **Product as a service model:** reducing overall demand for bioeconomy equipment by leasing equipment as a service instead of selling equipment (meal subscription services would also fit under this category).
4. **Sharing models:** increasing overall usage of bioeconomy equipment such as farming, forestry, and harvesting equipment that are often utilized for short time periods.
5. **Resource recovery models:** giving resources a new life via the valorization of organic by-products and waste, paper and wood recycling, and bioenergy production.

4.3.2 Emerging Trends

As global ambition to decrease GHG emissions intensifies, there is growing interest in the use of biomass to displace fossil-based energy and material production. Bioenergy can provide both an economic and environmental benefit over fossil fuels as well as contribute to energy security.[86] The financial difficulties that the Canadian forestry sector has faced in recent years have led to calls to identify increased use of forest biomass in addition, or as an alternative to, traditional forest products. High value bioproducts such as biomaterials and biochemicals that can be co-produced with bioenergy are also garnering increased interest.

The Province of British Columbia has passed the Low Carbon Fuel Standard[87] and the Government of Canada is working to implement the Clean Fuel Standard[88] – policies and regulations that seek to encourage the use of renewable and low carbon fuels. Advances in biorefineries and bioprocessing technologies have led to the possibility of creating bio-based polymers as a substitute to traditional fossil-based plastics.[89] Hemp and fiber residues are finding application in an increasing number of industrial applications.[90]

A recent report by McKinsey Institute found that there is an ongoing innovation wave in biology that, along with broader advances in fields such as computing, machine learning, artificial intelligence, and biological engineering, is enabling the growth of bio-based products and materials worldwide.[91] Bioproducts have seen strong uptake in the construction, automotive, and packaging sectors. Commercial bioproducts and bio-based solutions are available, and some are already competing in global markets. Several bioproducts are being developed for the plastics, textiles, and pharmaceuticals sectors as well.[92] The report estimates that the direct economic impact of this "Bio Revolution" could be $4 trillion USD/year over the next two decades,[93] with Canada potentially sitting on a $200 billion CAD/year sustainable economic development opportunity.[94] Moreover, the market value of bioplastics in Canada reached $465.6 million CAD in 2021 and the industry witnessed a market volume of 138.3 thousand tonnes the same year. Between 2017 and 2021, the Canadian bioplastics industry also recorded a CAGR of 1.9% in terms of value.[95]

4.3.3 Canadian Strengths

Canada ranks first amongst countries with the highest per capita biomass availability in the world.[96] It has the world's most abundant and sustainably harvested biomass resources with a legacy of sustained revenue. Historically, Canada's primary resource producing sectors such as forestry, fisheries, oil and gas, mining, and agriculture have been the backbone of the Canadian economy. As such, they have developed unique strengths, some of which are noted below:

- **Value-added wood products:** As a leading wood producing economy backed by significant government investments, Canada has capitalized on its abundance of forestry resources. Strategic governmental support has spurred massive R&D efforts that have transformed Canada from a traditional lumber product exporter to a global leader in value-added forest product exportation. Leveraging this, Canada currently exports mass timber, wood pellets, and other engineered wood products.

Boreal Bioenergy Corporation

Boreal Bioenergy is a biofuel innovator that provides renewable and sustainable forestry-based energy solutions. It transforms otherwise non-usable forestry waste into torrefied black pellets, creating a new highly efficient fuel that can be used as a clean energy coal replacement product.

It utilizes an innovative torrefaction technology called FlashTor™ that was developed by Blackwood Technology of the Netherlands. FlashTor™ allows for rapid conversion of 'green' woody biomass into torrefied wood pellets, to the precise specification of customers. This unique approach allows Boreal to use a wide variety of forestry biomass to create homogeneous end-product that has a consistent heating value and favourable material handling characteristics.

Boreal is in the process of building relationships with suppliers and consumers around the world, beginning with Japan. They aim to supply more than 3 million tonnes of torrefied pellets to global markets by 2027.

Click here for more details.

- **Advanced technologies to produce renewable and low-carbon fuels:** Currently, the majority of forest biomass being used for bioenergy production in Canada comes from waste or residues from manufacturing processes.[97] More than 50% of the total energy demand for the pulp and paper sector is already met by forest bioenergy.[98] Canada has advanced technologies that convert a significant portion of forest biomass into bioenergy with further technological advancements expected to expand possible feedstock inputs to include leftover biomass on harvested or disturbed sites.[99] Current research suggests that climate change, forest fires, and insect infestations will lead to twice as much dead wood production relative to today[100]; however, the Canadian forest biomass-to-energy sub-sector is well equipped to handle this challenge and capitalize on the economic co-benefit of recycling dead wood.[101] Canada also has matured torrefaction and pyrolysis technologies that can thermochemically convert organic by-products from various sectors into renewable and low-carbon fuels with low lifecycle greenhouse gas intensity.
- **Technologies to convert non-recyclable organic waste into renewable heat and power:** Canadian companies are global leaders in the development and supply of community scale gasification systems that can convert non-recyclable organic by-products into clean, renewable heat and power. These innovative systems are extremely versatile and have applications in an array of end uses including district heating and industrial process heating.

Pyrovac Inc.

Pyrovac is a pioneering expert in pyrolysis with a mission to transform industrial residues such as biomass and non-recyclable plastics into commercially valuable products and fuels, while minimizing GHGs.

Pyrovac's advanced pyrolysis consists of the thermal decomposition of organic materials into oils, solids, and gases which are fully recovered. Pyrolysis consists of thermal decomposition in the absence of air. Their products include: CoriphoITM, a biostimulant made from almond shells; and CoricharTM, a biochar used to enrich agricultural soils by increasing carbon in soil and as animal feed, produced from biocarbon obtained from forest residues and pyrolytic fuels obtained from thermal decomposition of plastic scraps.

Pyrovac currently exports its products to the US and South America and is developing partnerships to grow its export portfolio.

Click here for more details.

- Technologies to convert organic by-product into value added fertilizers, bioplastics, and biochemicals:
  - Canadian companies possess advanced technologies that can convert organic by-product and residue into an array of value added bioproducts such as bioplastic resin, biofertilizers, biochar, and biochemicals.

Lucent Biosciences Inc.

Lucent BioSciences is an Agtech company whose proprietary technology creates carbon-neutral and non-polluting fertilizers that regenerate the land and help farmers improve yields and grow higher quality crops.

Lucent has developed a patented process to bind essential plant micronutrients metals like zinc, iron, and manganese to bio-based substrates like cellulose creating a smart micronutrient fertilizer called Soileos. The bio-based substates are made by upcycling low value food processing by-products like wheat bran, pea, and lentil hulls. Soileos is a carbon positive, non-leaching, non-polluting, nutrient density booster that regenerates the soil.

Lucent currently exports to the US and is working to expand further in the US and in Mexico and Australia.

Click here for more details.

The past few years have seen a growing number of regulations, strategies, and roadmaps to enable the Canadian bioeconomy. While these strategies do not always explicitly refer to the circular economy, they broadly emphasize circular concepts such as material efficiency and industrial symbiosis. They include:

- Forest Bioeconomy Framework for Canada: published by the Canada's council of federal and provincial Forest Ministers in 2017, this framework aims to enhance policy coherence and collaboration amongst jurisdictions in Canada to position Canada as a global leader in the use of forest biomass to produce bioproducts.[102]
- Canada's Bioeconomy Strategy: published by a group of forestry and bioeconomy enthusiasts in 2019, the strategy recommends action on four key areas. These include (a) Creating agile regulation and government policy, (b) Establishing biomass supply and stewardship, (c) Building strong companies and value chains, and (d) Building strong sustainable innovation ecosystems.[103]
- Clean Fuel Standard: established under the Canadian Environmental Protection Act, this proposed regulation seeks to mandate liquid fossil fuel suppliers to reduce the carbon intensity of their fuel fleet from a 2016 baseline. The regulation creates economic opportunities in the credit trading market for voluntary parties such as biofuel and other renewable and low-carbon fuel suppliers.[104]

4.4 Construction

Construction is one of the most important economic sectors globally. In Canada, it is responsible for 7.5% of national gross domestic product (GDP) – equal to $141 billion in GDP in 2020 – and employs 1.4 million people.[105] Simultaneously, the built environment sector is one of the largest global consumers of raw materials and energy, consuming 3 billion tonnes of virgin resources every year,[106] or one-third of all global resources – with much of the value from these materials and resources currently being lost from the global economy at end of life.

At present, the construction sector generates between 30%-40% of total solid waste in North America and Europe,[107] with only 20-30% of construction and demolition (C&D) waste being recycled or reused. In Canada, 3.4 million tonnes of construction materials are sent to landfill annually, representing an estimated 1.8 million tonnes of embodied carbon.[108]

As global populations increase with a growing percentage in urban environments, significant investments in construction and infrastructure will be required to accommodate. If current trends continue, by 2025, it is expected that 2.2 billion tonnes of construction waste will be generated around the world; nearly double the amount of waste in 2018.[109] As such, the need for advancing circular economy practices and strategies in the construction sector is quickly growing,[110] presenting new opportunities for Canadian companies both domestically and abroad.

4.4.1 Circular Construction Solutions

Circular business models described in Section 2.1 can be applied to the construction sector in the following ways:

1. **Circular supply inputs into supply chain model:** use of renewable energy, bio-based building materials (such as mass timber), and recyclable building materials (such as decking from upcycled plastics, rubber flooring from recycled tires, carpets from recycled textiles, energy efficient window frames from recycled plastic or fiberglass products).
2. **Product life extension models:** prolonging the service life of products, components, and systems in the built environment via engineering and design solutions including disassembly and reassembly, repair, maintenance, and refurbishment.
3. **Product as a service model:** reducing overall demand for construction equipment and products through leasing and renting.
4. **Sharing models:** increasing overall usage rates of assets and equipment, as well as labour efforts, via collaborative models for sharing, access, and ownership.
5. **Resource recovery models:** recovery of usable building materials and products from construction and demolition waste.

4.4.2 Emerging Trends

As companies and governments address global challenges around climate change, resource consumption, waste, and energy use, several drivers have emerged that encourage the adoption of circular economy strategies in the built environment and construction sector.

With a growing focus on low-carbon and green building practices globally, an emphasis has been placed on reducing waste and the environmental footprint of buildings, including reducing the demand for virgin materials and extending the lifecycle of materials and resources. Interest in waste reduction practices, the adaptive use and reuse of buildings and infrastructure, and the end-of-life management of materials has necessitated alternative business models that integrate design for disassembly and adaptability, modular construction, durability, and deconstruction. In addition to considerations around building systems, pressure on freshwater resources and scarcity of water supplies is leading to water rescue management practices in form of greywater recycling and 'closed loop' systems.

Reducing GHG emissions has also been a key focus and a driver for more circular economy practices in construction and the built environment sector globally. Considerations around reducing building energy use are increasingly shifting the focus to embodied carbon within building materials and on its quantification through life cycle accounting (LCA).[111] At present, resource extraction and use accounts for 70% of all GHG emissions globally, with the embodied carbon associated with materials and the construction process estimated to be 11% of total global GHG emissions.[112] It is estimated that embodied carbon will be responsible for almost half of total new construction emissions between now and 2050.[113]

The emphasis on embodied carbon reduction, along with considerations around health benefits and pollution, has spurred an increase in lower-carbon and renewable or regenerative materials as circular inputs into products, buildings, and infrastructure. This emerging focus on the upstream components of the building life cycle presents new market and export opportunities

using a circular economy lens; including products such as mass timber and building products made with recycled content (e.g., decking from upcycled plastics, rubber flooring from recycled tires, carpets from recycled textiles, energy efficient window frames from recycled plastic or fiberglass products).

Leading jurisdictions are adopting building regulations and standards such as France's RE 2020 regulation for energy efficiency in new buildings, which is driving the market for LCA tools.[114] Green public procurement policies are also starting to integrate considerations for environmental product declarations to drive the demand for products and materials with lower environmental impact.[115]

While a lack of available open-sourced data makes it difficult to estimate the gross economic value of construction-related circular economy business models, a few specific examples include:

- The global recycled construction aggregates market is expected to grow by 6.0% from 2020-2027.[116]
- By 2030, modular construction is forecasted to account for more than $130 billion USD in the new construction market in Europe and the United States.[117]
- Canadian wooden prefabricated building exports accounted for 36.3% of the total global prefabricated building exports in 2019, amounting to $119.2 million CAD.[118]
- Research continues to support the business case for circularity in the built environment, with an increasing amount of evidence being compiled around the world.[119]

4.4.3 Canadian Strengths

Canadian companies have developed strengths related to circular economy business models, products, and innovation relevant to the built environment and construction sector – from innovative products with renewable and recycled content, to circular building design practices, to cutting-edge enabling technologies. Key strengths are profiled below.

- **Value-added wood products and technology:** Canada is a leading wood producing economy. Significant government investments through programs such as GCWood and Forestry Innovation Investment have capitalized on Canada's abundance in forestry resources. Subsequently, strategic governmental support has spurred massive research and development efforts.[120] These factors have provided the necessary conditions for the industry to move from being an exporter of conventional lumber products to a global leader in engineered wood products and mass timber (e.g., cross-laminated timber), as well as the related design and engineering services.

Structurlam Inc.

Structurlam is a leading manufacturer of glued laminated mass timber solutions for the construction and industrial markets across North America. It was the first producer of cross-laminated timber (CLT) in North America and is the first Canadian manufacturer of CLT to be certified to the SFI 2015-2021 Chain-of-Custody Standard.

It blends the expertise of wood science with the ingenuity of European fabrication to produce mass timber products, including CLT. Structurlam is offering products such as CrossLam® CLT panels and GlulamPLUS® columns and beams. Structurlam's mass timber solutions cover the spectrum – from simple beams and panels to the most complex and beautiful mass timber structures in the world. In industrial markets, the company's CrossLam® CLT ground protection matting products have provided safe and easy access to work sites.

Structurlam currently exports to the US and is looking to further expand its sales there to meet the growing demand for mass timber building products and industrial matting products.

Click here for more details.

- **Circular design and architectural practices:** Canada is known for its sustainability-focused engineering and architectural design expertise, owing to its diverse and talented workforce, and its project experience in world-class green buildings.[121] Canadian firms have adopted flexible and 'whole life value' designs that have facilitated the implementation of adaptive reuse and disassembly strategies.
- **Building products from upcycled materials:** Canadian companies are demonstrating growing capacity in innovation for circular building materials. Provincially-led EPR regulations have been a key driver to this innovation. By incorporating products with reclaimed and recycled content (such as plastic decking, carpets and flooring, and recycled window frames) in building materials, Canadian companies are successfully diverting waste from landfills and avoiding tipping fees.

Full Circle Plastics Inc.

Full Circle Plastics addresses the single-use plastics problem by recycling end-of-life plastic products into dimensional lumber and other products.

Full Circle Plastics works with local companies and municipalities to collect post-consumer plastics including paint pails, residential recycling, and oil containers. The plastic mixture is then recycled into plastic lumber – a product that does not degrade and is able to be recycled again. Plastic lumber has a large variety of uses from nailer board, fence posts, and bollard posts, to furniture and garden boxes.

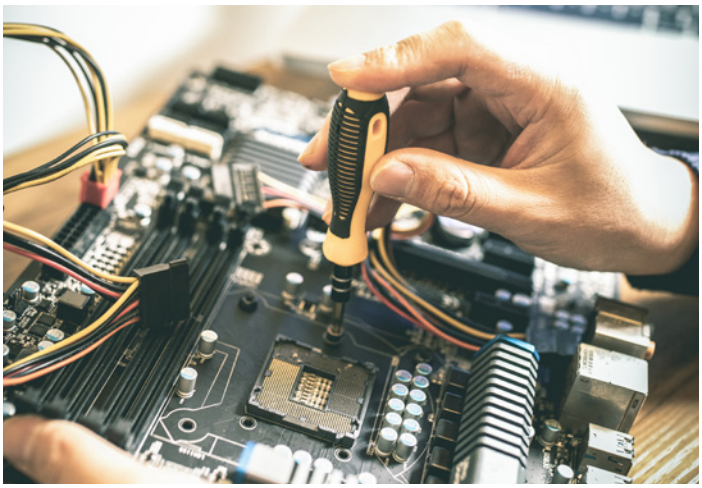
Full Circle Plastics sells its products to various residential, and industrial customers across United States and various countries in South America. The company is collaborating with transportation departments in United States to develop upcycled product for highway fencing.

Click here for more details.

- **Living walls and green roofs:** With regenerating nature one of the three key principles behind the circular economy, it is fair to recognize Canadian company strengths in manufacturing living walls and green roofs – due in part to progressive policies such as Toronto's bylaw and incentive program[122] that led to the rapid development of green roofs in the last decade.
- **Building information modelling (BIM) platforms:** There has been a breakthrough of digital software such as BIM in the Canadian construction industry, owing to robust industry and academia collaboration.[123] Consequently, architects and contractors can access and assess virtual 3D representation of buildings which leads to improved efficiency of construction systems and increased collaboration among project stakeholders.
- **Modular construction practices:** In recent years, Canadian industry has showcased its capability to produce and export world class modular construction. Its expertise in digital platforms during the design phase (including BIM and digital twin) has accelerated efficiency and 'lean' practices in the production and construction of prefabricated and modular structures.[124] The industry's move towards mass timber along with 'Wood First' policies have also allowed Canadian companies to integrate wood products in modular structures, to promote adaptive reuse and flexible building design.

Several federal policies and industry initiatives have emerged that have become key drivers of circularity in the construction industry. These include:

- Greening Government Strategy[125]: A pan-Canadian strategy that aims for a net-zero and climate resilient federal property. Specific targets include reducing embodied carbon in projects to 30% by 2025, as well as diverting 90% of construction and demolition waste from landfills by 2030. It also includes considerations around life cycle cost-benefit analysis to inform building decisions.
- Municipality led regulations in C&D material diversion and recycling: Local governments are driving the deconstruction practices through building codes and bylaws that mandate materials and recycling target. Examples include leading jurisdictions such include Vancouver and Toronto. Other municipalities, such as Victoria and Montreal have included considerations around demolition material salvage and C&D waste in their economic strategies.
- Canada-wide Action Plan (CAP) for Extended Producer Responsibility[126]: Introduced in 2009, the CAP included national commitment to mandate Extended Producer Responsibility for construction and demolition materials by 2017. However, there has been limited demonstrable success among jurisdictions to implement these EPR schemes.
- Lean Construction Institute Canada[127]: Established by the Canadian Construction Association in 2015, this organization facilitates cross-sectoral collaborations to promote lean construction principles across the building supply chain.



4.5 Enabling Technologies

The circular economy transition across all sectors can be enabled by several emerging digital and physical technologies and platforms, including artificial intelligence (AI), machine learning, big data analytics, robotics, Internet of Things (IoT) and blockchain. The characteristics of these technologies enable a shift towards circular business models by increasing energy and process efficiencies, reducing waste, aiding the innovation and scale up of circular design practices, improving information/data sharing and networking, and enhancing supply chain transparency for the flow of goods and secondary materials.

Coined by the World Economic Forum, the Fourth Industrial Revolution (4IR) is seeing rapid and disruptive change as it relates to new technologies and platforms that see a fusion between the physical and digital worlds.[128] These 4IR technologies also

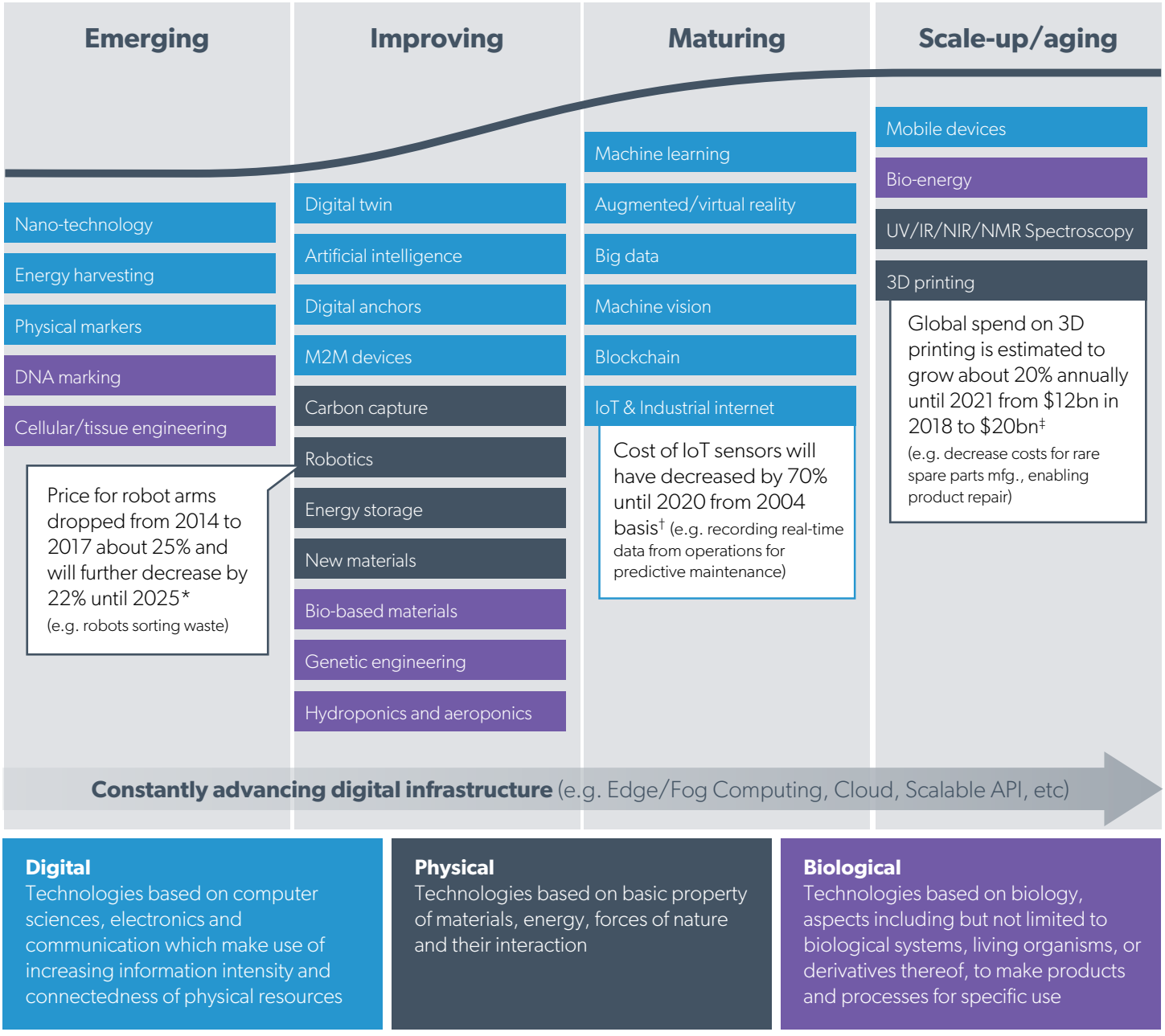
provide opportunities to leapfrog the linear economy and traditional supply chains while accelerating the transition to a more sustainable, low-carbon and circular economy.

Figure 6 shows the stage of maturity of digital, physical, and biological technologies that are enabling circularity, as it relates to 4IR technologies.

4.5.1 Emerging Trends

Given their ubiquitous application, enabling technologies allow sector-agnostic opportunities to be harnessed for sustainable and circular outcomes. Many of these technologies are already demonstrating their promise of delivering environmental sustainability across various sectors, including energy, plastics, agri-food, waste, buildings, and transportation.[130]

Artificial intelligence in combination with other technologies such as big data analytics, machine learning, and IoT, have the potential to revolutionize supply chains and deliver transformative circular solutions. An estimate by PWC suggests that AI



*IEEE Engineering360 †Bank of America, Merrill Lynch ‡International Data Corporation (IDC), Accenture

Figure 6: Evolution of 4IR enabling technologies.[129]
Adapted from Nordic Innovation. (2020). The Circular Economy Playbook.

could add $15.7 trillion USD in value to the global economy by 2030. From a sector-specific standpoint, the potential benefit to applying AI to agriculture and consumer electronic goods alone could be up to $127 billion USD and $90 billion USD in 2030, respectively.[131] The Ellen MacArthur Foundation has identified three key ways through which AI could incorporate circularity consideration in the supply chain[132]:

1. Enabling design and material selection processes through rapid prototyping and continuous feedback.
2. Facilitating the use of circular business models such as sharing economy and product-as-a-service, by predicting demand, setting dynamic pricing, and using smart inventory management.
3. Closing the loop on product life cycles by determining the optimal processes to sort, disassemble, re-manufacture, and recycle products and materials.

In addition to AI, big data or large volumes of data have the potential to redefine the global circular economy. The world-wide investment in big data and data analytics is projected to grow at 12.8% over 2021- 2025 from the current value of $215 billion USD.[133] Big data has played an integral part in capturing the wealth of information resulting from the synergy of different supply chains – a necessary component to understanding the flow of products, materials, and resources in a more circular economy. By offering producers data visibility on the different parts of the supply chain, such as material volumes at the end-of-life, and the resources available for recycling, big data analytics have led to the more efficient management of resources and reverse logistics. The availability and wealth of data has also enabled predictive maintenance and demand forecasting.[134]

IoT includes 'intelligent' or 'smart' products that are a hybrid of physical and digital assets and components, such as sensors and robotics. IoT is transforming the usage of products and services. Through its intrinsic networks of smart assets, IoT can collect detailed data and predict malfunction before they occur, allowing product life extension and better maintenance. Subsequently, this has led to development of service-based models that allow targeted repair and the upgrade of products and assets.[135] IoT has also enabled the rapid growth of 'pay-per-use' models that allow customers to pay for products and services based on usage and customized performance.[136]

Blockchain solutions allow for 'reuse and repurpose' models to be more streamlined by enhancing transparency and trace-ability within supply chains. Blockchain based tools, such as digital passports, have been used to improve supply chains for recycled plastics, mining, and critical minerals, and building and construction materials, allowing for traceability of resource and material flows for a more circular economy. Blockchain solutions help to build confidence in sustainability and circular economy claims as it relates to the reuse and repurposing of resources, leading to greater consumer brand engagement and sustainable and ethical supply chain practices.[137] Value assessment tools that are based on blockchain can also increase efficiencies in second-hand markets as customers assess product condition and resale value in real-time.[138]

Table 4, below, summarises the enabling technologies discussed, along with their value drivers and relevant circular business models.

Table 4: Summary of Enabling Technologies for a Circular Economy[139]

Technology	Value driver	Relevant business model	Illustrative application
Artificial intelligence	Enables process to become more efficient over time	• Circular inputs • Product life extension • Resource recovery	Categorisation of waste streams through AI-based robots
Big Data	Enables descriptive and predictive analytics	All	Design and material selection in certain industries through rapid prototyping
Machine learning	Enables predictive analytics through algorithms and optimization	All	Optimization of routing in reversed logistics based on historic patterns
Internet of Things	Enables exchange of data generated from sensors and smart assets	• Circular inputs • Product use extension	User customized "pay-per-use" models for services
Blockchain	Enables transparency and traceability in supply chain	• Sharing platform • Product use extension • Resource recovery • Product as a service	Materials origin tracing via material passports and provenance tools

4.5.2 Canadian Strengths

The enabling technologies sector is a subset of the software and computer services and information and communication technologies (ICT) manufacturing sectors, which cumulatively accounted for CAD $49 billion in GDP in 2020 for Canada.[140]

Canada is an emerging leader in the digital and advanced technology sector. Home to world-renowned post-secondary and research institutes, the country benefits from a robust R&D environment that is conducive to innovation. Canada has an abundance of highly skilled workers, as it has the highest share of working population with a post-secondary education among the OECD countries.[141] Its proactive immigration policies (like the Global Talent Stream program) also attract top talents in STEM from all over the world. Both national and international flows of high-skilled workers contribute to the success of the tech industry.

The synergy between incubators, accelerators, research institutes, and manufacturers has led to the emergence of four globally ranked technology start-up ecosystems in Canada: the Toronto-Waterloo Corridor, Montreal, Ottawa, and Vancouver. These ecosystems have fostered innovative homegrown start-ups – many of which have evolved into legacy companies. The success of Canadian start-ups has not only attracted government funding but also the attention of established leaders IBM, Microsoft, Google, and Ericsson who are interested in investing in emerging technologies. Growing interest from foreign venture capital investors has been a key driver to commercialization of companies – in 2021, the sector raised a record $11.8 CAD billion in funding.[142]

In relation to the circular economy, the following areas have emerged as areas of Canadian strengths:

- **Artificial Intelligence technologies:** Artificial intelligence has become a key technological strength in Canada, backed by decades of research experience and world-leading research nodes. The strategic government investment through the Pan-Canadian Artificial Intelligence Strategy[143] has catalyzed these research capabilities into private sector innovation. As such, the number of active AI start-ups crossed 600 in 2019, and over 11 IPOs have been filed over the decade.[144] Many innovative start-ups across Canada are using AI and machine learning to solve sustainability, climate, and circular economy related problems – including across sectors such as agriculture, mining, energy, plastics, construction, and recycling and waste management.
- **Sensor technologies:** Canada has well-proven expertise in sensors, developed as part of instrumentation and monitoring for its primary industries, such as forestry, mining and the oil and gas sectors.[145] The growing importance of precision agriculture has also led to the advancement of IoT and sensor-based technologies for collecting accurate data for crop and agri-food product management. While optical fiber sensors have been most widely used, some Canadian innovators are using advanced imaging technology like hyperspectral imaging in their sensors.

MineSense Technologies Inc.

MineSense Technologies is a frontrunner in IoT and sensor-based technologies that enhances sustainability of large-scale mining by improving ore recovery process.

Its sensor technology integrates with shovel and belt-based equipment to provide real-time grade control for ores. Its pioneering "ShovelSense" technology classifies ore and waste using X-ray Fluorescence sensors. Through the real time information from the sensors, and data analytics platform, the ore routing decisions are made at the earliest stage of extraction for optimal resource conversion and recovery.

MineSense has successfully deployed its technologies to mines in various environments across North and South American regions. It has also announced its plan to introduce its technologies to the African Copperbelt and further expand to South African mines.

Click here for more details.

- **Automation and robotics technology:** As automation across industries accelerates with the pandemic, Canadian capabilities in robotics have been bolstered for solving some of the supply chain challenges around manufacturing and logistics. Automation and robots are traditionally used in Canada for assembly tasks, quality control, and additive manufacturing, with the technologies mostly being used in automotive sector.[146] However, labour shortages and the precarious nature of work in many sectors such as agriculture and recycling and waste management have led to a rise in adoption of autonomous robots, with a niche of Canadian companies innovating in this space.

Prairie Robotics Inc.

Prairie Robotics uses its patented IoT solution on collection trucks to simplify recycling at household level, through targeted education materials.

Prairie Robotics works with municipalities and waste management companies to install its IoT solution on recycling trucks. Through camera and GPS, the technology can detect recycling contamination for each household as the recycling bin is emptied. Once households with recycling contaminants are identified, they receive customised educational material on improving their recycling practices.

Prairie Robotics is currently working towards expanding its operation across Eastern Canada and the United States.

Click here for more details.

- **Quantum computing:** Canada is demonstrating growing capabilities in quantum computing, as one of the leading nations in quantum research among all G7 countries.[147] Identifying quantum solutions as a long-term strategic technology, the federal government has committed $360 million to launch a National Quantum Strategy, in an effort to bolster Canada's research strength and to grow domestic quantum ready technologies.[148] IBM has recently announced plans to deploy its first quantum computer in Canada by 2023,[149] an effort which could catalyze industry-research engagement that may lead to even greater capacity in Canada and the emergence of more commercial applications that can support circular economy practices across sectors.

The following industry and government initiatives have been key to driving technological innovation across Canadian sectors:

- Pan-Canadian Artificial Intelligence Strategy: Launched in 2017, Pan-Canadian Artificial Intelligence Strategy[150] is a strategic government investment that aims to foster Canada's AI ecosystem. As the world's first national AI strategy, it earmarked $125 million CAD over five years to advance research and innovation in the AI field and develop a skilled talent pool. The 2021 federal budget commits to renew the strategy with a $443.8 million CAD commitment over 10 years, to solidify Canada's position in in the global race for AI.[151]
- Innovation Superclusters Initiative: The innovation supercluster is a $950 million CAD federally funded innovation program that provides opportunity to accelerate the development, adoption, and scale-up of Canada's capabilities in five innovation clusters including digital technology, next generation manufacturing and artificial intelligence. The clusters, composed of non-profits, academic institutions and accelerators, aim to work collaboratively to drive economic growth, develop talent and foster research and innovation.[152]
    - Digital Technology Supercluster: Based in British Columbia, this supercluster aims to accelerate the development and adoption of digital technologies in the Canadian supply chain. The initiative aims to solve productivity, health, and sustainability challenges using data, quantum computing, and virtual, mixed, and augmented reality.[153]
    - Next Generation (NGen) Manufacturing Supercluster: The NGen supercluster, based out of Ontario, aims to accelerate the development, adoption, and scale-up of Canada's capabilities in advanced manufacturing, including advanced robotics and sensors.[154]
    - Scale AI: Based in Quebec, Scale AI supercluster provides funding to accelerators and incubators to support the growth of AI start-ups and small and medium enterprises across Canada.[155]

The findings of this report suggest that Canada currently has or could further develop capabilities to play a significant role in furthering the circular economy transition globally through the export of products, services, technologies, and knowledge.

5 CONCLUSION

The high-level scan conducted in this report and summarized in Table 5 suggests areas where Canada and/or Canadian companies may currently have or could further develop capabilities to play a significant role in furthering the circular economy transition globally through the export of products, services, technologies, and knowledge.

Key findings of the kinds of circular export solutions Canadian companies can already offer include:

- In the mining sector: companies are developing leading solutions for waste and mining by-product management, as well as deploying innovative technologies such as electrified mining equipment to reduce the overall environmental footprint stemming from mining operations.
- In the plastics sector: companies are leveraging expertise in petrochemical engineering to create solutions for chemical plastics recycling, subsequently enabling a true circular outlook for end-of-life plastics management.
- In the bioeconomy sector: companies are leveraging existing strengths in torrefaction, pyrolysis, and gasification technologies to convert by-products from various sectors into bioenergy with low lifecycle greenhouse gas intensity.
- In the construction sector: companies are leveraging existing technological strengths to reduce embodied carbon emissions in the built environment, divert difficult-to-recycle materials from landfill, and produce high performance low-carbon building material alternatives.
- Companies are also leveraging technological strengths in the form of artificial intelligence, Internet of Things, and smart imaging technologies amongst others to enable and accelerate the application of circular economy principles across all sectors.

However, to determine how best to capitalize on the export opportunity the transition presents, further research and analysis is required, including:

- Conducting deeper sector analysis and market assessments through comprehensive business and industry association engagement, as well as an understanding of the emerging demand for circular solutions across sectors and value chains by market/region.
- Identifying financial, regulatory, and technical barriers for growing circular trade and how existing trade agreements as well as new policies and programs can be designed to overcome these.

- Understanding how emerging geopolitical trends are likely to impact circular economy related trade flows including: (a) the global low carbon transition, (b) growing economic nationalism and deglobalization, (c) increasing plurality of geopolitical alliances, and (d) growing South-South economic integration.
- Further validating the true 'circularity' of the industry capabilities identified in this study. While the industrial solutions surveyed in this report meet popular conceptions of what circularity entails, further work to validate and quantify their full material, waste, and life cycle benefits should be undertaken.

Based on the high-level study conducted, some initial recommendations to government are as follows:

- Build circular economy capacities across federal departments, including Global Affairs Canada and the Trade Commissioners Service, to socialize the circular economy as an emerging model and create a working knowledge of circular economy strategies, practices, and business models.
- Track nascent clusters of circular business solutions emerging across Canada, with emerging companies advancing circular solutions in a rapidly evolving space that can help meet growing net-zero and ESG goals
- Build partnerships across North America to create a supporting regional ecosystem for circular innovation, investment attraction, and trade, taking inspiration from the Nordic regional cooperation model
- Explore opportunities to participate in and lead multilateral efforts to push the circular economy transition through multilateral efforts, such as the WTO's Trade and Environmental Sustainability Structured Dialogues and the Global Alliance on Circular Economy and Resource Efficiency.

Table 5: Summary of findings

	Global trends	Canadian strengths
Mining	• Electrification of mining equipment • Increasing production efficiencies • Higher utilization of low-grade ores • Efforts to reduce mine tailings	• Electrified mining equipment • Process optimization technologies • Value recovery technologies (from low-grade ores, tailings, EoL products) • Equipment maintenance, sharing
Plastics	• Increasing regulations and bans on plastic waste • Increasing demand for post-consumer recycled plastics • Innovation in mechanical and chemical plastic recycling technologies • International collaboration on plastic waste reduction	• Chemical recycling technologies
Bioeconomy	• Growing demand for replacing fossil-fuel based products and energy with biomass sources • Innovation in biofuels, biochemicals, bioplastics and other biomaterials	• Value-added wood products • Advanced renewable and low-carbon fuels and energy • Agricultural technologies • Biochemicals
Construction	• Increasing energy efficiency and sustainable building regulations • Increasing demand for lower-carbon and renewable building materials • Innovation in business models that design for disassembly and adaptability, modular construction, durability, and deconstruction • Growing water recovery, recycling, and efficiency practices	• Value-added wood products • Circular design and architectural practices • Upcycled building materials • Living walls and green roofs • Utilization of Building Information Modelling platforms • Modular construction practices
Enabling technologies	• Increasing applications of Artificial intelligence, big data analytics, machine learning, and IoT and blockchain-based tools	• Artificial Intelligence technologies • Sensor technologies • Automation & robotics technologies • Quantum computing

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