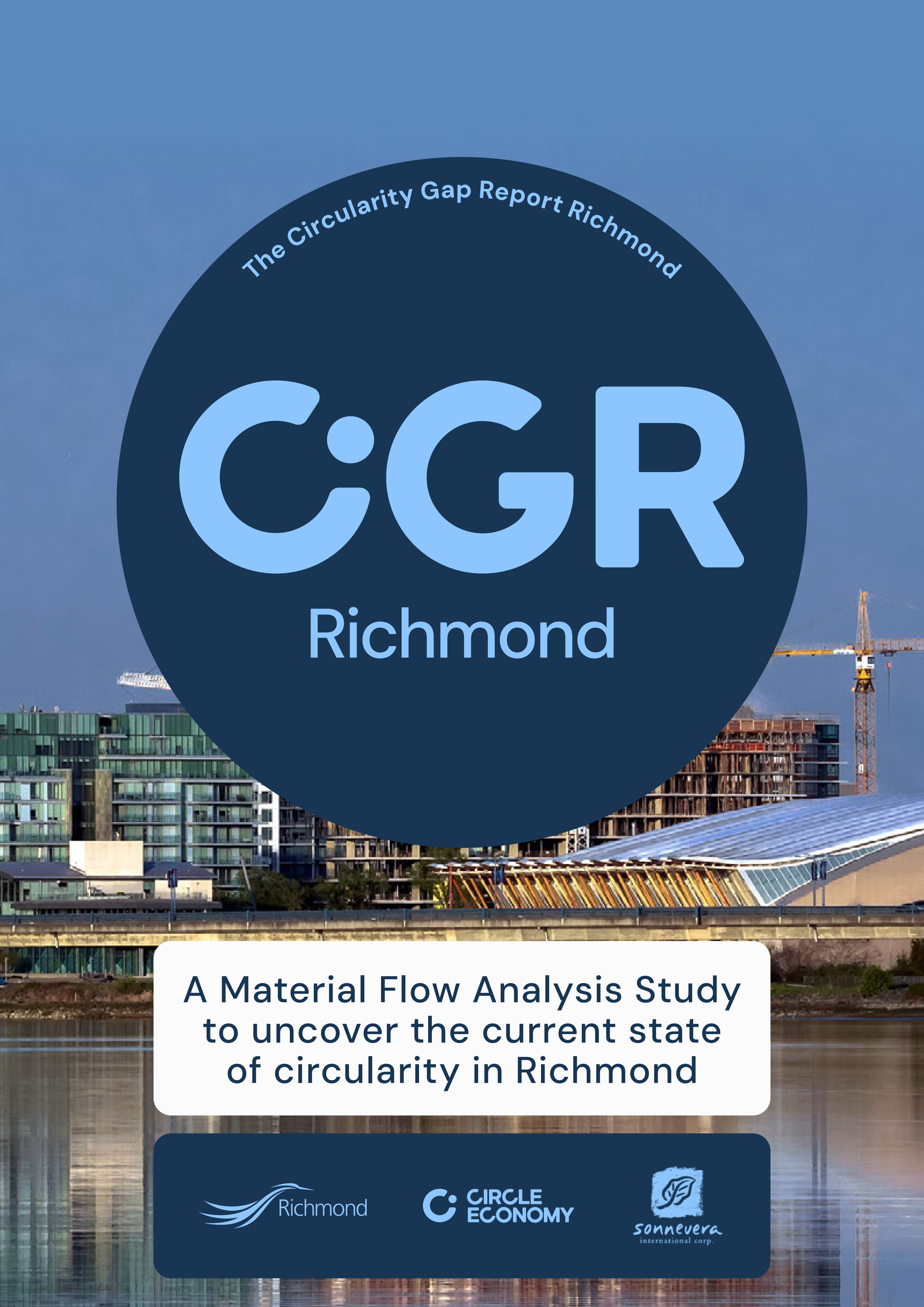

The Circularity Gap Report Richmond

CGR Richmond

A Material Flow Analysis Study to uncover the current state of circularity in Richmond

Richmond

CIRCLE ECONOMY

sonnevera international corp.

BEHIND THE COVER

The Richmond Olympic Oval encompasses the multitude of aspects critical to Richmond's circular economy transition: the construction in the background representing the built environment, the bridge signifying infrastructure, mobility, and the essential connections tying the city together, and the river conveying the many adaptation challenges posed by climate change and sea level rise. The urban landscape's reflection in the water shows the interconnected nature of the relationship between human and ecological systems.

CIRCLE ECONOMY

We are a global impact organisation with an international team of passionate experts based in Amsterdam.

We empower businesses, cities and nations with practical and scalable solutions to put the circular economy into action.

Our vision is an economic system that ensures the planet and all people can thrive.

To avoid climate breakdown, our goal is to double global circularity by 2032.

sonnevera international corp.

We are an experienced team of passionate waste management experts based in Western Canada.

We aim to work with municipalities in western and northern Canada to create prosperous and healthy environments by decreasing waste and increasing community circularity.

Our vision is a society that flourishes within Earth's planetary boundaries.

Richmond

Richmond, a vibrant and diverse urban center on the west coast of Canada, uniquely sits where the Fraser River meets the Pacific Ocean, forming a dynamic island community. As an ethnically rich and geographically distinct city, Richmond balances residential and commercial growth with expansive agricultural lands, industrial parks, and natural waterways. The City envisions a healthy island city that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is a place where people live, work, and prosper in a welcoming, connected, accessible, and vibrant community. Richmond is at the forefront of circular economy approaches in Canada, committed to maximizing the value of resources by design, through responsible consumption, minimizing waste, and reimagining how resources flow in a sustainable, equitable, low-carbon economy.

LIST OF ABBREVIATIONS/ ACRONYMS

ALR	Agricultural Land Reserve
CCRI	Canadian Circular Cities and Regions Initiatives
CEEP	Community Energy and Emissions Plan
CLTs	Community Land Trusts
DE	Domestic Extraction
DMC	Domestic Material Consumption
EEB	European Environmental Bureau
EPR	Extended Producer Responsibility
FLW	Food Loss and Waste
FSAAC	Food Security and Agricultural Advisory Committee
FTN	Frequent Transit Network
GHG	Greenhouse gas
ICI	Industrial, Commercial, and Institutional
IRP	International Resource Panel
NEA	Net Extraction Abroad
PaaS	Product-as-a-Service
RCCS	Richmond Circular City Strategy
RMC	Raw Material Consumption
RME	Raw Material Equivalent

EXECUTIVE SUMMARY

In 2023, the City of Richmond recognized the crucial role of the circular economy in bolstering its sustainability and resilience, unveiling the *Richmond Circular City Strategy* (RCCS) with the ambitious goal of attaining full circularity by 2050. Following the RCCS, this Circularity Gap Analysis represents a key step toward Richmond's circular transition by providing a baseline from which to measure progress. It is one of the first of such analyses produced for a local government in Canada.

Richmond has a Circularity Metric of 3%—meaning that 97% of the materials flowing through its economy come from virgin sources. This is considerably lower than the Circularity Metric for the global economy, measured at 7.2% in 2023.[1] The city's raw material consumption stands at 5 million tonnes, while its carbon footprint approaches 4 million tonnes of carbon dioxide equivalent (CO_2e). The Construction, Manufacturing, Agrifood and public sectors concentrate the largest share of Richmond's environmental footprint. Non-metallic minerals and fossil fuels dominate Richmond's total material footprint (5.5 million tonnes), contributing 2.4 million tonnes (43%) and 1.3 million tonnes (23%), respectively, with approximately 22% of non-metallic minerals used exclusively by the construction industry. The remainder of the material footprint consists of biomass (1 million tonnes, or 20% of the total) and metal ores (0.8 million tonnes, or 14% of the total) consumption.

Richmond has a relatively high consumption-based carbon footprint, partially owing to its low population density and emissions-intensive modes of transport. Only one-fifth (20%) of the City's total emissions are **direct emissions**: those originating from household consumption as direct energy use for private mobility and heating. Nearly two-thirds (60%) of Richmond's carbon footprint, 2.4 million tonnes of CO_2e, is generated outside city borders, with embodied carbon in Richmond's imports coming mainly from other areas of Canada (30%), trading partners in Asia and Pacific regions (15%) and the rest of North America (10%). The other four-fifths (80%) are **indirect emissions**, which can be attributed to industrial activities and emissions generated throughout supply chains from the rest of Canada and the world.

Food systems and the built environment are key areas for Richmond's circular transformation. This is due to their economic and social importance, as well as their material and carbon intensity and carbon emissions. Additionally, their activities relate to many local processes in Richmond, which the City can directly influence and redesign to foster more circular systems. The total food supply to fulfil the needs of Richmond's citizens is approximately 188,000 tonnes, equivalent to 2.3 kilograms of food, per capita, per day. This demand equates to an estimated 120,000 tonnes of CO_2e. Around 0.85 million tonnes of materials (15% of Richmond's total material footprint) enter the built environment yearly—primarily in the form of non-metallic minerals, which account for about 70% (0.6 million tonnes) of the sector's total material consumption.

Reviewing the Circularity Gap provides further insight into Richmond's economy. There are a range of circular and non-circular inputs and stock build-up that make up Richmond's material use:

- **21% of material consumption is considered to be Renewable Material Inputs**, such as wood and timber, manure, food products and agricultural residues. This is biomass with the potential for being considered circular.
- **23% of material consumption is Recyclable Inputs**, referring to metals, plastics, paper, and glass that can potentially be cycled but currently are not.
- **21% of material consumption is Fossil Fuel Inputs**, which are burned mainly for energy use and to produce chemicals and plastics. These cannot be cycled and are thus inherently non-circular.
- **32% of material consumption feeds into Net Additions to Stock**, meaning long-term goods like buildings, infrastructure, machinery and vehicles. As these materials won't be available for reuse or recycling for many years, it's important that circular elements—such as design for durability, recyclability and repairability—are considered from the outset to ensure positive future outcomes.

A set of five circular scenarios have the potential to tackle material use, lower emissions and accelerate Richmond's circular transformation. By applying circular interventions across five key action areas—the food system, the built environment, the manufacturing industry, consumer goods and mobility—Richmond can transform its economy. Although individually the scenarios have limited impact, combined, they could reduce the city's material footprint by 37% and its carbon footprint by 39%. They can also yield significant environmental, economic and social co-benefits, such as enhancing biodiversity and protecting ecosystems, fostering innovation and resilience, and promoting more community-centred lifestyles.

This report gives high-level recommendations, that have arisen from the analysis and stakeholder engagement process, for Richmond to advance its circular economy. These are:

1. DEVELOP A RESILIENT, LOCALIZED AND EFFICIENT FOOD SYSTEM:
    - Consolidate local production and diversify agricultural practices;
    - Promote the consumption of local and seasonal products;
    - Reduce food waste by changing the culture and practices associated with wasting food.
2. STRIVE FOR AN ADAPTIVE, LOW-CARBON BUILT ENVIRONMENT:
    - Efficiently utilize existing land and buildings while minimizing the use of virgin materials;
    - Utilize biobased and secondary materials and integrate low-carbon, energy efficient systems;
    - Shift to resource-efficient building practices at the design phase.
3. ADVANCE RESOURCE-EFFICIENT MANUFACTURING, CIRCULAR MOBILITY, AND PROMOTE MATERIAL-SUFFICIENCY LIFESTYLES

Richmond's circular transition must be realized through collective action toward a shared vision, involving the City, businesses and the community through a collaborative approach. By prioritizing impactful actions and focusing on system-level changes, Richmond can substantially reduce its material and carbon footprints and become a frontrunner in the circular economy in North America. Being a leader in this space creates many opportunities for the Richmond community, including innovation and growth, job creation, cost savings, sustainable development, and environmental benefits.

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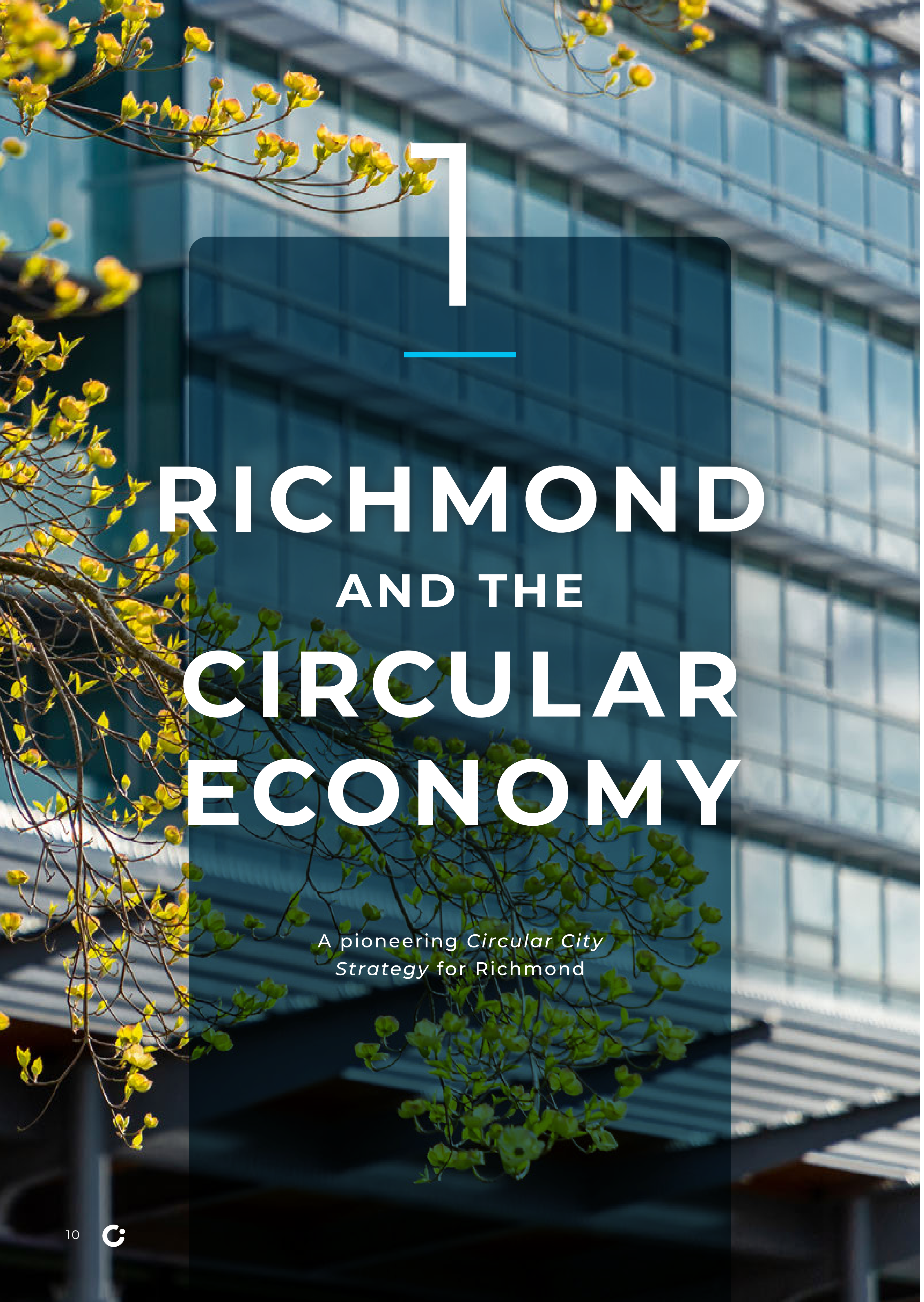


1

RICHMOND AND THE CIRCULAR ECONOMY

A pioneering *Circular City Strategy* for Richmond

In 2023, the City of Richmond recognized the crucial role of the circular economy in fostering sustainability and resilience within cities, unveiling the *Richmond Circular City Strategy* (RCCS) with the ambitious goal of attaining full circularity by 2050.[2]

The circular economy—increasingly seen as a new sustainability paradigm—is an alternative system that offers a way of producing and consuming within biophysical limits. In 2023, six of the nine planetary boundaries supporting life on Earth had been crossed at the global level. This suggests that humanity's current rate of material consumption is putting unsustainable pressure on Earth's resources and systems.[3] Cities are significant hotspots of consumption and environmental degradation. Responsible for over 70% of global greenhouse gas (GHG) emissions, material extraction, and waste generation, as well as 75% of the world's energy demand, cities are key actors for change. They are also vibrant hubs of culture, creativity and education; they are where people live, work, and gather, and are often pioneers of innovation and technology development. Despite covering a mere 3% of land area, urban areas host the majority (55%) of the world's population and contribute to almost 80% of global economic output.[4]

Richmond has acknowledged its community's potential to drive the circular transition. The City of Richmond's vision for the circular economy is "**to maximize the value of resources, by design, through responsible consumption, minimizing waste and reimagining how resources flow in a sustainable, equitable, low-carbon economy.**"

Figure one provides an overview of the elements forming the RCCS. By following the Strategy's principles, directions, goals, and actions, the City and its partners aim to achieve this vision and become a regenerative, fully circular city.

VISION

The City of Richmond's vision for circular economy is to maximize the value of resources, by design, through responsible consumption, minimizing waste and reimagining how resources flow in a sustainable, equitable, low-carbon economy.

PRINCIPLES

Design clean, Keep using, Collaborate to co-create, Regenerate, Maximize value.

DIRECTIONS

1. Maximizing ecosystem services
2. Regenerative food systems
3. Resilient and innovative economy
4. Shared mobility
5. Adaptive built environment
6. Consumer materials management

GOALS

30 directional goals, outcome focused.

ACTIONS

84 actions that will set Richmond on a path to achieve 100% circularity.

RESULTS

The Strategy makes room for other organizations to co-create, test and implement circular practices as partners with the City or within their respective context, fostering the transition towards a regenerative and circular city.

Figure one shows an overview of Richmond's Circular City Strategy toward a regenerative and circular city that operates within planetary boundaries. Source: the Richmond Circular City Strategy

CIRCULARITY AS A MEANS TO AN END

Within the RCCS, the circular economy is seen as a **means to an end**: a pathway toward a more sustainable urban future. By embracing circularity, Richmond aims to unlock many benefits, including economic opportunities, environmental regeneration, social equity, and innovation. Notably, Richmond was also the first city in Canada to adopt a circular approach to its *Community Energy and Emissions Plan 2050* (CEEP).[5] Recognising that approximately 70% of global emissions are linked to material use and handling, Richmond both acknowledges how a circular economy can help it operate within safe planetary boundaries as well as its role in accelerating the transition to a net-zero economy.[6] Combining the climate and circular agendas can mitigate some of the worst impacts of climate breakdown by limiting warming to well below 1.5 degrees.

A NEW STUDY TO SUPPORT THE CIRCULAR TRANSITION

Despite the recognized global imperative for circularity, recent trends reveal a concerning decline. Rising material extraction has shrunk global circularity from 9.1% in 2018 to 7.2% in 2023, indicating that over 90% of materials used are from virgin sources.[7] Due to high rates of material consumption, energy usage, and waste generation, Canada faces challenges in advancing circularity, with a recent report by the Council of Canadian Academies highlighting that only 6% of the country's material consumption comes from secondary sources.[8] Assessing Richmond's circularity is crucial to understand how it can contribute to advancing circular economy principles nationally and internationally. To this end, the City commissioned a pioneering study to map the current state of circularity within Richmond, providing evidence-based insights to support the RCCS.

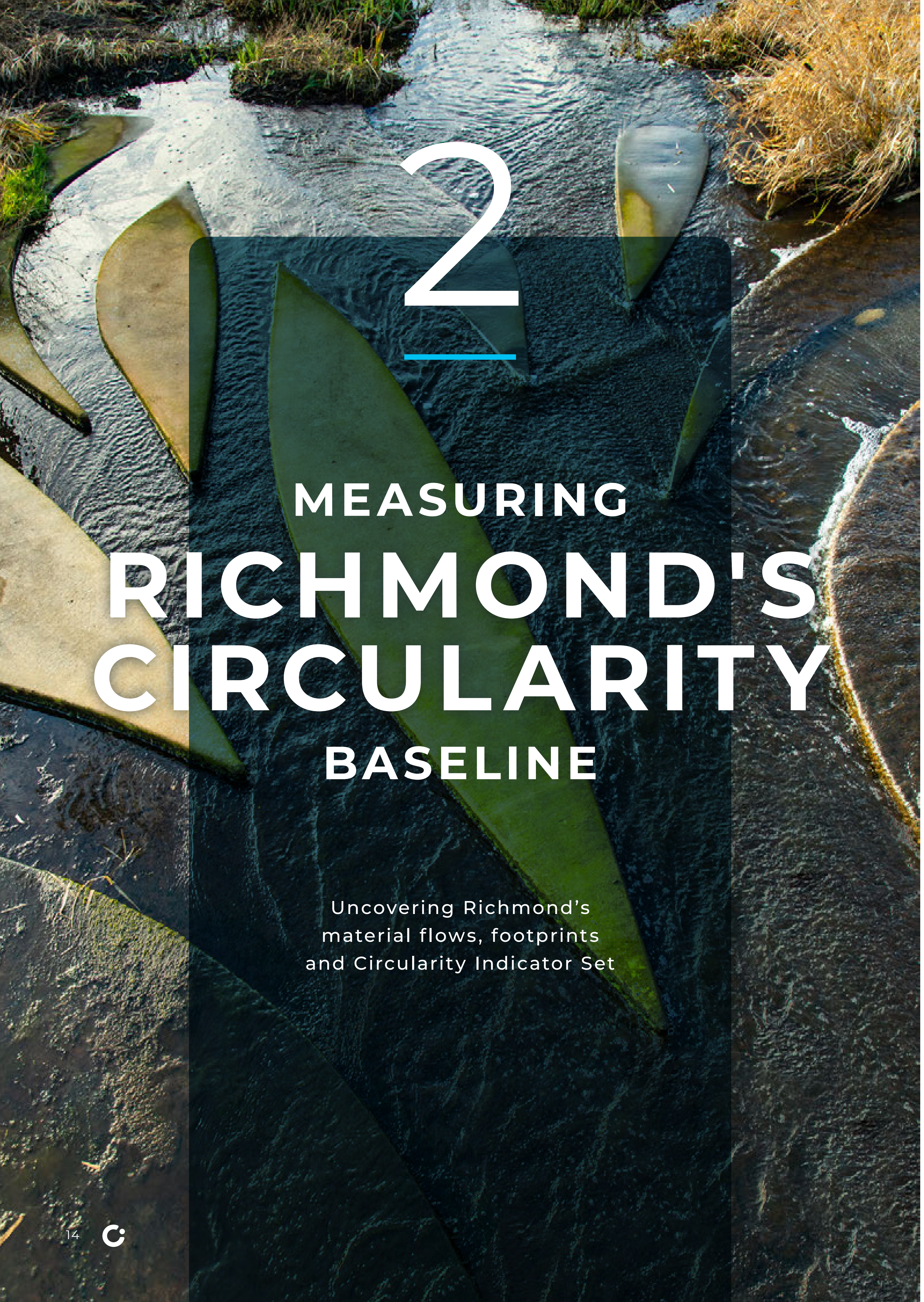
Similar to the RCCS, this report is one of the first *Circularity Gap Reports* produced for a local government in Canada. While this methodology has been deployed globally and nationally, Richmond is one of three pioneering cities in Canada to undergo this analysis, positioning it as a future circular leader. Considering the global Circularity Metric of 7.2%, Richmond's Circularity Metric stands at 3%. This means that of all the materials flowing through the city's economy, only 3% come from secondary sources. This report investigates possible explanations for these differences and highlights where caution must be taken in interpretation.[9] Beyond the Circularity Metric, the analysis allows us to understand Richmond in its context: it is British Columbia's fourth-largest city, and has an industrialized economy with population density and income levels below the Canadian average. These characteristics significantly influence Richmond's material and carbon footprints, which have impacts beyond the city's borders. Advancing overall circularity will be crucial in mitigating these impacts.

Using the *Circularity Gap Report Methodology*, this study provides a comprehensive, data-driven analysis for Richmond, focused on understanding how materials flow within the city's economy, commonly referred to as its "urban metabolism." This study specifically focuses on two key sectors previously identified by the City: food systems and the built environment. A scenario analysis is employed to quantify the potential impact of circular actions on reducing Richmond's material and carbon footprints. The ultimate goal of the study is to provide the City with actionable insights, enabling it to make informed decisions and progress with the implementation of the RCCS.

THE ROLE OF THE LOCAL COMMUNITY IN THIS PROJECT

The role of the local community in this project was crucial. Recognising that no single entity bears sole responsibility for transitioning to a circular economy, this study emphasizes collaboration and engagement with a wide range of stakeholders, including local businesses, non-profit organizations and governmental institutions. Stakeholder buy-in and active participation will be essential for the successful implementation of the RCCS.

Circle Economy conducted the study in collaboration with a local waste reduction firm, sonnevera, as well as City of Richmond staff. Additionally, the project organized two circular stakeholder roundtables involving representatives from the public and private sectors, civil society organizations, policymakers and academia, as well as one-to-one expert interviews. Through collaboration and engagement, local stakeholders play a crucial role in verifying findings, shaping narratives, and addressing Richmond's unique contextual factors, ultimately ensuring that each stakeholder recognizes their role in the transition to a more sustainable and circular future.



2

MEASURING RICHMOND'S CIRCULARITY BASELINE

Uncovering Richmond's material flows, footprints and Circularity Indicator Set

Measurements are critical to understanding the world around us. This study uses the city's urban metabolism as the starting point to measure circularity in Richmond. This chapter presents a first circularity baseline for Richmond.

First, it explores how, and in what proportions, (raw) materials flow through the economy to meet demand, as well as the emissions generated from their use.

Secondly, it presents a Circular Indicator Set to consider all types of inputs into Richmond's economy. The baseline reveals that Richmond exhibits higher-than-average global material and carbon footprints per capita, the impacts of which extend well beyond local and national borders.

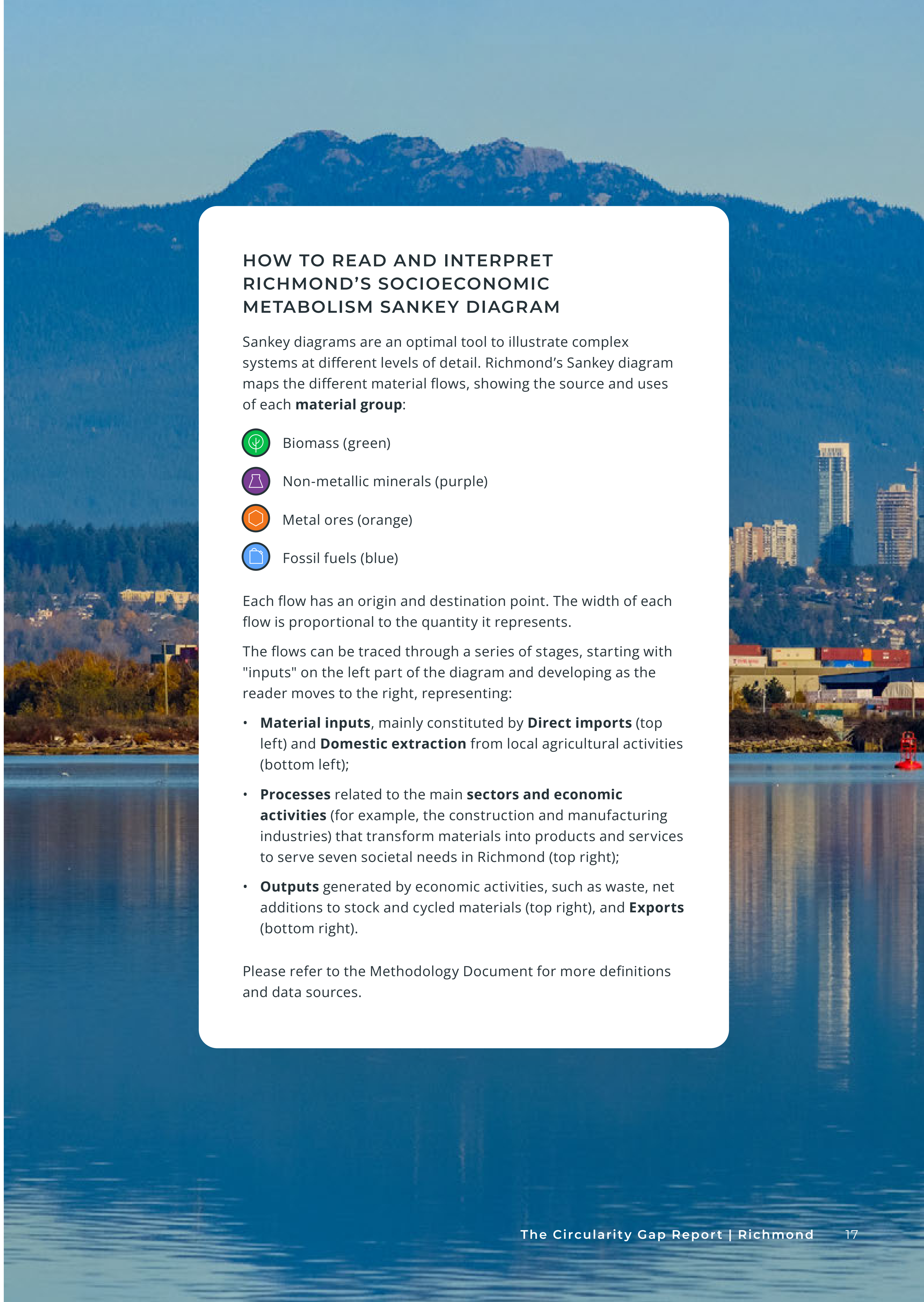
Richmond's raw material consumption stands at 5 million tonnes, while its carbon footprint reaches 4 million tonnes of carbon dioxide equivalent (CO_2e)—both exceeding estimated sustainable levels per capita. The Construction, Manufacturing and Agrifood sectors concentrate the biggest share of Richmond's environmental footprint (Figure four).

At the same time, secondary materials—materials that have already been used, are processed and become ready to be used as input—represent a low share (3%) of the total materials consumed. Visualizing Richmond's urban metabolism is ultimately a tool to identify key hotspots where the City can best advance circular economy actions to reduce raw material demand and emissions.

RICHMOND'S URBAN METABOLISM: SIZING MATERIAL FLOWS AND ENVIRONMENTAL FOOTPRINTS

The "urban metabolism" of cities refers to the set of processes describing the flows and consumption of resources to satisfy societal needs. This involves using both energy and materials to deliver social outcomes through provisioning systems, which consist of physical assets (such as infrastructure and technologies) and social elements (like governmental institutions, markets, and businesses).[10, 11] The urban metabolism analysis helps visualize Richmond's current level of circularity by examining how materials are extracted, transformed, used, and discarded. This baseline understanding is crucial for identifying priority interventions, untapped opportunities, and leverage points to promote a more circular Richmond. While the analysis focuses on materials, the use of natural resources such as land and water is also considered (read more in the Methodology Document). Figure two depicts Richmond's urban metabolism, showing the amount of materials—divided into four key material groups—embodied in Richmond's consumption and production.

Richmond's urban metabolism analysis reveals a material-intensive economy. This is largely due to high material consumption rates and systemic inefficiencies in materials used throughout different value chains, particularly those for manufactured goods and the built environment. As with any major city, Richmond's significant raw material consumption depends heavily on activities beyond the city's borders and across global value chains. Within Richmond's boundaries, there is limited material extraction, primarily in the form of biomass from agricultural activities. Consequently, Richmond's efforts to meet societal needs drive material extraction and associated negative impacts—such as GHG emissions, pollution and biodiversity loss—in the rest of Canada and abroad. It also generates significant negative impacts locally, such as waste generation and GHG emissions.



HOW TO READ AND INTERPRET RICHMOND'S SOCIOECONOMIC METABOLISM SANKEY DIAGRAM

Sankey diagrams are an optimal tool to illustrate complex systems at different levels of detail. Richmond's Sankey diagram maps the different material flows, showing the source and uses of each **material group**:

- Biomass (green)
- Non-metallic minerals (purple)
- Metal ores (orange)
- Fossil fuels (blue)

Each flow has an origin and destination point. The width of each flow is proportional to the quantity it represents.

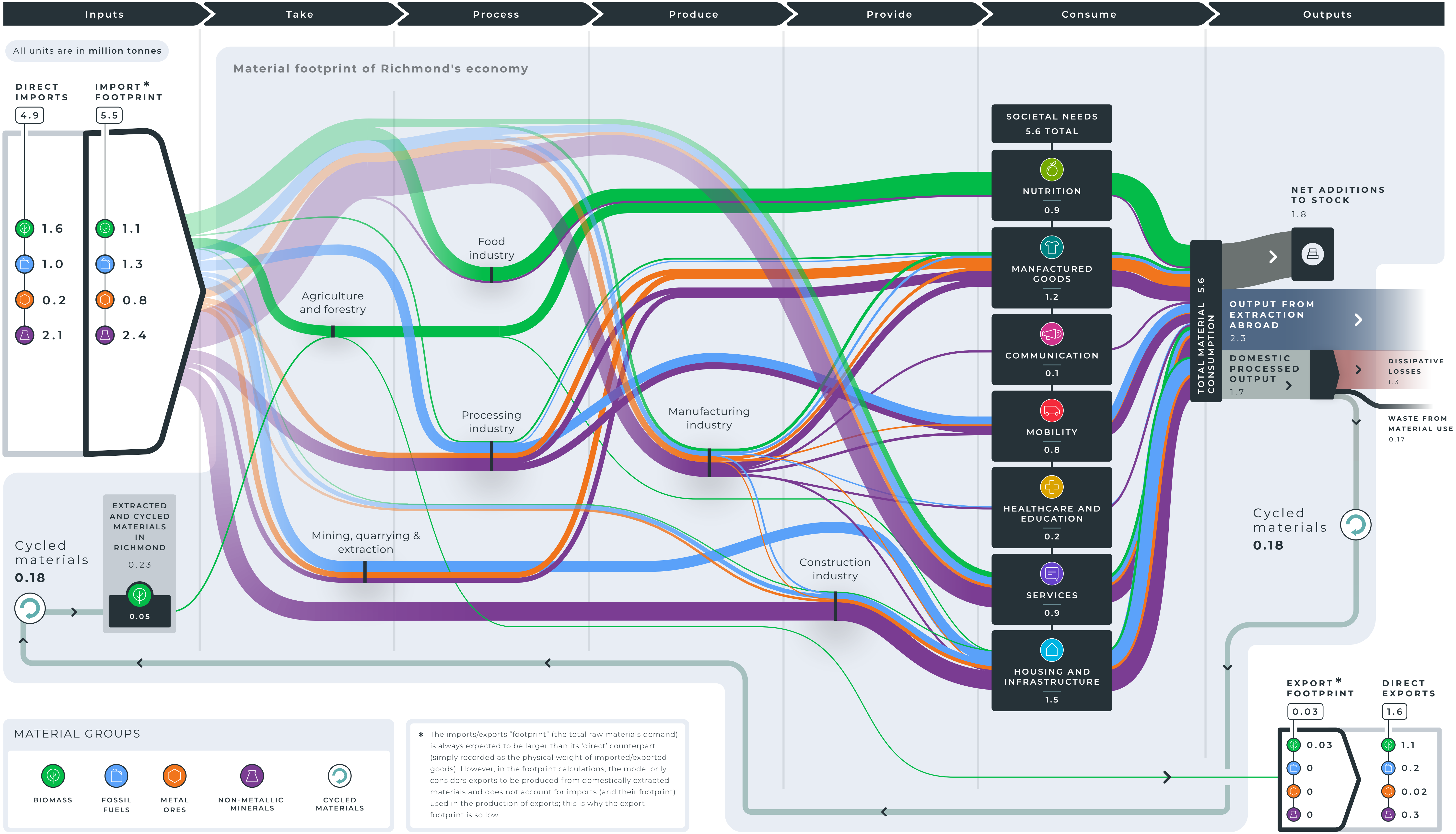
The flows can be traced through a series of stages, starting with "inputs" on the left part of the diagram and developing as the reader moves to the right, representing:

- **Material inputs**, mainly constituted by **Direct imports** (top left) and **Domestic extraction** from local agricultural activities (bottom left);
- **Processes** related to the main **sectors and economic activities** (for example, the construction and manufacturing industries) that transform materials into products and services to serve seven societal needs in Richmond (top right);
- **Outputs** generated by economic activities, such as waste, net additions to stock and cycled materials (top right), and **Exports** (bottom right).

Please refer to the Methodology Document for more definitions and data sources.

RICHMOND'S SOCIOECONOMIC METABOLISM

Figure two presents Richmond's socioeconomic metabolism, using 2019 as the baseline year.



* The imports/exports "footprint" (the total raw materials demand) is always expected to be larger than its 'direct' counterpart (simply recorded as the physical weight of imported/exported goods). However, in the footprint calculations, the model only considers exports to be produced from domestically extracted materials and does not account for imports (and their footprint) used in the production of exports; this is why the export footprint is so low.

RICHMOND'S MATERIAL AND EMISSIONS PROFILE

To understand a city's environmental footprint, impacts generated both locally and abroad may be considered. Therefore, this study takes a consumption-based perspective to calculate Richmond's material and carbon footprints. This provides a detailed look at how the city contributes to resource consumption and emissions globally. The material footprint calculation accounts for the amount of raw materials used to meet Richmond's material consumption needs, regardless of where these materials were extracted or where the products were produced.[12] The same approach is taken to measure Richmond's carbon footprint: this means measuring the GHG emissions generated by the consumption of goods and services in Richmond, accounting for both direct emissions (for example, from heating homes) and emissions embodied in imports (for example, those generated throughout the value chain from the extraction, processing and production of imported materials and goods).

MATERIAL FOOTPRINT

With an estimated yearly material footprint of 5.5 million tonnes (or 26 tonnes per capita), Richmond requires a high volume of raw materials to meet the material demand of its community and businesses. This data is comparable to other Canadian cities like Montreal (nearly 29 tonnes per capita), but is below the Canadian average (36 tonnes per capita). However, Richmond's yearly, per capita, material footprint is well above the global average of 12 tonnes and notably surpasses the estimated globally sustainable level of 8 tonnes by 325%.[13]

Non-metallic minerals and fossil fuels dominate Richmond's total material footprint (5.5 million tonnes), contributing 2.4 million tonnes (43%) and 1.3 million tonnes (23%), respectively. Approximately 22% of non-metallic minerals are used exclusively by the construction industry, primarily in the form of gravel and sand. The remainder of the material footprint consists of biomass (1 million tonnes, or 20% of the total) and metal ores (0.8 million tonnes, or 14% of the total). This split is characteristic of a highly industrialized economy: high consumption of minerals and fossil fuels, with the built environment substantially driving raw material demand. A detailed breakdown of Richmond's material footprint by material group and region of origin can be found in Figure three.

Meeting Richmond's material demand requires mobilizing large amounts of raw materials from national and international supply chains. From a raw material consumption perspective, Richmond's material footprint is almost entirely embedded in imported materials, since a very limited amount of resources are extracted within the city's borders. More than half of the footprint originates from North America (3.3 million tonnes, representing 60% of the total material footprint), of which 2 million tonnes (36% of the total) comes from within Canada. Imports from Asia and Pacific countries represent almost one-fourth of the total material footprint (1.5 million tonnes). This highlights the dependency of a city like Richmond on materials coming from other areas, and the importance of understanding and managing imported material flows from various regions to ensure local resilience and sustainability. Details about the different material groups imported from each region of origin can be found in Figure three.

CARBON FOOTPRINT

Richmond's total consumption-based carbon footprint is estimated at 4 million tonnes of CO_2e, equal to approximately 19 tonnes per capita. This value differs from the territorial emissions reported for Richmond in the CEEP because it is based on a consumption-based footprinting approach. This means that it accounts for all lifecycle emissions from imported goods and services consumed in Richmond, regardless of where these emissions actually occur. While the results align with the national average (19 tonnes of CO_2e per capita), Richmond's carbon footprint exceeds the estimated globally sustainable level of 2.3 tonnes per capita, defined by the Paris Agreement.[14] Unlike the per capita material footprint, Richmond's carbon footprint per capita is one-third higher than Montreal's (13 tonnes of CO_2e). Although Richmond is a considerably smaller city, its population is far less dense, and its available modes of transportation are more emissions-intensive. Richmond also tends to use more carbon-intensive heating sources such as natural gas compared to Montreal, where most heating originates from electricity produced from hydropower.[15]

UNCOVERING RICHMOND'S MATERIAL FOOTPRINT

Material footprint by country of origin refers to the country in which the raw material is extracted before being imported to the country of consumption.

Total material footprint
5.5 million tonnes

Material footprint per capita
26 tonnes

Material footprint by material group (million tonnes)

Non-metallic minerals	Fossil fuels	Biomass	Metal ores
2.4	1.3	1.1	0.8

Material footprint by region of origin (million tonnes)

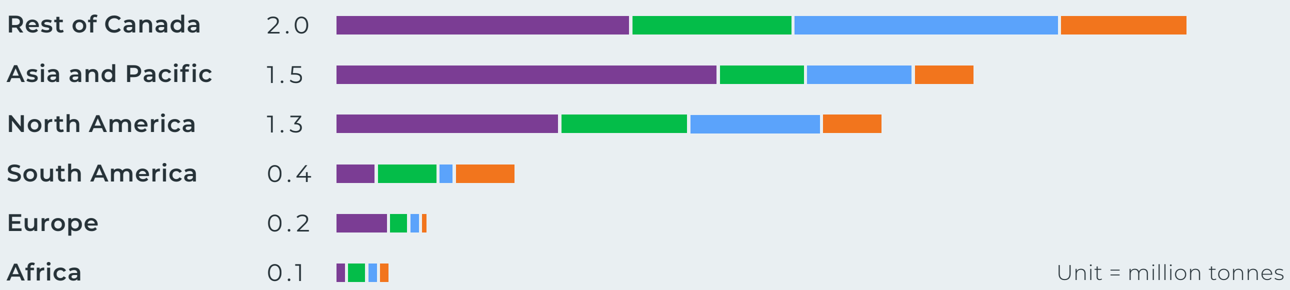


Figure three shows the breakdown of Richmond's material footprint by material group and region of origin.

Only one-fifth (20%) of the total emissions are **direct emissions**, originating from household consumption as direct energy use for private mobility and heating.[16] The other four-fifths (80%) are **indirect emissions**, which can be attributed to industrial activities and emissions generated throughout supply chains from the rest of Canada and the world.

Around 2.4 million tonnes of CO_2e (60%) of Richmond's carbon footprint is generated outside city borders. The composition of the carbon footprint highlights the large role of trade and imports in Richmond. The embodied carbon in Richmond's imports comes mainly from other areas of Canada (30%), trading partners in Asia and Pacific regions (15%) and the rest of North America (10%).

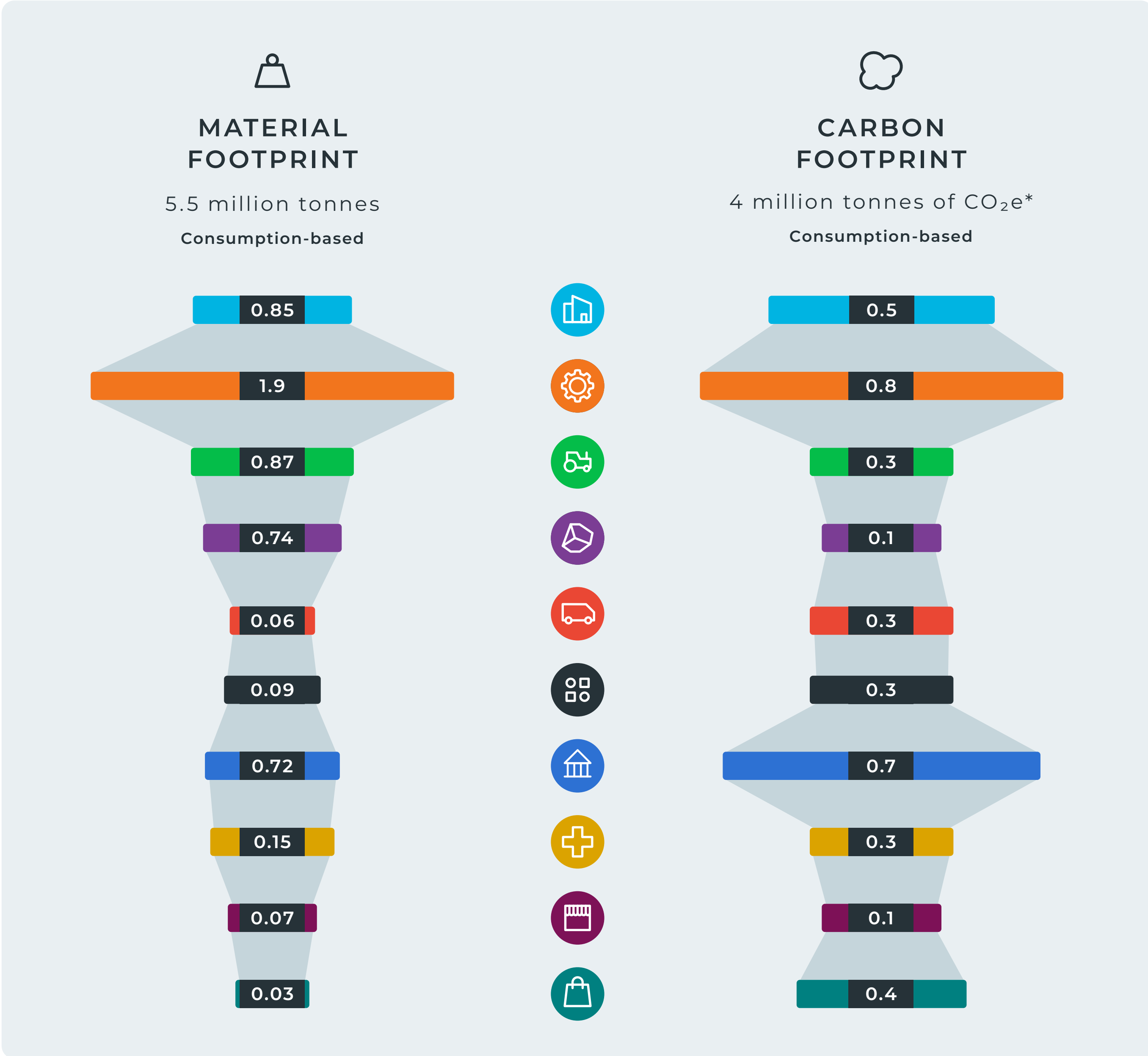
Imports from Europe and South America have a significantly smaller contribution (5% combined). The remaining 40% of Richmond's carbon footprint (1.6 million tonnes of CO_2e) originates within the city's boundaries.

	RICHMOND TOTAL	RICHMOND PER CAPITA	MONTREAL PER CAPITA	CANADA PER CAPITA	EU AVERAGE PER CAPITA	GLOBAL AVERAGE PER CAPITA	GLOBALLY SUSTAINABLE LEVEL PER CAPITA
Material footprint	5.5 million tonnes	26 tonnes	29 tonnes	36 tonnes	18 tonnes	12 tonnes	8 tonnes
Carbon footprint	4 million tonnes of CO_2e	19 tonnes of CO_2e	13 tonnes of CO_2e	19 tonnes of CO_2e	9.5 tonnes of CO_2e	5.5 tonnes of CO_2e	2.3 tonnes of CO_2e

Table one shows a comparison of Richmond's material and carbon footprints.[17]

When comparing the material and carbon footprints of different jurisdictions, it is important to remember that variations in affluence levels and population densities contribute significantly to different footprint patterns.[18] For example, cities with higher material and carbon footprints usually have higher levels of affluence and lower population densities (resulting in larger houses and yards with increased travel distances). For example, Richmond has a lower per capita material footprint than Montreal, which is likely due to its smaller population and slightly lower affluence level. On the other hand, Richmond has a higher carbon footprint per capita than Montreal, likely because of its lower population density compared to the metropolis of Montreal.

WHICH SECTORS CONTRIBUTE THE MOST TO RICHMOND'S MATERIAL AND CARBON FOOTPRINTS?



Legend

- CONSTRUCTION
- MANUFACTURING
- AGRIFOOD
- MINING AND EXTRACTION
- MOBILITY
- UTILITIES
- PUBLIC ADMINISTRATION
- HEALTHCARE, EDUCATION AND RECREATION
- HOTELS AND RESTAURANTS
- WHOLESALE AND RETAIL

* Direct emissions by households are excluded from the carbon footprint breakdown here.

Figure four shows Richmond's material and carbon footprints by sectoral contribution.[19]

CONSTRUCTION, MANUFACTURING, AND AGRIFOOD STAND OUT AS KEY SECTORS IN RICHMOND'S MATERIAL AND CARBON FOOTPRINT PROFILE, WHILE THE PUBLIC SECTOR ALSO CONTRIBUTES A SUBSTANTIAL AMOUNT

Together, these sectors contribute almost 80% of the total material footprint and 58% of the total carbon footprint, both through activities taking place directly in Richmond and activities taking place abroad (reflected in the products and goods that are imported). These high contributions reflect the **reliance of these sectors on material- and carbon-intensive resources**. For example, processing metal and chemical products and producing machinery and high-tech equipment are main contributors in the manufacturing sector. In the construction sector, the use of building materials, such as sand, gravel, cement, concrete and steel—among others—drive a significant amount of raw material extraction abroad, and are also associated with substantial GHG emissions both within and beyond Richmond. Agrifood activities represent the largest source of biomass consumption (crops, wild fish, animals and animal products) out of the total material consumption, and to a lesser degree, the consumption of fossil fuels (in the use of machinery) and non-metallic minerals (embedded in storage infrastructure, barns, *etcetera*).

The public administration sector's significant contribution to both footprints—but the carbon footprint in particular—is a result of all services provided by the City, including recreational facilities and waste collection. Given the consumption-based approach taken to estimate carbon and material footprints, the impacts associated with public administration should be viewed as the **effects of total (including global and Canadian) public administration spending** to provide services to **Richmond's citizens** (for example, social security, healthcare and education) and **businesses** (for example, administration, regulation or subsidy allocation for different sectors like agriculture, infrastructure and transport, energy, tourism, *etcetera*). This demonstrates the opportunity for the City of Richmond to significantly reduce the city's carbon footprint by demonstrating leadership through its own circular solutions.

As described in the results, the majority of the material and carbon footprints stemming from these top-contributing private and public activities originate **outside of Richmond** and are imported in the various goods and services reflected in final demand. However, looking at **what happens within the city's borders** allows us to understand what drives such impacts in more detail, and **how local circular actions** can reduce material and carbon footprints both locally and globally. For a more detailed explanation of this effect, please refer to Section 3.1 of the Methodology Document.

A CIRCULARITY INDICATOR SET FOR RICHMOND

The urban metabolism analysis doesn't only quantify the city's far-reaching impacts at a global level through the estimation of its material and carbon footprints: it also considers all types of materials flowing in and out of the urban economy. However, additional measurements can be used to answer more specific questions and fully grasp the current status of circularity in Richmond.

The **Circularity Indicator Set**, depicted in Figure five, considers all types of inputs into the urban economy: **Circular inputs**, such as secondary materials and carbon-neutral biomass, and **Linear inputs**, including fossil fuels and non-recycled materials, as well as **Stock build-up**. This approach allows addressing of questions such as: ***How much biomass is Richmond consuming? What volume of materials is being added to Richmond's stock—such as buildings and roads—every year?*** This measurement approach allows local stakeholders to track circular performance over time, establish consistent goals and targets, and guide future action in the most impactful way.

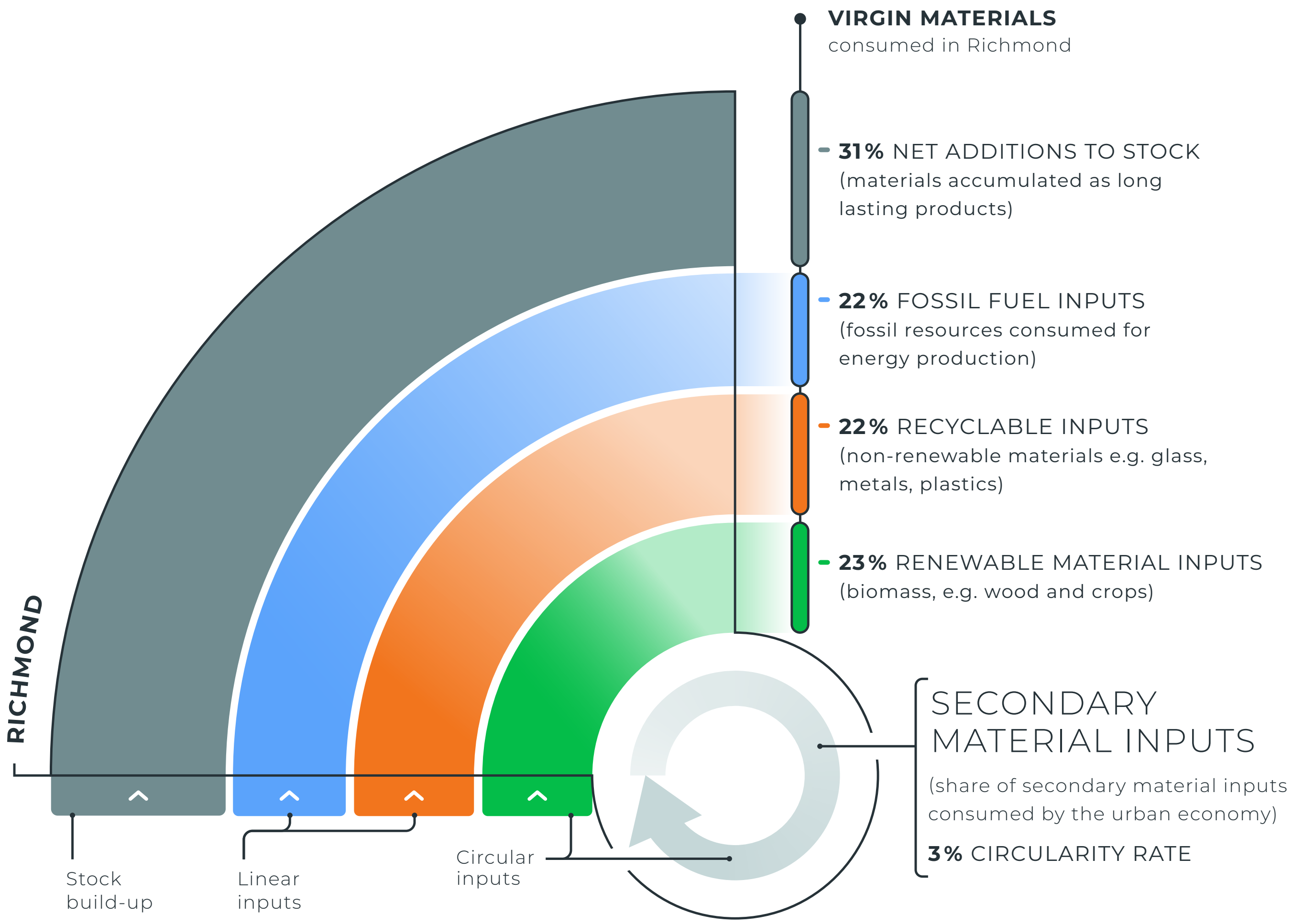


Figure five shows the full picture of circular and linear material inputs as well as stock build-up that make up Richmond's Circularity Indicator Set.[20]

CIRCULAR INPUTS

Indicator	Value	Explanation	What does this mean for Richmond?	What can Richmond do to advance circularity?
Secondary Material Inputs	3%	Secondary Material Inputs refers to the share of secondary materials out of the total consumption of an economy. It accounts for all materials that were formerly considered waste but are cycled back into use, including recycled materials from both the technical cycle (such as recycled cement and metals) and recycled biological inputs (such as paper and wood)	Richmond's Secondary Material Inputs stand at 3%, below the global level of 7.2%.[21] This means that only 3% of Richmond's total material consumption is from materials that have been recovered (around 165,000 tonnes). This percentage mainly consists of secondary material consumption that comes from construction and demolition waste being reused as aggregates in asphalt and concrete production (0.1 million tonnes out of 5.5 million tonnes) and agrifood waste that goes to compost (0.03 million tonnes).	Local and regional investments in management and processing capacity are needed to increase the consumption of secondary materials locally and regionally. Additionally, policies such as municipal by-laws are crucial to create the necessary conditions to develop the secondary material market and demand. The City's Demolition *Waste and Recyclable Materials (no. 9516) Bylaw* for single-family units is a step in the right direction to reduce and divert demolition waste from landfills. It sets construction and demolition reuse and recycling requirements. There are also plans to update and expand to other building types.
Renewable Material Inputs	21%	Renewable Material Inputs captures the share of primary biomass (such as trees, manure, food products or agricultural residues) over total material consumption. Part of this biomass can be circular, and, therefore, could be added to be considered as Secondary Material Input. However, data limitations make it difficult to distinguish the share of circular and non-circular biomass in Richmond. This is why a separate indicator is used to measure Renewable Material Inputs.	Richmond's input of renewable materials makes up 21% of the total material consumption (approximately 1.3 million tonnes). To maximize the consumption of carbon-neutral biomass, Richmond should continue responsibly sourcing biomass, including from forest and agricultural sources. British Columbia is well known for its sustainable forest management practices, which are reinforced by constantly improved policies, legislation and best practices.[22, 23] Ensuring that similar practices are used for all biomass sources will minimize non-carbon-neutral biobased inputs.	Through a combination of policy-making, incentives and partnerships, Richmond can support the consumption of renewable biomass locally and regionally. These include actions that are replicable by the City, businesses and the local community. For example, a wood upgrade centre and 'Circular Collaboration Hub' could foster industry symbiosis and identify new market opportunities for biobased materials. These initiatives can support better procurement practices in the City as well as in businesses and industry. Additionally, the City can advocate for the Provincial and Federal Governments to invest more in sustainable biomass use across all value chains.

LINEAR INPUTS

Indicator	Value	Explanation	What does this mean for Richmond?	What can Richmond do to advance circularity?
Recyclable Inputs	23%	Recyclable Inputs include the metals, plastics, paper and glass found in everyday products. This indicator does not include fossil fuels or any non-cyclable biomass but rather all materials that ***can*** potentially be cycled but are currently not.	Richmond's non-renewable input rate stands at 23% (approximately 1.2 million tonnes). This means that Richmond is consuming many raw materials that could be replaced with secondary materials.	To reduce the amount of virgin raw materials consumed in its economy, Richmond could support processes locally that help recover, retain or add value to the products already in circulation, while promoting recycling locally (for example, through secondary material markets) and across value chains in Canada and abroad.
Fossil Fuel Inputs	21%	This category centres on fossil-based energy carriers, such as fuel oil, gasoline, diesel and natural gas, among others. These fuels are burned mainly for energy and, to a lesser extent, to produce chemicals and plastics. As they burn, they release GHG emissions into the atmosphere that are inherently non-circular. Here, the circular transition will naturally prevent emissions through actions that aim to directly reduce the consumption of fossil fuels.	At 21% (roughly 1.2 million tonnes), this indicator highlights Richmond's dependency on fossil fuel consumption for many community needs. Fossil fuel consumption is driven by oil consumption to power transport (both light-duty and heavy-duty vehicles), as well as by using natural gas for residential, commercial space heating, and industrial processes in the manufacturing sector. The contribution of fossil inputs can be broken down by societal need: 41% to Housing and infrastructure, 28% to Mobility, 13% to Services, 9% to Manufactured goods, 4% to Healthcare, 3% to Nutrition, and 2% to Communications.	To minimize fossil fuel consumption, Richmond has already committed to targets identified in the CEEP: these include achieving carbon-neutrality for new buildings by 2027, accelerating deep energy retrofits to existing buildings, transitioning to zero-emission vehicles, supporting the Frequent Transit Network (FTN), prioritizing active mobility, implementing complete communities, and enhancing green infrastructure to maximize climate benefits. Richmond may also enhance the decarbonization of resource-intensive industrial processes via circular design principles, the application of cutting-edge technologies for material efficiency, and business model transformations.

STOCK BUILD-UP				
Indicator	Value	Explanation	What does this mean for Richmond?	What can Richmond do to advance circularity?
Net Additions to Stock	32%	Many of the materials that are needed to meet Richmond's material demand feed into goods and products that remain in use for a relatively long time, such as buildings, machinery and vehicles.[24] These materials are 'added' to the material reserves of an economy for longer than a year and are therefore referred to as Net Additions to Stock. They are key features of the urban environment, such as buildings, roads, bridges, cars, and typically make up a large portion of material flows due to their substantial weight.	At 5.6 million tonnes of total material consumption, Richmond's **stocking rate** stands at 32%, primarily consisting of non-metallic minerals and metal ores, followed by biomass. The configuration and quantity of these stocks are key factors in determining material demand, future material flows and (re) cycling potential.	Boosting circularity in net additions to stock means minimizing raw material consumption and optimizing stock accumulation. Richmond can achieve this by prioritizing renovation over demolition for aging assets that have not yet reached the end of their lifetime, and by promoting deconstruction, reuse, and recycling for those that have.[25] The City can also advocate for integration of circular building and infrastructure design (for example, durable and sustainable) in the B.C. Building Code, and support nature-based solutions for urban development projects, such as nature integration practices for climate regulation and other similar practices. Finally, the City can focus on tackling GHG emissions from the use of built-up stock by taking an embodied-carbon approach, promoting building practices that prioritize low-carbon materials.

Table two shows the relevant indicators to assess circularity for Richmond, including both circular and linear inputs.

Annexes B and C provide more detail on the dynamics influencing how circularity is measured and the practical challenges this presents. Please refer to the Methodology Document for a more exhaustive look into the methodology behind the Circularity Indicator Set.

CORE PRINCIPLES OF ADVANCING CIRCULARITY

The next chapters analyze key sectors for Richmond to advance its circular economy plans, and include a series of interventions modelled to calculate the potential impact of circular economy strategies. These interventions—which are aligned with many of the strategic directions of the RCCS—are ambitious measures that can actively reduce Richmond's material and carbon footprints.

The core principles behind the interventions are drawn from the Four Flows Framework,[26] which consists of four strategies to enhance resource efficiency and sustainability, as shown in Figure six. This translates into two core objectives and four strategies:

- **Objective one:** Resource extraction from the Earth's crust is minimized and biomass production and extraction is regenerative;
- **Objective two:** The dispersion and loss of materials is minimized, meaning all technical materials have high recovery opportunities, ideally without degradation and with optimal value retention; emissions to air and dispersion to water or land is prevented; and biomass is optimally cascaded.

The four strategies Richmond can use to achieve its objectives, which are also reflected in the RCCS, are:

- **Narrow flows—Use less:** The amount of materials (including fossil fuels) used in the making of a product or in the delivery of a service are decreased. This is through circular design or increasing the usage rates of materials and products. In practice: Sharing and rental models that increase product utilization whilst decreasing the number of products needed, material lightweighting (mass reduction), multifunctional products or buildings, energy efficiency, digital rather than physical products.
- **Slow flows—Keep using:** Material use is optimized as the functional lifetime of goods is extended. Durable design, materials and service loops that extend life, such as repair and remanufacturing, both contribute to slowing rates of extraction and use. In practice: Durable material use, modular design, design for disassembly, reuse, repair, remanufacturing, refurbishing, renovation and remodelling over building new structures and products.
- **Regenerate flows—Design clean:** Fossil fuels, pollutants and toxic materials are replaced with regenerative sources, thereby increasing and maintaining value in natural ecosystems. In practice: Regenerative and non-toxic material use, renewable energy, regenerative agriculture and aquaculture.
- **Cycle flows—Use again to maximize value:** The reuse of materials or products at end-of-life is optimized, facilitating a circular flow of materials. This is enhanced with improved collection and reprocessing of materials and optimal cascading by creating value in each stage of reuse and recycling. In practice: Design for recyclability (both technical and biological), design for disassembly, reuse and recycling.

Ultimately, strategies to narrow, slow, regenerate and cycle material flows can lead to a lesser amount and variety of materials being used to provide similarly for societal needs. If materials have longer lifespans and are being reused more effectively, the total amount of materials used by the economy will drop, reducing environmental impacts as a result.

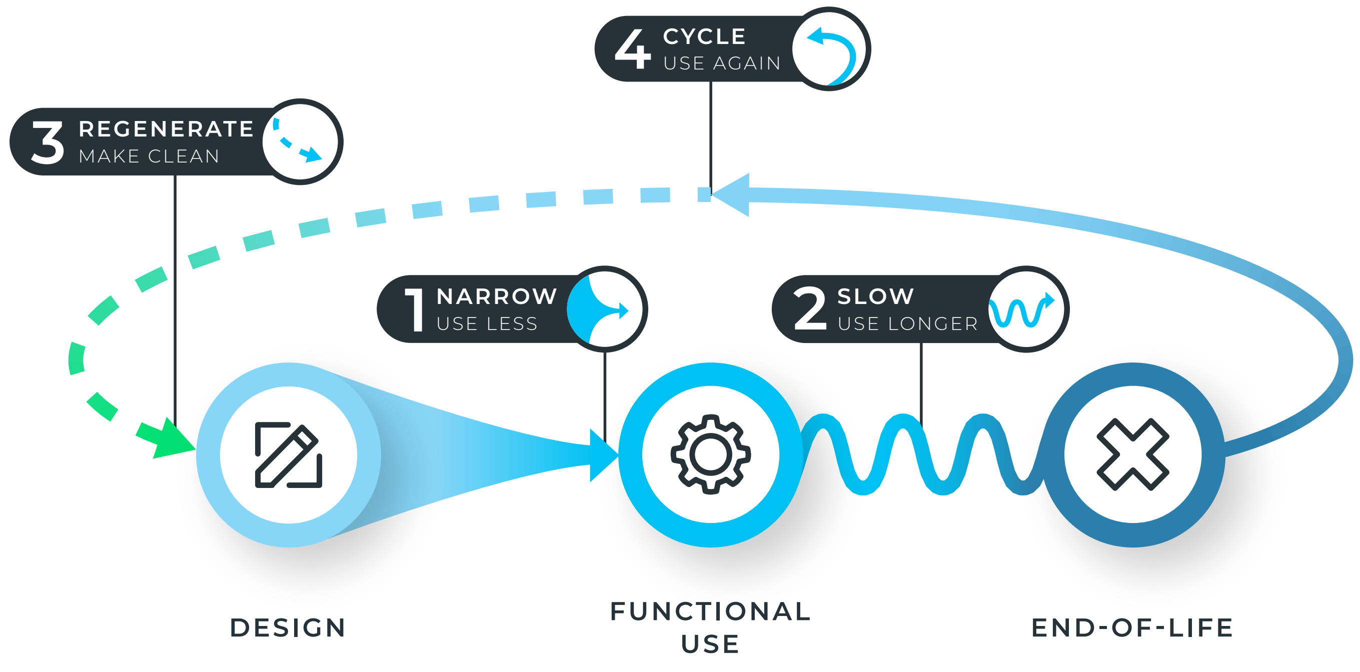
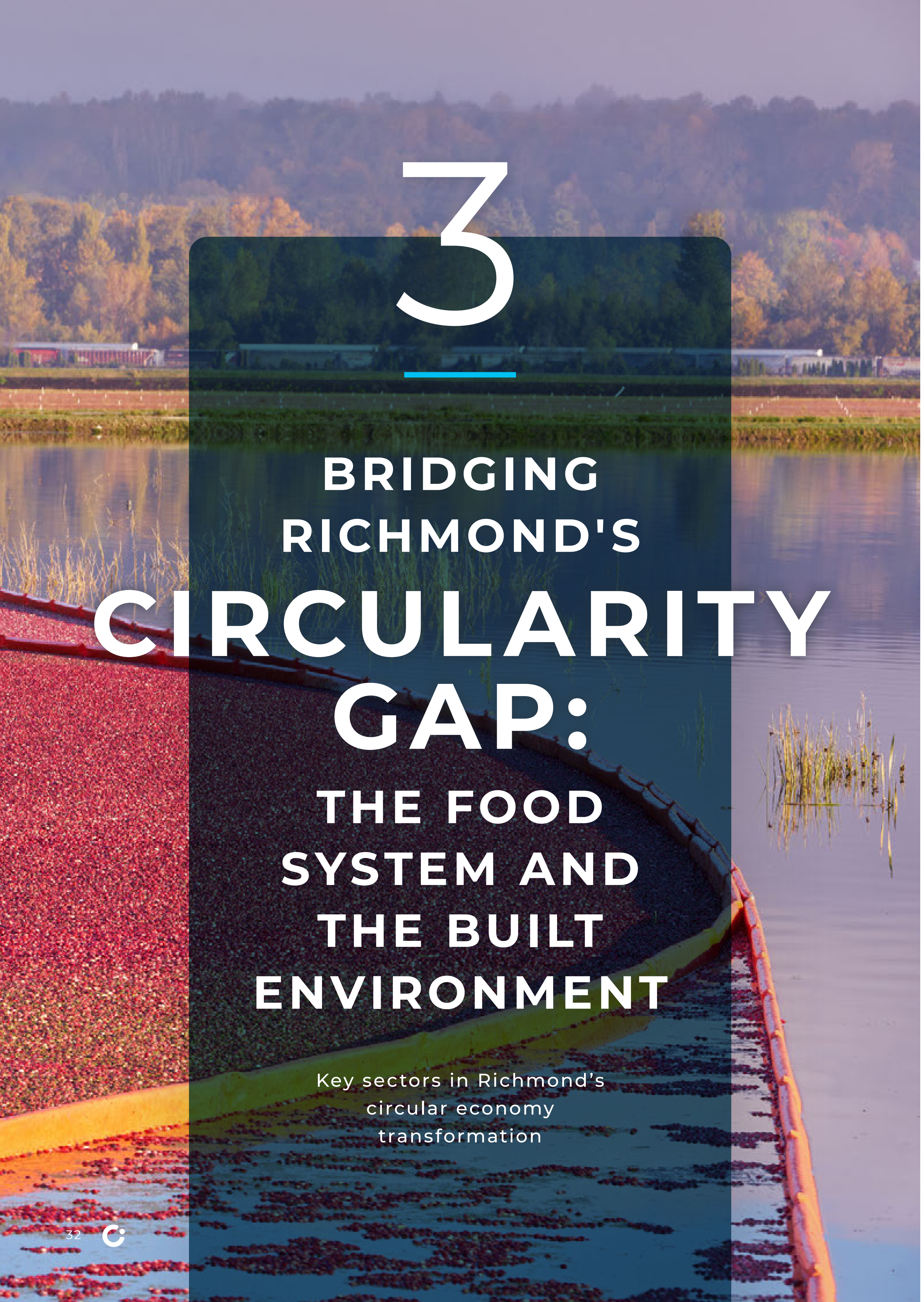


Figure six shows a visual representation of the Four Flows Framework.



3

BRIDGING RICHMOND'S CIRCULARITY GAP: THE FOOD SYSTEM AND THE BUILT ENVIRONMENT

Key sectors in Richmond’s circular economy transformation

The previous chapters revealed the sectors that concentrate the bulk of Richmond’s material and carbon footprints. Achieving Richmond's objectives of establishing a circular economy and reducing its contribution to climate change and resource depletion hinges on transforming its most impactful sectors. Food systems and the built environment are key areas for Richmond to transform, due to their economic and social importance as well as their material and carbon intensity.

Additionally, their activities relate to many local processes in Richmond, which the City can directly influence and redesign to create more circular systems. Richmond has a flourishing agricultural sector and a constantly expanding built environment. Hence, moving forward, both systems require a thorough analysis to understand challenges and leverage points to facilitate a circular transition.

This chapter includes a deep dive into both, complemented by interventions that can influence Richmond’s carbon and material footprints. The manufacturing sector, also being one of the three most impactful systems in Richmond, will be addressed in the following chapter.

3.1 THE FOOD SYSTEM

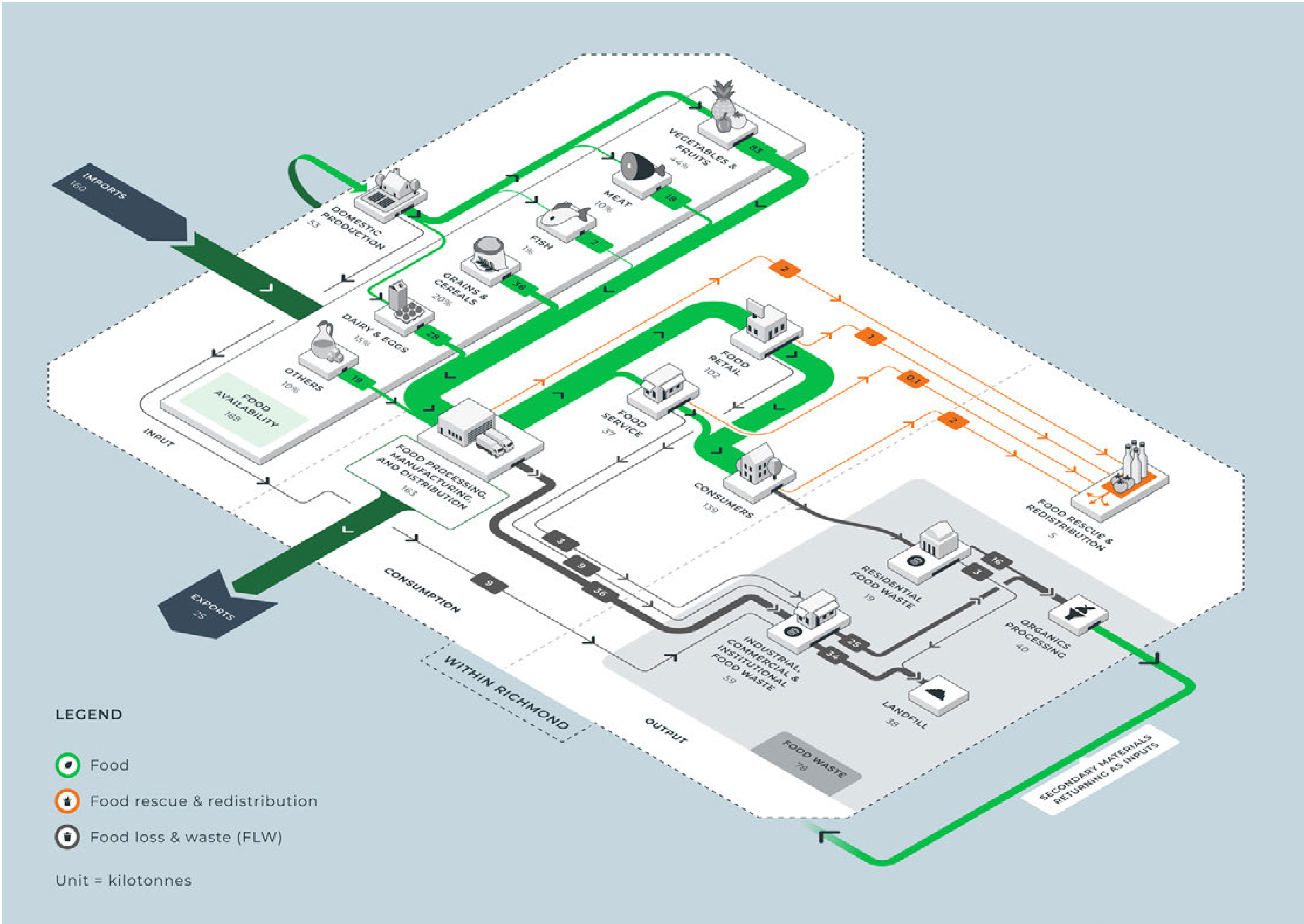
Cities greatly influence food systems, both within and beyond their physical boundaries. Most food is produced far from cities, yet they are centres of food consumption. The food system is a crucial element of any city and is intertwined with various aspects of the urban socioeconomic system, including health, businesses, culture, and land use in peri-urban areas and beyond. At a global level, the food system is known for its highly globalized value chains, which can cause negative impacts on the environment, contributing to climate change through the emission of methane and other GHGs, and potentially leading to nitrate pollution in air and water environments. These impacts, coupled with an increasing global population and growing urbanization rates, exert pressures on local agrifood activities, which in turn need to become more resilient to be able to achieve greater sufficiency and more sustainable practices. To satisfy Richmond's demand for food, agrifood activities across the world consume **0.9 million tonnes** of materials and generate **0.3 million tonnes** of CO_2e.

Similar to other cities, Richmond relies on imports from the rest of British Columbia, Canada and around the globe to meet its residents' demand for food products. The city is also located in one of Canada's more fertile agricultural regions—the delta of the Fraser River.[27] Endowed with fertile agricultural land, Richmond currently hosts 184 farms in its Agricultural Land Reserve (ALR), representing 39% of Richmond's land base (nearly 5,000 hectares). Beyond the ALR, additional agricultural plots make Richmond's total agricultural land surface span over 5,550 hectares.

While local agricultural activities obviously cannot provide for Richmond's entire food supply, its substantial land availability is not a common feature among Metro Vancouver's municipalities. Richmond can leverage this advantage in various ways to advance local sustainability and resilience. From agriculture to the food processing industry, including food service and retail, Richmond can advance circular practices across all stages of the local value chain to increase efficiency and productivity, while optimizing the use of imported products. These efforts can help achieve higher food security and quality, reduce food waste, make processes more cost-efficient, and contribute to the economic prosperity of local farms.

The following section dives into the complexities of Richmond's local food system, looking at food inputs and outputs at the main stages of the food value chain. This analysis is then used to highlight inefficiencies and areas where the actions identified in the RCCS could have significant impact.

Figure seven visualizes the material flow analysis of Richmond's food system.



FOOD SYSTEM INPUTS

The total food supply to fulfil the needs of Richmond's citizens is approximately 188,000 tonnes, equivalent to 2.3 kilograms of food per capita per day.[28] This demand equates to an estimated 120,000 tonnes of CO_2e.[29] Approximately 85% of Richmond's food supply (160,000 tonnes) is estimated to be imported from the rest of the province (±20%), Canada (±25%), the United States (±22%), and the rest of the world (±18%).[30] Local production contributes around 53,000 tonnes of food (see Table three), primarily consisting of fresh fruit and vegetables (35,000 tonnes in 2019).[31] Based on agricultural land use census maps, it is also possible to estimate the small local production of (poultry) meat, and dairy and eggs (see Figure seven), which only make up approximately 0.25% of the total local agricultural production. Most of this is assumed to be directly consumed in Richmond. Lastly, the Steveston Harbour Authority hosts Canada's largest small-craft commercial fishing harbour,[32] with an estimated seafood harvest of approximately 17,000 tonnes per year.[33]

FOOD PRODUCT	QUANTITY (TONNES)
Total fresh fruits and vegetables	**35,403**
Cranberries	19,613
Blueberries	3,805
Chinese cabbage	2,247
Cabbage	1,191
Squash and zucchini	720
Pumpkins	780
Cauliflower	121
Strawberries	104
Onions, green/shallots	78
Other field vegetables	6,745
Eggs	**50**
Poultry (chicken and turkey)	**79**
Fish and seafood	**17,157**

Table three gives an overview of total food harvested or produced in Richmond, labelled as "domestic production" (based on Circle Economy estimations).

Out of the total food produced or harvested in Richmond, about 25,000 tonnes of food is exported (predominantly cranberries and blueberries). In comparison, 28,000 tonnes is estimated to feed into the local food chain for direct consumption. This means that local production—mainly fresh produce and seafood—could only sustain 11% of the food consumed in Richmond. Richmond, is therefore highly dependent on imports, particularly for other food types like proteins (meat and poultry, dairy and eggs), field crops (cereals, rice, *etcetera*), sugars and fats. This reliance on food imports is expected to increase across British Columbia in the future due to projections for population growth and the expected impacts of climate change—such as drought—on the province's agricultural capacity.[34] This poses a notable risk to local communities' food security. However, as highlighted in Richmond's *Farming First Strategy*, the City is well aware of the need to rethink the current approach to agriculture and food production in a way that secures water quality and availability, the recovery of nutrients, and the preservation of agricultural land.

FOOD RETAIL

Retail is an important segment of Richmond's food industry and value chain, boasting 226 food and beverage retail companies..[46] Based on household expenditure on food retail (approximately 74% of food purchases by mass), it was estimated that 101,000 tonnes of food (54% of total food inflows) ultimately reaches consumers through these establishments. Compared with previous stages of the food value chain, food retail contributes to much smaller volumes of waste—about 3,000 tonnes, representing 4% of total food waste in Richmond. However, these losses are still concerning as they often involve edible food, making them more significant in terms of their economic value compared to prior steps in the value chain.[47]
At this stage, the main causes for food wastage relate to forecasting inaccuracies, poor-quality inputs, and issues related to date codes such as "best before" labels.[48]

ECOLOGICAL AND ECONOMIC FACTORS LIMITING THE POTENTIAL FOR INCREASING THE ACTIVE USAGE OF RICHMOND'S AGRICULTURAL LAND

Most of Richmond's territory originally consisted of wetlands—among the most effective ecosystems for carbon storage—and thus possessed high ecological value. A substantial portion of the land included within the ALR is designated as peatland for restoration and is not actively farmed (or at least not intensively),[35] given its enormous ecological value. The City is prioritizing the recovery of bogs and wetlands and to protect the environmentally sensitive areas that are essential to Richmond's natural ecosystem. While this limits the land surface available to increase agricultural production, the direction adopted by the City with the *Farming First Strategy* and the RCCS is to support the sector in producing more by protecting the agricultural land base from urban sprawl and increasing the implementation of regenerative practices, among other measures. Enhancing these local production capacities could play a crucial role in strengthening Richmond's food resilience and reducing its reliance on external sources.

The current land ownership model makes it difficult for Richmond's farmers to achieve long-term economic viability. Despite the City's efforts to preserve the ALR for agricultural purposes, some parts of the ALR and other agricultural land in Richmond remain privately owned by non-farmers and other private landowners.[36] Farmers often experience challenges purchasing land and end up signing expensive, shorter term rental agreements.[37] This exacerbates the challenges smaller farms experience in achieving long-term sustainability, creating additional risks for farmers in terms of economic viability,[38] and the sector's overall attractiveness. This could become an issue in the future, as younger generations do not seem to be willing to pursue agricultural careers, given the difficulty of establishing in the area, among other reasons.[39] In response to these challenges, the City of Richmond is giving institutional support to help realize local and resilient food systems, and has provided feedback to British Columbia's Ministry of Agriculture to provide more support for local farmers developing economically viable and regenerative practices.[40] For example, through its collaboration with experts from the Kwantlen Polytechnic University, the City can ensure that production is increased and diversified optimally, and that new cultivation practices have minimal consequences on the local ecosystem (by, for example, avoiding wetland draining by prioritizing cultivation on available mineral soils or through soil-free urban farming practices).[41]

THE IMPORTANCE OF PROCESSING, MANUFACTURING AND DISTRIBUTION ACTIVITIES

Before food reaches consumers in Richmond, domestic production, processing, manufacturing and distribution activities generate about 47,000 tonnes of food loss and waste (FLW), equivalent to 211 kilograms per capita. This represents **60% of total food waste** generated across the food chain (and 25% of the total food flows). Most of this (nearly 36,000 tonnes) occurs in the processing and manufacturing stages, mainly due to product quality issues and forecasting inaccuracies, as well as human error or equipment failure.[42] During production, about 9,000 tonnes of waste is generated, mainly fresh produce being lost due to weather, pests, or even through storage processes. The remaining waste (about 2,000 tonnes) can be attributed to distribution due to inefficient transportation and storage practices.

Food processing and manufacturing businesses are among the highest generators of FLW in food value chains. This is particularly relevant for Richmond, since more than 150 food and beverage manufacturing businesses are registered in Richmond, including seafood and meat processing, fruit processing, cold storage, and more.[43] These businesses are attracted by the easy access to key transportation routes and the sophisticated distribution networks of the wider Metro Vancouver area,[44] as well as the presence of local agricultural production.

It is also important to consider cultural perceptions of FLW in food processing and manufacturing industries, and particularly the need for improved efforts to optimize food flows through these processes. Currently, food waste at the processing stage is still considered "business-as-usual," and as such, is not necessarily seen as an issue—nor is it tracked or monitored with particular attention. This makes it complicated to accurately track local waste flows, and thus to implement innovative circular solutions.[45] While the RCCS rightly emphasizes the importance of local food production, it could expand the scope of opportunities to address the impacts of food processing and manufacturing.

Circular solutions at this stage of the value chain are crucial, and should focus on **optimizing processes and finding new opportunities and synergies** across the sector through principles such as **industrial symbiosis** between food businesses. **Maximizing resource efficiency** (including energy, water, and biomass), optimizing the use, processing, and storage of food products and by-products **while maintaining their nutrient value**, and adopting low-impact packaging are essential steps toward a circular food processing and manufacturing industry.

FOOD SERVICE (HOTELS, RESTAURANTS AND INSTITUTIONS)

The food service sector comprises businesses and institutions responsible for preparing meals outside the home (i.e., hotels, restaurants and institutions). Richmond hosts 1,092 food and accommodation establishments, employing the largest workforce across the agrifood value chain.[49] It was estimated that, aside from retail, consumers purchase the remaining part of their total food consumption (26% in mass) through food service, amounting to 36,000 tonnes. At this stage, total food waste generated is often higher than in retail establishments, with about 8,500 tonnes generated in Richmond. In food services, the main causes of food waste are meal preparation and plate waste (human error), although forecasting inaccuracies may also occur.[50] Losses at this stage also involve mostly edible food. Food waste stemming from the food retail and service sector in British Columbia represents $1.3 billion worth of food per year, 57% more than the estimated profit in those sectors.

HOUSEHOLDS (FINAL CONSUMERS)

After accounting for losses across all previous stages, the total volume of food available to the final consumers in Richmond is 137,000 tonnes: 73% of total inflows, equivalent to approximately 620 kilograms per capita, per year. Fresh produce, namely fruits and vegetables, represents 41% of this, followed by animal products (meat, poultry, eggs and dairy, and seafood), which account for over 25% of total consumption. Subsequently, beverages represent the third largest source (in mass), accounting for 17% of the total, followed by grains and cereals (10%) and "other products" like fats and sugars (7%). At the household level, 19,000 tonnes of food waste is generated (equivalent to 83 kilograms per capita per year), of which almost half is considered "avoidable," or still edible (for example, plate waste or food stored at home that was, at some point prior to disposal, edible). The remainder is primarily a result of meal preparation. The loss and wastage of edible food also represents an enormous loss in terms of economic value; on average, it is estimated that $1,100 worth of food is wasted each year in every home in British Columbia. For Richmond, this represents an estimated loss of nearly $81 million worth of food within the city (estimated using a household count of 73,455).

FOOD SYSTEM OUTPUTS

Food waste

Total food waste generation across Richmond's entire supply chain amounts to 78,000 tonnes (equivalent to 340 kilograms of waste per capita per year), meaning that roughly 41% of total food inputs (188,000 tonnes) end up as waste. More than 40% of this total is considered edible, and is thus classified as avoidable waste. Considering food types, fresh fruits and vegetables constitute the largest fraction of FLW across the value chain (46%), followed by grains and derived products like bread, baked foods, pasta or rice (24%), and animal products like dairy and eggs (11%), and meat and poultry (11%).

The Industrial, Commercial, and Institutional (ICI) sector generates significantly more food waste (59,000 tonnes) than the residential sector (19,000 tonnes). Best-available information regarding the fate of food losses at earlier stages of the value chain suggests that 58% of pre-consumer ICI food waste (34,000 tonnes out of the 59,000 tonnes) is sent to landfills, while the remaining 42% (25,000 tonnes) is directed to composting facilities.[51] At the residential level, noticeable efforts have been made by several Canadian municipalities, including Richmond, to curb the landfilling of food waste. In fact, since a ban on compostable organics in landfills was introduced by Metro Vancouver in 2015, the metropolitan region has positioned itself at the vanguard of food waste diversion.[52] Richmond's *Green Cart Program* aims to compost nearly all food waste generated in households to recover nutrients from non-edible food waste. This creates a nutrient-rich final product that can benefit local and regional farms by enhancing soil quality, offering a viable and sustainable alternative to synthetic fertilizers. However, a fraction of residential food waste still ends up in mixed waste streams going to landfills, representing significant environmental and economic losses through the generation of GHG emissions and a missed economic opportunity of capturing nutrient value for agricultural purposes.[53] It was estimated that the *Green Cart Program* manages to direct 83% of residential FLW to composting (16,000 tonnes), with the remaining 17% still going to landfill (3,000 tonnes). The diversion of food waste from landfill is crucial when considering carbon emissions, as composting can significantly reduce emissions in comparison to landfill disposal.[54]

Food rescue and redistribution

Food rescue and redistribution are crucial components of Richmond's sustainable food practices, encompassing the recovery of nearly 5,000 tonnes of unsold food products and beverages. This rescued food is transformed into meals and distributed to those in need. The pre-consumer level sees active involvement from farmers, processors, and manufacturers in rescuing and redistributing surplus food, accounting for 2,000 tonnes. Local organizations, predominantly the Richmond Food Bank Society and other smaller food banks and rescue services, are pivotal in connecting grocery shops, restaurants, and households with Richmond's most vulnerable populations. For example, in 2021, the Food Bank Society alone recovered over 800 tonnes of food through their recovery services, redistributing them via school meal programs, community partner services, and even home deliveries to clients unable to leave their homes.[55] However, as discussed with a local stakeholder, the few recovery and redistribution efforts from pre-consumer stages predominantly take place on an independent and business-by-business case, and that overall, there is still ground to cover to ensure that food rescue becomes an integral part of the food business culture. Therefore, greater harmonization of food recovery efforts could allow for better measurement of the impacts of such initiatives at a local scale (in terms of waste avoided, meals delivered, number of people helped, *etcetera*). The City can play a role in further coordinating efforts and enhancing collaboration between food banks, food recovery organisations like FoodMesh, and local food businesses.

SHIFTING TO A CIRCULAR FOOD SYSTEM

This section presents the scenario "Shifting to a Circular Food System," which complements the measures highlighted in the RCCS. The envisioned goal is a circular food system for Richmond, where agricultural production optimizes the use of all biomass, regenerative production is prioritized, resource inputs and pollution are reduced, and valuable resources from food loss and waste (for example, nutrients) are recovered and reintroduced in biological cycles. It is also one where sustainable diets are promoted, and human health and communities' livelihoods and wellbeing are protected. Changes to the food system can range from farm to fork—from the production of food in farms and urban community gardens, to the consumption of those products. This scenario looks at both, and includes the following interventions:

1. **Shift toward more localized and sustainable food production;**
2. **Promote local consumption of healthy, balanced and sustainable foods; and**
3. **Reduce food loss and waste by building a resilient and more efficient local food system.**

1. Shift toward more localized and sustainable food production

Shifting to diverse, regenerative, local and seasonal food production will **regenerate** and **narrow** flows by reducing the need for synthetic fertilizers, lowering transport distances and lessening dependence on foods grown in heated greenhouses, thus reducing fuel consumption for heating. The vision is a food production system that works alongside nature, protects biodiversity and cuts emissions and chemical inputs.

Richmond is already deploying measures to protect its agricultural base and support local producers. The City relies on imports for 85% of all food inputs. As the local population continues to increase, this will only grow unless efforts are made to efficiently and sustainably ramp up local production. Richmond has reasons and means to do so, given the high share of fertile agricultural land out of the city's total land base. As such, the City seeks to ensure that land designated as "agricultural" (in particular within the ALR) is prioritized for farming purposes over other potential activities (recreational, institutional).[56] It tries to limit plot vacancies to maximize the yield from available agricultural land. To do so, the City has established several regulations aimed at restricting the residential use of farmland, as part of the *Protecting the Farmland Action Plan*. For example, regulations take into account numbers of residential setbacks and house size limits.[57]

INDUSTRIAL, COMMERCIAL, AND INSTITUTIONAL (ICI) FOOD WASTE

While the City of Richmond is making noticeable efforts to divert residential food waste, non-residential waste collection currently operates on a business-to-business, fee-per-service structure, where waste diversion costs are not yet offset by government programs or stipulated through regulation. For most waste streams, including organic waste, this means disposal is the least expensive option. Therefore, approximately half of the total food waste generated across the value chain is still assumed to end up in landfills. However, there are still substantial information gaps concerning how private sector food waste is managed and by whom.

Looking forward, it is clear that the City of Richmond must continue its current efforts to progressively deploy a combination of measures, innovative solutions and cross-sectoral coordination to target food waste at the farm stage and in ICI establishments in order to bring food waste landfilling near to zero. While the RCCS aims at enhancing collaboration with local businesses to tackle this challenge, a more explicit focus on mandatory reporting or certification programs related to food waste management by private businesses could further enhance transparency. Establishing clear benchmarks or standards for waste reduction and reporting requirements could also encourage businesses to openly share their practices and progress. These types of reporting requirements could most effectively be coordinated with the region (Metro Vancouver) and/or other levels of government. Additionally, improved food management will result in important cost reductions and more resilient processes. These benefits can also be complemented by incentives or recognition for businesses with transparent waste management practices to further motivate participation.

FOOD INDUSTRIAL SYMBIOSIS IN CANADA: TAKING EXAMPLE FROM METRO VANCOUVER AND MONTREAL

The presence of most, if not all, stages of the food value chain in a single area like Richmond presents a truly unique opportunity to leverage industrial symbiosis solutions for the food industry. This can help maximize resource efficiency and ensure the highest possible value applications of non-edible or unavoidable losses. At the same time, this would position Richmond at the forefront of agrifood sustainability in British Columbia and Canada.

A number of initiatives are already taking off in Metro Vancouver, demonstrating creativity in the food industry and highlighting the range of benefits circular agrifood practices can generate for businesses.

- Susgrainable: Rescues spent grain from breweries, preventing landfilling and transforming it into high-quality baking mixes that are commercialized in local food stores and markets. This initiative prevents food waste and recovers valuable resources while also reducing disposal costs for local businesses, and creating new jobs and revenue streams for food-related businesses.
- ReCruz Produce: Upcycles fresh produce losses generated during processing and manufacturing stages. Recovered produce is either sent to further manufacturers or is used as animal feed in dairy farms, at a low cost, while minimizing waste and eliminating GHG emissions from landfill.

Other examples of similar circular food initiatives in Canada, highlighting the creativity of the industry, include:

- Blanc de Gris: This mushroom farm produces high-end mushrooms from brewery spent grains (beer production), recycling two tonnes of spent grain per week and producing over 300 kilograms of mushrooms marketed locally in short circuits.
- Valorisons MTL: Sheds light on inter-industrial symbiosis opportunities such as heat recovery from (non-agrifood) industrial processes to feed urban greenhouses, as well as recovering sludge and digestates for soil enhancement and fertilization purposes.

With the Agrifood sector playing such a key role locally, Richmond would be well-suited to promote and encourage additional circular food initiatives. In this sense, Richmond could take inspiration from these ventures both from a technical implementation perspective, but also as an example of long-term collaboration and engagement between the City and different value chain stakeholders. The Circular Innovation Hub could be a catalyst for such opportunities at the local level, ensuring that their implementation bears clear benefits, in terms of both environmental aspects (avoided emissions, reduced waste, resource recovery), as well as local jobs, opportunities for businesses creation, exploring innovative revenue solutions, contributing to the development of a local, high-quality and more affordable market for alternative and sustainable food products.

The City of Richmond aims to transform the local food system by exploring novel opportunities and leveraging local strengths. Various actions to transition toward a more resilient and productive food system are mentioned in the RCCS. These include: encouraging more regenerative agricultural practices, such as the use of nature-based solutions, multi-cropping or agroforestry to increase productivity on land, and establishing a comprehensive urban agriculture program that incorporates novel practices such as rooftop farming.[58] The City also proposes to work on shortening the food chain. For this, local stakeholders have pointed out that taking advantage of the existing community garden networks (for example, those established by the City in partnership with Urban Bounty) may be an opportunity.[59]

Richmond can also count on its highly skilled and trained experts in the field of agrifood technology and science. The importance of fostering collaboration between industry and knowledge experts through pilot projects, training programs and educational initiatives on the novel practices mentioned above cannot be stressed enough. Beyond assisting in the training of farmers on the implementation of new techniques, educational institutions can also contribute greatly to raising overall awareness of the importance of sustainable farming.

2. Promote local consumption of healthy, balanced and sustainable foods

Consolidating local production capacity is only the first step toward building a truly resilient and sustainable food system. While local research revealed that the demand for local foods is on the rise,[60] further efforts will be needed to make sure that Richmond's consumers have access to those foods. Consumers also need to be aware of the benefits of consuming local, seasonal, healthy and balanced ingredients, both for their own health and for the environment. Additionally, promoting more local consumption will directly benefit local farmers, who primarily operate smaller-scale farms where economic viability can be limited due to small profit margins.[61] Overall, it is important to both build capacity to produce sustainable and seasonal local products and raise awareness among the food system industry and stakeholders to create a circular food system in Richmond.

Incentivize a preference for consuming "local," Local authorities could promote partnerships between farmers and food processing companies, as well as local retailers, restaurants and cafés. The City itself could lead by example by adopting circular and sustainable food procurement practices, prioritizing purchasing from local producers and retailers as much as possible. The City could also go one step further and inform residents about local food suppliers, publishing circular menus and recipes. On the other hand, purchasing locally-grown and organic produce often results in higher costs for the consumer. This is why local authorities have stressed the need to monitor the affordability of more circular consumption, and track access to healthy and nutritious products.[62]

Create stronger connections between the food industry and consumers. Raising the overall level of awareness and knowledge on more sustainable consumption across the industry and among Richmond's citizens can help bridge the gap between farmers and local consumers. Local stakeholders have stressed the importance of constructing stronger and more direct relationships between farmers, producers, residents, and food business owners. For example, workshop participants suggested taking advantage of cultural events such as the Richmond Night Market and the Spot Prawn Festival, or even the use of video series to share farm stories and disseminate new knowledge and ideas around circular and sustainable farming and consumption. Additionally, the City is considering supporting local production and consumption through food tourism initiatives, as a way to encourage local food supply and consumption. For example, per the *Richmond Farming First Strategy* the local food map is updated annually to help connect visitors and residents to local produce and seafood.[63]

3. Reduce food loss and waste by building a resilient and more efficient local food system

While Richmond is already doing a lot to recover nutrients from food waste through composting, more of an emphasis needs to be placed on reducing food loss and waste in the first place to maximize resource and nutrient value. Reducing excessive FLW can improve the efficiency of food systems while also decreasing their associated carbon footprints. FLW resulting from the inefficient use of food products—as well as the natural resources necessary to produce and supply these products to end consumers—represents a deadweight loss to the local socioeconomic system. For example, FLW in Canada is estimated to cost $50 billion based on food value at the retail point, equivalent to $1,100 per family, per year.[64] To this end, applying circular principles to the food system would help mitigate these impacts and create new opportunities for innovation, circular business models, and overall efficiency gains.[65] The RCCS envisions a refined food system in which resource use is optimized and the community's approach to food and nutrition naturally minimizes waste.

Richmond has an excellent foundation for industrial symbiosis for agrifood. In Richmond, a substantial proportion of pre-consumer food loss and waste is still directed to landfill. This is a significant source of GHG emissions and pollution, and causes significant losses of valuable biomass, nutrients, and even edible food products that other industries or businesses could benefit from. However, Richmond is particularly well positioned to shift the management of these industrial food flows. The presence of different agrifood activities spanning the entire value chain, in a relatively compact geographical area, demonstrates the high concentration of local expertise, infrastructure, and academic support (such as Kwantlen Polytechnic University's Sustainable Agriculture program). This combination favours the strong development of synergistic activities. Similarly, Richmond's cultural diversity was also mentioned as potentially a key advantage to developing a local circular food processing hub—cultural diversity is an asset for food items or parts that some cultures would typically discard (for example, chicken feet, vegetable or fruit trimmings), whereas others might find some use for them in their culinary habits.

Establishing synergies requires coordination efforts and greater transparency. A major obstacle for scaling up industrial symbiosis solutions within the local food system could be the limited transparency and awareness surrounding which food flows are available as by-products, in which form, and where. There is a need for facilitating and enabling partners to play a key role in coordinating synergies between various value chain actors. For example, the City of Richmond began collaborating with FoodMesh in 2019 to create a Richmond Food Recovery Network. That was later collapsed into the Regional Food Recovery Network.[66] Since then, FoodMesh has started bringing together local food businesses (in Richmond and other Metro Vancouver municipalities) with charities and farmers to recover unused or unsold items turning them into meals, animal feed or compost. While such initiatives look promising, conversations with local experts and stakeholders revealed that individual programmes like FoodMesh currently only scrape the surface when considering the entire FLW issue across the value chain. Greater harmonization of circular efforts will be necessary for a more connected and efficient food recovery system. The City of Richmond can play a key role in this by matchmaking stakeholders to facilitate partnerships, stimulating innovation and offering support to find industrial symbiosis solutions.

As part of the RCCS, the Circular Innovation Hub expects to contribute to catalyzing innovation in the food sector by reducing wasted materials and recovering value. The hub will focus on using "materials as alternative raw resources" to create new food products and recover essential nutrients for humans, animals, and soil. By fostering collaboration and research, the hub also aims to transform wasted materials into valuable resources, unlocking economic, social, and environmental benefits. This approach not only promotes sustainability and enhances food system resilience but also boosts innovation and supports a resilient economy.

3.2 THE BUILT ENVIRONMENT

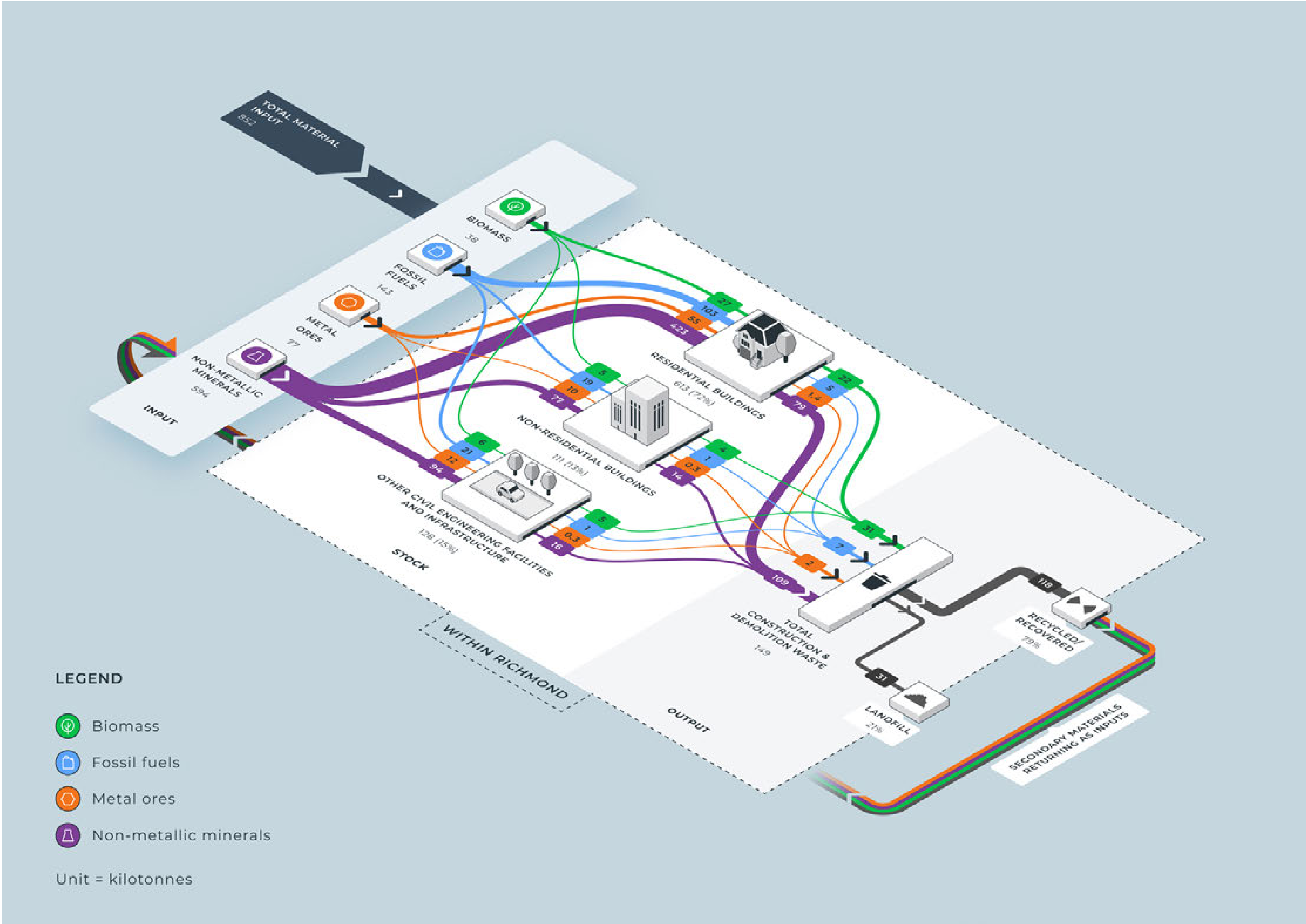
The built environment is a crucial component of a city's circular economy landscape. It determines how Richmond makes use of its land through its different building structures, road and utility infrastructure (energy, water, and sewage networks), urban spaces, and digital systems essential for the city to function.[67] In essence, it represents the human-made environment where people live and work, serving societal needs. The sector's current linear practices have significant, far-reaching impacts on the environment—including biodiversity loss, resource depletion, waste generation, GHG emissions, and pollution. In Richmond, the built environment contributes **15% (0.85 million tonnes) of the total material footprint and approximately 13% (0.5 million tonnes of CO_2e) of Richmond's overall carbon footprint.**

The need to focus on the built environment sector is emphasized in the RCCS,[68] particularly through Direction 5, "Adaptive Built Environment." This strategy emphasizes an action-oriented approach to maximize the optimal use of construction materials, buildings, infrastructure, and land. The City envisions a circular built environment with ambitious goals, such as transforming from a source of carbon emissions to becoming a carbon sink built environment, as outlined in the Community Energy and Emission Plan 2050.[69] Additionally, with the adoption of the B.C. Energy Step Code in 2018, the City aims to have net-zero energy-ready buildings by 2032.[70]

Richmond's infrastructure projects, including structural upgrades for dikes for flood defence and the development of roads, sewage, and water systems, further increase the sector's material demands. Richmond, the fourth most populous municipality of Metro Vancouver, is witnessing substantial infrastructure growth. With its population increasing 6% between 2016 and 2021,[71] demand for housing and infrastructure development has surged, making the construction sector an even more significant contributor to the city's material and carbon footprints.

As in Richmond, the built environment is one of Canada's most economically significant sectors, generating nearly 7% of the country's GDP and employing approximately 7.5% of the workforce. It is also one of the heaviest consumers of raw materials and energy, and a critical contributor to waste streams by weight. Annually, a total of 3.4 million tonnes of construction material is disposed of in landfills in Canada, resulting in an estimated 1.8 million tonnes of embodied carbon. With Canada estimated to need over $1.6 trillion in infrastructure investments between 2016 and 2040 and an anticipated 230 billion square metres of new construction over the next 40 years, if the built environment continues to rely on linear "take-make-dispose" models, the environmental and social impacts and lost economic opportunities could be substantial.[72]

Figure eight visualizes the material flow analysis of Richmond's built environment.



However, this challenge also presents an enormous opportunity. The circular economy offers significant benefits, such as increasing efficiency in the sector, adding value to existing materials, reducing material loss, and generating savings. It also opens up opportunities for new materials and methodologies to support the need for new houses and infrastructure in more vibrant and sustainable neighbourhoods. By using circular business models and collaborative partnerships, buildings in Richmond can be more sustainable. Implementing innovative products and technologies can maximize material reuse, boost secondary materials markets by offering high-quality products for new construction and renovation projects, extend building lifetimes, and maintain materials at their highest intrinsic value.

The following section aims to enhance understanding of Richmond's built environment material flows. This analysis showcases various points in the value chain, directly aligning with key actions outlined in the RCCS for an adaptive built environment. By deriving and highlighting key insights, priority is given to actions that advance circularity in the sector while generating co-benefits for Richmond's natural ecosystems and society. Various opportunities are emerging throughout the material flow analysis of buildings and infrastructure that drive the adoption of circular business practices.

CONSTRUCTION INPUTS

Around 0.85 million tonnes of materials (15% of Richmond's total material footprint) are used by the built environment yearly, primarily in the form of non-metallic minerals, which alone account for about 70% (0.6 million tonnes) of the sector's total material consumption. Large quantities of these non-metallic minerals, especially gravel and sand, are consumed as raw materials for cement and concrete production.[73] Other non-metallic minerals contributing to the material footprint include limestone/gypsum (calcium), clay, building stone, salt, slate, fertilizer, and other minerals. **Metal ores account for about 9% (77,000 tonnes) of the total material footprint**, with iron and copper ore being the major contributors.[74] Other significant metal contributors include aluminum, nickel, zinc, silver, and platinum-group metals. Uranium, lead, and tin only contribute a small portion to the material footprint. Gold is an important contributor to the total material footprint purely due to the highly intensive resources required to produce the product, rather than the quantity used in Richmond.

In contrast to these materials, **wood (industrial roundwood) and biomass (other non-timber biobased materials) comprise only 4.4% (38,000 tonnes). The remaining 17% (143,000 tonnes) is due to the use of fossil fuels in the sector**, primarily in the form of oil products and natural gas.

Understanding the sector's material footprint breakdown is key to understanding its embodied carbon emissions. The relatively smaller proportion of wood and biomass indicates **that timber-based construction has the potential to be explored at scale in Richmond's built environment sector**. In addition to biobased materials, various low-carbon alternatives significantly contribute to reducing embodied carbon emissions. Manufacturers in the sector have demonstrated the capacity to produce such alternatives at scale, as evidenced by stakeholder consultation meetings. The City government can substantially enhance these opportunities by implementing incentives and procurement strategies, such as green public procurement, to scale up adoption.

The circular economy emphasizes reducing the extraction and consumption of raw materials, with secondary materials as crucial substitutes. Although determining the exact proportion of the built environment sector's consumption sourced from secondary materials is challenging due to data limitations, stakeholders emphasized the underutilization of these resources. This underscores the potential for increased reuse of Construction, Demolition and Renovation (CDR) waste. Richmond has already successfully begun utilizing such waste flows as aggregates for activities such as asphalt and road pavement, but there are untapped opportunities for further initiatives in the same vein.

USE PHASE

This section examines the distribution of materials consumption within various segments of the built environment, including residential buildings, non-residential buildings, and other infrastructure. Here, the 'use' phase refers to the lifecycle of a built asset **between its construction and demolition phases**—mainly operation and maintenance. **Residential buildings emerge as the largest consumers, accounting for approximately 72% (613,000 tonnes) of the total material input. Non-residential buildings (industrial, commercial and institutional) follow, consuming around 13% (111,000 tonnes), while other non-building related infrastructure represents 15% (128,000 tonnes)**. Residential buildings have the most impact on material, energy and water use, and are the segment of the building stock expected to grow the most in absolute terms given population growth dynamics.[75] While population growth naturally drives increased demand for new structures, it's crucial to prioritize the monitoring and efficient utilization of existing built stock to minimize the necessity for new construction wherever feasible. **A study reveals that Canada boasts an average of 618 square feet (57.4 m^2) of living space per person, ranking third highest among major global countries.[76]** This statistic highlights the imperative of reevaluating how existing spaces are used while increasing comfort, well-being and life quality, with strategies for optimizing both the building stock and the associated land discussed in subsequent sections of this chapter.

As major drivers of resource use, buildings are **responsible for 40% of total community emissions (398,000 tonnes) in Richmond**,[77] with the majority of these emissions resulting from the use of natural gas for heating, cooling and electricity consumption. As the RCCS and the CEEP highlight, a comprehensive discussion on the use phase within the built environment sector would therefore be incomplete without addressing operational carbon emissions. While acknowledging the ample discourse on this topic within Richmond, it's worth noting that the City is at the forefront of operational carbon reduction and energy efficiency initiatives. Notably, it has integrated the BC Energy Step Code requirements into its *Building Regulation Bylaw* since June 2018. This section underscores the significance of the opportunity to improve energy efficiency in the existing built environment. This is already highlighted in the CEEP and can be achieved through retrofitting efforts in existing buildings. The importance of energy efficiency is also illustrated via the scenario modelling explored in Chapter four.

CONSTRUCTION, DEMOLITION AND RENOVATION WASTE

The built environment sector in Richmond places considerable strain on local waste management facilities. The volume of CDR waste to be handled is likely to continue to rise due to increased activity in the construction sector, which has grown to meet demand for housing. **Richmond's built environment sector generates about 149,000 tonnes of CDR waste annually**,[78] with **almost 79% (118,000 tonnes) currently being recycled** and **only 21% (around 31,000 tonnes) disposed of in landfills or incinerated.** The types of waste fractions constituting the CDR waste largely include concrete and asphalt, along with metal, glass, ceramics, masonry and other miscellaneous waste (for example, rubber, plastics, *etcetera*). The high recycling rate is attributed to the high weight and relative ease of recycling concrete and asphalt. These account for 80% of the total CDR waste recycled. The remaining 20% of the recycling rate is contributed mainly by materials such as wood, metals and gypsum.

It must be noted that a high recycling rate does not always imply that the CDR waste management complies with the fundamental principles of a circular economy. Circular models must understand the lifecycle of materials and include technical considerations that ensure materials flow through an economy in a way that minimizes environmental impact while maximizing social and economic value. Therefore, where possible and if it complies with standards, the high-value reuse of "waste" should be prioritized over lower-value recycling. For example, reclaiming and reusing a concrete structural element without subjecting it to any physical and chemical processes is an example of reuse, while crushing old concrete to be used as aggregates is an example of "recycling." Metro Vancouver introduced a "Reuse" metric in 2017,[79] which quantifies the amount of waste that is reused rather than recycled or disposed of. Richmond has initiated a process to update the *Demolition Waste and Recyclable Materials Bylaw* (No. 9516) in collaboration with other peers and stakeholders aimed at increasing the recycling rate of CDR materials and integrating more high-value reuse applications for secondary materials by developing the secondary materials market. The City, in collaboration with the construction sector, could coordinate efforts to research and develop a new understanding and processes to maximize high-value material recovery, improving the necessary metrics and reporting already requested in the bylaw, that support the business opportunity for CDR materials. Additionally, exploiting the learnings and success of the demolition bylaw specifics for single-family homes, the regulation can now be expanded to include multi-family units as well as the institutional, commercial and industrial buildings, therefore increasing the volume of CDR waste and materials that could potentially be salvaged, reclaimed and used in new projects.

The City's pilot projects on Recycled Asphalt Pavement demonstrates the economic and environmental potential for high recycling rates and the role of material recovery facilities and industrial symbiosis in mitigating net carbon emissions. Such facilities could further be explored to increase the high-value reuse of construction materials, products and elements. CDR waste will continue to be abundant into the near future and all industry players will have a role to play in reducing the volume of materials sent to landfill. Local waste management companies need to develop strong partnerships with other industries to optimize material flows via practices such as industrial symbiosis and a well functioning secondary materials market. To catalyze this process, the City and its partners can provide industry incentives through policy approaches.

The material flow analysis reveals that, in Richmond, wood waste constitutes about 19% (27,800 tonnes) of the total CDR waste generated and has a recycling rate of around 47%. This recycling rate is largely attributed to dimensional lumber, pallets, wood shakes and shingles. However, stakeholder validating meetings stated that a significant amount of wood waste, for example, from older single-family housing units primarily made of wood, is not being recovered and utilized at its highest value. Instead it is often used for lower-value applications as fuel or shredded into wood fibres for filling. This contradicts circular economy principles and results in higher waste management costs and the loss of opportunities for tapping into alternative sources of affordable secondary materials. Currently, wood poses significant challenges to recycling efforts, with dimensional lumber proving particularly difficult due to the need for re-grading when repurposed for structural applications. Instead, it is often relegated to lower-value uses like fuel or landfill cover. Traditional wooden buildings—designed without reuse in mind—further complicate the recycling process. There is a pressing need to explore innovative approaches to designing new wooden buildings with reuse as a central consideration, as well as expand the demolition bylaw to other sectors to ensure high-quality materials are being efficiently managed (i.e. reuse as opposed to recycling).

SHIFTING TO A CIRCULAR BUILT ENVIRONMENT

This section explores three important interventions for the accelerated transition toward a circular built environment. In a circular economy framework, additional phases are introduced between these two endpoints, including renovation, adaptive reuse, retrofitting, and repair—essentially any activity that prolongs the use of the built asset until the end of its technical lifecycle. These scenarios align seamlessly with the RCCS for an adaptive built environment, which focuses on championing circular business models and collaborative partnerships. Through the adoption of cutting-edge technologies and strategies, Richmond's buildings can amplify sustainability by maximizing material reuse and extending their lifespan. Monitoring tools play a crucial role in ensuring resource efficiency across the construction lifecycle, tracking material flows, carbon footprints, and resource use. The transition toward a circular economy demands innovative solutions to enhance the flexibility and efficiency of both existing and new structures. Incorporating circular principles into design, operation, and maintenance means that buildings can be readily adapted, employ renewable materials, and facilitate thorough deconstruction when necessary. This approach signifies a natural progression from the comprehensive methodologies already embraced by urban planners, architects, and engineers, marking a significant stride toward a circular built environment.

1. **Optimize the use of existing and new buildings;**
2. **Encourage low-carbon, energy-efficient buildings; and**
3. **Shift to resource-efficient building practices.**

1. Optimize the use of existing and new buildings

The anticipated population growth in Richmond is projected to result in the addition of more than 28,000 new housing units over the next 20 years.[80] This rising demand for housing, coupled with a shortage of buildable land and sky-high property values is putting significant pressure on housing supply and fuelling region-wide

redevelopment of single-family homes into denser multi-family housing.[81] Addressing these challenges while simultaneously achieving the larger decarbonization goals put forward by the City is a challenge. Municipalities across the province are responding to this demand for new construction by implementing policies and zoning bylaws that densify neighbourhoods, with the aim of optimizing the city's expansion. **Recently, the Government of British Columbia also announced legislation overriding municipal zoning to allow up to four homes on single-family detached lots.[82] This presents a great opportunity for the city to increase land use efficiency.**

An alternative viewpoint involves examining the utilization of the current built infrastructure before delving into new construction. **The City should explore the prevalence of vacant homes, assess the feasibility of subdividing larger residences into multiple smaller housing units, and consider adapting existing non-residential buildings for residential purposes.** Prioritizing adaptive reuse and repurposing of buildings, along with extending their lifespan through refurbishment, renovation, and disassembly for reuse, should progressively become the norm in a circular economy.

Exploring the efficient utilization of existing land and buildings, alongside innovative ownership models, contributes significantly to optimizing land and building stock usage. Housing affordability challenges in Richmond underscore the need for such approaches, with a 12% increase in the British Columbia housing waitlist since 2019.[83] The disconnect between real estate pricing and intrinsic value often stems from prevailing economic models, in which environmental costs remain externalized. However, aligning profit maximization with circular principles can be achieved by internalizing environmental costs and transparent tendering processes. Community Land Trusts (CLTs) offer a promising solution by acting as non-profit landowners, facilitating long-term lease agreements and sustainable land use planning. Historical precedents, like the CLT established by the Co-operative Housing Federation of British Columbia in 1993,[84] exemplify the potential for collaborative efforts in advancing circular affordable housing.

While maximizing use of the existing building stock should be the priority when addressing urban development needs, new construction is unavoidable to a certain degree. In this case, a sufficiency-based approach to expanding the building stock should be taken. For example, if there is a need to sanction new construction projects, the focus should be on using less virgin materials and embracing diverse inputs coming from secondary sources—for example, by building using 3D-printing technology that uses secondary CDR materials as inputs.[85] Considering that Richmond's built environment sector has high collection rates of CDR waste, measures that prescribe the substitution of virgin materials with secondary materials could be both feasible and beneficial. These could reduce the construction sector's material footprint, along with its associated costs and volume of imported materials for the sector, while creating demand for secondary materials and thus incentivizing and enabling circular practices. In this regard, the RCCS' *Adaptive Built Environment Strategic Direction* includes different relevant action points emphasizing the importance of promoting and investing in recovering material flows. This can be done by more efficiently utilizing salvage and secondary materials as well as less resource-intensive materials for new builds. The City could encourage these practices by researching and developing, or incentivizing, pilot projects to prove successful business cases.

2. Encourage low-carbon, energy-efficient buildings

Existing buildings in Richmond contribute to 40% of total community emissions (398,000 tonnes), mainly from natural gas usage for heating, cooling, and electricity. Richmond leads in operational carbon reduction, integrating BC Energy Step Code requirements since June 2018. Richmond has also started emphasizing the importance of embodied carbon in the building design phase, by working with industry stakeholders to increase the use of construction materials with low embodied carbon content.

Richmond aims to cut over one million tonnes of GHG emissions by 2050 through district energy systems managed by Lulu Island Energy Company. Retrofitting existing buildings is a priority in Richmond's CEEP. Namely, the City plans to accelerate deep energy retrofits to existing residential and ICI buildings, and shift to low-carbon heating and cooling by using in-building systems or district energy. Additionally, all new buildings will be serviced by low-carbon energy systems and built to the top performance level of the BC Energy Step Code by 2027. Targets include a 70% GHG reduction from buildings by 2030.

While these initiatives support a sustainable, low-carbon built environment, there is currently limited focus on embodied carbon in the built environment. Circular economy strategies explicitly address this gap by emphasizing the importance of considering embodied carbon emissions from retrofit measures. While Richmond is now focused on reducing embodied carbon in new construction projects, considerable benefits can also be derived from extending embodied carbon reduction actions to renovation and retrofit projects as well. For example, retrofit measures sometimes can cause an increase in embodied carbon emissions, even though the retrofits may reduce operational emissions. Therefore, it is important to consider both operational and embodied carbon emissions associated with projects to fully understand the entire carbon lifecycle.

Examples of circular strategies capable of reducing the embodied carbon of buildings include **utilizing biobased materials for insulation[86] and integrating secondary materials in retrofitting solutions. Circular business models**, like offering façade-as-a-service[87] or implementing take-back systems for heat pumps, are significant opportunities. Stakeholders such as homeowners should also be given the due responsibility and opportunity to make relevant decisions around energy retrofitting. For example, **introducing Building Renovation Passports[88]** could provide property owners with the information and direction needed to enhance their properties and lower emissions. These include a digital record of renovations specific to a property, detailing its historical and current data regarding construction and operational performance. They also outline a long-term renovation plan to decarbonize the property, providing connections to contractors, service providers, and financing options.

3. Shift to resource-efficient building practices

Richmond foresees a substantial surge in construction activity, **offering a prime opportunity to experiment with and implement circular design principles, create innovative circular products and adapt prevailing building regulations, standards, and frameworks.** Building a circular built environment requires a fundamental shift in how construction is approached from the project's inception to completion. Traditional practices must evolve at every stage to prioritize resource efficiency and sustainability. Embracing a whole lifecycle analysis of built assets is crucial to track and optimize the value of materials, ensuring they are retained at their highest value before being discarded as waste. Integrating circular design principles is integral to the sector's transformation. Architects and design engineers play a pivotal role in this space, and should endeavour to make principles like design for deconstruction, adaptability or reuse the standard in future projects. **Innovative practices like material passports, digital twins, and materials exchange markets also need to be explored and implemented in the sector.**

Richmond's emphasis on CDR waste management is commendable. **Yet, alongside managing waste, equal attention must be given to design and construction practices as the next step.** Proactive measures like the ones described in this section are currently being discussed in Richmond to complement efforts to manage CDR waste and create a circular built environment in the future.

Considerable impacts can come from updating the *Demolition Waste and Recyclable Materials Bylaw (No. 9516)* to promote new practices and include more building types. Richmond can focus on introducing circular design principles such as design for disassembly or reuse, monitoring material efficiency, implementing product certifications to enhance reliance on recycled or reused materials, and streamlining processes to eliminate bureaucratic hurdles. Richmond has taken important steps to incorporate circular economy principles in its procurement activities: it's the first municipality in Canada to have introduced a circular procurement policy (February 2021).[89] If harnessed effectively, public procurement stimulates demand for circular construction products, encouraging an equitable market for secondary materials and innovative circular products. Establishing metrics and indicators for monitoring and evaluating circular procurement progress will be key to ensure the potential of circular procurement in this area is effectively adapted and leveraged. The development of a secondary resource market has also been emphasized as a very important measure from multiple stakeholders. This measure is also connected to the increasing demand for soil for both traditional construction works and the implementation of the Dike Master Plan, which will require considerable amounts of soil in the near future.[90] Circular strategies in this field, employed to efficiently manage the available soil along with other similar resources, can reduce pressures on resource demand while offering economic opportunities (see text box on pages 52–53). **The study also reveals that concrete manufacturing plants in the city have substantial potential to produce and supply materials using recycled materials, yet limited demand hampers manufacturing activities.**

In addition, **practices such as integrating circular procurement policies in public tenders drives demand for circular projects and thus fosters the demand for circular skills.** Recognising and addressing the skills gap and mindset shift required for circular initiatives is essential. Education and training programs funded at national and local levels can play a significant role in this transformation. The RCCS and CEEP state the need to develop the sectoral capacity and required skills to enable a circular transition. Targeting the City government officials responsible for approving building permits and professionals overseeing quality assurance during implementation is a crucial first step.

Through concerted efforts across education, procurement, and workforce development, Richmond can pave the way for a truly circular built environment that maximizes resource efficiency and reduces material consumption.

FLOOD PROTECTION, DIKES AND THE ROLE OF A CIRCULAR ECONOMY

Context

The City of Richmond, nestled in the floodplain of the Fraser River,[91] faces complex challenges due to its geographical location and the ever-present threat of rising sea levels. Lulu Island, home to Richmond's urban core and significant agricultural areas, relies heavily on an extensive, 56 kilometre-long dike system to safeguard against potential flooding. Anticipating the challenges posed by climate change, the City of Richmond has adopted forward-thinking measures, integrating an assumed 1-metre rise in sea level by 2100 and 2-metres by 2200 into current perimeter dike designs. As residential, commercial, and administrative nodes continue to flourish, particularly in West Richmond, the need for ongoing monitoring and flood mitigation planning is becoming increasingly vital to mitigate potential damage from future flood events.

Retaining the economic value of excavated materials provides an opportunity for dike enhancement:

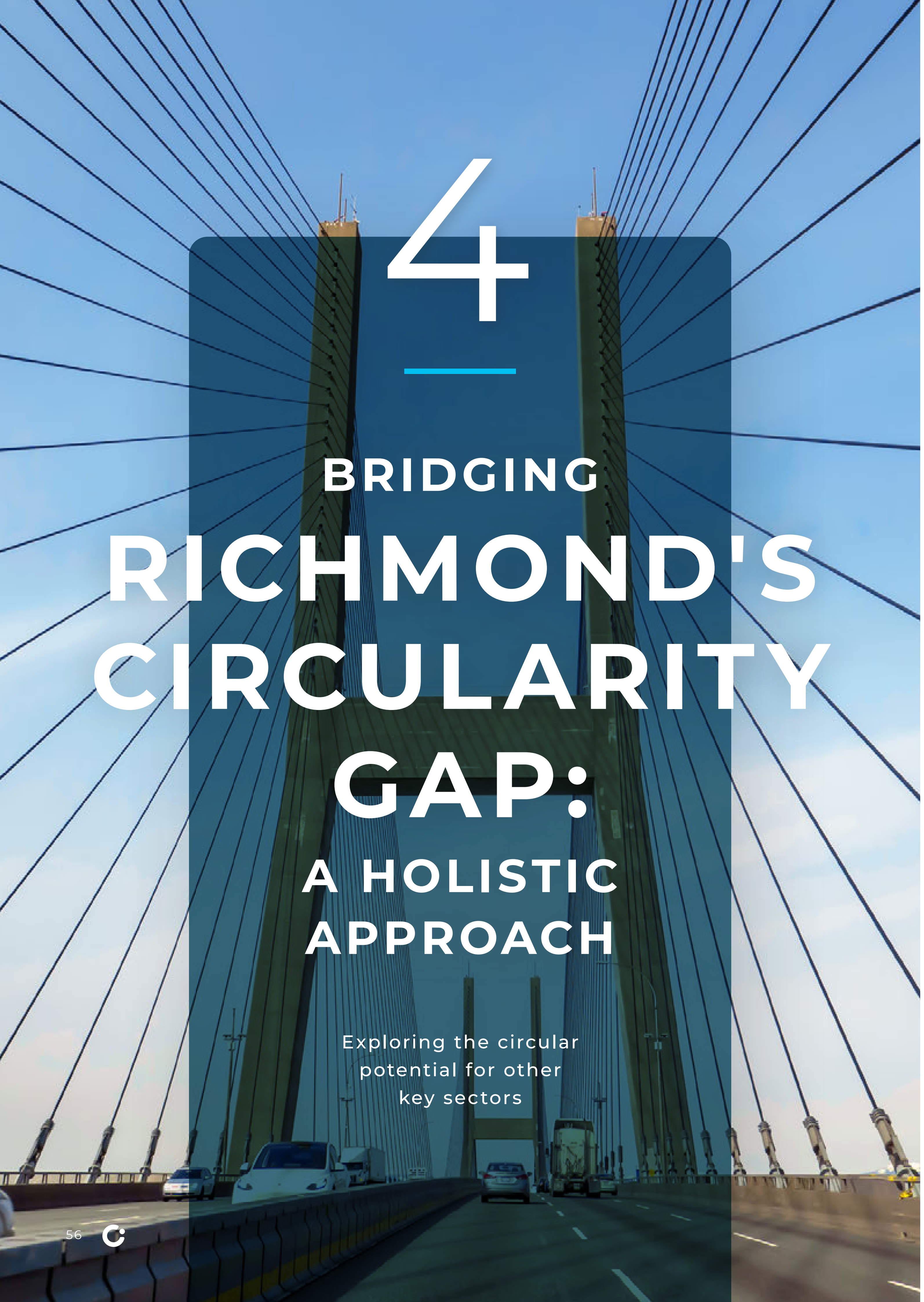
The scale of the dike enhancement project calls for an enormous amount of material consumption in the form of bulk fill as well as reinforcement materials such as concrete and steel. These materials need to be procured from virgin resources. Bulk fill can often be substituted with excavated soil from other building and infrastructure projects, reclaimed aggregates and gravel or recycled concrete, thus retaining the economic and residual value of these materials. In an effort to reduce reliance on new materials, the City's dike enhancement initiative has already incorporated the reuse of various existing materials, including: recycled road base and sub-base, type 2 dike bulk fill, and topsoil.[92] Currently, the City does not have a clear indication of the volume of extracted soil or other reusable bulk-fill materials specific to dikes due to a lack of data. From the material flow analysis, about 1,835 tonnes of rubble and soil is currently being disposed of in the landfill. There is potential to redirect these material flows and substitute the virgin material used in dikes and present it as a pilot initiative for circular business models in dike infrastructure projects.

Case study from the Netherlands: Advancing circular economy in dike reinforcement with sludge-based cladding stones

Water board Scheldestromen, responsible for dike safety in the Zeeland region of the Netherlands, is embarking on a groundbreaking dike reinforcement project near Hansweert. In collaboration with innovation partner NETICS (sediment engineering company), Scheldestromen is exploring the use of dredging sludge to create sustainable cladding stones for dike protection. The Hansweert dike, a primary water defence system, requires reinforcement to meet the new safety standards. To address this challenge, Scheldestromen aims to incorporate circular economy principles and aspires to be fully circular by 2050. The focus is on reducing environmental impact, particularly in the production and transport of cladding stones. It carried out the following circular economy strategies and technological innovations:

- **Local Sourcing and Reduced CO_2 Emissions:** Traditional cladding stones often come from distant quarries. Scheldestromen aims to use dredged sludge from the immediate vicinity, minimizing the need for transportation and reducing the project's carbon footprint. By utilizing NETICS' technology, the need for traditional concrete production is eliminated. The dredged material is transformed into cladding stones directly on-site, significantly lowering the CO_2 emissions associated with transportation and manufacturing.
- **Reuse and Recycling:** The innovative GEOWALL cladding stones made of dredged material are designed for easy reuse. This contributes to a closed circular chain where no waste is generated, aligning with Scheldestromen's commitment to sustainability.
- **Innovation and Collaboration:** Scheldestromen's collaboration with NETICS exemplifies a commitment to innovation. NETICS' patented GEOWALL technology creates high-quality construction elements from low-grade dredging waste, fostering a circular economy approach.
- **Stabilization Methods and Pilot Starch Testing:** The project involves thoroughly researching stabilization methods for dredged material. Biological, physical, chemical, and mechanical stabilization techniques are explored to improve the environmental and geophysical quality of the sludge. Practical tests and pilot starch testing are crucial in determining sludge-based cladding stones' feasibility. The tests evaluate strength, durability, erosion sensitivity, and other properties to ensure the stones' suitability for large-scale implementation.

The innovative sludge-based cladding stones have the potential to revolutionize dike reinforcement projects. If successful, this circular economy approach could be applied to various infrastructure projects beyond the Netherlands, contributing to global sustainability efforts.



4

BRIDGING RICHMOND'S CIRCULARITY GAP: A HOLISTIC APPROACH

Exploring the circular potential for other key sectors

Drawing from the baseline analysis, Richmond's most resource- and carbon-intensive sectors are construction, agrifood and manufacturing. After investigating two of the key sectors of Richmond's economy, agrifood and the built environment, and exploring potential pathways for change, it is important to focus also on manufacturing activities within the city. Manufacturing consumes the largest amount of non-metallic minerals and is associated with considerable GHG emissions.

For this reason, transforming the manufacturing sector is crucial and can be facilitated through leverage points across the value chain. In addition to manufacturing, the mobility sector also requires special attention, as demonstrated by the baseline analysis in Chapter two. Similar to most urban environments, Richmond has a complex and highly active mobility system associated with significant carbon emissions.

This chapter explores circular scenarios, ultimately sketching a future for more circular manufacturing and mobility sectors in Richmond. The manufacturing sector has two separate scenarios: manufacturing from a supply perspective ("Circular Manufacturing" scenario) and manufacturing from a demand perspective ("Circular Consumer Goods" scenario). The "Circular Mobility" scenario explores a redesigned mobility system, defined by circularity and sustainability principles.

4.1 CIRCULAR MANUFACTURING

Richmond is an industrialized city with an advanced manufacturing sector covering different activities. It follows a similar trend to British Columbia more broadly, which has had one of the fastest growing manufacturing sectors in Canada (in terms of GDP percentage).[93] Richmond's manufacturing sector produces goods for both domestic and international markets. The sector comprises traditional industries like wood and paper product manufacturing as well as highly advanced applications such as clean energy systems, telecommunications equipment and green building materials, along with food processing companies and consumer product packaging makers. There are more than 700 manufacturing companies located in Richmond.[94]

The highly advanced manufacturing sector is the most material- and carbon-intensive sector in Richmond, as demonstrated in Chapter two. Despite its prevalence in Richmond, the manufacturing sector's footprint is relatively difficult to reduce compared to other sectors, because not all products used in Richmond are manufactured within the city. Therefore, measures taken by Richmond do not necessarily affect the whole value chain of such products. Since Richmond cannot actively intervene in processes outside of its borders, the focus in the RCCS has turned to the parts of the value chain that can be influenced by the City and its residents.

In this sense, the RCCS emphasizes the importance of integrating circular manufacturing principles into current business models and fostering cross-sector collaboration. The RCCS's strategic direction of fostering a resilient and innovative economy aims to build businesses' capacity to adopt circular business models and implement R-strategies (such as reuse, refurbishment and redesign) in their daily processes while fostering knowledge sharing and awareness raising. This can be done through circular innovation hubs and the on-the-ground implementation of case studies and pilots.[95] Moreover, circular manufacturing-related actions, including R-strategies, take the form of overarching principles in the RCCS. Some concrete examples are related to mobility and built environment, where circular manufacturing principles can greatly impact current processes.

Advancing circular manufacturing can support Richmond companies' competitive advantage and allow them to tap into fresh market opportunities while reducing their operational costs and generated waste. Specifically, establishing more efficient resource management, promoting local products, fostering collaborative and symbiotic relations between stakeholders, and adopting a lifecycle approach can benefit businesses and the sector holistically. Additionally, Richmond's geographical position and proximity to different sea and air transportation modes provide an opportunity to share best practices and reform the sector's value chain. Richmond can further leverage existing expertise and governmental support for research and innovation to foster the transition, while focusing on promoting sustainable products, closing material loops and making the economy more resilient.

In this context, the "Circular Consumer Goods" scenario follows the same direction as the RCCS. The envisioned goal is a circular manufacturing sector for Richmond, where design optimizes product lifetimes, components are reused at their highest value and in which current modes of production and sales radically change where possible.[96] To this end, this scenario includes the two interventions described below:

4.1.1 ADVANCE RESOURCE-EFFICIENT MANUFACTURING PROCESSES

This scenario's first intervention centres on adopting cutting-edge technologies to improve manufacturing's material efficiency—both during the initial stages, where materials are formed, and in the final stages, where products are created (the creation of machinery and electronics, for example) and at the end of their lifecycle (once vehicles reach their end of life, for example). Metals are key material inputs for manufacturing processes that drive demand for other materials, such as fossil fuels for energy purposes. Reducing the need for key industrial metal inputs—such as steel, aluminum and others depending on the manufacturing company—by improving production processes will serve to flows, not only for metals but also subsequent resources such as fossil fuels. This scenario also envisions industrial symbiosis principles implemented at scale. Hence, businesses can leverage collaboration and ensure the beneficial use of byproducts and other similar materials, through their proximity to other businesses and knowledge sharing. This will also serve to increase their material efficiency. Gains in material efficiency should be integrated into the early stages: cutting yield losses involves making the most of technological advances to get more from less. Further along the value chain, where metals will be used to make equipment, for example, process improvements will bring similar benefits. Reducing scrap material—a by-product of standard procedure—would also boost efficiency and reduce the need for virgin material inputs, further **narrowing** flows. All unavoidable scrap can also be reused, **cycling** flows.

4.1.2 EXTEND PRODUCT LIFETIMES THROUGH VARIOUS R-STRATEGIES

Richmond can advance its circular economy transition by focusing on practices higher up the strategy hierarchy, such as remanufacturing, repair and reuse. Remanufacturing and refurbishment practices can be leveraged to extend product lifetimes, **slowing** flows. Richmond could also benefit from a shift to more circular supply chains, using leasing or other Product-as-a-Service (PaaS) systems as an alternative to ownership-based models. In an ownership-oriented system, the aim is to maximize the number of products sold. PaaS circumvents this and therefore contributes to **narrowing** flows. Incorporating circularity in the early phases of design, both at the process and material levels, will also be crucial to enable high-value and value-retention circular processes.

4.2 CIRCULAR CONSUMER GOODS

Canada has the fourth largest ecological footprint in the world, indicating highly unsustainable material consumption patterns.[97] This becomes clear when looking at the lifestyle and consumption patterns of products like electronics, textiles and plastics, which are among the fastest-growing waste streams in Canada.

Canada's e-waste has more than tripled in the last two decades, and the increase is expected to continue.[98] In Metro Vancouver, while e-waste currently only represents 2% of total waste per capita by mass, this is steadily growing.[99] Richmond is following the same trend: its strong IT sector combined with its increasing population and economic development facilitates higher electronic consumption.[100]

Similarly, Canada is one of the top importers of new clothing in the world.[101] The consumption of textiles and apparel products constitutes a key activity for Metro Vancouver, with textiles representing one of the fastest-growing waste streams and over 2% of the region's garbage.[102] From the total amount of discarded clothes, the vast majority (up to 95%) could be reused, repaired, or recycled.[103] However, the volume of recycled textiles is less than any other material tracked.[104]

Plastic consumption is also comparatively high in Metro Vancouver, being the second most common material in the region's household waste stream.[105] For the inner municipalities, including Richmond, plastic waste has been increasing over the last years, with single-use items like retail bags, disposable plastic cups and takeout containers contributing an important share.[106]

Even though e-waste and textile waste comprise a small percentage of the total waste by mass (2% each), it is important to account for their high environmental footprint. Such products require a considerable amount of resources and energy, and are associated with considerable chemical pollution at their end-of-life stage, potentially impacting all different kinds of ecosystems, causing problems for multiple organisms, and contributing to biodiversity loss. Similarly, plastics constitute one of the largest environmental pressures in the world.[107] On the other hand, there are significant opportunities yet to be exploited around valorising electronics, textiles and plastic waste through the direct reuse, repair and recovery of valuable minerals.

Richmond has already started taking measures to tackle the problems caused by these waste streams and tap into the missing potential.[108] An important example is the *Single-use Plastic and Other Items Bylaw* adopted in 2021.[109] Additionally, Richmond has recognized the need for better waste management and has been investing in methods to divert waste from landfill with strong results.[110] While these measures have positively contributed to improving the situation, they have not alleviated the pressures completely.[111, 112]

While improving waste management is key, circular economy strategies hold significant potential to reduce the consumption of these impactful product categories. Emphasis should now be placed on waste avoidance efforts by moving toward responsible consumption, shifting consumer patterns, and promoting more sustainable and sufficiency-based lifestyles. The RCCS's consumer material management direction is aligned with this goal and emphasizes that recycling should only be considered as a management option when reuse, refurbishment, remanufacturing, and repair are not viable. Important points of action include raising awareness through education and promoting behaviours like reuse by establishing repair and reuse centres, coupled with boosting innovation and collaboration among stakeholders from different fields—including academia, businesses and consumers—to meet the necessary systemic change and support these behaviours.[113]

Aligned with the RCCS, this scenario's only intervention models the potential impact of embracing a sufficiency-based[114] lifestyle transformation related to consumer goods in Richmond:

4.2.1 EMBRACE A "MATERIAL SUFFICIENCY-BASED" CIRCULAR LIFESTYLE

A range of circular strategies can contribute to minimizing raw material demand, hence **narrowing** flows, encouraging Richmond's residents to use products for longer, thereby **slowing** flows, and using more sustainable alternatives and recycling as much as possible, **regenerating** and **cycling** flows. Cutting the number of consumables in circulation—**narrowing** flows—is the most impactful strategy. To achieve more circular, sufficiency-based lifestyles, excessive consumption and the constant pursuit of material possessions must be avoided. Instead, new ownership models should be embraced, along with repair schemes and other similar circular practices to reduce the consumption of new products on the market. Applying these strategies to plastics, electronics, and textiles will be key to fully embracing a sufficiency-based circular lifestyle. Therefore, this scenario considers the promotion of new circular consumption behaviours and material use, the establishment of upcycling infrastructure for consumer goods and materials and the overall reduction of electronics, textiles and plastic consumption through circular practices. These could include sharing schemes and the prioritization of durable goods, product-as-service, reuse and repair.

4.3 CIRCULAR MOBILITY

In Canada, domestic transport-related emissions are steadily increasing, with road transport making an important contribution.[115] This stems partially from a turn toward more carbon-intensive vehicles, such as bigger passenger cars.[116] Similarly, in Richmond, the majority of GHG emissions are emitted by vehicles.[117] To counter this, the Government of British Columbia is promoting zero-emission vehicles through a number of measures: while this has resulted in the province having one of the highest uptake rates in Canada, further action is needed to alleviate pressure from the mobility sector.[118]

Richmond has an extensive transport infrastructure network and is characterized by heavy car use.[119] Following the Provincial Government's direction, the City is actively working toward reducing mobility-related emissions through investments in infrastructure to increase walking and biking, facilitating electrical mobility for all residents and businesses and promoting green mobility options. For example, already-set goals include significantly increasing the use of public transit, walking or cycling and cutting light duty vehicle emissions 50% below 2017 levels and heavy-duty vehicle emissions 33% below 2017 levels before 2030.[120, 121]

Richmond's priorities lie in enhancing public transit accessibility, promoting sustainable options and expanding infrastructure like bike lanes to shift the city's modal split. Special attention has been dedicated to transitioning the urban fleet toward "green" operations, boosting the adoption of electric vehicles and facilitating easy charging. On top of these measures, outreach programs further aim to raise awareness about sustainable transportation.[122]

The RCCS's shared mobility strategic direction consolidates and complements the existing measures, outlining key actions to achieve the already-set goals and create a circular mobility sector. Emphasis is put on minimizing miles travelled, promoting shared mobility and mobility-as-a-service options, and reducing the sector's material intensity by optimizing material use and minimizing waste.[123]

Aligned with the RCCS and CEEP, this scenario provides a reimagination of transport and mobility in Richmond by modelling two interventions:

4.3.1 REDUCE DISTANCES TRAVELLED AND SHIFT THE PREFERRED MODES OF TRAVEL

Ensuring the optimization and decarbonization of all transport across Richmond will require broader and more systemic change. This scenario's first intervention explores the benefits of decreasing or avoiding the kilometres travelled or the need for travel by rethinking the mobility system and the community's travel reasons. This will require Richmond to facilitate the implementation of integrated mobility sharing infrastructure and "mobility-as-a-service" solutions. Additionally, Richmond can reduce distances by increasing access to co-working spaces and exploiting digital solutions and virtual services so that individuals continue to embrace workplace flexibility where possible. Doing so could cut the need for private car use and fuel consumption, both serving to **narrow** flows.

4.3.2 DRIVE CLEANER MOBILITY FORWARD

While the main focus should be on rethinking Richmond's mobility system, and reducing or avoiding unnecessary car travel, clean new technologies are also needed. This intervention comprises several strategies that tackle the production and use phases of vehicles. The RCCS includes action toward reducing the use of virgin materials in the mobility system, which can be achieved through small(er), more lightweight, fuel-efficient vehicles to **narrow** material flows. Moving toward the future, all new public and private transport vehicles should be electric: this would cut fossil fuel use, and **narrow** and **regenerate** flows if the vehicles are powered by renewable energy. Richmond's CEEP emphasizes the importance of electrification, since most of the province's electricity comes from renewable sources. It is worth mentioning the need to take a balanced approach when looking at environmental impacts from a lifecycle approach. For example, while entirely electrifying the current mobility system will result in carbon footprint reductions,[124] it could also come with great challenges, such as the rising demand for critical materials, concerns about accessibility, or equity issues due to generally higher acquisition costs.[125] In mitigating the environmental footprint of electric vehicles in the future, leveraging green electricity, optimizing vehicle weight, developing battery technologies free from critical raw materials, ensuring supply chain due diligence, and meeting efficiency standards emerge as crucial strategies. This is why this intervention must be understood in the context of the previous one. Namely, a substantial shift in modal split and reduction in vehicle use can mitigate negative trade-offs and knock-on effects with which a completely electric fleet could be associated.

THE IMPACT OF COMBINED SCENARIOS

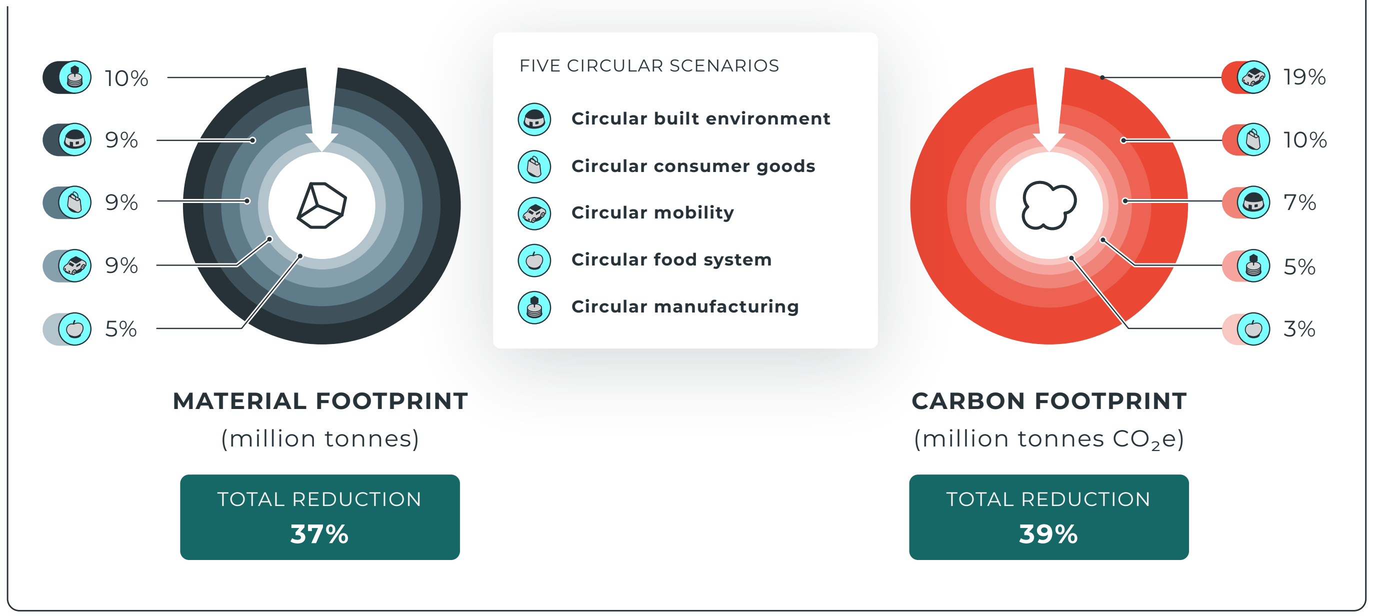
Implementing a circular economy in Richmond can yield a wide array of co-benefits spanning environmental, economic, and social dimensions. While the scenario modelling captures the potential reduction of Richmonds' material and carbon footprints—two strong proxies for measuring environmental impacts—the circular interventions described can also have positive co-benefits. **Environmentally**, it can enhance biodiversity protection by reducing habitat destruction and pollution, and contribute to cleaner air and water through minimized waste and emissions. **Economically**, it can foster innovation, create new business opportunities, and boost local employment through recycling, repair, and remanufacturing industries. **Socially**, it can improve public health by reducing pollution-related diseases, enhance community resilience through local resource utilization, and promote social equity by creating inclusive job opportunities. These combined benefits can lead to a more sustainable and resilient Richmond.

MATERIAL AND CARBON FOOTPRINT REDUCTION POTENTIAL

The effectiveness of the proposed interventions is truly evident when combined. Current levels of material consumption and GHG emissions reflect the pressures on the planet's life-support system, making their reduction a key strategy for easing this environmental burden, benefiting both Richmond's economy and its people. Increasing materials' circularity—by replacing raw materials with secondary ones—is one method to reduce overall material and carbon footprints. However, reducing overall material demand has an even greater impact on lowering these footprints with fewer interventions. The scenario analysis is useful for illustrating the limits of cycling in reducing material consumption.

By harnessing cross-intervention synergies, Richmond can cut its material footprint by a remarkable 37%, reducing it from 5.5 million tonnes to 3.5 million tonnes. On a per capita basis, the material footprint could be reduced from 26 tonnes to around 16.4 tonnes per year. The combined scenarios also offer potential for deep emissions reductions: the carbon footprint could decrease by 39%, reducing it from 4 million tonnes of CO_2e to 2.5 million tonnes of CO_2e, or 11.6 tonnes of CO_2e per capita.

MATERIAL & CARBON FOOTPRINT REDUCTION



CIRCULARITY POTENTIAL

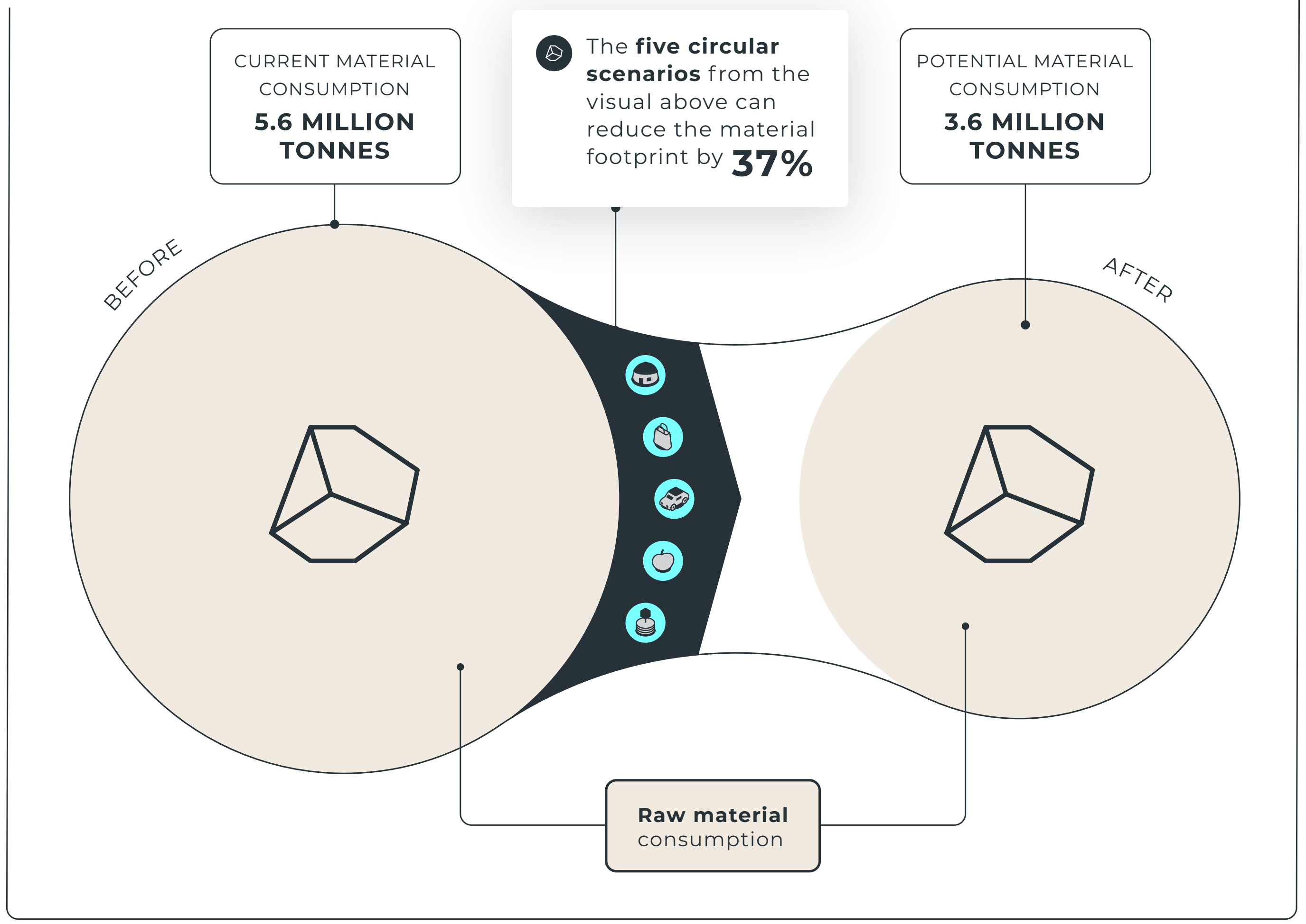


Figure nine shows the combined scenarios' impact on Richmond's material and carbon footprints.

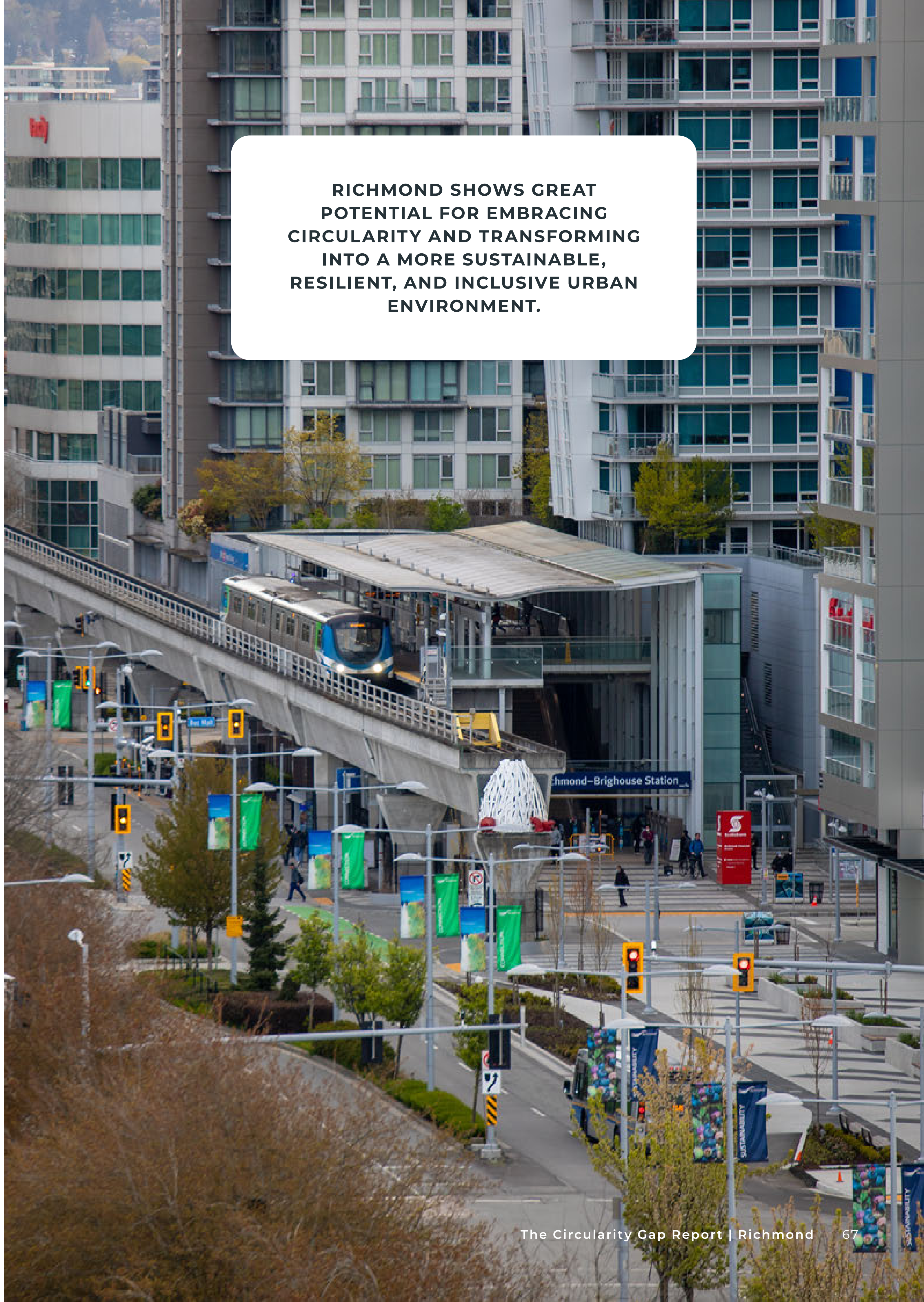
COMMUNITY CO-BENEFITS

Advancing a circular economy in Richmond can yield numerous additional co-benefits for the local community by:

Enhancing biodiversity protection, improving air and water quality, and contributing to healthier soils and flourishing natural ecosystems. For example, circular mobility can result in nature-based solutions and increased green areas by repurposing the urban spaces currently used for private cars, such as parking lots. The RCCS aims to maximize natural ecosystems by enhancing local sustainable farming practices and promoting a circular lifestyle that fosters a positive relationship with nature. As Richmond's residents and businesses adopt this lifestyle and embrace community-based solutions, there will be more opportunities to preserve and improve green infrastructure within the city such as parks and natural spaces.

Fostering innovation, building resilience and creating new business opportunities. The circular economy can create new opportunities for the City to support local businesses and industries by increasing the consumption of local products. The City can promote the creation of new circular economy business models, whether related to local food production, reuse of construction materials, building retrofitting and in sectors like recycling and repair. With more local production and consumption, Richmond can also experience increased local employment, reduced importation costs, and greater resilience against supply chain disruptions and price volatility. A circular food system stimulates new business models that capitalize on circular food production and processing. Business models may include innovative concepts, from circular kitchens to more efficient food waste management, creating new employment opportunities and encouraging collaboration with local farmers, increasing food affordability. Besides creating a healthier urban environment, improving interregional and intercity connectivity with green mobility options can provide economic benefits by boosting regional productivity and encouraging multiple economic centres.

Promoting more sustainable and community-centred lifestyles. Enhancing connectivity and interaction within the community emerges as a significant co-benefit, fostering a stronger sense of unity and collaboration among residents. By promoting sustainable circular practices, Richmond's community can build resilient networks that support more sustainable and community-centred lifestyles, ultimately creating a more cohesive and vibrant urban environment. For example, a flexible, hybrid mix of co-working spaces and office time could positively influence productivity, health and wellbeing, while bringing social benefits. A more circular approach to consumer goods enhances community wellbeing and inclusivity by supporting local businesses, creating new job opportunities, and reducing the cost of living through access to durable, second-hand products. Public health is improved by reducing pollution-related diseases and encouraging active lifestyles through sustainable mobility options.[126]



RICHMOND SHOWS GREAT POTENTIAL FOR EMBRACING CIRCULARITY AND TRANSFORMING INTO A MORE SUSTAINABLE, RESILIENT, AND INCLUSIVE URBAN ENVIRONMENT.

5 THE WAY FORWARD

Call to action

Following the RCCS, this analysis represents one of the key steps in Richmond's circular transition. By prioritizing impactful actions and focusing on system-level changes, Richmond can substantially reduce its material and carbon footprints. The following recommendations for advancing a circular economy in Richmond are the result of industry research and interactions with community stakeholders during the engagement roundtables conducted as part of this project.

CIRCULAR FOOD SYSTEM

Richmond has the unique potential to develop a resilient, localized and efficient food system by:

- **Consolidating local production and diversifying agricultural practices.** This can increase the city's self-sufficiency by leveraging existing strengths and employing new practices including nature-based solutions.
- **Promoting the consumption of local and seasonal products**, strengthening the local food value chain while creating socioeconomic and environmental benefits.
- **Reducing food waste** by changing the culture and practices associated with wasting food, making the food system considerably more efficient and creating added value for Richmond.

To achieve these actions, it will be essential to secure farmers' livelihoods. Supporting farmers through easy access to land and stable revenue streams, which are currently at risk, is crucial for sustainable local production. The City can provide support by:

- **Encouraging alternative forms of agriculture** to diversify production without pressuring environmentally important lands. Promoting the development of small-scale farms, scaling up community gardens and incorporating alternative systems like greenhouses and home gardens to enhance food security. To this end, the City should consider streamlining the permitting process for such practices to encourage implementation.
- **Promoting shared agricultural spaces and equipment schemes.** The joint initiative between Richmond's Food Security Society, the City of Richmond and Kwantlen Polytechnic University is a good example in this regard. The organizations collaboratively provide guidance, space and equipment to train new and/or young farmers.

Fostering a culture of food appreciation and preference for local consumption is key. Given Richmond's highly diverse population, the following initiatives should be considered by the City of Richmond:

- **Invest in awareness programs** to demonstrate the incorporation of healthy and sustainable foods into peoples' diets.
- **Encourage the implementation of circular menus** in restaurants and schools that recognize low impact and local food choices.
- **Work with industry to expand and enhance Richmond's farmers' markets** to increase operational days, locations, resources, and competitive pricing.
- **Encourage partnerships** between food processors, grocers, restaurants, schools, local governments, and farmers located in Richmond to strengthen local food connections and boost revenues for all local stakeholders.
- Proactively lead stakeholder engagement by **creating networks** that connects producers, processors, consumers and food recovery groups. Already existing successful initiatives can become the core of related activities and can be supported and expanded to reach their highest potential.
- **Raise awareness** through workshops and other interactive forms of stakeholder engagement, including large food waste generators.
- **Explore policy measures to increase food recovery** by promoting programs that encourage donation instead of disposal, or by advocating for senior governments to require food waste separation for other sectors, for example.

Richmond needs to recognize the importance of all stages of the food value chain to improve efficiency in food production and reduce food waste. By leveraging symbiotic relationships and investing in innovation, Richmond can achieve high-value valorization of food waste and potentially establish itself as an "agrifood industrial symbiosis" hub within Metro Vancouver.

CIRCULAR BUILT ENVIRONMENT

Richmond can work collaboratively with industry to strive for an adaptive, low-carbon built environment designed for deconstruction by:

- **Efficiently utilizing existing land and buildings** while **minimizing the use of virgin materials** to optimize the expansion of the built environment.
- **Utilizing biobased and secondary materials** and continuing to integrate low-carbon, efficient energy systems to reduce Richmond's embodied and operational carbon emissions.
- **Shifting to resource-efficient building practices** by integrating sustainable practices at the design phase.

Considering the above, achieving circularity in Richmond's built environment requires a major shift from traditional practices, supported by bold administrative and regulatory actions. The regulatory framework can facilitate circular practices and mandate low-carbon, circular buildings with clear targets for monitoring and measuring progress. The City can encourage and foster innovation in the sector through policy and financial approaches. It can:

- **Provide benefits and incentives** to increase the retrofit rate in Richmond. For new construction, it is important for the City to encourage the use of low-carbon construction materials and energy-efficient systems. Prioritizing local, sustainable materials over carbon-intensive imports, while focusing on material efficiency, can reduce the material intensity of Richmond's built environment.
- **Leverage procurement processes** to incentivize projects using local or circular materials through approaches such as fee waivers and public tender criteria. This rewards companies offering circular products and services.
- **Revise City design specifications/guidelines**, where possible, to enable resource-efficient circular building practices and address the private sector's perception of risk and the market's resistance to change. It is essential for future construction to integrate circularity into the design, following circular economy principles for the built environment such as flexibility, modularity, and design for disassembly while focusing on reducing embodied carbon.
- **Revise Richmond's *Demolition Waste and Materials Bylaw* (No. 9516).** The collaborative effort of engaging different stakeholders to expand and improve the bylaw has already identified the need for additional measures, including recycling critical materials, implementing online traceability tools for salvaged materials and establishing reporting requirements for embodied carbon to compare building types and practices.
- **Further advance circularity through regulatory frameworks and guidelines**, which include designing for disassembly, setting embodied carbon targets for existing and new buildings and material specifications, implementing Extended Producer Responsibility (EPR) frameworks, and addressing administrative challenges. For changes that the City is not able to influence directly, such as the provincial Building Code (2018) and EPR, working together with the provincial government and advocating for change will be important.
- **Develop a Soil Management Strategy** to account for future pressures, including the city's climate resilience and adaptation needs. Exploring strategies for efficiently managing scarce resources while incorporating circularity is crucial.
- **Encourage investment in infrastructure** from different stakeholders—including the private sector and the Province—to develop the secondary material market as a means to reduce virgin inputs and embodied carbon. To capitalize on this, it will be essential to establish trust in these materials, ensure their quality and help build a market for their use. While there is already some interest in using salvaged material for high-value applications, for practical implementation Richmond needs to collaborate with industry and the Provincial Government to **establish new processes and quality standards. The City could provide space or facilities for storage and logistics and encourage industry professionals** to utilize the materials (for example, the Recycled Asphalt Pavement Pilot). Creating a shared space for salvaged materials within Richmond and offering industry training and capacity-building programs are important initial steps in this process.

To support the circular management of construction, demolition and renovation waste, action is also needed by the Provincial Government in collaboration with municipalities. This could be realized through the development of a **provincial "Waste Construction Management Plan."** This could strengthen action at the local level, as municipalities need to have permitting processes that align with the provincial government's goals and targets. The City of Richmond can advocate for a provincial "Waste Construction Management Plan" that considers circular solutions and is developed in conjunction with municipalities. Richmond's role here can be **advocating and working collaboratively to develop an effective and implementable provincial plan** so the City can increase circularity through its permitting processes.

OTHER KEY SECTORAL APPROACHES

Richmond should not neglect the role of other important sectors in its circular transition. Advancing resource-efficient manufacturing and promoting material-sufficiency lifestyles will have a positive contribution to reducing the city's material and carbon footprints. For example:

- **Use incentives, and promote best practices** to support circular business models such as repair and remanufacturing. These measures can also be used to encourage the business sector to adopt cutting-edge manufacturing technologies and incorporate R-strategies such as repair and remanufacturing.
- **Promote sustainable products and alternative ownership models** to support sharing and upcycling infrastructure for consumer goods.

In terms of mobility, reducing unnecessary travel and rethinking the mobility system based on the community's needs can ultimately shape car-free lifestyles in Richmond. The City should continue investing in public transport, shared mobility options, and extending the transport network to facilitate access and increase the community's use of such modes of transportation.

COMMUNITY COLLABORATION

Richmond's circular transition must be realized through collective action toward a shared vision. The City, business sector and community all have crucial roles to play in advancing circularity to reduce Richmond's material and carbon footprints. Community actions that need to be prioritized include:

- **The City can reevaluate policies and regulations to enable circular practices**, advocate for change at regional or national levels when needed, and manage the transition through public procurement. Where applicable, the City can provide the required infrastructure and space. The City's role also includes mobilizing, incentivizing, and educating relevant stakeholders through capacity-building programs and public-private partnerships.

- **The City of Richmond should continue to share experiences** with other Canadian municipalities while continuing to learn from leading best practice communities around the globe. The City is already actively participating in the Canadian Circular Cities and Regions Initiatives (CCRI) and can consider other collaborative approaches with communities exploring circular economy concepts.
- **The business sector must explore synergies to close existing loops**, increase circularity in the different value chains, and foster industrial symbiosis relations to collectively work toward resource efficiency. Bold action is also needed to shift to circular business models and abandon unsustainable practices.
- **Lastly, the involvement of Richmond's community is necessary to shift consumption patterns** and adopt more circular lifestyles. While the journey to circularity is long, Richmond has the vision, assets and willingness to drive circularity forward.

This report uncovers Richmond's raw material consumption and and carbon footprint, both of which exceed estimated per capita levels, and highlights a low Circularity Metric of 3%. However, it also nods to the city's strong foundation for change, noting where Richmond is already taking steps toward circularity while further charting a course for the transition. To this end, this report gives insight into key material and emissions hotspots, from food systems to the built environment, spotlighting transformational strategies for key sectors. By tackling the actions laid out in this report and prioritizing industry and community collaboration, Richmond has the ability to advance its circular economy leadership in North America. Being a leader in this space creates many opportunities for the Richmond community including innovation, job creation, cost savings, sustainable development, and environmental benefits.

ADVANCING THE IDENTIFIED ACTIONS WILL GIVE THE CITY OF RICHMOND A STRONG OPPORTUNITY TO ENHANCE ITS CIRCULAR PRACTICES AND ESTABLISH ITSELF AS A LEADER IN CANADA'S TRANSITION TO A CIRCULAR ECONOMY.

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75. With a population of 230,500 expected to increase to 280,000 by 2041, the focus of the built environment expansion will be on new housing units, with over 28,000 expected to be incorporated in the next two decades, and 40% of this growth concentrated in the city centre. Source: City of Richmond. (2022). *Community Energy & Emissions Plan 2050*. Retrieved from: [City of Richmond website]

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106. Plastics waste per capita has increased significantly from previous years, from 34.6 kilograms per capita in 2021 to 29 kilograms per capita in 2013. [Source]

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120. Richmond's goal is to increase the percentage of trips using public transit, walking or cycling from 17% to 51% and reduce the emissions from light-duty vehicles 50% and heavy duty vehicles 33% below 2017 levels. [Source]

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APPENDIX A: GLOSSARY

Carbon Footprint is the total set of greenhouse gas (GHG) emissions caused by an organisation or individual, or by a single event, service, or product. The emissions are calculated over a set period, generally a year (or the lifetime of an event or product), that can then be used as a baseline against which reduction efforts can be measured. Carbon emissions are categorized into three scopes based on their source and origin. Scope 1 emissions are direct emissions from owned or controlled sources, Scope 2 emissions are indirect emissions from purchased electricity, heat, or other similar resources, and Scope 3 emissions are all other indirect emissions that occur as a result of different activities but from sources not owned or controlled by the reporting entity. This analysis accounts for all three scopes of emissions. [Source]

Consumption refers to the use or consumption of products and services meeting (domestic) demand.[127] *Absolute consumption* refers to the total volume of either physical or monetary consumption of an economy as a whole. In this report, *consumption* refers to absolute consumption.

Consumption-based approach/perspective allocates the use of natural resources or the related impacts throughout the supply chain to the region where these resources, incorporated in various commodities, are finally consumed by industries, governments and households. It equals the domestic impacts plus the impacts of imports minus the impacts of exports.

Cycled Materials, also referred to as Secondary Materials, are materials that have already been used, are processed and become ready to be used as input. It refers to the amount of the outflow which can be recovered to be re-used or refined to re-enter the production stream. One aim of reducing material footprints and dematerialisation is to increase the amount of secondary materials used in production and consumption to create a more circular economy. [Source]

Cycling refers to the process of converting a material into another material or product of a higher (upcycling), same (recycling) or lower (downcycling) embodied value and/or complexity than it originally was.

Direct Exports include the goods or services produced within the city that are shipped or provided directly to external markets without passing through local distribution channels.

Direct Imports refer to the procurement of goods or services from external sources. It involves the direct purchase of products or raw materials from suppliers, manufacturers, or producers outside of the city's borders.

Domestic Extraction (DE) is an environmental indicator that measures, in physical weight, the amount of raw materials extracted from the natural environment for use in any economy. It excludes water and air. [Source]

Domestic Material Consumption (DMC) is an environmental indicator that covers the flows of both products and raw materials by accounting for their mass. It can take an 'apparent consumption' perspective—the mathematical sum of domestic production and imports, minus exports—without considering changes in stocks. It can also take a 'direct consumption' perspective, in that products for import and export do not account for the inputs—be they raw materials or other products—used in their production. [Own elaboration based on Source]

Economy-wide material flow accounts (EW-MFA) are a 'statistical accounting framework describing the physical interaction of the economy with the natural environment and with the rest of the world economy in terms of flows of materials.'. [Source]

Environmental stressor, in Input-Output Analysis, refers to the environmental effects happening within the area being studied. There is an overlap with the footprint, which also shows the impact happening locally due to local consumption. But there is an important difference: while the rest of the stressor comprises impacts occurring within a region as a result of consumption abroad (embodied in exports), the footprint includes impacts occurring abroad as a result of domestic consumption (embodied in imports).

Export Footprint refers to the total raw material consumption associated with the export of goods and services embedded throughout the entire supply chain, including their extraction or production, manufacturing, transportation, and distribution processes.

Greenhouse gases (GHG) refers to a group of gases contributing to global warming and climate breakdown. The term covers seven greenhouse gases divided into two categories. Converting them to **carbon dioxide equivalents** (CO_2e) through the application of characterisation factors makes it possible to compare them and determine their individual and total contributions to Global Warming Potential (see below). [Source]

High-value recycling refers to the extent to which, through the recycling chain, the distinct characteristics of a material (e.g., polymer, glass or paper fibre) are preserved or recovered so as to maximize their potential to be re-used in a circular economy. [Source]

Import Footprint refers to the total raw material consumption associated with the import of goods and services embedded throughout the entire supply chain, including their extraction or production, manufacturing, transportation, and distribution processes.

Materials, substances or compounds are used as inputs to production or manufacturing because of their properties. A material can be defined at different stages of its lifecycle: unprocessed (or raw) materials, intermediate materials and finished materials. For example, iron ore is mined and processed into crude iron, which in turn is refined and processed into steel. Each of these can be referred to as materials. [Source]

- **Biomass** is a renewable organic material from plants and animals containing stored chemical energy. Biomass can include various forms of organic matter, including wood, agricultural residues, crop waste, animal manure, algae, and municipal solid waste. These materials can be used as a renewable energy source through processes such as combustion, fermentation, or chemical conversion. [Source]
- **Fossil fuels** are hydrocarbon-containing materials such as coal, oil, and natural gas, formed naturally in the Earth's crust from decayed organic materials that have undergone geological processes over millions of years. These materials are not renewable and are primarily used for electricity generation, transportation, heating, and industrial processes. Fossil fuels have a negative impact on the environment by releasing carbon dioxide and other greenhouse gases. [Source]
- **Metal ore** is naturally occurring rock or minerals that contain a high concentration of one or more metallic elements, such as iron, copper, aluminium, gold, or silver. These ores typically need to be extracted and processed through mining and refining techniques and are essential raw materials for various industries, including manufacturing, construction, electronics, and transportation. Metal ore extraction and processing can have significant environmental and social impacts. [Source]

- **Non-metallic minerals** are naturally occurring substances that do not possess metallic properties. They lack the characteristics of metal elements but often exhibit physical properties such as transparency, hardness, brittleness, and non-conductivity of electricity. Examples of non-metallic minerals include limestone, gypsum, quartz, clay, granite, sand, gravel, and various types of gemstones. These minerals have diverse uses in construction, manufacturing, agriculture, and other industries, ranging from building materials and ceramics to abrasives and fertilizers. [Source]

Material footprint, also referred to as Raw Material Consumption (RMC), is the attribution of global material extraction to the domestic final demand of a city. In this sense, the material footprint represents the total volume of materials (in Raw Material Equivalents) embodied within the whole supply chain to meet final demand. The total material footprint, as referred to in this report, is the sum of the material footprints for biomass, fossil fuels, metal ore and non-metallic minerals. It is composed of the sum of domestic extraction and imports in raw material equivalents, minus exports in raw material equivalents. This allows us to allocate the footprint to the consumption. [Source]

Material flows represent the amounts of materials in physical weight that are available to an economy. These material flows comprise the extraction of materials within the economy as well as the physical imports and exports (such as the mass of goods imported or exported). Air and water are generally excluded. [Source]

Net Extraction Abroad (NEA) represents the difference between the trade balance of products and that of the raw materials needed to produce them. The difference between the two represents the 'actual' or net quantity of raw materials that have been extracted abroad to satisfy domestic consumption.

Planetary boundaries define the ‘safe operating space’ for humanity, based on the planet’s key biophysical processes. Originally developed by Rockström et al. (2009), the framework quantifies nine ‘limits’: 1. Climate change, 2. Novel entities, 3. Stratospheric ozone depletion, 4. Atmospheric aerosol loading, 5. Ocean acidification, 6. Biogeochemical flows (nitrogen and phosphorus), 7. Freshwater use, 8. Land-system change, and 9. Biosphere integrity. Six of nine boundaries have now been transgressed. [Source]

Production-based approach/perspective: The production perspective allocates the use of natural resources or the impacts related to natural resource extraction and processing to the location where they physically occur.

Raw Material Equivalent (RME) is a virtual unit that measures how much of a material was extracted from the environment, domestically or abroad, to produce the product for final use. Imports and exports in RME are usually much higher than their corresponding physical weight, especially for finished and semi-finished products. For example, traded goods are converted into their RME to obtain a more comprehensive picture of the ‘material footprints’; the amounts of raw materials required to provide the respective traded goods. [Source]

Raw Material Consumption (RMC) represents the final domestic use of products in terms of RME. RMC, referred to in this report as the 'material footprint', captures the total amount of raw materials required to produce the goods used by the economy. In other words, the material extraction necessary to enable the final use of products. [Source]

Resources include, for example, arable land, freshwater, and materials. They are seen as parts of the natural world that can be used for economic activities that produce goods and services. Material resources are biomass (like crops for food, energy and bio-based materials, as well as wood for energy and industrial uses), fossil fuels (in particular coal, gas and oil for energy), metals (such as iron, aluminium and copper used in construction and electronics manufacturing) and non-metallic minerals (used for construction, notably sand, gravel and limestone). [Source]

Renewable materials are resources that have a natural rate of availability and yield a continual flow of services which may be consumed in any time period without endangering future consumption possibilities as long as current use does not exceed net renewal during the period under consideration. In this case, this refers primarily to bio-based material resources (biomass), rather than renewable resources like solar energy, wind, hydro etc. [Source]

Recycling rate vs true recycling. Recycling of waste is defined in the EU Waste Framework Directive as any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes. [Source] However, several differentiations must be noted, as the exact way it is calculated can vary depending on different factors such as location, scale of study, data availability etc.

- Waste sent toward a recycling or anaerobic digestion (if organic waste) facility.
- Amount of recycled waste material recovered after the recycling processes, subtracting any recycling or efficiency losses during the process. These are considered secondary materials.

Secondary materials are materials that have been used once and are recovered and reprocessed for subsequent use. This refers to the amount of the outflow which can be recovered to be re-used or refined to re-enter the production stream. One aim of dematerialisation is to increase the amount of secondary materials used in production and consumption to create a more circular economy. [Source]

Sector describes any collective of economic actors involved in creating, delivering and capturing value for consumers, tied to their respective economic activity. Different levels of aggregation are applied here—aligned with classifications as used in Exiobase V3. These relate closely to the European sector classification framework NACE Rev. 2.

Societal Needs are essential requirements of a city’s residents that reflect the collective well-being and development priorities of a community. These are linked to different provisioning services which consume energy and materials.

- **Nutrition** refers to agricultural products such as crops and livestock that are used to create food and drink products. These tend to have short lifecycles in our economy, being consumed quickly after production.
- **Manufactured Goods** account for an important share of material consumption and consist of a diverse group of products such as appliances, furniture, clothing, cleaning agents, personal-care products and paints. These products generally have short to medium lifetimes in society and require multiple raw materials for their production. Textiles, for example, consume resources such as cotton, synthetic materials like polyester, dye pigments and chemicals. Manufactured goods belonging to other societal needs such as vehicles and capital equipment for healthcare, are not included in this category.
- **Communication** is an increasingly important aspect of today’s society, provided by a mix of equipment and technology ranging from personal devices to data centres.
- **Mobility** as a service is responsible for an important share of material consumption. Specifically, two material types are used: the materials (especially metals) used to build transport technologies and vehicles like cars, trains and aeroplanes and, most importantly, the fossil fuels used to power them.
- **Healthcare and Education** provision is crucial to improving quality of life. This requires materials for buildings and their operations including maintenance, heating, cooling and food services, as well as a wide range of medical and educational equipment.

- **Services** delivered to society range from all public services, except healthcare and education, to commercial services like banking and insurance. These typically involve the use of buildings, professional equipment, office furniture, computers, and other infrastructure.
- **Housing and Infrastructure** is usually one of the largest drivers of cities' total material consumption. This includes the construction, maintenance and renovation of housing with materials such as concrete, steel and timber

Socioeconomic cycling (or Secondary Material Inputs) is the technical term for the Socioeconomic Cycling metric. It comprises all types of recycled and downcycled end-of-life waste, which is fed back into production as secondary materials. Recycled waste from material processing and manufacturing (such as recycled steel scrap from autobody manufacturing) is considered an internal industry flow and is not counted as a secondary material. In the underlying model of the physical economy used in this report, secondary materials originate from discarded material stocks only. The outflows from the dissipative use of materials and combusted materials (energy use) can, by definition, not be recycled. Biological materials that are returned back to the environment (for example, through spreading on land) as opposed to recirculated in technical cycles (for example, recycled wood) are not included as part of socioeconomic cycling. Energy recovery (electricity, district heat) from the incineration of fossil or biomass waste is also not considered to be socioeconomic cycling, as it does not generate secondary materials.

Socioeconomic metabolism describes how societies metabolize energy and materials to remain operational. Just as our bodies undergo complex chemical reactions to keep our cells healthy and functioning, a city undergoes a similar process—energy and material flows are metabolized to express functions that serve humans and the reproduction of structures. Socioeconomic metabolism focuses on the biophysical processes that allow for the production and consumption of goods and services that serve humanity: namely, what and how goods are produced (and for which reason), and by whom they are consumed. [Source]

Territorial-based carbon footprint is based on the traditional accounting method for GHG emissions, with a focus on domestic emissions, mainly coming from final energy consumption. A **Consumption-based carbon footprint** uses input–output modelling to not only account for domestic emissions but also consider those that occur along the supply chain of consumption (e.g., accounting for the embodied carbon of imported products).

Total material consumption is calculated by adding Raw Material Consumption (material footprint) and secondary material consumption (cycled materials).

APPENDIX B: DYNAMICS INFLUENCING HOW WE MEASURE CIRCULARITY

Understanding the current status of the global circular economy is relatively simple, largely because there are no exchanges of materials in and outside of planet Earth. For smaller-scaled systems such as countries and cities, however, trade dynamics introduce complexities to which we must adapt our calculations, resulting in certain methodological choices. These are:

1. **We take a consumption-based perspective.** This means we only consider materials consumed within Richmond, and allocate responsibility to consumers by excluding exports. Essentially, it accounts for the ecological impacts of the local population based on what they consume, regardless of where the goods and materials are processed and produced.
2. **We use demand-based indicators.** This approach reallocates the environmental stressors or impacts from the producers (those who manufacture goods) to the final consumers (those who buy and use goods). By doing this, the method ensures that resource depletion is allocated to economies that drive production through their consumption. In other words, it considers the impact on the environment caused by the demand for products and services in a particular area, regardless of where those products are actually produced. With our assessment approach, most production is ultimately driven by consumer demand for certain products or services. In an increasingly globalized world, the chain that connects production to consumption becomes more entangled across regions. Demand-based indicators—applied in this analysis—allow for a reallocation of environmental stressors from producers to final consumers. This ensures transparency for countries with high import levels and also supports policies aimed at reducing or shifting consumer demand, at helping consumers understand the material implications of their choices, or at ensuring that costs of, and responsibilities for, resource depletion and material scarcity are allocated to entities and regions based on their roles in driving production processes through consumption.
3. **We consider both imports and exports in terms of their Raw Material Equivalents (RMEs).** This allows us to assess the true impact of finished and semi-finished products more accurately. Considering what Richmond's residents, businesses and government consume to satisfy their material demand, we must apply a nuanced lens to the direct imports; meaning we work out the full material footprints of the products. To account for the material footprint of raw materials is straightforward, but this is not the case with semi-finished and finished goods. To represent actual material footprints in imports and exports, we apply so-called RME (Raw Material Equivalents) coefficients in this study. As an open, high-income economy doing so in the case of Richmond is more complex than for a less integrated economy.
4. **In addition to secondary materials recovered locally, we also consider secondary materials imported from abroad.** With this approach, we give 'credit' to economies for reducing virgin materials extraction by either processing secondary materials (recovered from former 'waste') locally or importing them from abroad. The total amount of waste recycled in treatment operations is therefore adjusted by adding waste imports to—and subtracting waste exports and by-products of recovery from—the amount of waste recycled in local recovery plants. When we adjust the volumes of recycled waste in treatment operations using imports and exports of secondary materials, 'credit' for saving virgin materials is ascribed to the system that uses that secondary material—recovered from former 'waste'. This perspective is similar to national accounts' logic, in which most re-attributions are directed at final use. Richmond's and British Columbia's waste management sector has invested heavily in domestic reuse and recycling infrastructure. However, the market is not bound by geographical borders and materials can be transported wherever it makes most logistical and economic sense. Difficult-to-recycle materials and those that arise in smaller quantities can often be bulked and then transported for treatment in regional facilities. However, it's also possible to take a more 'production-oriented' approach, in which 'credit' for recycling efforts is given to the city that collects and prepares waste for future cycling. This is, for example,

the perspective taken by Eurostat in its calculation of the Circular Material Use Rate (at a national level). For more information on this, refer to the Methodology Document.

Applying our Circularity Gap methodology to cities is complex, and has required us to make a number of methodological choices. In a bid to generate actionable insights for local economies, our *Circularity Gap Reports* take a consumption perspective: we consider only the materials that are consumed domestically, and allocate responsibility to consumers by excluding exports. However, the more 'open' an economy is, calculating the import content of exports becomes more difficult within the material flow analysis and input-output analysis frameworks, the latter in particular.

APPENDIX C: PRACTICAL

CHALLENGES IN QUANTIFYING CIRCULARITY

The circular economy is full of intricacies: quantifying it in one number presents a number of limitations. These are:

- **There is more to circularity than (mass-based) cycling.** A circular economy strives to keep materials in use and retain value at the highest level possible, with the aim of decreasing material consumption. The cycling of materials measured by the Secondary Material Inputs rate (or the 'Circularity Metric') is only one component of circularity: we do not measure value retention, for example. Secondary Material Inputs focuses on the end-of-use and mass-based cycling of materials that re-enter the economy but does not consider in what composition, or to what level of quality. As such, any quality loss and degradation in processing goes unconsidered.
- **Secondary Material Inputs only focuses on one aspect of circularity.** We focus only on material use without examining other factors such as biodiversity loss, pollution, toxicity, *etcetera*. This reveals the limitations of focusing solely on materials' cycling or on the 'closing-the-loop' effect. The Secondary Material Inputs rate is calculated as the share of secondary materials (numerator) over the total consumption of the urban economy (denominator). In a system with high total material consumption like Richmond, increasing material cycling has a much smaller impact on the overall material cycling indicator: the bigger the denominator, the smaller the impact of increasing the numerator is on the overall percentage. This also means that in consumption-driven economies, it is not only important to increase material cycling but also to decrease consumption in order to increase the percentage metric significantly.
- **Relative compared to absolute numbers.** The Secondary Material Inputs rate considers the relative proportion of cycled materials as a share of the total material consumption: as long as the amount of cycled materials increases relative to the extraction of new materials, we see the statistic improving, despite the fact that more virgin materials are being extracted—which goes against the primary objective of a circular economy.
- **It is not feasible to achieve 100% circularity.**

There is a practical limit to the volume of materials we can recirculate—in part due to technical constraints—and therefore also for the degree to which we can substitute virgin materials with secondary ones. Some products, like fossil fuels, are combusted through use and therefore can't be cycled back into the economy, while others are locked into stock like buildings or machinery and aren't available for cycling for many years. Products that can be cycled, such as metals, plastics and glass, may only be cycled a few times as every cycle results in lower quality and may still require some virgin material inputs. Because of this, reaching 100% circularity isn't feasible: this calls for a more nuanced approach to calculating circularity and setting targets.

ACKNOWLEDGEMENTS

Circle Economy would like to thank the funders, authors, contributors and interviewees for their contribution to the preparation of this material flow analysis for Richmond. Authors, contributors and interviewees have contributed to the report in their individual capacities. Their affiliations are only mentioned for identification purposes.

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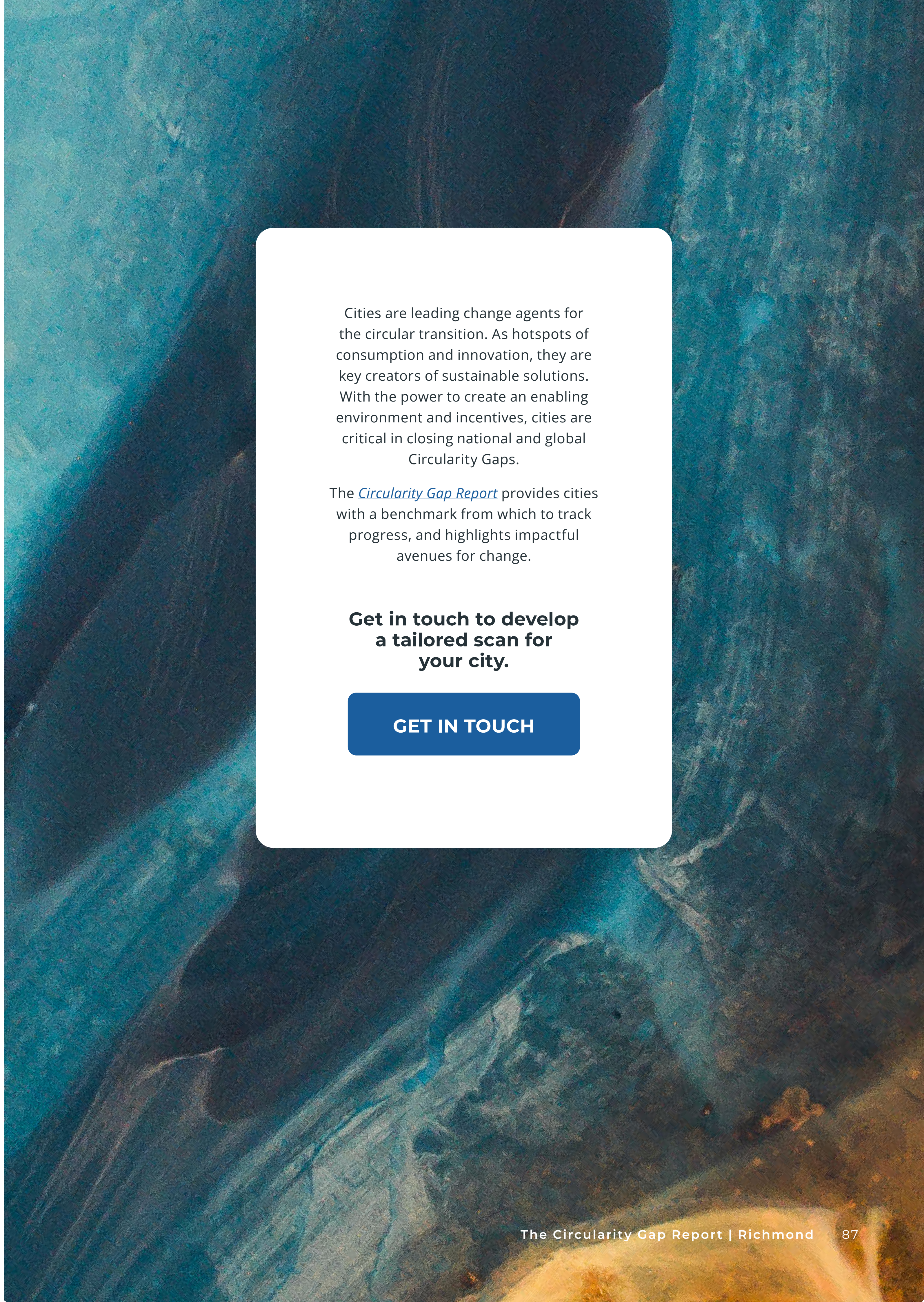

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