Canada's

VENTURES TO VALUE CHAINS

ENERGY STORAGE TECHNOLOGY FOR TRANSPORTATION

NOVEMBER 2024

FORESIGHT CANADA

Foresight is Canada's cleantech accelerator.

Foresight Canada helps the world do more with less, sustainably. As Canada's largest cleantech innovation and adoption accelerator, we de-risk and simplify public and private sector adoption of the world’s best clean technologies to improve productivity, profitability, and economic competitiveness, all while addressing urgent climate challenges.

ABOUT

ACKNOWLEDGEMENTS

Foresight acknowledges that the lands on which we conducted this work are the traditional, ancestral, and unceded territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), and səlilwətaɬ (Tsleil-Waututh) Nations.

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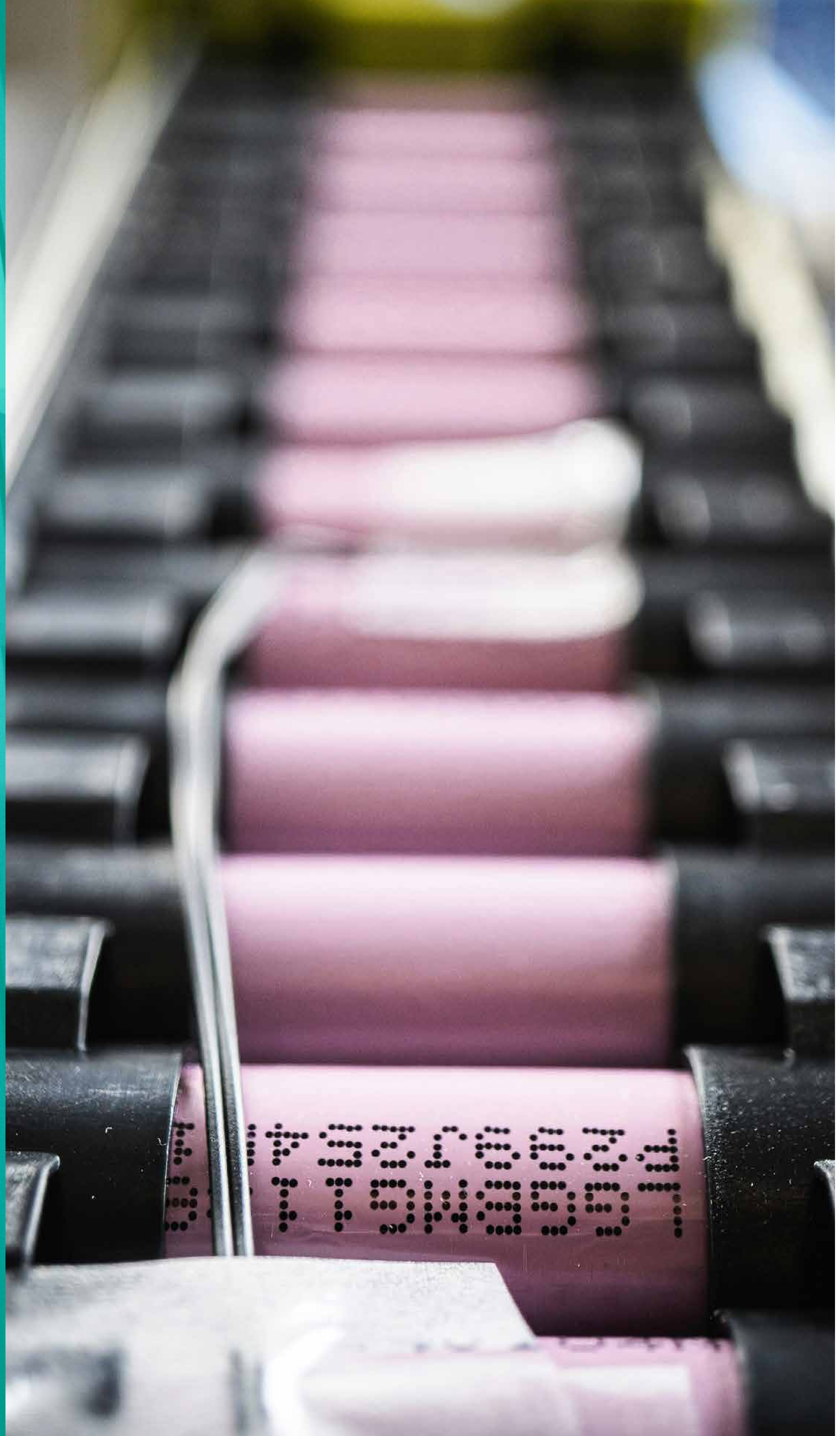

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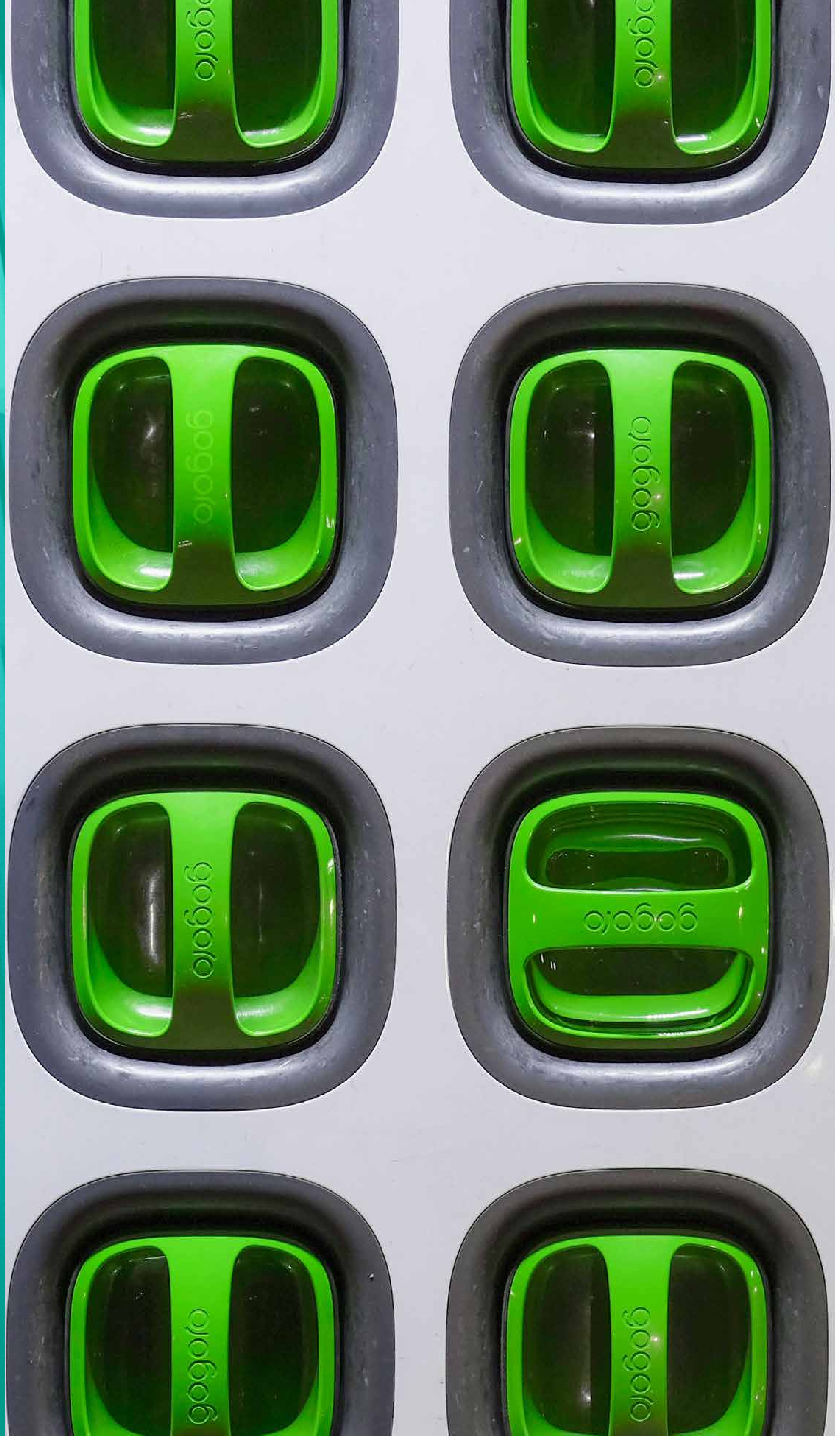
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INTRODUCTION

CANADA HAS THE POTENTIAL TO BE A LEADER IN THE ZERO EMISSIONS VEHICLE (ZEV) ECOSYSTEM

In 2024, Canada surpassed China as the top-ranked country according to the BloombergNEF lithium-ion battery supply chain ranking, which ranks countries based on their potential to build a "secure, reliable, and sustainable" supply chain.[1] Production and manufacturing advancements, strong ESG credentials, raw materials, and policy commitments are all noted as reasons for Canada's advancement in the rankings.

Canada is also doing well in terms of ZEV adoption and market share. For example, S&P Global found that battery electric vehicle (BEV) market share in Canada is increasing at a much faster rate when compared to the United States, citing federal and provincial incentives as key drivers.[2]

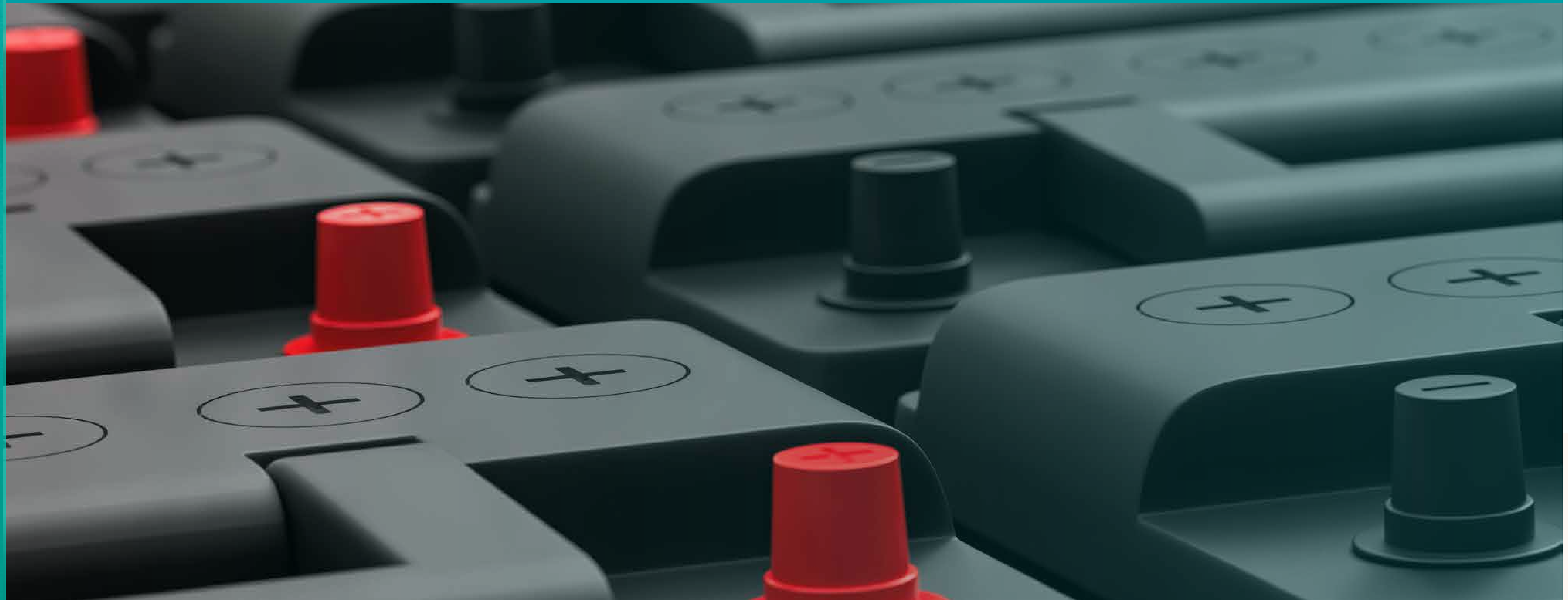
Canada's opportunities in this space have been recognized by federal and provincial governments, and key industry associations and think tanks. As a result, an extensive body of existing research has been done to map and provide recommendations for the sector from various angles. Some key examples of existing reporting include:

- ***A Roadmap for Canada's Battery Value Chain*** (2022), Battery Metals Association of Canada (BMAC).[3] This roadmap outlines a comprehensive strategy and action plan for the battery metals supply chain from raw materials to end of life. It focuses on operations and capacity building from a national perspective. BMAC also has a supplementary online interactive ecosystem map.[4]

- ***Developing Canada's Electric Vehicle Battery Supply Chain: Quantifying the Economic Impacts and Opportunities***, Clean Energy Canada and the Trillium Network for Advanced Manufacturing (2022).[5] This report focuses on key economic benefits of developing the supply chain and key opportunities to build on.

- ***Canadian Automotive Supplier Capability and EV Value Chain Analysis***, Next Generation Manufacturing Canada (2022).[6] This report covers the electric vehicle automotive supplier landscape and market development, focusing on manufacturing capability across the value chain to highlight Canada's competitive advantages and potential investment opportunities. It includes a discussion of all forms of electric road vehicles, including both BEVs and fuel cell electric vehicles (FCEVs).

- ***Canadian Battery Innovation Roadmap*** (2024), Accelerate ZEV.[7] This roadmap describes a strategy focused on Canadian battery technology, covering Canada's place in the global technology landscape, and key innovation enablers such as infrastructure, policy, and skills.



With this Ventures to Value Chains (V2VC) report, Foresight aims to add to this existing body of knowledge by focusing on the current ecosystem of energy storage technology innovation, research, and development companies with transportation applications. These insights are based on a dataset of 109 companies across Canada, each assigned to relevant value chain steps (VC steps). It identifies regional and topical clusters of companies and potential innovation trends that are suggested in the dataset, while also referencing the existing body of work in this space to provide context and support. It covers the energy storage system value chain specific to key transportation subsectors (road, marine, and rail) and includes a variety of forms of energy storage (batteries, hydrogen, and other non-battery energy storage).[1]

Although these findings reflect only a snapshot of the current technology ecosystem, this installment of Foresight's V2VC initiative aims to contribute to the evolving dialogue on the energy storage value chain and the sustainable transportation sector and provide insights on possible areas where Canada can build on its strengths and potential opportunities for growth.

[1] Note that small-scale e-mobility technologies (e.g., e-bikes, scooters) are not included.

RATIONALE

VENTURES TO VALUE CHAINS

is a Foresight initiative that leverages data from technology companies and other key stakeholders to map and categorize strategically important industry value chains for Canada in the clean economy.

This initiative will result in a report and web map, which can be used as a tool to inform stakeholders on Canada's competitive strengths, ecosystem gaps, and areas of opportunity and growth. These insights can assist in identifying where targeted programming, research and development, or funding will bolster Canada's leadership and economic development as we transition to a net zero economy.

ENERGY STORAGE TECHNOLOGY FOR TRANSPORT: THE VALUE CHAIN

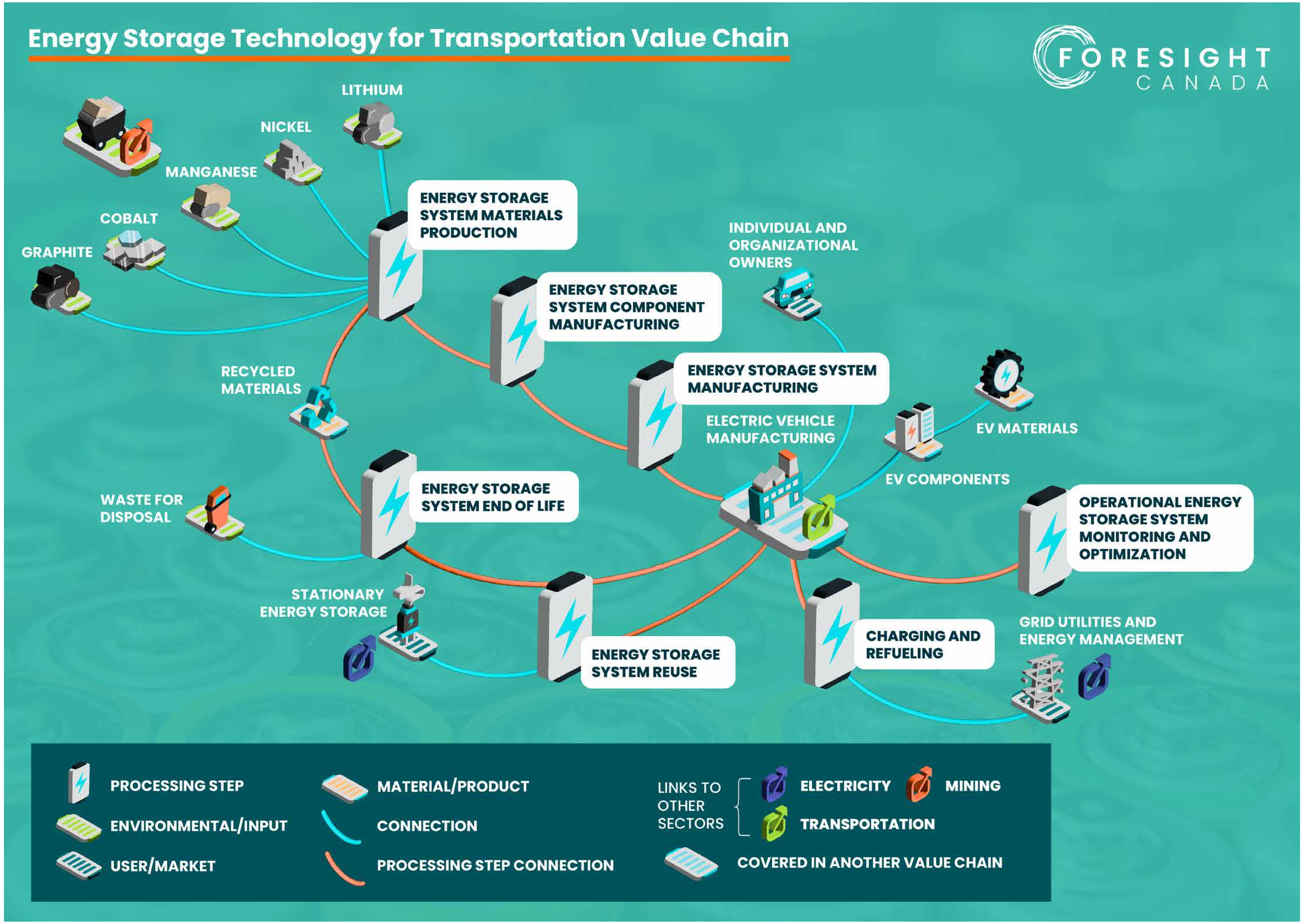


Figure 1

Energy Storage Technology for Transportation Value Chain

The energy storage technology for transportation value chain

describes the steps from energy storage system materials production to end of life by outlining a series of processing steps and inputs and outputs along the value chain. The VC steps mapped in the dataset cover the energy storage value chain from midstream to end of life. (Figure 1)

- **Midstream:** materials production (battery grade materials, precursors, and active electrode materials) and component manufacturing (finished materials and cell components such as anodes, cathodes, electrolytes, and separators)
- **Downstream:** energy storage system manufacturing, including battery cells, modules, and packs as well as fuel cells and other energy storage systems
- **Operations and end use:** charging and refueling and operational monitoring and optimization
- **End of life:** recycling and disposal (end of life VC step) and energy storage system reuse

This value chain is intended to represent the cyclical lifecycle aligned with other depictions of the value chain by the Government of Canada[8] and BMAC's ecosystem map.[4] Unlike these broader value chains, this one also includes non-battery energy storage and focuses only on transportation applications.

Because this value chain intersects with other sectors, it also identifies areas where there are overlaps with other sectoral value chains that Foresight is mapping. For this reason, upstream processes (mining and initial raw material processing) are not covered in this value chain and are instead covered in the mining V2VC report.[9] Similarly, downstream vehicle manufacturing is not covered as it will be covered in the forthcoming clean transportation sector value chain project.

[2] While these are labelled as processing steps, they include all types of actions within the value chain. For definitions of each of the processing steps, see Appendix A.

METHODOLOGY

This research was conducted by mapping the ecosystem of energy storage technologies for the transportation sector, categorizing companies based on VC steps, and analyzing how the companies were distributed across the value chain.

The energy storage for transportation database comprises technology companies, enablers, and knowledge generators. The value chain mapping and analysis focused on the technology companies, while the knowledge generators and enablers were used to provide additional context. Companies are included in the dataset based on the following criteria:

- **Are involved in energy storage system innovation, research, and development in the transportation sector.** Excluded based on these criteria are project developers, charging networks, suppliers, distributors, service providers, and consulting/law firms, unless they also have their own technology.
- **Are headquartered in Canada or have a strong Canadian presence in energy storage for transportation technology innovation, research, and development.** Examples of a strong presence would include companies with a dedicated research and development branch located in Canada or a Canadian subsidiary with its own technology that has retained its brand identity.
- Although manufacturing facilities have been excluded from other V2VC datasets based on the above criterion, some manufacturing facilities for materials production, component manufacturing, energy storage system manufacturing, and some recycling facilities are included in the dataset, even if the technologies and intellectual property applied are not Canadian. These are identified with a keyword so they can be discussed separately. These are included because manufacturing capacity is central to this value chain and understanding potential clusters, areas of strength, and opportunities.
- **Have a valid website or online presence.**

Companies were assigned to up to two VC steps based on their innovation focus, then analyzed in an aggregated manner to identify both regional and national clusters and potential trends. Keywords and comments were used to provide additional context to the potential trends. Secondary research was used to identify possible external factors (e.g., policy, natural resource availability, adjacent industries) that could contribute to clusters or trends. Because the data can only indicate clustering and concentrations, and not why trends exist, observations are communicated as:

- **Areas of strength:** Areas or clusters where the data and supporting research suggests that energy storage technology for the transportation sector is advancing and should continue to be supported.
- **Opportunities:** Areas where the data and supporting research suggests that there is an opportunity to grow, either because of minimal or uneven concentrations or because it is an area that can help meet the growing need for sustainable solutions.

See Appendix B for a more detailed methodology used for mapping and analyzing companies.

CANADA'S
ENERGY STORAGE TECHNOLOGY FOR TRANSPORTATION COMPANIES

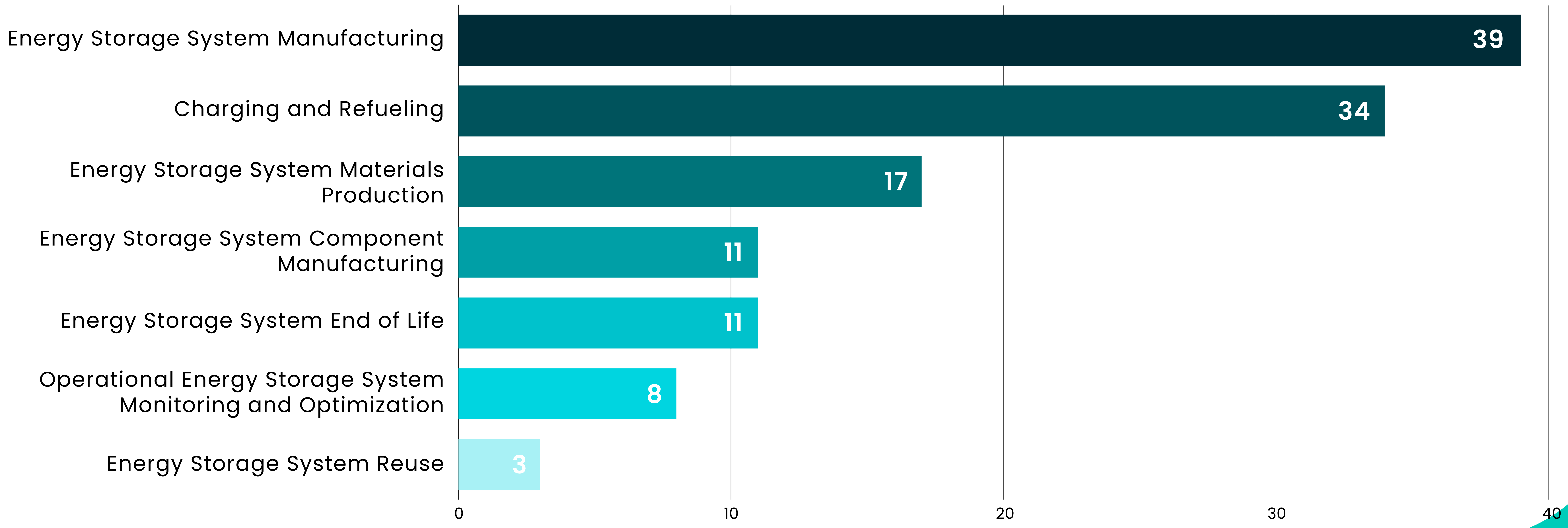


Figure 2 Distribution of Energy Storage for Transportation Companies Across the Value Chain

109 **companies are assigned to the energy storage for transportation value chain.**

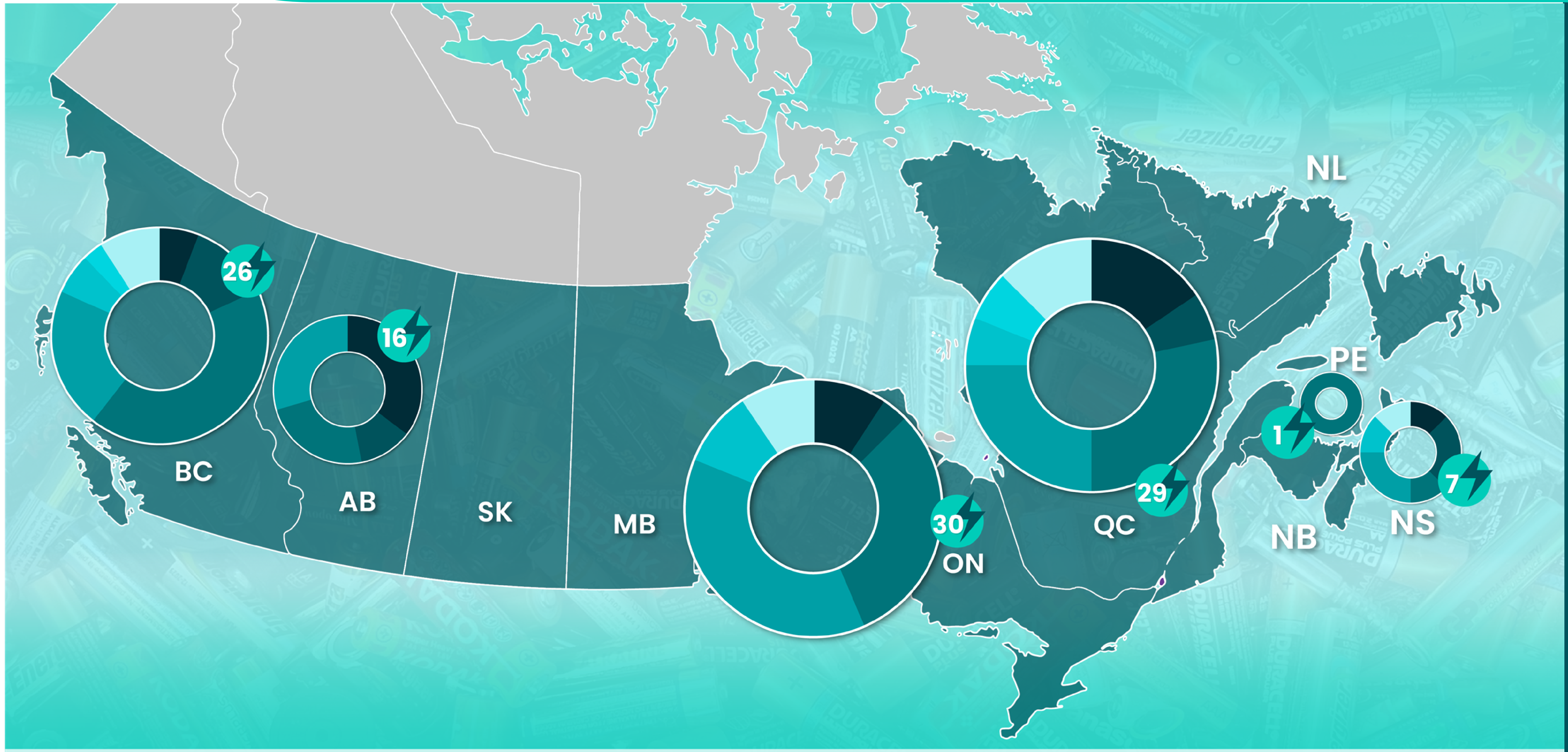
- The top two VC steps with the highest number of companies assigned are in the middle of the value chain: Energy Storage System Manufacturing **(39)** and Charging and Refueling **(34)**.
- While non-battery energy storage was also included in the scope, most companies **(96)** focus on batteries, predominantly lithium-ion batteries.
- **12** companies relate to hydrogen fuel cell electric vehicles.
- Road transportation, including light vehicles and medium to heavy vehicles, is the most represented transportation sector.

PROVINCIAL AND REGIONAL CLUSTERS

This section explores how companies are distributed geographically and considers key clusters both provincially and regionally.

The development of regional production clusters was a key recommendation in Accelerate ZEV's *Canadian Battery Innovation Roadmap* for the near future (2026-2035).[7] They envision these clusters to include co-located university industrial assets, research centers, and government agencies that can enable collaboration, knowledge transfer, and technical advancements (p. 74).

Understanding where technology companies are clustered provincially and regionally can provide some insights on how provinces can play to their existing strengths and build on potential growth opportunities.



- Energy Storage System Materials Production
- Energy Storage System Component Manufacturing
- Energy Storage System Manufacturing
- Charging and Refueling
- Operational Energy Storage System Monitoring and Optimization
- Energy Storage System Reuse
- Energy Storage System End of Life
- Number of Energy Storage for Transportation Companies per province

Figure 3 Provincial Value Chains

SUMMARY:

- **Ontario (30)**, **Quebec (29)**, and **British Columbia (26)** are the most represented provinces.
- The distributions of the value chains in **Ontario** and **Quebec** are the closest to the national one.
- **British Columbia** has the largest number of hydrogen fuel cell technology companies.
- **Quebec** and **British Columbia** have the most end-of-life and reuse companies.
- **Alberta** is strongest in materials production.
- **Nova Scotia** is the most represented Atlantic province.
- **59%** of the companies are located in Canada's three largest census metropolitan areas (CMAs): **Vancouver (23) Montreal (21)**, and **Toronto (20)**
- The energy storage system manufacturing and charging and refueling VC steps are generally well represented across Canada, proportionate to population.

QUEBEC

Innovation in battery energy storage for transportation is an area of strength in Quebec.

Quebec has the most well-distributed value chain with companies represented across every step.

With **26** companies total, Quebec is also the second most represented nominally (after Ontario) and by population (after British Columbia, which has more representation in the hydrogen sector).

IN Q1 2024, QUEBEC ZEV REGISTRATIONS MADE UP 47.6% OF ALL ZEV REGISTRATIONS IN CANADA.

-Statistics Canada[17]

KEY VC STEP OBSERVATIONS

- The most represented VC steps in Quebec are energy storage system manufacturing **(nine)** and charging and refueling **(eight)**. This clustering is consistent with the overall value chain; however, Quebec is neither highest nominally nor by population in either of these VC steps.
- Quebec has areas of strength at the end of the value chain including the highest number of end-of-life companies (**four** of 11 total) and reuse (**three** of four total).
- Quebec has the second highest number of companies assigned to materials production (**five**), and most of these are **manufacturing facilities** or operators with in-house technology (e.g., Nouveau Monde Graphite, Ultium CAM, EcoPro CAM, and Northvolt), rather than companies that focus predominantly on technology.

REGIONAL CONSIDERATIONS

- **Montreal:** There are **21** companies in the Montreal CMA, which makes Montreal the second most represented CMA after Vancouver. The value chain distribution is similar to the provincial one, but most manufacturing facilities are outside of Montreal. The large population density and presence of academic institutions and industry associations are likely key contributors to this cluster.
- **Energy Transition Valley (Bécancour, Shawinigan, and Trois Rivières):** Quebec is investing in Bécancour, Shawinigan, and Trois Rivières to be a formal innovation hub for energy transition technologies.[10] The Bécancour "pole" is focused on battery technology and the Shawinigan pole focused on transportation electrification. This region is only minimally represented in the dataset—only two manufacturing facilities listed in the database are located in Bécancour, and another one (Nouveau Monde Graphite) is headquartered elsewhere but has their primary manufacturing facility there. However, as this innovation hub grows, it may attract new technology innovation and provide opportunities for testing or proving new technologies.

DISCUSSION

Several factors are at play to enable innovation in energy storage for the transportation sector in Quebec, especially for battery energy storage. Quebec is abundant in natural resources, including key battery minerals such as lithium, iron, graphite, and nickel.[11] The province is also abundant in renewable energy at the lowest rates in Canada.[12] It is also centrally located with easy access to the US markets and to automotive manufacturing clusters in Southern Ontario.

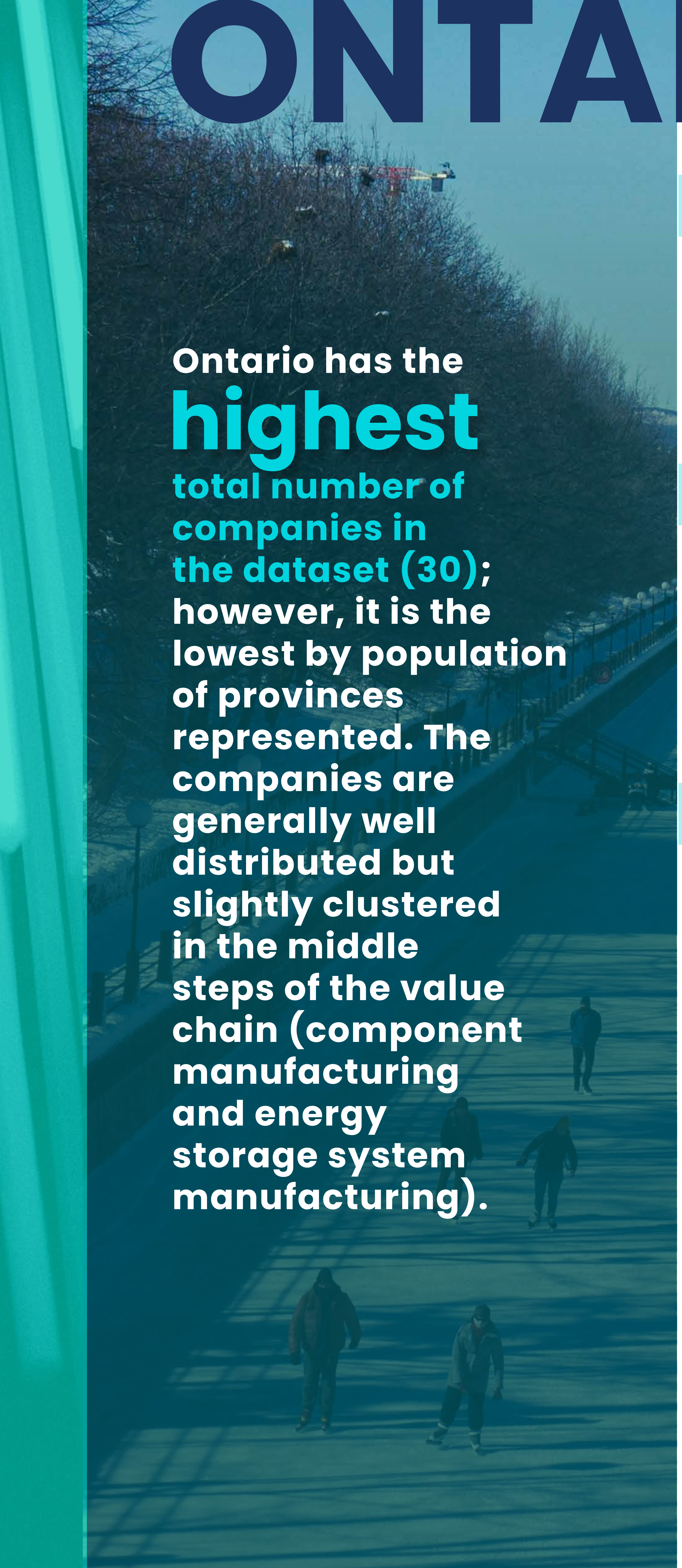
The province has a clear economic development strategy for the battery sector that focuses on leveraging mineral resources, developing manufacturing capacity for components such as anodes and cathodes, developing commercial electric vehicles, and developing recycling technologies and capacities.[13]

Quebec is also home to a strong ecosystem of research and development (e.g., Hydro Quebec's Center of Excellence in Transportation Electrification and Energy Storage and the Quebec Centre for Functional Materials), associations (e.g., Propulsion Québec, Electric Mobility Canada), and supportive programming (e.g., EV Battery Recovery Program and Electric Circuit charging network).

Quebec has been recognized as a national leader in ZEV policy.[14] However, some of the policies that encouraged adoption are being rolled back, which could affect adoption in the future. Quebec's Écocamionnage rebate program for medium- and heavy-duty vehicles was temporarily suspended in September 2024.[15] Another key policy to incentivize adoption of personal ZEVs has been the Roulez Vert rebate policy, but in March 2024, the provincial government announced plans to cut these incentives by 2027.[16] Nevertheless, the policy framework in Quebec has enabled the province to build a strong foundation for transportation electrification.

[3] For the purposes of this report, provinces with under 10 companies are not included in the discussions of companies per capita as the data is skewed by the low totals.

ONTARIO



Ontario has the highest total number of companies in the dataset (30); however, it is the lowest by population of provinces represented. The companies are generally well distributed but slightly clustered in the middle steps of the value chain (component manufacturing and energy storage system manufacturing).

KEY VC STEP OBSERVATIONS

- Ontario has the highest number of companies in charging and refueling (**12** of 34 total).
- Ontario has the second highest number of companies in energy storage system manufacturing (**10** of 39 total). Three of them are manufacturing facilities.
- Ontario has the highest number of companies in operational monitoring and optimization (**three** of eight total), and they are all in Toronto.

REGIONAL CONSIDERATIONS

20 of the 30 companies in Ontario are clustered in the Greater Toronto Area (GTA). The distribution of the value chain in the GTA looks similar to Ontario's distribution overall, but it has a lower concentration of energy storage system manufacturing companies. This clustering is consistent with Toronto being a major population centre and with major cities being most conducive to EV infrastructure and adoption. The remaining companies in Ontario are mostly in Southwestern Ontario (e.g., Sarnia, Windsor, Kitchener), which are key areas in the manufacturing sector, particularly in the automotive space.

DISCUSSION

Due to several factors such as large population density, central location, and strong presence of industry, academia, and government institutions, Ontario has a strong innovation ecosystem and manufacturing sector. However, although Ontario is one of the top provinces in terms of ZEV adoption, the uptake has been slower compared to Quebec and British Columbia.[18] An S&P report from January 2024 suggests that this slump is likely due in part to a lack of provincial incentives.[2] The pressures of EV infrastructure on already strained electricity demand could also be a challenge going forward.

According to Ontario's Critical Mineral Strategy, "work is already underway to establish a supply chain for electric vehicle battery manufacturing in the province. This supply chain will connect two economic powerhouses in Ontario: mining and automobile manufacturing."[19] Ontario's strong automotive manufacturing sector includes several EV manufacturing facilities for major car brands and some made-in-Canada electric vehicles that were not covered in this dataset.[5] Some efforts are ongoing to strengthen the local electric vehicle manufacturing industry to establish an electric vehicle manufacturing hub in Southwestern Ontario. For example, the Windsor-Essex region has developed an EV Career Pathways Guide that aims to support workers with the transition from internal combustion engine manufacturing to electric vehicles manufacturing.[20] Ontario also has a cluster of electrification related technology companies in the mining industry.[9]

In general, infrastructure gaps between urban and rural regions have been recognized as a key ZEV adoption challenge in Ontario and elsewhere in Canada. To help bridge the gap, the provincial government launched and invested $91 million through the ChargeON program, which focused on reaching small and medium sized communities.[21]

BRITISH COLUMBIA

With **26 companies** total, British Columbia is the third most represented province and the most represented by population.[4]

This is consistent with statistics on ZEV adoption where, like Quebec, adoption is almost double the national average.[18] The value chain steps are well distributed across the value chain, with an area of strength in energy storage system manufacturing. Overall, companies related to hydrogen fuel cells are clustered in British Columbia.

KEY VC STEP OBSERVATIONS

- British Columbia has the highest number of companies in energy storage system manufacturing both nominally (**14** of 39 total) and by population. **Six** of these are technologies related to hydrogen fuel cells.
- Energy storage system component manufacturing is the highest nominally (**four** of eleven total). **Two** of these are technologies related to hydrogen fuel cells.
- British Columbia is the second most represented in the end-of-life steps (**one** in reuse and **three** in end-of-life).
- In general, companies related to hydrogen fuel cells are clustered in British Columbia (**eight** of 12 in the whole dataset), especially in the VC steps where the province is strongest.

REGIONAL CONSIDERATIONS

23 of the 26 companies in British Columbia are located in the Vancouver CMA, which is the largest regional cluster in the dataset. The distribution across the VC steps is similar to the provincial distribution. Vancouver has a strong ecosystem of educational institutions, think tanks (e.g., Clean Energy Canada) and accelerators and hubs (e.g., Zero Emissions Innovation Centre). There could be opportunities for further innovation outside the major centres. For example, the existing circular economy cluster in the West Kootenays, Metal Tech Alley, released a feasibility study for a battery metals hub in March 2024, which found that there is a strong foundation of "subject matter expertise and entrepreneurial spirit" to enable lithium-ion battery recycling the region.[22]

DISCUSSION

In general, British Columbia has been serious about ZEV adoption, and this is present in the policy and regulatory landscape. For example, the Zero Emission Vehicles Act, passed in 2019, sets a 100% sales target for ZEVs, making the province the first jurisdiction in the world to do so.[23]

Hydrogen fuel cells are an area of innovation expertise in British Columbia, and the province is home not only to globally recognized companies such as Ballard, but also a strong ecosystem of research and development and associations such as the Canadian Hydrogen Association.[24]

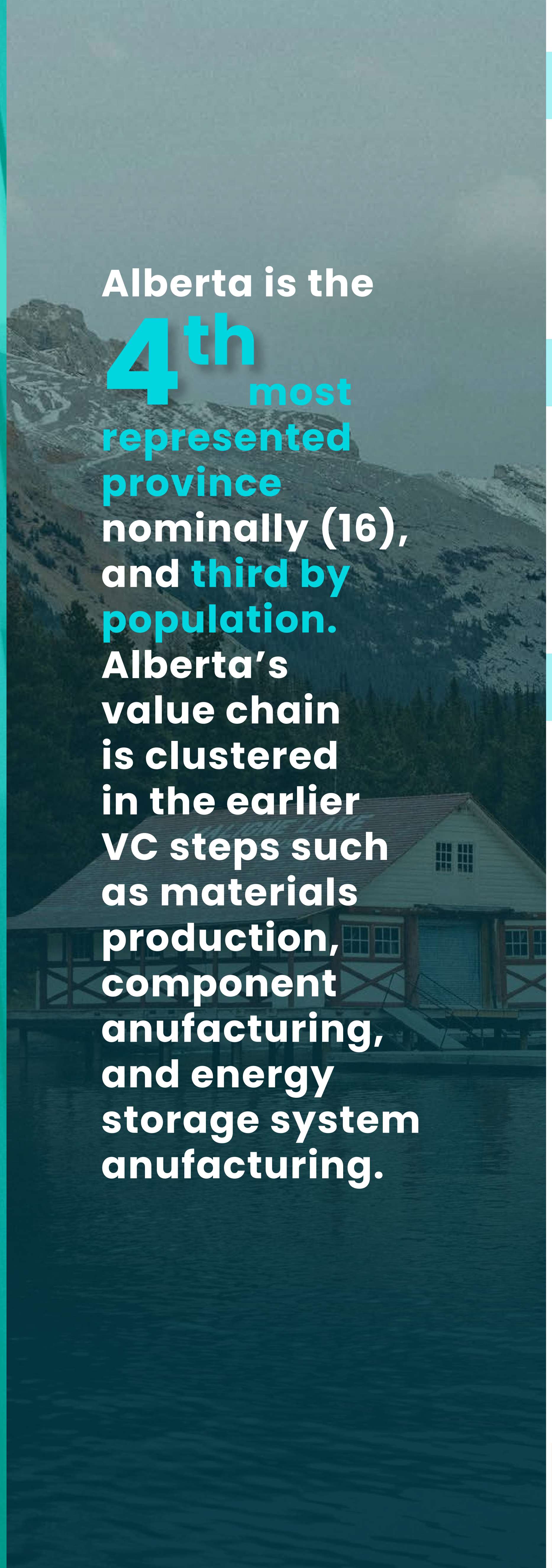
A more in depth discussion of the hydrogen value chain is planned in a future V2VC report.

There may be further opportunities to also grow the battery metals value chain. British Columbia's mining sector produces some key battery metals. Most notably, the province is Canada's highest producer of copper.[25] The provincial and federal governments have been investing in building this sector. For example, in 2024, the federal government invested $9 million in lithium processing in British Columbia[26] and the provincial government invested $2 million in a battery innovation centre at the University of British Columbia's Okanagan campus.[27] In 2023, there was a $1.05 billion partnership between the provincial and federal governments and E-One Moli to develop a lithium-ion cell factory.[28]

Battery end of life is also a potential area of opportunity in the future. This opportunity has already been recognized in the Extended Producer Responsibility Five-Year Action Plan 2021-2026, which identifies EV batteries as a planned expansion, applying a phased approach to "establish B.C. as a leader in battery recovery and management."[29]

[4] Excluding provinces with under 10 companies.

ALBERTA



Alberta is the 4th most represented province nominally (16), and third by population. Alberta's value chain is clustered in the earlier VC steps such as materials production, component anufacturing, and energy storage system anufacturing.

KEY VC STEP OBSERVATIONS

Alberta has the highest number of companies by population (1.3 per 1 million) and highest nominally (**six**) in materials production. Compared to Quebec, where materials production is mostly represented by manufacturing facilities, the companies in Alberta are all technology companies. The technologies represented are mostly related to producing battery-grade, carbon-based electrode materials or battery-grade lithium.

REGIONAL CONSIDERATIONS

11 of the 16 companies in Alberta are located in Calgary. Calgary is a growing centre of technology innovation with a particular focus on clean technology (cleantech) and the energy transition.[30] A combination of municipal support, a lively ecosystem of enabling organizations (e.g., Calgary Economic Development, Platform Calgary), and academic institutions is supporting this development.

Calgary is also home to several of the battery materials and energy storage-related knowledge generators and enablers, which are discussed below.

DISCUSSION

Alberta's areas of strength lie in the earlier stages of the value chain, and this can likely be tied to natural resources industries such as oil and gas and mining.

When it comes to carbon-based technologies, Alberta was also found to be one of the strongest provinces represented in the Carbon Tech V2VC report.[31] The strong presence of the Oil and Gas sector in Alberta could be a key contributing factor in the development of carbon-based electrode materials.

While not included in this value chain, Alberta is also home to some key primary lithium production technology companies, which are discussed in more depth in the mining V2VC report.[9] Extracting lithium from oilfield brines is recognized as an emerging opportunity for Alberta and considered in key provincial strategies such as Alberta's Recovery Plan and minerals strategy and action plan.[32] Battery-grade materials production is an extension of this area of strength.

Research and development activity is also quite present in Alberta. For example, the Western Canada Battery Consortium, a pan-institutional organization to support the development of the battery supply chain in Western Canada, is headquartered at the University of Calgary.[33] They aim to leverage local lithium and sulphur resources to develop innovative battery technologies. Alberta is also home to key knowledge generators such as the Calgary Advanced Energy Storage and Conversion Research Technologies (CAESR-Tech) Institute and enablers such as BMAC and the Transition Accelerator.

The lower concentrations of technology development in the later stages of the value chain could be linked to lower levels of adoption in Alberta, likely due to factors such as a lack of provincial incentives and limited charging infrastructure.[34] While policy will likely play a large role in encouraging adoption, technological advancements in later areas of the value chain such as charging and operational monitoring and optimization could be areas of opportunity to explore.

[5] With provinces with less than ten companies excluded.

ATLANTIC PROVINCES

Of the Atlantic provinces, only Nova Scotia (seven companies) and Prince Edward Island (one company) are represented in the database. There is not enough data to identify any clusters; each category only has one or two companies, if they have any.

REGIONAL CONSIDERATIONS

Six of the seven companies in Nova Scotia are in the Halifax CMA. In a general sense, Halifax has a thriving innovation ecosystem with over 300 startups and scaleups, internationally recognized educational institutions, and several innovation startup accelerators and incubators.[35]

DISCUSSION

Nova Scotia being the strongest Atlantic province has been consistent across most sectors covered in Foresight's V2VC reporting, likely due to it being the most populated Atlantic province and home to several universities.

Some key Canadian battery-related research and development has been done in Nova Scotia, in particular at Dalhousie University. In 2001, a research partnership between Dalhousie professors and 3M resulted in advancements in NMC batteries.[7] More recently and building on this research strength, the federal government announced a $10.5 million investment to establish a Canadian Battery Innovation Centre at Dalhousie University, focusing on next generation battery cells.[36]

The current legislation in Nova Scotia has made ZEV uptake challenging by preventing utility ratepayer money to be used for provincially funded charging stations, but the province has recently proposed adjustments to manage this barrier.[37]

More broadly, the marine sector in Atlantic Canada could be an area of opportunity in the future when it comes to transportation electrification. Though only one marine company (Bluegrid) is represented in the current dataset, electrification in the marine industry is projected to grow and has been recognized by sector leaders as a particular opportunity for Atlantic Canada.[38]

PROVINCES AND TERRITORIES NOT REPRESENTED

Several provinces and territories are not represented in the dataset. These include Saskatchewan, Manitoba, New Brunswick, Newfoundland and Labrador, and all three territories. For the most part, it is likely due to the limited population and is consistent with other V2VC datasets where these provinces were minimally represented, if at all. However, there is still relevant activity, outside the scope of this dataset (i.e., operational, primary production, earlier stage research and development), and there are still opportunities these provinces could build upon. For example:

- **Battery metals:** Saskatchewan and Manitoba both have raw lithium resources.[39] Saskatchewan is also investing in facilities for other key materials in the ZEV supply chain such as a rare earth processing facility in Saskatoon.[40] Newfoundland and Labrador has potential for 23 of the 31 critical minerals identified in the Canadian critical minerals strategy, many of which are essential to the battery supply chain.[41]

- **Manufacturing:** Manitoba has a large transportation manufacturing industry,[42] including the headquarters of electric bus company NFI Group. The province is also home to the Manitoba Vehicle Technology Centre, which aims to accelerate growth in Manitoba's heavy equipment and vehicle industry, including ZEV technology.[43]

- **ZEV adoption incentives:** New Brunswick, Newfoundland and Labrador, and Yukon are among the provinces and territories that offer provincial ZEV adoption incentives.[44]

A 2023 Indigenous Clean Energy report identifies grid integration, the effects of distance from larger population centres on maintenance considerations and vehicle economics, and cold climate impacts as key considerations for rural and remote communities.[45] Innovation often occurs naturally in larger population centres due to the presence of government entities, academic institutions, and the competitive environment. Although the key recommendations for enabling ZEV adoption tend to focus on policy- and infrastructure-related solutions, there could also be some value in also encouraging more innovation outside of larger centres to better address these specific challenges.

GENERAL TRENDS

This section covers some of the key overall trends within the national value chain and discusses how **certain types of technologies and innovations can provide support in addressing key challenges, support adoption, and improve sustainability as the sector grows.** Because resources such as the Accelerate ZEV Canadian Battery Innovation Roadmap cover the innovation ecosystem, key drivers, and types of supportive technologies in depth, **this section focuses on quantifying and contextualizing the ecosystem of current technology companies** as represented in the dataset.

THE MIDSTREAM – ENERGY STORAGE MATERIALS AND COMPONENTS

In their battery metals roadmap, BMAC identified the midstream, which they define as the refining of battery grade materials into precursors and battery active materials, as an area where Canada needs to expand as most production occurs in Asia.[3] Definitions of the battery supply chain midstream vary. For the purposes of this report, the midstream is defined to include the production of battery grade minerals, precursors, and active materials covered in the materials production VC step and finished cell components, covered in the components VC step, in alignment with broader definitions such as the ones provided by the BDC and Clean Energy Canada.[46,47] Based on the dataset, the later midstream (i.e., active materials and components) is more represented than the early midstream, which is consistent with recognized gaps by organizations such as BMAC.

MATERIALS PRODUCTION

17 companies are assigned to energy storage system materials production, **five** of which are identified as manufacturing facilities, while the remaining **11** are technology development, including both technology-focused companies and technology development by operating companies.

- **Seven** focus on silicon-based and graphite-based anode materials.
- **Six** focus on cathode materials, and most of these (4) are manufacturing facilities producing cathode active materials.
- The remaining **four** companies are innovations related to precursor materials such as battery-grade lithium.

Precursor materials have limited representation compared to active materials, but there have been some recent investments to bring production to Canada. For example, Umicore and the Ontario and federal governments have invested in an industrial-scale cathode active material and precursor manufacturing plant in Loyalist, Ontario, set to be commissioned in 2025 and begin production in 2026.[48]

COMPONENTS

11 companies were assigned to the component manufacturing category. One of these is a manufacturing facility. For battery technology, components in this VC step include finished materials and cell components such as anodes, cathodes, electrolytes, collectors, and separators. Three companies are related to hydrogen fuel cell components, and these technologies include membranes and cell materials (see further discussion on hydrogen fuel cells in the next section).

RECYCLING

Recycling is another way to supplement the midstream. Within the end-of-life VC step, **10** of the 11 companies are focused on recovering and refining recycled materials. These technologies include those that extract lithium, graphite, and other battery materials from black mass. The demand for end-of-life solutions will continue to increase, so continuing to leverage recycling as ZEV adoption grows can be a strategy to not only manage battery waste but also produce valuable materials.

THE PFAS CHALLENGE

Depending on the processing methods used, lithium-ion batteries and their manufacturing can be sources of per- and polyfluoroalkyl substance (PFAS) pollution—sometimes termed "forever chemicals" due to the fact they do not easily degrade, persist in the environment, and can impact human health. Some PFAS-containing materials can be fire retardant and improve battery safety and some battery processing methods generate PFAS waste.[49,50] For example, hydrometallurgical processing is less energy-intensive than some alternatives, but does not degrade PFAS byproducts.[50] However, as awareness grows and PFAS materials become more highly regulated (e.g., Canada's new PFAS reporting regulation),[51] Canadian companies are taking key steps to reduce their impact. For example:

- RecycLiCo partnered with electrode materials producer Nanoramic to test their process on PFAS free materials.[52]
- Li-Cycle has been recognized for their process that does not produce PFAS.[53]

Canada also has a strong presence of water treatment technologies, many of which have PFAS remediation capabilities, especially when it comes to potable water treatment. With 132 companies, potable water treatment was the second most represented VC step in the V2VC water dataset, and several of those companies have PFAS remediation technologies (e.g., Quest Water Solutions, Fixed Earth Innovations, Amatis).[54]

ENERGY STORAGE SYSTEM MANUFACTURING

Energy storage system manufacturing is the most represented VC step in the dataset with 39 total companies (three of which are manufacturing facilities).

This VC step includes companies that develop or support the development of batteries, cells and modules, and non-battery energy storage systems used in transportation applications.

LITHIUM ION BATTERIES

Lithium-ion batteries (19 companies) are the most represented type of energy storage system in the VC step. This concentration is expected as lithium-ion batteries are the most widely used energy storage system type for electric vehicle applications because of their energy density to weight ratios.[55]

Battery chemistries represented:

- **Six** are Lithium-Iron-Phosphate (LFP)
- **Five** are Lithium-Nickel-Manganese-Cobalt (NMC)
- **One** Lithium-Titanium-Oxide (LTO)
- **Six** are not specific about which battery chemistry. These include larger companies that might develop more than one type, companies that develop cells and modules as opposed to the full energy storage system, and cell gigafactories.

These findings are consistent with BMAC's roadmap to 2040, which has set a target pathway of 50% nickel-rich (e.g., NMC) and 50% LFP.[3] LFP has some advantages over NMC chemistries in terms of safety and lifespan, while NMC has higher specific energy and low self heating rate and are lower cost per kWh.[56] BMAC further notes that Canada has a history of LFP innovation, so leveraging that expertise could encourage growth of Canada's LFP market.[3]

INNOVATIVE BATTERY TYPES

Newer, innovative battery types are also represented in the dataset (**six** companies in the energy storage system Manufacturing VC step and **two** in the energy storage system component manufacturing VC step). Most of these are in pre-commercial stages. These include solid-state batteries, li-metal batteries, metal-air batteries, and silicone batteries. Other innovative battery types such as zinc-ion and sodium-ion are also being developed in Canada, but these are currently being developed for stationary applications and covered in the Electricity V2VC report.[57] BMAC notes that some of these innovative battery types could eventually compete with lithium-ion, but likely not until after 2040.[3]

Among the innovative battery technologies in the dataset, solid-state battery technologies are the most represented (**four** companies). Accelerate ZEV's Roadmap identifies solid-state batteries as a key enabling technology due to the high energy density and improved safety.[7] A lot of pre-commercial innovation is happening in this space in Canada. For example, solid-state batteries are a key focus areas of some knowledge generators across Canada, including the Hydro Québec Center of Excellence in Transportation Electrification and Energy Storage, the Western Canada Battery Consortium (University of Calgary), the Canadian Battery Innovation Centre (Dalhousie University), and the Battery Innovation Research Excellence Cluster (University of British Columbia).

HYDROGEN AND NON-BATTERY ENERGY STORAGE

Ten companies assigned to the energy storage system manufacturing VC step are non-battery energy storage systems. Nine are hydrogen fuel cell technologies, and one specializes in supercapacitor cells for multiple applications, including transportation.

Canada is recognized as a leader in hydrogen innovation including fuel cell electric vehicles (FCEVs).[58] However, as BEVs are more widely adopted, FCEV adoption faces challenges with limited infrastructure and generally higher costs.[59] Although BEVs are likely to continue to be the most widely adopted ZEVs, FCEVs are still expected to continue to exist alongside BEVs because of their advantages in energy density and longer range, which could be beneficial for long-distance, heavy duty transport applications.[6]

SUPPORTIVE TECHNOLOGIES

Six of the companies represented are technologies that support energy storage system manufacturing (e.g., software, monitoring, analytics, smart battery management systems, and protective coatings to improve existing energy storage systems). These technologies focus on battery safety and efficiency.

CHARGING AND ENERGY MANAGEMENT TECHNOLOGIES

With **34** companies, charging and refueling is the second most represented VC step in the dataset.

All but one of these companies is focused on some form of BEV charging (the other is hydrogen fuel cell refueling). Recent projections show that as ZEV adoption increases, the demand for charging infrastructure will grow dramatically in the next ten years, and it will require significant investment.[60] Many of the technologies are aimed at personal vehicles or commercial fleets and are relevant to level 1 or level 2 chargers, and most are either charging stations and equipment or energy management solutions. Most systems are commercially available.

Although energy resources, infrastructure, funding, and supportive policy will be key to enabling the expected level of growth and mitigate strains on already strained electricity grids, technologies such as optimized charging systems, energy management solutions, and bidirectional charging could provide additional support.

Across Canada, an average of 40,000 public ports will need to be installed each year between 2025 and 2040 to meet projected growth in demand.

- Natural Resources Canada [60]

ENERGY MANAGEMENT SOLUTIONS

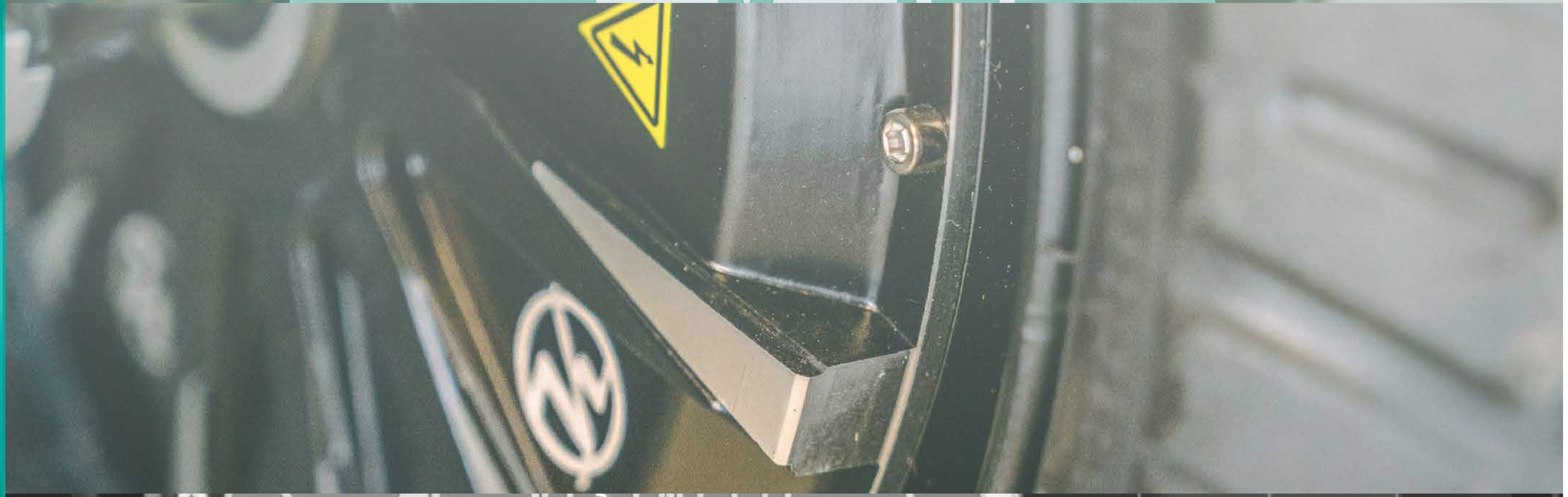
15 of the 34 companies were assigned the energy management keyword. Although most charging technologies have some form of integrated energy management system, this keyword was assigned to companies for which energy management-related data collection and analysis was a primary focus. This includes technologies focused on optimization, analytics, and “smart” charging systems that automatically optimize charging. These technologies can support demand management as adoption increases, optimize costs and performance across multiple charging systems, and monitor systems for potential safety issues.

BIDIRECTIONAL CHARGING

Bidirectional charging, which refers to technologies that convert battery power to pass to another recipient (e.g., vehicle to grid technology, vehicle to home technology) is a potential opportunity for growth. Only **three** of the technologies are identified as bidirectional charging systems. Vehicle-to-home or building bidirectional charging can allow the EV to function as a generator and provide a backup power source in the case of power outages or emergencies, and can support demand management.[61] Although not all EVs have the capability for bidirectional charging, this type of bidirectional charging application is expected to grow as more EV manufacturers integrate this capability.[62]

Vehicle-to-grid technologies refer to bidirectional charging where electricity from EVs is directed back to the grid. This form of bidirectional charging can be used to balance the energy grid, with the vehicle functioning similarly to a stationary energy storage system while it is charging. Although this technology could support energy management as adoption grows, there are some regulatory barriers that would need to be resolved to enable adoption.[62]

OPERATIONAL OPTIMIZATION



Eight companies in the dataset were identified as the operational energy storage system optimization and monitoring VC step, which covered external supportive technologies used to monitor, optimize, and analyze energy storage system health, performance, and other factors while the energy storage system is in operation.
While batteries have built-in battery management systems, these kinds of technologies can provide additional support to help users improve safety, optimize maintenance and performance, and extend battery life.

The technologies represented are varied and are often a secondary product offered by companies that also offer integrated solutions (e.g., Lion Electric's Lion Beat telematics system), and most are AI-driven technologies. These types of technologies could be an area of opportunity as ZEV adoption increases and AI-driven technologies advance.

END-OF-LIFE OPTIONS

As ZEV adoption grows, end-of-life options for energy storage systems—especially lithium-ion batteries—are an increasing concern. Lithium-ion batteries are considered hazardous waste, and when degraded, damaged, or stored incorrectly, they can pose a fire and explosion risk.[63]

Recycling is one of the key priorities identified in the BMAC roadmap. They suggest a combination of policy-based and innovation-focused approaches including implementing strong extended producer responsibility and the development of battery active material plants from recycled batteries to create a strong ecosystem that can produce over 7 kt of battery active materials per year.[3]

RECYCLING

End-of-life processes involve several steps: removal, separation of materials, recovery and refining of relevant materials, and safe disposal. Of the **11** companies in the end-of-life VC step, **nine** are identified as recovery and refining, while **two** are identified as full service. Traditional processes for battery recycling can be energy intensive and generate waste and GHGs.[64] Improving battery recycling technologies not only contributes to meeting raw material needs (as discussed earlier in this report), but also in enabling a more sustainable battery lifecycle, which will be required to support the expected growth in the coming years.

It is to be expected that there is more concentration in recovery and refining, as innovations in other stages such as separation and disposal may be more procedural than technological. However, there could still be an area of opportunity for growth as automated or AI-driven technologies also play a role in improving recycling efficiency and recovery rates.[7]

BATTERY REUSE

Battery reuse, often referred to as "second life," is another end-of-life option. This option is applied to undamaged batteries that have reached the end of their capacity for electric vehicle use, but could be refurbished or reconditioned for other uses such as grid storage. These technologies could be an area of opportunity for growth, as only **three** companies are assigned to this VC step. That said, some of this work may be done by system integrators, which are not included in this dataset.

In addition, enabling batteries to have a second life also needs to be considered much earlier in the value chain. Accelerate ZEV identifies "second life adaptability" as a key environmental driver and suggests that it can be enabled by design improvements and measured by the development of an Ease of Repurposing Index that can be applied to "measure and enhance the adaptability of second-life applications."[7]

ELECTRIFICATION ACROSS TRANSPORTATION SUBSECTORS

Most of the technologies represented in this dataset are for road vehicle applications, including both smaller scale passenger vehicles and medium to heavy freight vehicles. This is to be expected as road transport is the highest emitting form of transportation,[65] and smaller vehicles are easier to electrify.

Marine and, to a lesser extent, rail transport applications are also present. Electrification, both in terms of battery-powered and hybrid vessels, in the marine industry is projected to grow.[38] Efforts are underway to develop electrification technology in this subsector, such as the Ocean Supercluster's announcement of their $7 million Canadian Electric Propulsion Acceleration Coalition (CEPAC) Project in May 2024.[66] Europe, especially Norway, currently has the dominant market share in this space, attributed to supportive regulations and infrastructure.[67] Due to this higher demand, Canadian-founded Corvus Energy moved their corporate headquarters to Norway in 2019.[68] Continued efforts to grow the marine electrification subsector in Canada could be an opportunity to attract companies to the Canadian market and provide the demand to keep existing companies here.

In the rail sector, alternative propulsion methods such as electrification (battery or catenary) and hydrogen fuel cells are considered, but may not be the subsector's most immediate solutions. For example, Towards Net Zero: Developing a Rail Decarbonization Roadmap for Canada (2022) lists electrification as a third wave after efficiency improvements and low carbon fuels, and catenary electric rather than battery-electric technologies are identified as the highest rated of these in terms of commercial availability.[69]

SAFETY

Safety is a primary concern for all forms of energy storage, especially when it comes to fires and explosions. In the dataset, only **four** companies were assigned the safety keyword. However, this keyword was only applied to technologies where safety is the primary or only application, for example, fire extinguishers developed with advanced solutions for fighting lithium-ion battery fires, a hydrogen fuel cell leak detection system, and specific battery components for fire prevention. That said, safety-specific technologies only paint part of the picture of battery safety technology, as safety is embedded across all stages of the value chain and a key consideration for most companies in the dataset (e.g., battery management systems monitoring state of health, non-flammable battery components). Overall, while there may be opportunities to grow in developing safety-specific technologies, safety remains at the forefront of most energy storage system innovations.

RECOMMENDATIONS

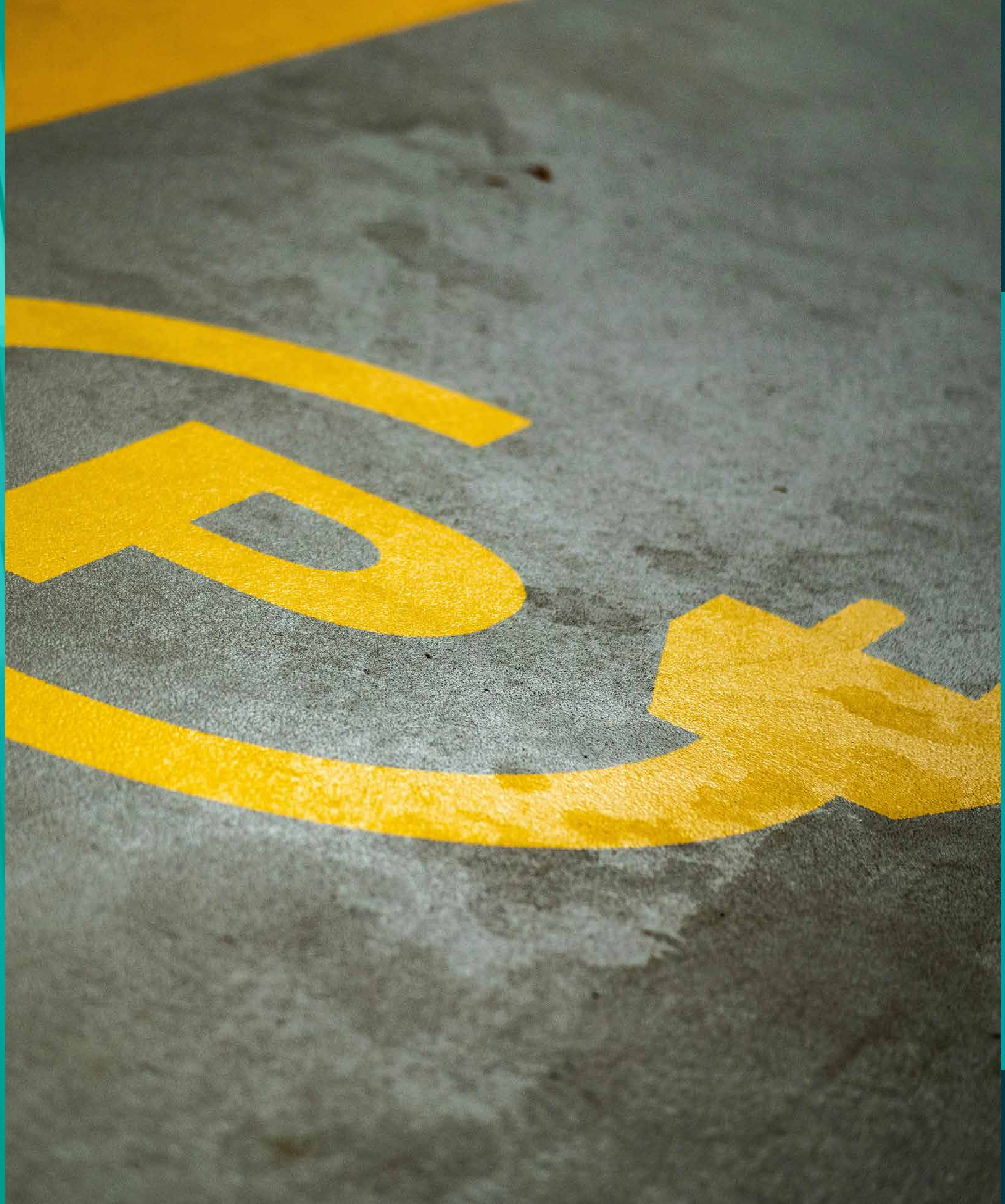
VENTURES, INVESTORS, GOVERNMENT, AND INDUSTRY CAN ALL BENEFIT FROM THE INSIGHTS THIS ANALYSIS PROVIDES ABOUT THE SECTOR AS WE TRANSITION TO A NET ZERO ECONOMY.

VENTURES ARE RECOMMENDED TO USE THIS REPORT AND WEB MAP TO GLEAN VALUABLE INSIGHTS ON GAPS AND OPPORTUNITIES WITHIN THE ECOSYSTEM TO:

- Identify innovation opportunities, potential partnerships, and competitors segmented both by geography and position in the value chain.
- Apply a broader understanding of where technologies fit on the value chain to better promote their existing strengths and make informed business decisions.

INVESTORS AND INDUSTRY WILL ALSO FIND THIS REPORT AND WEB MAP TO BE AN INVALUABLE TOOL WHEN EVALUATING INVESTMENT AND/OR ACQUISITION OPPORTUNITIES TO:

- Understand the value-add prospective ventures provide by identifying their role in the value chain
- Determine what competitors might exist for any given company
- Identify strengths, opportunities, and potential trends in the Canadian market to inform business decisions



ADDITIONALLY, GOVERNMENTS CAN CONSIDER THE KEY INSIGHTS FROM THIS ANALYSIS TO IDENTIFY TARGETED AREAS FOR SUPPORT IN A MORE COORDINATED AND INTENTIONAL WAY. KEY RECOMMENDATIONS FOR GOVERNMENT INCLUDE:

- Leverage and build on provincial strengths and regional clusters (e.g., Vancouver, Montreal, Toronto) to support a thriving innovation ecosystem.
- Consider opportunities to foster strategic technology innovation in less represented regions.
- Continue to support continuous improvement in areas such as energy storage system manufacturing, energy management, and recycling in order to enable projected increased adoption, especially in the road transportation subsector.
- Continue to grow and develop the midstream, as recommended by organizations such as BMAC.
- Continue funding research and development into innovative battery types, battery reuse applications, and innovations outside of the road transport subsector.

CONCLUSION

THE CANADIAN ECOSYSTEM OF ENERGY STORAGE TECHNOLOGY FOR TRANSPORTATION DEMONSTRATES THE SECTOR'S STRONG TRACK RECORD OF INNOVATION AND EXPERTISE, AS SHOWN IN THE REPORT AND WEB MAPPING. THIS IS A GROWING SECTOR THAT WILL LIKELY EXPAND DRAMATICALLY IN THE COMING YEARS, AND **THERE ARE MANY OPPORTUNITIES FOR CANADA TO LEAD AS WE STRIVE TO REACH NET ZERO.**

Interested in learning more about Canada's energy storage technology for transportation value chain?

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