A Roadmap for Canada's Battery Value Chain

Building a national strategy for critical minerals and green battery metals

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About us

The Transition Accelerator exists to support Canada's transition to a net-zero future while solving societal challenges. The Transition Accelerator works with innovative groups to create visions of what a socially and economically desirable net zero future will look like and build out transition pathways that will enable Canada to get there. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground. transitionaccelerator.ca

The Battery Metals Association of Canada (BMAC) is a national non-profit association of industry participants and champions from across all segments of the battery metals value chain. From mining to specialty chemical refining, manufacturing, end use and recycling, BMAC is focused on coordinating and connecting the segments of this value chain, ensuring Canada captures the economic potential of the sector and is able to attain its electrification targets. Together, our members collaborate to accelerate the development of the battery metals ecosystem in Canada. bmacanada.org

Accelerate, Canada's ZEV supply chain alliance, works across sectors to leverage strengths and experience to ensure Canada becomes a global ZEV leader as the world shifts to net-zero and zero-emission vehicles. Bringing together companies and organizations from across the ZEV landscape – from mining to mobility, R&D to commercialization, and vehicle assembly to infrastructure – with labour unions, ENGOs, researchers and post-secondary institutions, Accelerate is a forum for members to collaborate, strategize and advance priorities that will support the accelerated development of a ZEV supply chain in Canada. acceleratezev.ca

The Energy Futures Lab was created to address a growing sense of polarization in Canada. Since its inception in 2015, the EFL has brought together stakeholders from across the energy system to collaboratively develop solutions for a low-emissions energy future. This approach has highlighted the importance of drawing on diverse perspectives to address complex, system-level challenges. energyfutureslab.com

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A Growing Global Opportunity

Demand for electric vehicles is outstripping even the most optimistic projections.[1] Battery pack prices are rapidly declining and exciting new models are hitting showroom floors.[2] Just weeks after unveiling the F-150 Lightning, Ford announced it was doubling production to meet demand.[3] We are witnessing the mainstreaming of electric vehicles in real time.

The transition to electric vehicles (EVs) is already having a disruptive impact. The rapid demand growth in EV and electricity storage is putting enormous pressure on the supply of metals and minerals used for the production of these decarbonizing technologies. In the near-term, global market uptake of EV metals production is likely to absorb Canadian output of nickel, cobalt, lithium, phosphorous, and rare earths faster than new production can be developed.

What must be done today to build a Canadian battery metals industry that will be a significant contributor to Canada's long-term prosperity?

The economic imperative to develop an EV ecosystem in Canada is clear. Cars and automotive parts are Canada's number 2 export, behind oil and gas.[4] Both the internal combustion vehicle and the oil and gas industry will be disrupted by the energy transition. Canada needs to act fast to replace these exports. Meanwhile, the development of an EV ecosystem represents a once-in-a generation opportunity to support long-term Canadian prosperity.

In order for Canada to secure a place in the global economy of a net-zero world, it must urgently build its supply chains for the battery and EV industry. Both government and industry are working hard on this and there have been a number of recent positive developments. Vale will supply nickel from its Sudbury operation for cathode production in Sweden, BASF and POSCO will make cathodes in Bécancour, while LG will make battery cells and modules in Windsor.[5] Ford's doubling of the F-150 Lightning production led Magna to expand its battery housing production in Chatham.[6] While these projects are exciting, Canada needs a comprehensive strategy to ensure that

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these investments produce a viable supply chain and support the broader battery and EV industry.

What must be done today to build a Canadian battery metals industry that will be a significant contributor to Canada's long-term prosperity?

To seize the opportunity at hand, Canada needs collaborative partnerships between governments, firms, indigenous communities and organizations, universities, and civil society organizations. These public-private-indigenous partnerships are needed to accelerate development along each segment of the battery metals supply chain. Ensuring that the strategy, roadmap and action plan include proactive, meaningful collaboration with indigenous groups is of particular importance and these efforts must be undertaken in a manner that recognizes historical inequities and promotes economic success of indigenous groups and communities.

This report is a call to action from the Battery Metals Association of Canada (BMAC), along with its partners the Energy Futures Lab, Accelerate ZEV and The Transition Accelerator for a bold national strategy, roadmap, and action plan.

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The report makes four main interventions:

1. Canada needs a bold and clear target for battery metal and EV production.
2. Canada must systematically build homegrown capacity in strategic niches along the supply chain.
3. The midstream segment of chemical production is the key to an integrated supply chain.
4. Canada can use co-produced roadmaps to underwrite catalytic investments that connect the upstream, the midstream, and the downstream.

To retain its global position and meet its climate goals, Canada must produce 1,300,000 electric vehicles by 2030 as well as the raw materials, processed metals, and batteries for 100 gigawatt hours (GWh) of battery capacity.

A Bold and Clear Target

The bold and clear target in this report rests on two key premises. First, Canada should, as an initial benchmark, build an EV supply chain from mines to vehicles that replicates its current 10% share of North American automotive manufacturing.

Second, Canada should develop this capacity at a pace necessary to meet the government's ZEV sales mandates of 60% of light-duty vehicles by 2030 and 100% by 2035.

There are many geopolitical and technological uncertainties in the battery space. This report begins from three forward-looking assumptions to streamline our analysis and simplify the exercise of navigating these uncertainties:

- The North American EV industry will be tightly integrated, just as the internal combustion engine (ICE) industry is, and there will be prioritization of local content in battery metals for geopolitical reasons.
- An effective Canadian strategy must be aligned with the Canada-US critical minerals strategy and privilege domestic North American businesses while preserving Canada's interests in an equitable manner.
- EV battery technology will continue to progress, but for the next 20 years, markets will be dominated by nickel-rich and lithium-iron-phosphate cathode chemistries. Emerging technologies will not fundamentally alter metal needs in the next two decades.[7]

These premises form the basis for a clear goal and national target:

To retain its global position and meet its climate goals, Canada must produce 1,300,000 electric vehicles by 2030 as well as the raw materials, processed metals, and batteries for 100 gigawatt hours (GWh) of battery capacity.

While this is an ambitious target, it is achievable and comprises a vital foundation for Canada's future economy and prosperity.

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Building Canada's Homegrown Capacity and Ecosystem

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The battery value chain includes mining of raw materials (upstream), processing of these mined materials into battery active materials (midstream), manufacturing the batteries themselves, the use of these batteries (e.g. EVs) (downstream), and the end-of-life recycling of batteries.

Recent announcements and reports suggest that the government's strategy is to use foreign direct investment (FDI) to build a chain starting with automotive original equipment manufacturers (OEMs), moving "up" to cathode active material production, pulling in existing local metals where possible. This is an essential starting point.

However, it is critical that this FDI and downstream-driven strategy be complemented by efforts to maximize the potential of an integrated Canadian battery supply chain, leverage foreign investments into homegrown capacity, and build a vibrant innovation and industrial ecosystem.

If foreign automotive OEMs dictate the strategy, they may build the supply chain in ways that do not serve the long-term economic and security interests of the country.

Canada must leverage investments in the EV and battery supply chain to build homegrown capacity and establish a strong national ecosystem.

A Strong Midstream is the Linchpin of the Battery Metals Supply Chain

A strategy can originate in the upstream, midstream, or downstream. Conventional wisdom suggests that we need to start downstream, with consumers and automotive OEMs. This report presents an alternative vision. Rather, **it is the midstream, i.e. chemical processing of mined materials into battery active materials, that should serve as the linchpin** in an integrated supply chain that is competitive over the long run. The value of downstream manufacturing and upstream mining is clear and well understood. But, their success depends on the midstream.

Canada must leverage investments in the EV and battery supply chain to build homegrown capacity and establish a strong national ecosystem.

Building the midstream helps the whole supply chain by driving demand-pull for upstream mining and providing the supply-push needed to feed downstream production.

The midstream produces battery active materials, which are high-value added, exportable, and can be aligned with collaborative efforts such as the Canada-US critical minerals strategy to insulate against competitive national targets. The midstream anchors an integrated supply chain that uses Canada's expertise in green chemistry to establish efficient pathways from mines to battery active material.

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The midstream anchors an integrated supply chain that uses Canada's expertise in green chemistry to establish efficient pathways from mines to battery active material.

An acute issue facing Canada's battery metals industry today is that there is very little midstream production within its borders, and Canada risks falling further behind as other nations jockey to ramp up. This is why Nano One's purchase of Johnson Matthey's lithium-iron-phosphate (LFP) cathode production facility in Québec is so important.[8] Johnson Matthey's facility is the only cathode production facility in North America, so this project leverages existing expertise in a segment of long-term strategic value.

As another example, nearly all global natural graphite processing occurs in China.[9] Canada is endowed with large graphite resources, and bolstering and scaling Canadian graphite production would create security and a myriad of economic benefits.

Canada should seek to mine and process lithium, nickel, cobalt, manganese, iron, phosphate, and graphite here in Canada.

Canada Needs Major Catalytic Investments

Catalytic investments pool public, private, and indigenous finance to deliver a national strategy. Catalytic investments could allow Canada to overcome the chicken-and-egg problem that often plagues new industries, in which development is incremental instead of transformative, and there is insufficient capital deployed on a timely basis to unlock the full potential.[10] A catalytic investment program can take many forms, including subsidies, direct equity investments, loans and loan guarantees.

A coordinated program of catalytic investments within a national industrial strategy has tremendous potential to help establish a battery and EV supply ecosystem in Canada on a timely basis. However, this requires urgent action and a strong government commitment to begin to build local supply chains that tie existing and new funds to strategic priorities.

Catalytic investments are pro-active—they seek to build an industry in accordance with an overarching vision. Many of Canada's business development and net-zero funds are set up to passively accept applications from existing firms, rather than sourcing opportunities and collaborating to fill holes in the supply chain. Moreover, existing funds and programs tend to privilege individual firms, especially commercial stage ones. Large, public demonstration funds would help build strong ecosystems and firms in tandem.

Canada needs a roadmap that provides the targets, timetables, and priority actions to guide and align investments. A roadmap is, in turn, the foundation of a national industrial strategy that positions the industry in the broader domestic and international landscape.

A Roadmap for Canada's Battery Material Industry

To be effective, catalytic investments need clear timetables and targets. Canada needs a roadmap that provides the targets, timetables, and priority actions to guide and align investments. A roadmap is, in turn, the foundation of a national industrial strategy that positions the industry in the broader domestic and international landscape. This report provides a preliminary roadmap for Canada's battery metals industry building from key discussions and addressing key challenges identified in a series of targeted workshops engaging the BMAC community.

Building out the midstream is the most critical near-term priority which will allow Canada to capture high value-added segments of the supply chain and develop the homegrown capacity necessary to secure a strong global position.

This roadmap articulates four high-level goals corresponding to four segments of the supply chain: mining, chemical processing, cell manufacturing, and recycling, each with a concrete priority action along with additional cross-cutting actions and policy recommendations (Table 1).

Priority actions in a national strategy

1. **Mining:** develop creative financial mechanisms to unlock nickel, lithium, graphite and rare earth development.
2. **Chemical production:** create a hub and spoke system for integrated chemical processing to produce battery active materials.
3. **Cell manufacturing:** evaluate which cell components Canada has the greatest opportunities to compete in and strategize how to learn from foreign direct investments in cell manufacturing.
4. **Recycling:** put in place strong extended producer responsibility requirements to catalyze the recycling market and harmonize regulations and standards to activate the ecosystem.

Cross-cutting themes: to create an integrated supply chain, government and industry must work together to co-create an industrial and innovation ecosystem that builds homegrown capacity over time.

Policy recommendations: use roadmaps to guide and align public funds; refocus existing and future funds to take an active role in forging supply chains; and ensure there are ample funds for large demonstrations of new technologies and business models.

Taken together, the action plan detailed in this report does two things. First, it highlights near-term actions to bring the supply chain online fast and identify where to effectively target catalytic investments and policies. Second, it outlines the building blocks of a battery and EV supply ecosystem. Building out the midstream is the most critical near-term priority. This is priority action 2 of the 4 point priority action list, involving the establishment of a hub and spoke system for integrated chemical processing. It will allow Canada to capture high value-added segments of the supply chain and develop the homegrown capacity necessary to secure a strong global position.

In addition to an industry-level strategy, this report also outlines specific battery metal strategies for key metals. These metals strategies include details of how battery metals are mined and processed, which must be understood to develop effective strategies. This report focuses on four commodities as a starting point: lithium, nickel, graphite, and rare earths. For each metal, we have evaluated the current supply chain and the Canadian landscape, and identified a proposed path forward. This report does not address details pertaining to other metals that will form part of a full battery and EV supply chain, including cobalt, manganese, copper, iron, phosphate, and aluminum, which we note should be evaluated in the future as part of a robust national strategy.


Spodumene


Neodymium


Nickel


Graphite

Time To Get Started

The best way to advance these priority actions, grow an ecosystem, and further refine an industrial strategy, is by setting collective targets and increasing coordination. It sounds simple but research on industrial strategy shows that clear goals and increasing communication can catalyze action up and down the supply chain.[11]

The forging and fostering of a public-private-indigenous partnership that brings together an independent organization and a small, autonomous government agency or task force is a key component of creating and delivering an action plan guided by clear targets and an adaptive set of policy tools tailored for the challenge at hand.[12]

The Battery Metals Association of Canada, the Energy Futures Lab, the Transition Accelerator and Accelerate ZEV have the desire, knowledge, skills and actors to foster this partnership and are keen to explore and support next steps.

The best way to advance these priority actions, grow an ecosystem, and further refine an industrial strategy, is by setting collective targets and increasing coordination.

Introduction

Canada's EV supply chain and ecosystem is rapidly growing. A network of firms is beginning to emerge covering the value chain from mining through to electric vehicle assembly. There is also evidence of strong political support for the development of a sophisticated, substantial EV supply chain and ecosystem in Canada. The federal government has been busy delivering on the *Mines to Mobility* strategy, lining up investments in cathode processing, cell manufacturing, and EV assembly.[13] The government has also mandated the creation of a battery innovation and industrial ecosystem.[14]

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Establishing a Vision for the Industry

Key actors in civil society, government, and industry have articulated the enormous opportunity for Canada to develop a domestic industry in battery metals that fits within the greater EV supply chain and ecosystem.[15] The impetus to seize this opportunity within the context of a North American-focused ecosystem has been reinforced by geopolitical developments in Europe and Asia.[16]

Energized by these developments, the Battery Metals Association of Canada (BMAC) and the Energy Futures Lab (EFL) convened BMAC's members to determine how best to capitalize on this opportunity.[17] In October of 2021, BMAC partnered with EFL again to create a bold, ambitious vision for the development of the battery metals industry in Canada (see box 1). The vision workshop concluded with a mandate for BMAC to spearhead a national strategy with a "a clear policy roadmap" that would catalyze the "development of a national critical minerals strategy."

Vision

In October 2021, the Battery Metals Association of Canada (BMAC) and the Energy Futures Lab convened the BMAC community to establish a bold vision for the industry.

Our Vision as the BMAC Community

By 2041, Canada's battery metals supply chain will be a significant contributor to Canada's prosperity and the global energy transition. We know that we have been successful if the Canadian battery metals value chain:

1. ...is a sought-after supplier of battery metals and of value added, finished goods and exportable technologies that meet our decarbonization needs domestically and support world markets.
2. ...sets world-leading ESG standards and transparency for the global industry in responsible and sustainable mining.
3. ...contributes significantly to social and economic well-being in the communities we work in and the equity seeking groups we work with.
4. ...attracts, builds and retains talent through research, development & deployment.
5. ...serves to build and grow the value chain as a whole to expand opportunities for all.
6. ...collaborates North American-wide in battery metal/mineral extraction and processing.
7. ...recycles and reuses materials and components as part of a geographically-optimized circular economy connected to the rest of North America.

The roadmap set out in this report aims to spearhead a national strategy and is the product of these sessions, workshops and collaborations.

Executing Industry Mandates

To carry out BMAC's mandate of building an enduring Canadian battery metals industry in Canada, BMAC partnered with the Energy Futures Lab and the Transition Accelerator to convene a strategic advisory group for a series of small sessions and two member workshops conducted between October 2021 and January 2022. The roadmap set out in this report aims to spearhead a national strategy and is the product of these sessions, workshops and collaborations. It is intended to serve as a starting point for government, indigenous communities, and industry to collaborate on a national strategy for the accelerated development of a battery metals value chain in Canada and ultimately for the industry to become a significant contributor to Canada's long-term prosperity and the broader global energy transition.

This report includes analysis and recommendations on the following key components:

- Strategic elements that position Canada in global markets;
- Targets and timelines for delivering raw materials and battery metals;
- An action plan to achieve the targets;
- Policy priorities;
- Investment required.

Monument of Nikola Tesla at Niagara Falls - Ontario, Canada.
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While the report touches on the critical role of indigenous communities in any strategy, one of its major limitations is that it was not co-created with First Nations, Métis, and Inuit communities. A key recommendation of this report is to conduct broad engagement with indigenous communities to listen, learn, and create the foundation of two-eyed seeing and walking together.[18]

The foundation of our approach to this report rests with a thought experiment or a forcing device: *what would we have to do to position Canada, as the BMAC vision states*, as "a sought-after supplier of battery metals and of value added, finished goods and exportable technologies that meet our decarbonization needs domestically and support world markets"?

To establish a clear benchmark, this report defines a strong Canadian industry as producing battery materials equivalent to its domestic vehicle sales, which works out to be 10% of the integrated North American automotive market. Canada currently produces about 10% of North American vehicles, so this benchmark is line with current realities.

This benchmark provides the basis of a specific, tractable thought experiment or forcing device: what would Canada have to do to produce 10% of the metals for the North American EV supply chain?

The short answer is that Canada will have to go from producing a few thousands EVs to producing 1.3 million EVs in 8 years and 2.3 million EVs in 19 years. To provide a supply chain that meets these objectives will require mining and processing of approximately 200 kilotonnes per annum (ktpa) of elemental lithium, nickel, manganese, cobalt, iron, phosphate, and graphite by 2030 and 500 ktpa by 2040. The details for these numbers and all the assumptions are outlined later in this report. But these top line numbers make it clear that this an enormous undertaking.

A key takeaway of the sessions with the BMAC community is that the industry believes we can achieve these battery and EV supply chain goals— and, industry is ready to work in partnership with the government, Indigenous communities, civil society, and finance.

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Components of the Report

This report is broken down into three components. First, it defines an industry roadmap and what role it can play in a national industrial strategy. Then the report lays out some targets that are used to focus and align the Roadmap based on a "mandated benchmark" in which Canada produces battery metals equivalent to its share of the North American automotive market.

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Developing detailed strategies for key metals is a complex undertaking that this report only begins to address. The report proposes specific strategies for lithium, nickel, graphite, and rare earth elements.

Next, the report presents the roadmap which consists of four goals, each with their own targets and action areas. Each goal is intended to strategically place a segment of the value chain in a competitive global position. The action areas focus on near-term actions that will help Canada deliver on the 2030 and 2040 targets.

Finally, the report presents strategies for the development of individual battery metals within the value chain. Developing detailed strategies for key metals is a complex undertaking that this report only begins to address. The report proposes specific strategies for lithium, nickel, graphite, and rare earth elements. The strategic landscape for cobalt, manganese, iron, phosphate, and copper are also mentioned and additional examinations for aluminum, vanadium, and other metals are recommended. Overall, these strategies represent a starting point, and a key recommendation of the report is to form government-industry working groups to expand and develop them.

An Industry Roadmap and a National Strategy

A 'roadmap' is a policy document that identifies clear goals to achieve a set of objectives and outlines the key actions, policies, and investments necessary to achieve them. It needs to contain more than broad principles, but instead be specific, getting down to concrete initiatives that an industry alliance or a public-private partnership can pursue. A roadmap is intended to serve as the foundation of a national industrial strategy.

A national industrial strategy is a collaboration between government and industry designed to build or shift an industry.[19] Such a strategy is focused on positioning the industry in the broader domestic and international landscape. It is strategic in the sense that it must have a comprehensive grasp of key challenges and include a plan to overcome them through specific goals and actions. A strategy is high-level and requires a roadmap to translate its core principles into action.

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What is Industrial Strategy?

The climate crisis and geopolitical shifts have increased interest in industrial strategy by creating new economic goals and creating incentives to reshore supply chains. To tackle climate change, there is a clear need to produce and scale decarbonization technologies.[20] To make those supply chains robust to geopolitical uncertainty, those supply chains need to favor domestic production. As business and countries race to occupy key positions in the resulting value chains, competition among states spurs further action.

An industrial strategy can accelerate the uptake of clean technologies, enable Canada to seize economy opportunity, respond to geopolitical shifts, build homegrown capacity, and help capture high value-added segments of the supply chain.

Industrial strategies are usually established to achieve one of three overarching goals in a jurisdiction:

- To create a new industry (novel innovation)
- To improve and scale an existing industry (production advancement)
- To establish a homegrown version of a global industry (learning)

All three of these goals can be included in an industrial strategy to build a successful Canadian battery metals supply chain: we need to invent and commercialize new technologies; we need to deploy and reduce the costs of existing technologies; and we need to learn how to deploy existing technologies in the Canadian context with Canadian homegrown capacity.

To achieve these goals, industrial strategies can encompass a wide variety of policy tools.[21] They can be classified as supply-push and demand-pull policies. Supply-push tools include innovation policy, skills training, supply chain coordination, infrastructure builds, and public financing. Demand tools can include procurement policy, local content requirements, trade measures, carbon taxes and other price interventions, and external market development. The key is to align and coordinate push and pull to bring new industries online.

In short, an industrial strategy drives the development and scaling of technologies and fosters the creation of an industry by directing and coordinating efforts along the supply chain.

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Why do we need an industrial strategy for battery metals?

An industrial strategy can accelerate the uptake of clean technologies, enable Canada to seize economy opportunity, respond to geopolitical shifts, build homegrown capacity, and help capture high value-added segments of the supply chain.

Climate change is an emergency and an industrial strategy can help accelerate the energy transition. The technologies are here, but work must be done to coordinate the supply chain development and finance the capital projects needed to expedite clean energy materials and technology to market. There is also a risk of failing to seize the battery metals opportunity in an increasingly competitive global landscape. Canada has a significant opportunity and many advantages, but global supply chains are forming now and concerted efforts are needed to ensure that Canadian resources and firms are not shut out.

A coherent industrial strategy that is supported and resourced by both government and industry is critical to the development of a homegrown battery metals supply chain.

COVID, the Russian invasion of Ukraine, and ongoing geopolitical realignment have accelerated plans to reshore supply chains in Europe and the United States. In North America, President Biden will use the Defense Production Act to boost American lithium, nickel, graphite, cobalt, and manganese production.[22] In Europe, the drive for strategic autonomy has also been accelerated with the European Parliament calling in February 2022 for new measures to enhance the EU's already formidable battery strategy with strong supply chain standards.[23] Canada must act decisively and with purpose in order to capture a share of the market.

Under these intense conditions, it would be naïve to simply rely on the forces of the marketplace in Canada alone as the basis to build a successful industry in Canada. A coherent industrial strategy that is supported and resourced by both government and industry is critical to the development of a **homegrown** battery metals supply chain.

Canada's historical experience with resource industries provides a strong argument in favour of adopting an industrial policy for the battery metals supply chain. Canada has long suffered from an inability to add value to its resource extraction industries. In mining, forestry, agriculture, and oil & gas, Canada has failed to leverage its vast and abundant resources into value-added industries.[24] In this regard, the transition to EV's and battery energy storage presents a significant opportunity to build value-added capacity in chemical processing and manufacturing industries in Canada given the current nascent status of this industry in North America.

COVID, the Russian invasion of Ukraine, and ongoing geopolitical realignment have accelerated plans to reshore supply chains in Europe and the United States.

However, Canada's history of industrial policy for natural resources is a history of colonial dispossession and violence.[25] A new industrial policy must reckon with this past and actively pursue partnership with indigenous communities based on the principles of UN Declaration of the Rights of Indigenous Peoples (UNDRIP). This means respecting and supporting indigenous sovereignty in all decisions.

Observers have long noted that the Canadian economy suffers because many innovative firms are acquired by companies abroad, which then house R&D and other key ecosystem pieces in their foreign headquarters.[26] If Canada is to support growing companies and increase business R&D domestically, attention must be directed to build homegrown capacity in strategic segments of net-zero industries.[27]

This report builds on BMAC's earlier report entitled "Maximizing Canada's Battery Metals Sector" and previous vision workshops in October 2021 which addressed steps 1-3. As such, this report delves directly into specific targets and roadmapping.

As global industries are actively disrupted, Canada has an opportunity to establish a battery metals value chain in the growing EV ecosystem, but actions must be taken now. These must go beyond traditional reliance on foreign automotive original equipment manufacturers (OEMs) to build key components for an industrial ecosystem in Canada with the goal of nurturing and scaling Canadian firms that will drive innovation and domestic job growth.

What are clean competitiveness roadmaps?

Strategies are high-level. They need a plan to become reality. A clean competitiveness roadmap articulates **the priority actions, policies, and investments** necessary to catalyze industrial transformation in a sector.

There are many uncertainties in the energy transition, and an effective roadmap needs to be both robust and adaptive. Robust means that it is both bold and resilient. It must chart a pathway toward an envisioned future but also be appropriately hedged. Adaptive means that it is flexible enough to respond to geopolitical, economic, social, and environmental change.

This iterative process means that a roadmap can never be truly final and must remain fluid to changing circumstances and uncertainty. Evaluation and iteration is an ongoing process that updates both the broader strategic framework and the action plan.

Creating a clear roadmap for a sector involves a number of steps:	
STEP 1: **VISION**	Create a clear vision for the industry and define success.
STEP 2: **ANALYZE**	Understand the present and future of your industry. What technologies will be needed? What are the barriers and solution pathways?
STEP 3: **ORGANIZE**	Develop a framework that divides the industry into work streams and focus areas.
STEP 4: **TARGET**	Use models and frameworks to establish clear targets for each workstream. Use the vision and goals to focus efforts.
STEP 5: **ACTIONS**	Identify the priority actions, investments and policies that are needed to achieve the targets in each stream. Identify interdependencies and synergies across the streams. Integrate the work streams into a coherent strategy.
STEP 6: **ADVANCE**	Secure commitment from industry members, governments, indigenous communities and civil society to carry out the task list.

EVALUATE, LEARN, AND ITERATE.

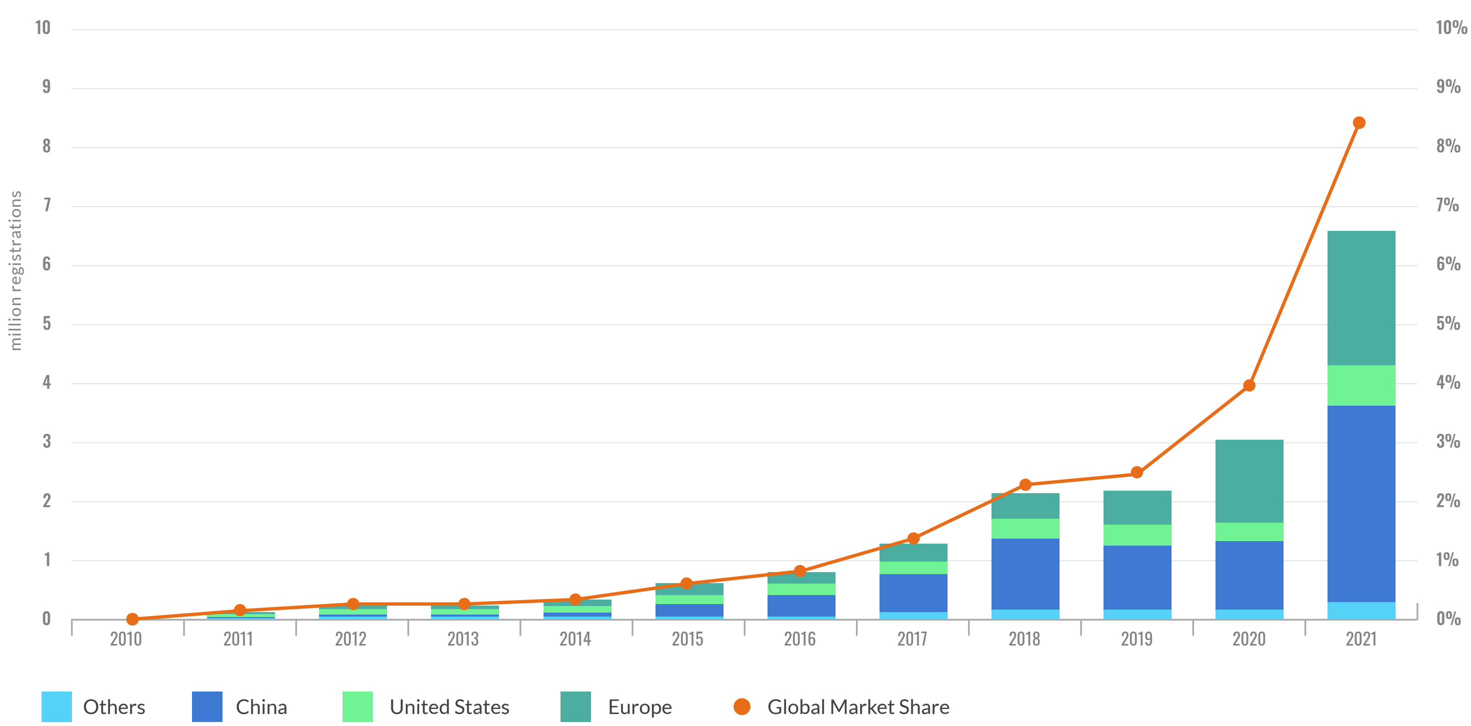
This report builds on BMAC's earlier reports, entitled "Maximizing Canada's Battery Metals Sector" and "Creating a Bold Transformative Vision for Canada's Battery Metals Industry," which address steps 1-3. As such, this report delves directly into specific targets and priority actions.

Background: Markets and Supply Chains

The global energy transition is underway and the rapid changes we have seen in the power sector are arriving in the passenger vehicle market. Cost declines in solar and wind since 2010 disrupted and have begun to rapidly transform the power sector, as coal phaseouts accelerate and even natural gas demand is being squeezed.[28] Passenger electric vehicles (EVs) look poised to follow the same path.

Cost declines mean that the total lifetime costs of EVs are already lower than those for internal combustion engines. And, battery pack costs are on the cusp of the $100/kWh threshold that will make the sticker price of EVs equal to that of fossil fuel vehicles.[29] This fueled a doubling of EV sales in 2021 (see Figure 1). That increasing demand, along with other supply chain challenges, threatens these gains.[30]

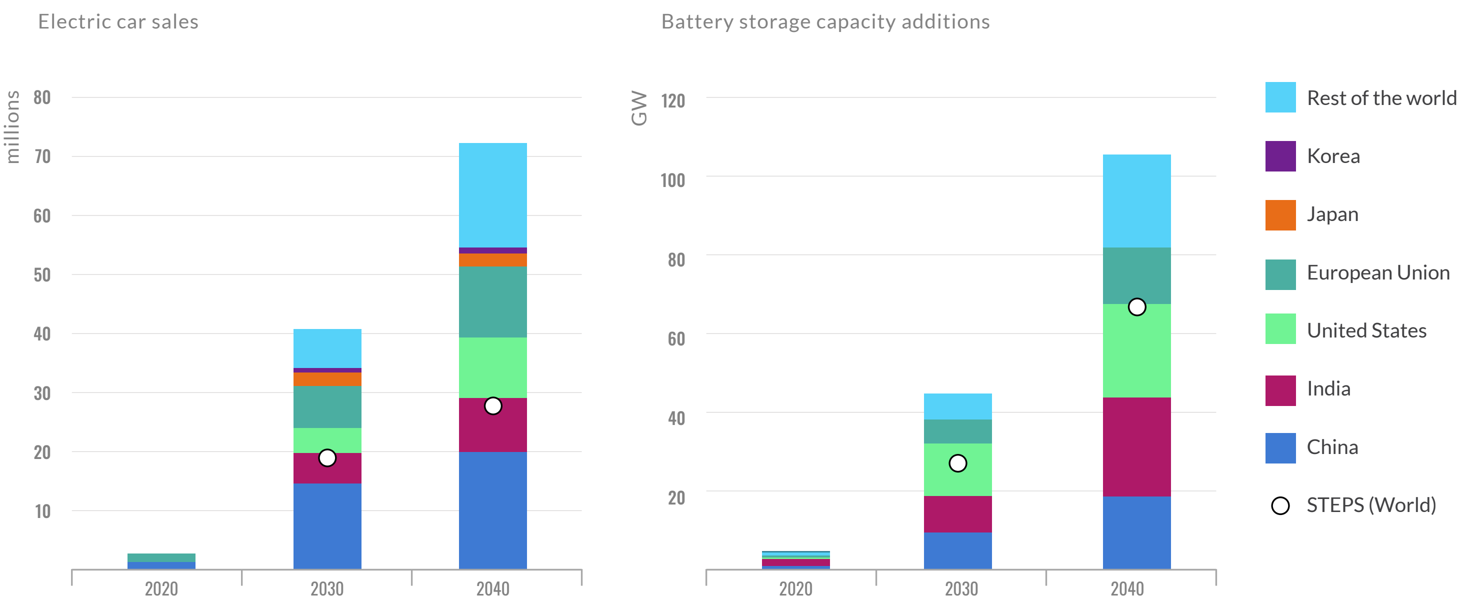
Figure 1. Global EV sales have reached a tipping point.[31]



Pressures on the EV supply chain are now driving up spot market prices. One EV metal index shows battery metals prices quadrupling year over year to July 2021.[32] In order to facilitate the creation of a stable, sustainable market, **governments and firms must work together to build and manage supply chains.**

The pressure is not going to ease and the scale of the challenge at hand is massive. To meet the goals in the IEA's sustainable development scenario, the world needs to go from 6.5 million vehicle sales in 2021 to 40 million vehicle sales in 8 years. And the The International Energy Association (IEA)'s SDS scenario is not even net-zero in 2050 (it reaches net-zero around 2070), so the pace must increase rapidly.

Figure 2. Annual electric car sales and battery storage additions in the IEA's SDS scenario[33]

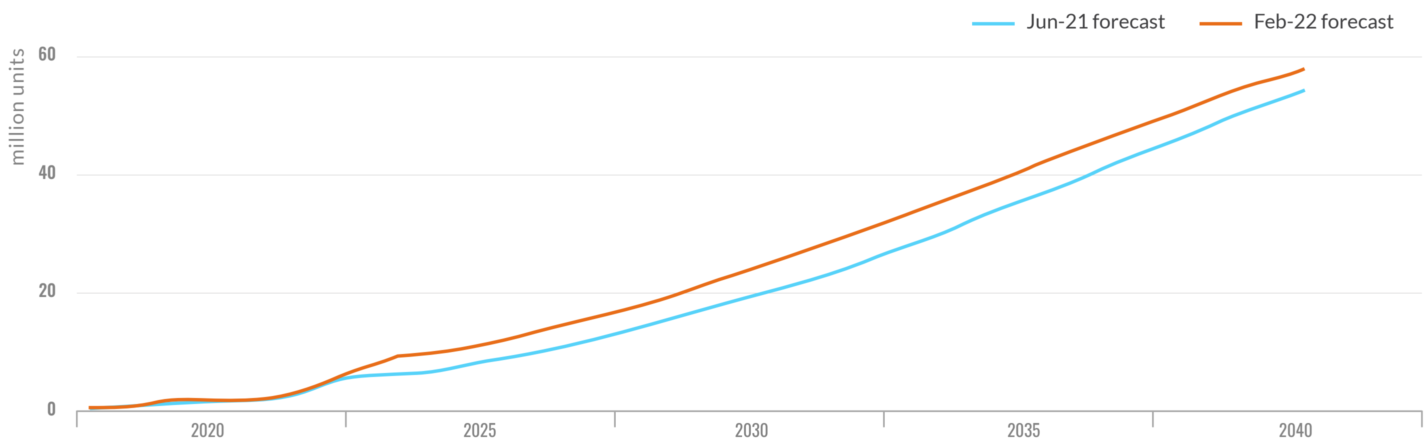


Notes: Electric cars include battery electric and plug-in hybrid electric passenger light-duty vehicles, but exclude 2/3-wheelers.
Source: IEA (2020c)

While the IEA's goals are aspirational, they are in line with market forecasts from BNEF, S&P, and others.[34]

Other battery markets will play a role.[35] The largest of these – energy storage systems (ESS) – is growing. But the IEA estimates that ESS will only comprise 1.6% of the global market in 2040. There are certainly opportunities there, but the ESS market is bracketed for the purpose of this analysis.

Figure 3. Global light duty EV sales forecasts show strong growth to 2040[36]

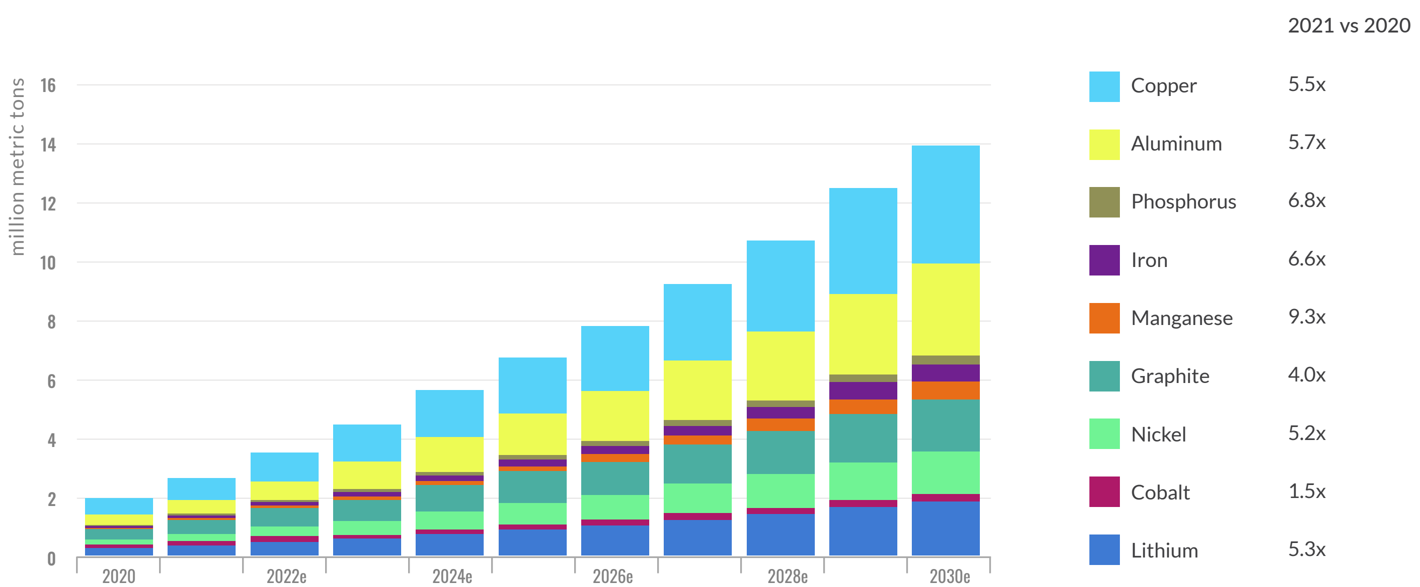


Source: S&P Global Platts Analytics

The market for critical minerals

A booming EV market needs vast amounts of critical minerals (figure 4). These projections are helpful for conveying the scale of market development over the coming decades. They suggest that current price pressures will not be alleviated in the short-run.

Figure 4. Metals demand for lithium-ion batteries is rising.



Source: BloombergNEF. Note: Metals demand occurs at mine mouthm one-year before battery demand. All metals expressed in metric tons of contained metal, except lithium, which is in lithium carbonate equivalent (LCE)

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Market projections are highly sensitive to assumptions about which battery chemistries will dominate the market. At present, nickel-rich chemistries are dominant given their higher energy densities (longer ranges) than other batteries. However, these cathodes use significant amounts of nickel and cobalt, which are expensive and often contentiously sourced. As a result, car companies have been shifting away from nickel-rich to lithium-iron-phosphate (LFP) and other low-nickel battery chemistries. LFP batteries are less costly and more stable than nickel based chemistries however they do not provide quite the same energy density and, consequently, driving range. New chemistry variations such as lithium manganese iron phosphate (LMFP) aim to increase density while providing lower costs. However, as charger speeds increase and charging infrastructure expands, range anxiety is likely to decrease and the market for LFP will continue to grow.[37] Car companies like Tesla, Ford, and VW are adopting this approach for a portion of their planned fleet.[38]

Researchers in Québec pioneered lithium-ion batteries between 1996 and 2008. A Québec-based consortium holds the LFP patents. Critical patents are poised to expire in 2022. However, Québec, and Canada, did not benefit from these patents as much as they might have because the consortium agreed to allow Chinese companies to use the patents to serve the Chinese market. CATL, the Chinese battery juggernaut, is now the world's leading producer of LFP cathode and batteries. Thus, the recent news that Ford was in talks with CATL to produce batteries for Ontario's Oakville plant is somewhat ironic.[39]

A roadmap for the battery metal supply chain should be forward looking and consider upcoming battery technologies such that innovation strategies can be established to develop the intellectual property (IP) and capacity necessary to capture value over the broader energy transition. This roadmap outlines an innovation strategy to build on Canada's world leading battery research, but assumes that the current makeup of metals (dominant battery chemistries) demand will not fundamentally change before 2040.

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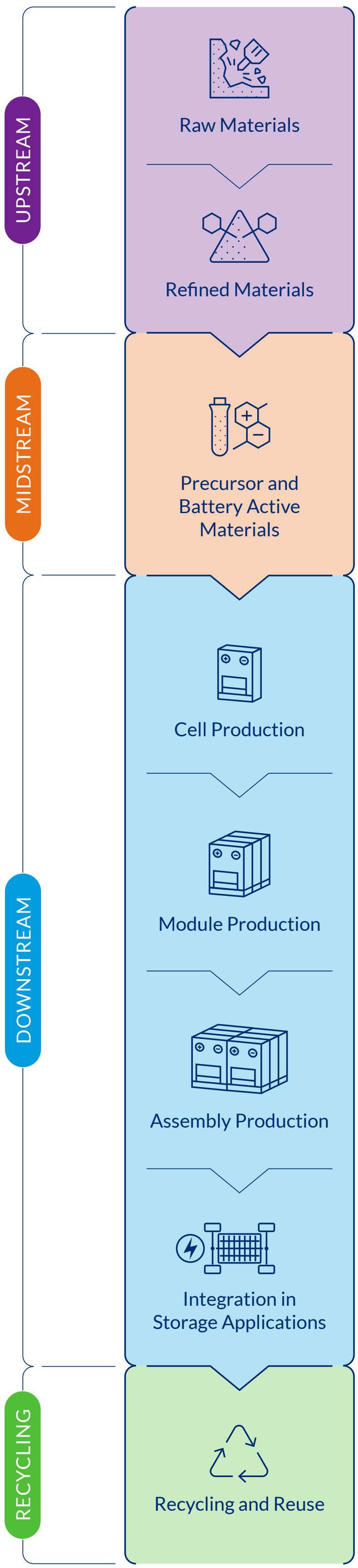

Solid-state batteries will increase energy density, safety, and charge cycles. These will be available in the next decade, but won't change metals demand. Silicon anodes will improve performance as well, but are unlikely to play a major role for a decade or more. Lithium-sulfur and sodium-ion batteries promise to increase energy density while reducing costs, but they are at least a decade from even small commercial applications. Furthermore, in considering the timeline and capital required to commercialize current lithium-ion battery manufacturing to the GWh, gigafactory scale, it is reasonable to anticipate that new storage technologies will develop on a similar decadal timescale. Therefore, the next two decades are likely to be dominated by nickel-rich and LFP chemistries with graphite anodes.

Confidence in metals demand is needed to bring metals projects online. Long commitments to metals and chemistries by OEMS are needed for mining development because there is a long lag from investment to metal production and because the capital expenditures (capex) need to be financed over long periods in order to be profitable.

A brief introduction to the battery metals supply chain

The mines to mobility supply chain is a complex journey from raw materials to batteries and vehicles, and ultimately to recycling. For the purposes of this report, the supply chain is divided into upstream, midstream, and downstream segments, with recycling feeding into both the upstream and the midstream segments.

The **upstream** segment covers the extraction of raw materials as ore (in the case of the transition metals, rare earths, and lithium from spodumene) or brine (in the case of lithium from aquifers). In transition metals, the first step of the supply chain is usually done at the mine where ore is physically separated into a concentrate. Metals also occur geologically alongside other metals so this initial separation is key. Since this is usually done as part of the mining process, we consider it part of the upstream.

In the **midstream**, concentrates are chemically processed into precursors and ultimately battery active materials. This process is unique for each metal and there are multiple pathways for each metal. It is complex, and a sense of this is offered in the final section of this report, Metals Strategies. Battery active material includes cathode active material (CAM) and active anode material

(AAM). This step is all chemistry: various forms of metallurgy that separate, concentrate, and purify minerals into useable, battery active (also referred to as battery grade) metals and powders for use in battery manufacturing.

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In the **downstream** segment, battery active materials are incorporated into batteries, vehicles, and other end-use products. The first step in this process is cell manufacturing which brings together cathode materials, anode materials, and separators. Cells are then assembled into modules which are further configured together into batteries and battery packs. These are ultimately installed in vehicles and other end-use platforms.

Recycling converts spent batteries back into either upstream or midstream precursor products, depending on the processes and business models. Recycling can include collection and storage of end-of-life batteries, shredding and other forms of mechanical reduction, and metallurgical processes to separate and refine the materials into new usable feedstock to be reintegrated into the value chain in a circular fashion.

This report does not consider all metal needs for EV manufacturing more broadly, which could increase overall targets when factored in. Future work is recommended to assess this in more detail along with similar roadmaps for other components of the EV supply chain.

In the midstream, concentrates are chemically processed into precursors and ultimately battery active materials. This process is unique for each metal and there are multiple pathways for each metal.

Targets: Production goals for vehicles and battery metals

This exercise is grounded and based upon EV targets.[40] The EV market is the largest market for lithium-ion batteries and a strategically important industry for Canada. The 2030 and 2040 targets estimate mineral development and battery production that will deliver materials for 10% of the North American market, which is approximately equivalent to Canada's domestic vehicle sales. This amounts to 100 GWh per annum of batteries and equivalent materials by 2030 and 200 GWh per annum by 2040.

Overarching targets	2030	2040
Vehicles	1,300,000	2,300,000
GWh	100	200

VEHICLE PRODUCTION

These targets are based on a benchmark model with 4 simple assumptions:

- Canada should aim, at a minimum, to maintain its roughly 10% market share of the North American automotive manufacturing market.
- EV manufacturing should scale to meet Canada's ZEV purchasing mandates – 60% of light duty sales by 2030 and 100% by 2035.
- No growth in the number of vehicles in North America.[41]
- Assume that light-duty (72% of current vehicle registrations), medium-duty (3.5%), and buses (0.5%) will electrify completely, but that only 25% of heavy-duty trucks (24% of current market) will be electric by 2040.

These assumptions establish a goal of producing the battery materials to build 1,300,000 vehicles by 2030 and 2,300,000 vehicles by 2040.

GWh

To calculate the required battery capacity for these vehicles, a number of assumptions are made regarding pack size. These include an average pack size in kilowatt hours (kWh) based on respective vehicle classes:

Vehicle Class	Average Pack Size	Rationale
Light-duty	60 kWh	Pack sizes range from 40 kWh (Nissan Leaf) to 130 kWh (Ford F-150 Lightning). Considered together, this report assumes an average light-duty pack size of 60 kWh. This lower pack size is justified by price (battery costs will push the North American market to lower ranges, vehicle size notwithstanding) and energy density improvements, which are expected to deliver higher range at lower pack sizes.
Medium-duty	100 kWh	Based on new and upcoming medium-duty model capacity.[42]
Buses and mass transport	200 kWh	Based on new and upcoming electric vehicle capacity.[43]
Heavy-duty trailers	400 kWh	Assuming full electrification by 2040 effectively triples metals requirements. This supports a case for building complimentary energy systems such as a hydrogen cell market for heavy duty transport. As such, this report assumes only 25% electrification of this class.

Modeling these parameters generates a battery fleet of approximately 100 GWh for 2030 and 200 GWh for 2040.

From this basis, the critical question is: what would the requirements be to produce battery metals for these vehicles? Here, things get more complicated given that a reasonable assessment needs take into account the uncertainty of future battery chemistries and recycling rates.

BATTERY CHEMISTRY MIX

A key premise of this report is that the next generation of battery chemistries, with markedly different chemical makeups to today's versions, is still decades away. For this reason, a roadmap to 2040 can rely on the chemistries that are dominant today: nickel-rich cathodes (including both nickel-manganese-cobalt (NMC) and nickel-cobalt-aluminum (NCA)) and lithium-iron-phosphate (LFP). While solid state, silicon anode, and lithium-metal batteries are expected to be commercial around 2040, these technologies will not fundamentally change metals demand. Solid state batteries are also likely to be nickel-rich. Solid-state sulfur batteries may be the future but also use lithium and remain a ways off. Sodium-ion batteries could compete with lithium, but not until after 2040 and not for every application. Even graphite, which will face competition from new anode materials within 10 years, will be needed through 2040.

The key question is how much LFP and other low-nickel cathodes will penetrate the vehicle mix. The IEA base scenario estimates the LFP will account for 10% of LDV and almost all HDV batteries over the coming decades. But in China, LFP accounts for over 50% of produced and installed batteries.

The key question is how much LFP and other low-nickel cathodes will penetrate the vehicle mix. The IEA base scenario estimates the LFP will account for 10% of LDV and almost all HDV batteries over the coming decades. But in China, LFP accounts for over 50% of produced and installed batteries.[44] The current surge of LFP globally has led some modellers to examine up to 60% LFP mixes.[45] Considering that solid state and silicon anodes will further increase the energy density of LFP (as well as nickel-based batteries), such numbers are more than reasonable.

A major advantage of LFP batteries is that they are inherently more stable and safer than nickel-rich cathodes. There is a

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reduced risk of fire which will reduce transport costs and makes it more suitable for utility and residential battery storage. LFP batteries also typically last longer than nickel-based batteries. In addition, current research is addressing many of the weaknesses associated with LFP. Adding manganese to create LMFP increases energy density and extends the range of LFP-based vehicles. While LFP performs poorly compared to nickel-rich chemistries in cold weather, research is underway to mitigate these challenges.[46]

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This roadmap sets a target pathway of 50% nickel-rich and 50% LFP.

Moreover, there are Canadian specific reasons to target a large LFP market. Canada has a long history of leading in LFP through Hydro Québec and Johnson Matthey. There is already a cluster of expertise and IP that can be leveraged for long-term economic development. And Canada has all the raw materials needed in abundance. Incentivizing LFP within a Canadian strategy builds on pre-existing strengths.

Finally, planning for and incentivizing high-LFP uptake will alleviate some pressure on nickel and cobalt supply.

For these reasons, this roadmap sets a target pathway of 50% nickel-rich and 50% LFP. However, given the uncertainties, considerations should be prepared for a range of outcomes, +/-20% either chemistry (30% nickel-rich/70% LFP; 70% nickel-rich/30% LFP).

RECYCLING

The model incorporates recycling rates in a simple way. It assumes that EV batteries last 12 years and so we recycle a battery 12 years after it has been purchased. The model sets aside the possibility that EV batteries could have a second life in home or grid storage, which would delay recycling. It assumes, aggressively, a 95% recovery rate for the metals in batteries. This means, for example, that in 2032, 12 years after the model begins, we start to see recycled materials coming into the materials mix. By 2045, recycled and fresh materials are contributing about equally.

The next step of the analysis is to ask: what would the battery metal requirements be to produce batteries for these vehicles?

BATTERY METAL NEEDS

The mandated benchmark scenario can be summarized as follows:

Table 1

Overarching targets	2030	2040
Vehicles	1,300,000	2,300,000
GWh	100	200

Table 2

Battery production	2030	2040
Lithium-iron-phosphate batteries	50 GWh	100 GWh
Nickel-rich batteries	50 GWh	100 GWh
Gigafactories	2-4	5-8

The next step of the analysis is to ask: what would the battery metal requirements be to produce batteries for these vehicles?

For this, an index of metal requirements in kg per kWh or tonnes per GWh (which are equivalent) is required. Simplifying assumptions are taken based on nickel-manganese-cobalt (NMC) 811 and LFP chemistries. Table 3 presents figures from Argonne National Laboratory's BatPaC model as a framework for the index metal requirements.[47]

Table 3

Battery Material Specs	NMC811	LFP
Capacity (1GWh)	1	1
CAM (t)	1563	2122
Anode (t)	1035	1194
Lithium (t)	120	93
Cobalt (t)	92	
Nickel (t)	736	
Manganese (t)	86	
Iron (t)		751
Phosphorous (t)		417
Graphite (t)	1035	1194

Calculating from the data in tables 2 and 3, the total battery active material requirements are derived and presented in Table 4.

Table 4

Battery active materials needed per year (elemental)	2030	2040
Capacity (GWh)	100	200
Lithium (ktpa)	11	21
Cobalt (ktpa)	5	9
Nickel (ktpa)	37	74
Manganese (ktpa)	4	9
Iron (ktpa)	38	75
Phosphorous (ktpa)	21	42
Graphite (ktpa)	111	223
Cathode active material plants needed	4	10
Anode active material plants needed	3	5

Given the scale of these material requirements, there is a clear takeaway:

Canada can produce nickel, cobalt, lithium, iron, phosphorous, and rare earths as hard as possible without altering world markets. There will be a market for these products, especially if Canada develops its own refining and chemical production capacity.

These targets are 10% of the North American market. There are opportunities, elaborated below in the individual metals strategies, to go well beyond that 10% threshold in some areas.

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Even if these or expanded production goals are met, electrification will continue to push for increased battery capacity for heavy trucks, stationary storage and more. The Li-ion battery is a general-purpose technology that will continue to find new applications, especially if scale continues to drive costs lower. The demand is expected to far exceed the material supplies over the next 30 years and rapid development of additional supply is required. Canada has the resources and capacity to build into this growing gap in the supply chain as an important global participant.

Cobalt

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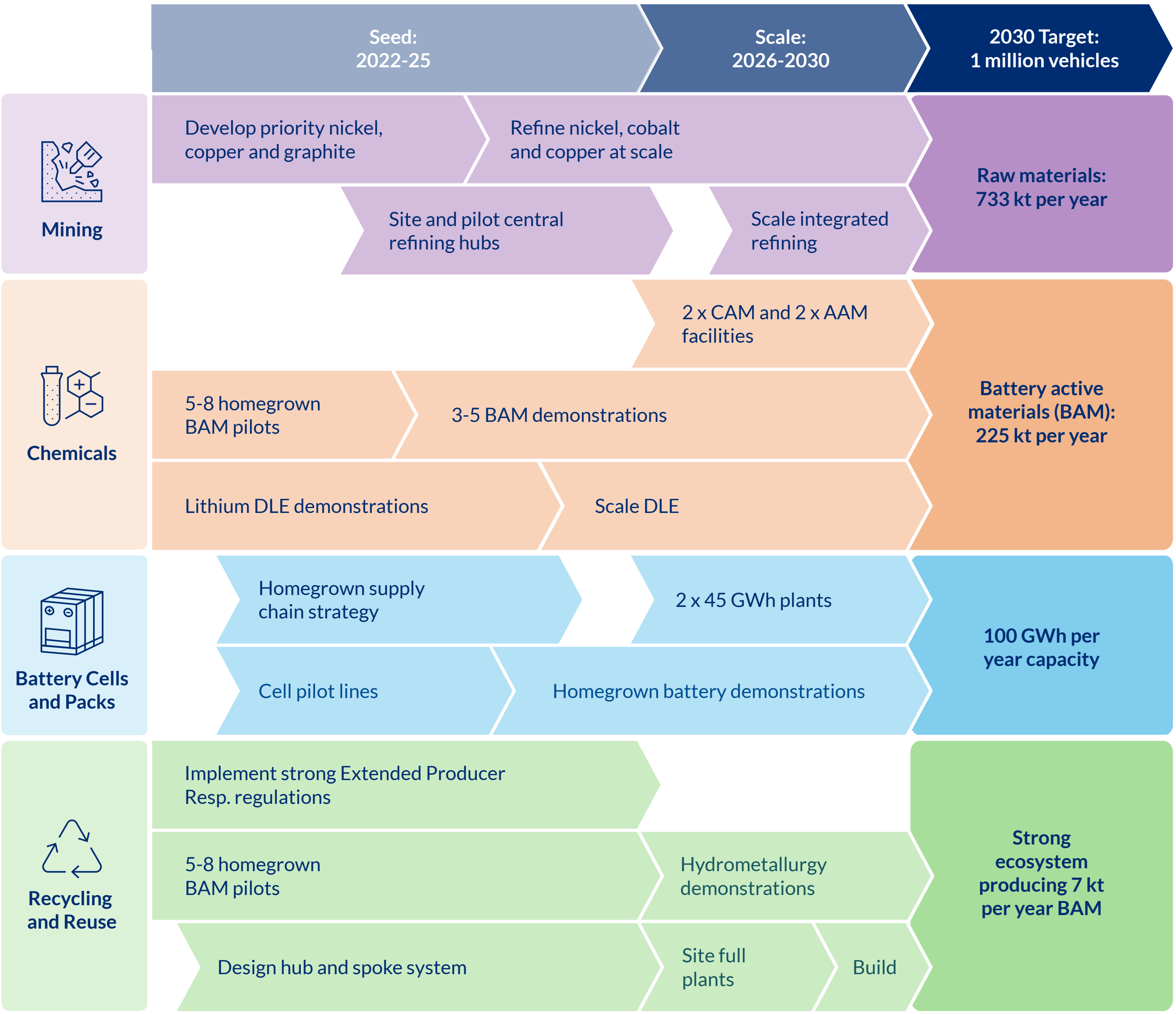
The Roadmap



Action Areas and Initiatives

Cross-cutting themes

This report is built around four goal areas corresponding to the upstream, midstream, downstream, and recycling streams of the supply chain. But emerging from these goals are four cross-cutting priority actions.

1. Leverage foreign investments into homegrown capacity.

The top priority across the streams is to leverage the exciting downstream investments into homegrown capacity in mining, refining, chemical processing, and cell components. Canada needs a plan for scaling Canadian firms into the space and to foster and ensure technology transfer from foreign investments over time.

2. Co-create industrial and innovation ecosystems to innovate over the transition.

The top priority across the streams is to leverage the exciting downstream investments into homegrown capacity in mining, refining, chemical processing, and cell components. Canada needs a plan for scaling Canadian firms into the space and to foster and ensure technology transfer from foreign investments over time.

3. Build an integrated supply chain.

If a plan is devised now and uses public and private finance for support, Canada can build a supply chain that makes sense for its specific needs and circumstances. Government and private investments in mining, cell production, and vehicle manufacturing must be linked to the development of an integrated supply chain. If facilities are built piecemeal with ad hoc material flows, Canada risks ending up with a complex and inefficient system with numerous redundancies. An integrated supply chain can strategically use natural resource and transport advantages to achieve greater value-added manufacturing. NRCan's critical minerals strategy should include a plan for an integrated supply chain and create a secretariat that liaises with other Ministries to deliver on the buildout.[48]

4. Prove out the ESG case.

Demand for Canadian materials hinges on Canada's ability to meet high environmental, social, and governance (ESG) investment standards. In particular, clean power is imperative to ensure that battery ESG metrics will privilege Canadian goods in an emerging transatlantic market led by European standards. A power requirements study for the industry is needed as well as a plan to build either behind the fence power or expanded grid capacity to ensure Canadian battery companies can claim an ESG advantage.

In particular, clean power is imperative to ensure that battery ESG metrics will privilege Canadian goods in an emerging transatlantic market led by European standards.

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Goal 1. MINE: Maximize lithium, nickel, cobalt, and graphite production

Canada can and should maximize the development and refining of nickel, cobalt, manganese, iron, phosphorous, lithium, graphite, and copper. If these are extracted and refined, there will be a market for all these metals over the period 2022-2035.

Canada has the resources, the expertise, and the ESG advantage to be a world-leader in sustainable production. To deliver on this potential, Canadian miners need two anchors: investment and downstream customers. The action areas below are focused on delivering these elements.

This report proposes to provide demand-pull by building an industry for made-in-Canada battery active materials. A dedicated fund for development can incentivize investment, as can innovative private finance mechanisms. A public-private-indigenous partnership could lead on these issues.

Engagement with indigenous peoples on the terms laid out by UN Declaration of the Rights of Indigenous Peoples (UNDRIP) is essential. Settler governments and organizations must support the sovereignty of First Nations, Métis, and Inuit governments in co-developing mining

TARGETS

Raw materials needed (ktpa)	2030	2040
Nickel (concentrate 12% nominal)	300	600
Lithium (lithium carbonate equivalent)	57	114
Graphite (raw, natural)	223	446
Cobalt (concentrate 8% nominal)	58	116
Manganese (concentrate 38% nominal)	11	23
Iron (concentrate 62% nominal)	61	121
Phosphate (concentrate 38.6% P2O5 nominal)	24	47

projects. Canada has an opportunity to demonstrate how settlers can pursue opportunities in conjunction with indigenous communities while taking a strong stance in defense of the rights and territories of indigenous communities. More deeply, settlers will need to learn to operate in ethical space, listen, and incorporate indigenous knowledge in these partnerships.

Overall, a shift from the standard Canadian practice of supporting one or two leading firms to a strategic approach that builds an ecosystem benchmarked to key targets.

The Government of Canada recently announced it will invest $3.8bn in critical minerals. This is an important step. The plan for the fund should seek to ensure that minerals development will feed into midstream chemical processing in support of an integrated supply chain.

KEY ACTION AREAS 2022-2025

1.1 Incentivize nickel, lithium, graphite, and rare earths development

To meet 2030 and 2040 targets, development of strategic battery metals must accelerate now. The literature on industrial strategy is clear that demand-pull is needed to create catalytic change.[49] An effective way to create this demand pull would be to establish Canadian content requirements for downstream operators. Governments could condition deals with foreign OEMs to ensure that they utilize local supply on specific timelines such as the ones laid out here. This would mitigate investment risk and have an immediate and catalytic effect on mining and midstream development.

However, an explicit local content requirement could be challenged in the World Trade Organization and so may be an unstable policy instrument. A government commitment to critical minerals development could start the crowding-in of capital required. A key start includes a large strategic development fund. Government finance in the net-zero space is often earmarked for "innovation," but miners need development funds that are not necessarily tied to innovation.

This is an example of catalytic investment. The critical minerals fund needs to be connected to a strategy, like the one outlined here, but co-produced by government and industry in an ongoing way. Aligning the pieces of the supply chain can accelerate development and coordinate financing.

Co-development needs to prioritize structured partnerships and discussions with indigenous rightsholders. These discussions must enact UNDRIP principles, incorporate indigenous knowledge, and include support

In pursuing co-development, the Government should also adopt an expanded, future oriented conception of industry that includes major market players, industrial alliances, and smaller, emerging market players. The goal is to build an industry for the future, not simply to replicate Canada's existing industrial structure. To do this, it must go beyond working with the familiar firms and industry associations.

Manganese

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Public, private, and indigenous finance must be tied to an integrated supply chain. A system must be designed for each metal (see Metals Strategies below) to ensure that the flows of these materials are efficient and cost competitive.

Canada needs to act fast to develop nickel reserves and ensure that refining capacity exists to feed it into the EV supply chain. Canada has advantages, but these will progressively be eroded as Indonesian capacity comes online and competition increases.

Manganese demand is set to rise given its key role in low-Cobalt and other cost effective, high-performance batteries. Canada has a number of manganese projects and development should be prioritized.

Manganese demand is set to rise given its key role in low-cobalt and other cost effective, high-performance batteries. Canada has a number of manganese projects and development should be prioritized.

Exploration incentives are adequate, but the government and industry need to collaborate on a strategy that explores in a strategic, long-term manner, rather than only responding to the short-term incentives that may guide junior miners.

On average, it takes 10-15 years for a mineral project to go from exploration to production. In Canada, given stringent environmental standards and uncertainties over indigenous legal rights, this process will typically be on the longer end. Canada needs a focused effort on streamlining the permitting and legal approval process. This would be of fundamental importance to meeting the ambitious timelines and ensure Canada is successful in capturing a significant market share. Clear regulatory frameworks and accelerated permitting timelines for critical minerals will help juniors create certainty and secure offtake agreements.

As an example of problematic regulations, there remains significant uncertainty in mineral tenure instruments for subsurface lithium brines. While most provinces which host these resources are building from existing regulations to provide clarity, BC currently has no mineral tenure right mechanism in place to capture lithium from subsurface brines. These types of ambiguities in regulatory frameworks must be addressed immediately as a matter of strategic national interest and coordination should occur between provinces and the federal government to expedite and streamline these frameworks.

How can we advance this action area?

1.1.1 The government should create a large critical minerals development fund:

1.1.1.1 That fund should lay out a concrete materials requirements plan with timelines such as those in this roadmap.

1.1.1.2 It should focus investment on the roadmap; i.e., mineral extraction that feeds into an integrated supply chain.

1.1.2 NRCan should reinvigorate the Major Projects Management Office to ensure priority battery metals projects are permitted on a guaranteed timeline.

1.1.3 NRCan should partner with an independent Critical Minerals Task Force (with working groups for Exploration, Development, Refining, and Financing).

1.1.4 The Exploration Working Group should:

1.1.4.1 Refine the exploration timeline and goals. What new reserves would Canada need to meet expanded development and materials goals? What are realistic expectations about what our long-term targets should be?

1.1.4.2 Create a map of priority exploration areas and work with industry to ensure the best areas are explored.

1.1.4.3 Integrate this work into a development plan.

1.1.5 The Development Working Group should:

1.1.5.1 Create a development strategy based on material needs keyed to this roadmap.

While most provinces which host these resources are building from existing regulations to provide clarity, BC currently has no mineral tenure right mechanism in place to capture lithium from subsurface brines.

Private finance is often hard to secure for two reasons. First, miners need an offtake agreement to secure finance and that depends on downstream certainty. Second, sometimes reserves are too small to secure an offtake.

- 1.1.5.2 Create a priority list of known deposits and work to bring feed online quickly.
- 1.1.5.3 Design offtakes and policies to ensure that feed created goes into the battery supply chain.
- 1.1.5.4 Liaise with the Major Projects Management Office and others to advance regulatory certainty and timelines for mining development.

1.1.6 The Refining Working Group should:

- 1.1.6.1 Design an efficient hub and spoke system for each of the transition metals.
- 1.1.6.2 Create an investment plan with costed numbers to build refining capacity for 2030 and 2050 goals.
- 1.1.6.3 Liaise with the Battery Metals Task Force to standardize flows into battery active material production.

1.1.7 The Government of Canada should create a provincial roundtable for lithium to clarify mineral tenure and royalty frameworks for subsurface brines.

1.2 Develop creative financial mechanisms to support mine development

Government finance in the net-zero space is often earmarked for "innovation," but miners need development funds that are not tied to innovation. A pot of development funds keyed to an overall, long-term strategy (such as the one outlined here) is needed.

Private finance is often hard to secure for two reasons. First, miners need an offtake agreement to secure finance and that depends on downstream certainty. Second, sometimes reserves are too small to secure an offtake. A joint venture would solve this problem, but joint ventures can reduce investor interest. This is a communication problem: the industry needs to educate potential partners about how joint ventures unlock the industry.

One potential solution is a pooled index, so investors can bet on the industry rather than on an individual firm. Another possibility is blended finance. Creative things can also be done with flow through shares.

How can we advance this action area?

1.2.1 The Critical Minerals Task Force needs a Financing Working Group that:

- 1.2.1.1 Includes members from the financial community to bring in new sources of capital and help develop new financial mechanisms.
- 1.2.1.2 The industry should make a "wish list" of financing types and terms that would be useful (e.g. patient, etc.) and co-develop solutions with finance.
- 1.2.1.3 Key question: how can industry build joint ventures of upstream mines that feed into downstream processing?
- 1.2.1.4 Key question: can green bonds and other ESG funds be brought in? What ESG conditions would those have?

1.3 Articulate "A New Industry" e.g., Clean Energy Materials, to the general public, governments, and educators.

The Industry needs to make the case for battery metals development. Part of the work is building out this roadmap and developing communications and GR pieces that educate the public about the need and opportunity.

But underlying this is a rethink that articulates a new kind of industry. The key message here is that this is not the old mining industry. This is a world-leading, high-ESG industry that is critical for the energy transition.

1.3.1 Step 1 is to create the narrative around Clean Energy Materials that is forward looking and grounded in ESG plans (1.4)

1.3.2 The Industry should plan public events that publicize this work and convey its importance to a broad network of stakeholders.

1.3.3 Liaise with NGOs and media, incorporating them into events.

1.3.4 The Industry should identify members willing to write op-eds, do webinars, and educate members of the press.

The Industry needs to make the case for battery metals development. Part of the work is building out this roadmap and developing communications and GR pieces that educate the public about the need and opportunity.

1.4 Push for and help design carbon border adjustments or ESG standards that make Canadian metals competitive and desirable.

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Canada wins in a world of tough ESG standards for the battery supply chain. Canada must push for and help design maximal environmental, social, and governance standards. These standards are needed to secure investment and to ensure the long-term competitiveness of Canadian products.

There are two main environmental factors: carbon footprint and waste streams. Just as the initial processing in the mining stages requires lots of electricity, so does chemical production. Canada must build out clean power for chemical processing to prove out the ESG case. Waste streams need to be addressed in an integrated supply chain for Canada.

Canada must build out clean power for chemical processing to prove out the ESG case. Waste streams need to be addressed in an integrated supply chain for Canada.

How can we advance this action area?

1.4.1 Government and industry need to work together to create a national ESG strategy that positions Canada globally as an ESG producer.

- 1.4.1.1 Leverage Canadian expertise on environmental and social lifecycle assessment, such as the new center in Montreal, to set standards.
- 1.4.1.2 Research the Global Battery Alliance and educate industry about potential long-term dynamics it and similar initiatives will create.
- 1.4.1.3 Game out how border adjustments could affect industry long-term. Integrate insights into system design.
- 1.4.1.4 Think about governance standards. The war in Ukraine has highlighted the importance of this as geopolitics and sanctions hit nickel markets. Canada needs standards development and communications on governance. Who should profit and get supply chain leverage in this new world?

1.4.2 Push for mandatory use of materials produced subject to Extractive Industries Transparency Initiative (EITI).

1.4.3 The industry needs a clean power plan. Current projections state that Canada needs to expand power production by 2-3.4x in order to meet electrification needs[51] —but those projections don't include additional mining, chemicals or manufacturing facilities. A first step would be an analysis of the power requirements of this roadmap. A plan can then be implemented through the MPMO in conjunction with the Critical Minerals Task Force.

1.5 RD&D to reduce costs and environmental impact

To compete globally over the energy transition, Canada needs to build an innovative mining industry. Part of this means developing low-impact, net-zero operations.[52] But it also means building on competitions like Crush-it to improve separation and milling. In addition, integrating mining and chemical processing will help to reduce costs. Joint ventures in that space will help.

This is the opportunity in lithium brines, where new technologies like direct lithium extraction use a hydrometallurgical process to go directly from extracting lithium to producing a battery grade product (lithium carbonate or lithium hydroxide).

Other metals need to explore R&D opportunities, which can reduce transport costs and capture value in the supply chain.

How can we advance this action area?

1.5.1 The starting point is the creation of a Battery Metals Research Network.

1.5.2 The research network should set an agenda for research into innovative processes.

- 1.5.2.1 The overall focus should be on creating efficient flowsheets from the mine to active materials.
- 1.5.2.2 Key question: from Crush-it, can we transform how energy is used to crush and grind rock? Work in this vein needs to be integrated.
- 1.5.2.3 Key question: How can we reduce the environmental impact of mining & processing?

This is the opportunity in lithium brines, where new technologies like direct lithium extraction use a hydrometallurgical process to go directly from extracting lithium to producing a battery grade product.

Lithium Carbonate

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In the midstream of the supply chain mining products are transformed into battery active materials.

1.6 Develop clean firm power in mining hubs

The ESG case in Canada is dependent on the availability of clean firm power at the mining site. This is an infrastructure problem that needs to be resolved. This opportunity is a structural enabler across a number of sectors. Synergies with First Nations and remote community decarbonization should be pursued.

How can we advance this action area?

1.6.1 The Industry should forge strategic connections with First Nations, governments, and other sectors that require clean, off-grid power.

1.6.2 NRCan is studying the issue, including awarding a contract to Dunsky to investigate. Those efforts should tie in with the battery metals roadmap.

1.6.3 The results of the study, and other inputs, must be used to create an experimental strategy to guide RD&D. A portion of the critical minerals fund should be earmarked for demonstrations.

1.6.4 Demonstrations for clean remote power should be closely studied by the Critical Battery Minerals Research Network and an ESG working group to ensure they prove out the ESG case. This will help secure further financing for the sector.

Goal 2. CHEM: Develop a world-leading chemical industry to produce and export battery active materials.

Mr.1/Shutterstock.com

In the midstream of the supply chain, mining products are transformed into battery active materials. This stream is all about chemical production: putting metals through a set of metallurgical and other processes that produce the high-grade materials battery manufacturers need. Battery active materials include cathode powder, processed and coated graphite, and battery grade lithium hydroxide or carbonate. Canada can and should produce all three.

Globally, the midstream is currently dominated by China. Almost all battery chemicals and components are processed in Asia.[53] If Canada brought mining online today, those materials would have to flow to China in order to come back into the battery supply chain here in Canada.

Developing this stream now is essential for numerous reasons. First, it provides **downstream pull** to unlock the upstream potential and it helps to forge an integrated supply chain.

In addition, the move from raw materials to active materials is one of the **highest value-added** components of the supply chain. For example, moving from spodumene lithium ore to lithium hydroxide or lithium carbonate increases the value by 4 or 5 times.[54]

Also, cell pack costs will decline until they are marginally above active material costs.[55] Therefore, it will be very difficult to compete on batteries. Efficient CAM production is a **durable, competitive source of value.** In an open economy strategy, this is a good place to invest, versus cell manufacturing, where processes can be completely standardized and well-capitalized firms can achieve economies of scale unachievable by others.

Battery active materials are **exportable**: even if Canada does not have domestic EV manufacturing online, battery active materials are in high-demand and a booming global market will ensure that there are buyers.

Finally, the midstream is key to long-term success because it will help to forge an **integrated supply chain** that efficiently processes minerals.

Almost all battery chemicals and components are processed in Asia. If Canada brought mining online today, those materials would have to flow to China in order to come back into the battery supply chain here in Canada.

Gorodenkoff/Shutterstock.com

Canada is in a strong initial position. Recent announcements indicate that Canada will be home to two cathode active materials facilities focused on producing high-nickel batteries.[56] This is a crucial first step. But right now, Canada's chemical processing system is being led from the downstream up. That may not serve Canada's long-term economic interests and help to bolster homegrown capacity. If Canada is not strategic about it, it could end up with a piecemeal supply chain dominated by foreign firms and imported upstream metals.

To take advantage of these opportunities and build a strong long-term ecosystem, government and industry must design a national system for chemical processing and innovation.

Beyond Foreign Direct Investment

How can Canada build a strong midstream? Investments from big players like POSCO and BASF are essential pieces of an industrial ecosystem but they need to be complemented by a number of other components.

First, there needs to be a plan to leverage these investments into homegrown capacity. The government's deal teams need to ensure that technology transfer is built into the plan for securing foreign direct investment.

Second, there needs to be a plan for building an integrated Canadian supply chain. Each metal has a number of different pathways or flows it can take from the mine to the battery. A problem many firms have is that they do not know exactly what their flowsheets should look like to deliver products the sector needs given how fast technology is advancing. Government and industry must partner to design a national system that will provide clarity on this and work to create an efficient supply chain tailored to Canadian metals and skills.

One significant opportunity is to design an efficient national system. Existing announcements follow the traditional precursor route for battery metals. However, Canada has a significant opportunity to build an integrated supply chain that cuts out this middle step.

Both Nano One and American Manganese are pioneering this new method which could be the backbone of a new supply chain. Similarly, in lithium, companies like E3 and Prairie Lithium are advancing direct lithium extraction which will change the game in lithium extraction. Neo Performance Materials is a world-leading firm that processes rare earths and could help design a national supply chain for critical alloys.

In addition, these pathways can and should be tailored specifically to the form in which we find the metals in Canadian geology. This is an opportunity because it means that a homegrown, intelligently designed ecosystem would be protected from foreign competition. Large global firms succeed when they can standardize across all countries. But metal varieties mean that efficiency gains can be made by customizing the system to local requirements.

Third, Canada needs to build innovation into the ecosystem. An innovative, knowledge-intensive midstream is essential to compete globally. A number of Canadian firms are creating new processes for the midstream journey. Nano One, E3, American Manganese, and others are innovating in this space. Sherritt has been a leader in innovative refining for decades and has exported Canadian metallurgical processing technologies to dozens of processing facilities on six continents.

Our universities are also teeming with expertise that can be more effectively deployed. Canada must incorporate a national plan for R&D to ensure the chemical processing plan is always on the cutting edge.

To take advantage of these opportunities and build a strong long-term ecosystem, government and industry must design a national system for chemical processing and innovation.

TARGETS

Battery active materials needed per year (elemental)	2030	2040
Capacity (GWh)	100	200
Lithium (ktpa)	11	21
Cobalt (ktpa)	5	9
Nickel (ktpa)	37	74
Manganese (ktpa)	4	9
Iron (ktpa)	38	75
Phosphorous (ktpa)	21	42
Graphite (ktpa)	111	223
Cathode active material plants needed	4	10
Anode active material plants needed	3	5

KEY ACTION AREAS 2022-2025

2.1 Develop chemical production facilities to produce battery active materials

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Immediate investments in facilities to produce battery active materials is a high-impact action. Active material production occupies a strategic place in the supply chain because it provides downstream pull, produce an exportable product, and add significant value to the product.

In the near-term, investment in this space is likely to take the form of foreign direct investment, as recent announcements from BASF and POSCO illustrate. The long-term priority must be to develop domestic capacity in this critical segment of the supply chain. Canada is home to emerging firms and strong chemical expertise that can provide the base for long-term competitiveness. The key is to support the scaling of an innovative national midstream industry.

Thus, Canada needs a plan that allows homegrown firms to learn from joint ventures with foreign partners. This is known as technology transfer, and Canada needs institutions and a plan to ensure that Canada learns the skills and acquires the knowledge to support a domestic midstream.[57] Investments in foreign partnerships must be designed with such a plan in mind.

Further, we must start building the domestic ecosystem around these investments right away. The goal should be to make technology and innovation clusters around the CAM facilities.

How can we advance this action area?

2.1.1 The industry should conduct immediate government engagement to clarify the role of the midstream in the long-term Mines to Mobility strategy.

2.1.1.1 This means conveying the importance of a major investment in the midstream beyond foreign direct investment.

Thus, Canada needs a plan that allows homegrown firms to learn from joint ventures with foreign partners. This is known as technology transfer, and Canada needs institutions and a plan to ensure that Canada learns the skills and acquires the knowledge to support a domestic midstream.

2.1.2 Create a plan to leverage foreign investment into homegrown capacity.

2.1.2.1 Create a plan to build the domestic ecosystem around the foreign facilities. Where are the opportunities for local firms to supply the facilities?

2.1.2.2 The long-term aim should be to create full technology transfer. This means creating research institutes around CAM, funding accelerators to support startups, integrating universities into the ecosystem, and ensuring that finance understands and is involved.

2.1.2.3 Condition the government support on use of Canadian minerals and IP to ensure downstream pull and ecosystem development.

2.1.2.4 Encourage joint ventures between foreign firms and domestic players.

2.1.3 One benchmark of homegrown success would be to have Canadian firms producing CAM at scale by 2030. To do this, the Government should earmark critical minerals funds for midstream demonstrations. These demonstrations should seek to rapidly build capacity for homegrown chemical processing and fund RD&D for the next generation.

2.1.3.1 Target 2-3 CAM pilots by 2025. Select 1 for a major investment by 2027.

2.1.3.2 Learn quickly from these experiments seeking 3-4 CAM facilities with Canadian tech and IP by 2030.

2.1.3.3 Target 2-3 lithium DLE pilot facilities by 2023.

2.1.3.4 Learn from these quickly and launch DLE demonstrations by 2025.

2.1.4 Private finance is a crucial piece of the ecosystem. They must be educated about the supply chain and the opportunity.

2.1.4.1 A good initial target: matching funds for 2025 pilots.

2.1.4.2 Long-term: ensure critical minerals finance plan has a chemicals budget and build the relationships now to foster local investment.

2.2 Establish a hub and spoke system for efficient chemical processing that meets high ESG standards.

Canada has to build a smart, high-tech chemical processing system to compete. It is essential to minimize transportation and capex costs, which means designing a hub and spoke system that moves products from mines to battery production effectively. The system must meet a high ESG standard, built on clean power and dealing with waste streams effectively.

Marcin Balcerzak/Shutterstock.com

Another consideration is volume. Processing that reduces the volume of battery metals should be located near the mine or brine source whenever possible. Then, to limit capex costs, these intermediates should be further refined at centralized hubs.

This means that some cooperation and standardization between firms is necessary. The hub and spoke system only works if the hubs take in standardized feed material. A public-private partnership is needed to work out the details of this national strategy.

Wherever possible, this system should eliminate waste and plan for waste management. Canada cannot simply replicate Asian chemical methods because they will produce damaging waste streams that are impractical to manage.

Wherever possible, this system should eliminate waste and plan for waste management.

Canada must eliminate this waste and build in innovation that will help us deal with waste over time.

How can we advance this action area?

2.2.1 The first step is to create a public-private partnership, potentially in the form of a Midstream Task Force that feeds into NRCan's battery executive committee, to define a work agenda.

2.2.2 The Midstream Task Force should begin by developing metal strategies: a national strategy for each critical mineral (such as those sketched in this report). This involves creating an ideal flowsheet for each metal. These hubs must be designed to work with standardized metals.

2.2.2.1 Key question: What precursors should the system privilege? E.g., for nickel, do we want mixed hydroxide precipitate vs nickel sulphate at the core of the nickel supply chain?

2.2.3 The metals strategies should then be used to develop an efficient hub and spoke system design that integrates miners and processers into an efficient supply chain.

2.2.4 Metal strategies should consider process efficiency and environmental impact (See 2.3). Canada must design processes that don't produce damaging waste streams and build in waste management.

2.3 Advance rigorous environmental standards for chemical production

Canada must design and push for maximal environmental standards. These standards are needed to secure ESG investment and to ensure the long-term competitiveness of Canadian products.

The Global Battery Alliance's battery passport will provide full lifecycle information for batteries. This will provide incentives for producers along the supply chain to meet high standards. In the future, this could be integrated with carbon border adjustments. Canada needs to be ready to meet these standards.


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There are three main environmental factors: carbon footprint, waste streams, and ecosystem impacts. Just as the initial processing in the mining stages requires vast amounts of electricity, so does chemical production. Canada must build clean power for chemical processing to prove out the ESG case.

Waste streams create pollution in the form of tailings that must be handled appropriately, as well as air and water pollution. As it is currently done in Asia, chemical production for nickel-rich cathode material creates unsustainable sulfate waste streams. Canadian supply chains cannot replicate this. The hub and spoke and R&D strategies need to be optimized for environmental standards.

Canada must design and push for maximal environmental standards. These standards are needed to secure ESG investment and to ensure the long-term competitiveness of Canadian products.

Ecosystem impacts such as land-use change and biodiversity loss may also be lower in Canada than in other jurisdictions as most mines are located in the Boreal forest, which is considered lower risk than tropical forest.

Ecosystem impacts such as land-use change and biodiversity loss may also be lower in Canada than in other jurisdictions as most mines are located in the Boreal forest, which is considered lower risk than tropical forest.

It is important to accelerate permitting timelines for priority projects without sacrificing environmental factors. Governments must work with industry to design regulations that make business sense. Business must take the long-view and support regulations that increase costs in the short-run to enable the design of a sustainable system. Businesses can only take that long view through a commitment such as the one this roadmap represents.

Then these lifecycle and waste standards must be enforced at the border, by harmonizing Canadian industry with European and American standards. They also must be communicated to the public in accessible ways so everyone understands the importance of these measures.

How can we advance this area?

2.3.1 Government and industry need to work together to create a national ESG strategy that positions Canada globally as an ESG producer.

- 2.3.1.1 Research Global Battery Alliance and educate industry about potential long-term dynamics it and similar initiatives will create.
- 2.3.1.2 Game out how border adjustments could affect industry long-term. Integrate insights into system design.

2.3.2 The Midstream Task Force should design waste management standards and integrate these into the hub and spoke design.

- 2.3.2.1 Key question: What are the gas-liquid-solid waste streams for each battery chemistry and how can they be avoided or addressed?

2.3.2.2 Key question: How can high environmental standards be built into global passport systems and carbon border adjustments? What technical work needs to be done to harmonize this across countries and chemistries?

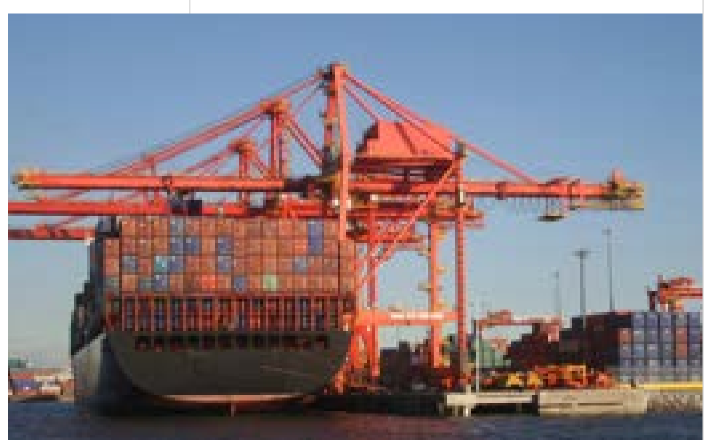
2.3.3 Communications: clarify and publicize the importance of batteries made without generating huge waste streams.

2.3.3.1 Work with environmental NGOs and media to publicize the damaging waste streams from batteries made in other jurisdictions.

2.3.3.2 Engage the Global Battery Alliance to ensure it takes waste streams seriously.

2.3.4 The Midstream Task Force should work with the Critical Minerals Task Force on a clean power for battery metals strategy. (See 1.6 for more details.)

2.4 Build global export markets for battery active materials



Stephen Finn/Shutterstock.com

Battery active materials (BAM) present an opportunity for Canada because they are easy to export and robust to protectionist measures such as local battery content or vehicle assembly requirements. Global supply is likely to be highly constrained so Canada will find willing buyers in most metals markets.

The materials-cell-EV chain created by FDI could pull lots of active material into local manufacturing. But Canada should also seek to build additional BAM capacity for export. To achieve this, Global Affairs and Export Development Canada need to work with NRCAN and ISED to build markets for battery active materials in parallel to building chemical production capacity.

A key to building export markets is integrating current standards into carbon border adjustments and other global passport systems. Market development for Canadian materials will happen in lock-step with the development of global ESG standards and the creation of regional trading blocs amongst geopolitically aligned countries.

Canada needs an R&D strategy to identify where cost reductions can be achieved in order to keep Canada's supply chain globally competitive.

How can we advance this area?

2.4.1 Build export targets into future roadmaps.

2.4.2 The industry should reach out to Global Affairs Canada and Export Development Canada to understand what is being done and what is needed here.

2.4.3 The industry must engage in concerted efforts for global networking to ensure Canada is a recognized leader in innovative battery metals.

2.4.4 A key to building export markets is integrating current standards into carbon border adjustments and other global passport systems. We need to study the implications of these for processing and link it to market development and the ESG plan (2.3).

2.5 Develop an R&D strategy to reduce costs in chemical production

Canada needs an R&D strategy to identify where cost reductions can be achieved in order to keep Canada's supply chain globally competitive. The R&D strategy needs to be grounded in chemistry expertise and be a truly collaborative product between government and industry.

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There are a number of reasons why Canada needs a chemical innovation strategy.

First, innovation is needed to design new methods that do not replicate what is done in China, where waste streams are not dealt with in an environmentally friendly manner.

Second, metals are geologically specific and chemical processes must be designed with specific geological features in mind. This means that there are potentially long-term advantages from made-in-Canada flowsheets that would keep competitors out. What secures Canada's position in competitive global CAM production? An integrated supply chain with low costs and efficiently designed flowsheets will help prevent late, low-cost entrants.

The foreign OEMs that will dominate the phase 1 supply chain are unlikely to invest in Canadian specific processes. They will seek to use off-the-shelf processes they are familiar with. But, designing Canadian specific strategies to produce local advantages will help keep OEMs here in the long-term and encourage new Canadian firms to scale into the space.

But in the medium-term, Canada needs a national centre of excellence for critical minerals and battery research. The mandate for this centre should be to innovate across the supply chain to drive cost reductions and maintain Canadian competitiveness.

Right now, Canada needs a nationwide research network that gathers together all the amazing work being done. But in the medium-term, Canada needs a national centre of excellence for critical minerals and battery research. The mandate for this centre should be to innovate across the supply chain to drive cost reductions and maintain Canadian competitiveness.

On this foundation, an innovation ecosystem with strong interconnections between industry, finance, government, and researchers can be built.

How can we advance this action area?

2.5.1 The starting point is the creation of a Battery Metals Research Network that brings together all of Canada's world-leading researchers from the upstream, midstream, and downstream.

2.5.2 The research network should set an agenda for research into innovative processes.

- 2.5.2.1 What geological features of Canada present the greatest challenges and opportunities to long-term competitiveness? Where do we need research and development to reduce costs and remove bottlenecks?
- 2.5.2.2 What strategies can reduce the cost of and de-risk direct lithium extraction?
- 2.5.2.3 How can we reduce the environmental impact of chemical processing?
- 2.5.2.4 What is the future of battery chemistry and what are the areas where Canadian IP and research expertise can excel?

2.5.3 Canada must seed a larger research ecosystem with a variety of technical institutes, research centers, and conferences where firms, researchers, government officials, and financiers can interact regularly.

2.5.4 One potential model is the Centre for Excellence in Mining Innovation which recently received a $40m grant from the Strategic Innovation Fund (SIF). A Centre for Excellence has funding to do its own demonstrations and learn collectively. This is what we need in the long-term battery space.

2.5.4.1 The Research Network should write a concept paper for a battery centre for excellence that outlines a strategy for evaluating and updating investments in technology experiments and demonstrations.

2.5.4.2 Reach out to successful applicants to talk about the SIF process.

2.5.5 But R&D needs to go beyond battery chemistry to integrate battery development into a broader materials science strategy for the energy transition. Canada needs to leverage its national expertise in green chemistry to drive innovation across industries.

Goal 3. MAKE: Advance innovative research & production lines for made-in-Canada nickel-rich and LFP batteries.

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The *Mines to Mobility* report identified securing investments in battery manufacturing as a key goal.[58] The government is actively working to bring foreign cell manufacturers to Canada so they can feed into Canadian automotive production.[59] Stellantis and LG recently announced a $5bn joint venture to produce 45 GWh of battery cells and modules per year in Windsor.[60] This is an essential first step and a real achievement by the government in a competitive global space.

The priority over the medium-term must be to leverage investments into homegrown cell manufacturing capacity and vibrant battery ecosystem that contributes to cell and pack production.

The current wave of projects is paving the way for 2030 production. But to achieve 2035 and 2040 targets, Canadian manufacturing will need to scale rapidly after 2030. Government and industry need to prepare for the next phase today and think hard about where Canada's competitive niches will be. Canada cannot replicate every piece of a complex global supply chain for cell manufacturing and battery packing. Instead, we should seek to support companies that can occupy strategic niches in global value chains and feed local battery production.

Building additional ecosystem capacity now will help attract and retain anchor tenants and build export markets in battery components and batteries. This broader ecosystem will be robust to forms of protectionism that focus on final vehicle assembly—which is the lowest value-added segment of the battery and EV supply chain. Canada can build a rich ecosystem even if battery and automotive OEMs are pushed over the border due to tariffs or Buy American provisions.

To build homegrown capacity, Canada needs innovation infrastructure independent of the big players. Canada should develop pilot, demonstration, and production lines for both lithium iron phosphate and nickel-rich batteries. These can build on the expertise and existing facilities at the National Research Council and Hydro Québec.[61]

Stellantis and LG recently announced a $5bn joint venture to produce 45 GWh of battery cells and modules per year in Windsor. This is an essential first step and a real achievement by the government in a competitive global space.

For example, this roadmap argues that Canada should develop innovation capacity in lithium iron phosphate (LFP) cathodes. To do that, pilot and demonstration facilities for LFP batteries are needed. This expertise already exists in the Québec LFP consortium, but building manufacturing facilities will help enhance LFP capacity over the medium-term.[62] Such facilities will allow innovators to test their products at scale and encourage learning-by-doing along the production line.

In short, Canada's battery manufacturing plays shouldn't be dependent on foreign OEMs. Batteries are an essential part of Canada and the world's EV future – bold steps today will help secure Canada's position in the value chain.

Demonstration and pilot lines should then be used as experiments to reveal where Canada has niche opportunities. There are many opportunities to develop cell component niches. A battery cell has cathode, anode, separator, current collector, pouches, housing, sealants and adhesives, bus bars, and cables. Putting cells into packs adds more housing and connectors, and putting packs into batteries adds power controls, insulation, cooling plates, harnesses, and more. The supply chains are incredibly complex and as the EV industry scales there will be opportunities to improve materials and manufacturing processes.

This capacity is needed to replicate Canada's current position in the North American market. But targets for individual pieces of the cell and battery manufacturing supply chain should also be established.

TARGETS

Battery production	2030	2040
Lithium-iron-phosphate batteries	50 GWh	100 GWh
Nickel-rich batteries	50 GWh	100 GWh
Gigafactories	2-4	5-8

KEY ACTION AREAS 2022-2025

3.1 Attract foreign direct investment to build cell manufacturing and use those facilities to build homegrown capacity

Valeriya Zankovych/Shutterstock.com

The government is clearly already working to attract cell manufacturers to Canada so we focus our recommended action areas on building the ecosystem.

Still, it is worth noting that these foreign direct investment deals should include clauses to ensure that local suppliers are being used, otherwise they may not deliver the local economic value-added necessary to justify public funds.

Moreover, there must be a plan for learning from these joint ventures and supporting Canadian expertise in the sector. The goal must be to do what Ballard, Tesla, and others do: create a network of knowledgeable, skilled workers and innovators that produce economic spillovers and enhance local capacity. Then we need to build supportive infrastructure tailored to the sector so the proposed actions in this report focus on building the broader ecosystem.

Expertise in ISED (especially the National Research Council of Canada battery group) and NRCan should be leveraged in creating these strategies.

3.2 Evaluate which cell components Canada has the greatest opportunities to compete in

The first step is to identify each element of the cell, and conduct a rigorous analysis of value-added and Canada's capacity to compete in these segments. From there, opportunities and priority areas can be identified.

An industrial strategy must choose a focus, and then adapt. In Ireland, for example, government support for high-tech accidentally built a software industry.[63] The strategy must remain open to these possibilities.

3.2.1 Create a strategy for focusing research and demonstrations to build industries.

The goal must be to create what Ballard, Tesla, and others do: create a network of knowledgeable, skilled workers and innovators that produce economic spillovers and Canadian capacity.

3.2.1.1 Map the cell manufacturing value chain. Break out the cell pack into all its components, identify where the opportunities are, and identify the targets for each separate component

3.2.1.2 Are there opportunities for integration with expertise in adjacent industries? E.g., map the Canadian ecosystem for automotive parts—what elements can be transitioned to batteries?

3.2.1.3 Are there opportunities for integration with natural resources and supply chain efficiencies?

3.2.2 Evaluate and adapt based on where expertise and capacity get traction.

3.3 Demonstrate the capacity to produce innovative batteries here in Canada.

There is a high-impact, low-cost opportunity here: invest in research and production lines that allow innovative researchers and companies to test and validate their products at low cost. These demonstration lines can be used to pilot techniques and technologies for new technologies coming out of labs.

This isn't just about piloting new batteries. It will benefit the whole supply and ecosystem: innovators along the cell manufacturing supply chain need to be able to test their materials in cell applications.

This would provide the basis of an innovative battery ecosystem and demonstrate that Canada has domestic capacity already.

These demonstrations should be located in at least 3 regional hubs. The first should expand the Hydro Québec Center of Excellence. The second should build out and increase access to the NRC labs. Another should be located in the West so it can connect Alberta and BC into a future Canada-to-Fremont battery and vehicle corridor.

3.3.1 Establish a fund for 3 regional battery manufacturing hubs with pilot and demonstration lines.

3.3.2 Create research institutes or centres of excellence to co-locate research and development capacity with these hubs.

3.4 Elevate research and development capacity

The future of battery chemistry is unknown but Canada needs a national centre of excellence for battery research that ensures that innovative chemistry experiments happen here in Canada.

One clear goal could be to develop the next battery chemistry, likely to be lithium-sulfur, here in Canada. Canada is already home to researchers working toward this end. They need support and integration with the supply chain.

Canada can raise the level of research and development by providing access to labs and pilot facilities that will allow researchers and entrepreneurs to test and validate new technologies.

3.4.1 In the near-term, fund pilot and demonstration facilities for cell manufacturing. Canada needs smaller research pilot lines to be operational, at a minimum, at each of the three manufacturing hubs identified in 3.2-3.3.

3.4.2 Support funding for the Western Canada Battery Consortium, to be hosted at the University of Calgary and the University of British Columbia Power Hub.

3.4.3 Work to scale these into a national level ecosystem around research institutes and centres that create spaces for industry, academia, government, and finance to come together.

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Goal 4. RECYCLE: Establish a world-leading, closed loop battery recycling industry

Recycling plays a critical role in the battery metals ecosystem. Canada cannot meet long-term metals demand under even the most conservative uptake models without it. It will be cheaper and more environmentally friendly to design and incentivize a system with high recycling rates. Canada has to get this right.

Recycling battery materials is, like other parts of the value chain, a complex process that involves both mechanical and chemical procedures. In the upstream-midstream-downstream framework, recycling is part upstream and part midstream. It produces materials, so is analogous to mining; but it can also produce chemicals, so may contribute to the midstream.

What this means is that a recycling strategy can leverage Canada's expertise in green chemistry to build a competitive, innovative recycling industry that delivers value over the energy transition.

What this means is that a recycling strategy can leverage Canada's expertise in green chemistry to build a competitive, innovative recycling industry that delivers value over the energy transition.

Recycling technology is here and Canada has a strong, nascent ecosystem. Technologies with high recovery rates can be deployed at scale today. However, there is not yet enough domestic feed and downstream demand. This strategy focuses on solving those problems.

If Canada is a major producer of batteries, as this report envisions, it needs a world-leading recycling industry to handle scrap. Although it will be 10 years before major volumes of end-of-life batteries are available for recycling, there will be significant volumes of scrap from battery factories that needs to be collected and recycled.

Battery factories budget 10% for waste and these available volumes are built into our recycling model. The more batteries produced in Canada, the more volumes will be available for recycling. In our 2030 targets, 75% of recycling volume will be from scrap. In 2040, almost 30% will be from scrap.

Canada could also seek to be a world-leader in recycling and import waste and scrap for processing. This would entail a programme of work to simplify import rules and duties on these materials while maintaining safety. But it could potentially add volumes that would help the Canadian industry scale today.

There are two main business models: independent recycling and integrated recycling. Independent recyclers focus a little further upstream to source end-of-life batteries from third parties to produce intermediate materials that are sold for further refining and upgrading. Integrated recyclers co-locate their technology alongside waste production to directly produce precursor or battery active material. Integrated recyclers are likely to be vertically integrated into the supply chains for automotive OEMs, battery manufacturers, or chemical producers via licensing or joint venture. The two models have slightly different ecosystem needs and the ecosystem should be designed for both.

A key enabling factor is that safety regulations need to be harmonized by the federal government and the provinces. Safety regulations are needed because lithium-ion batteries can be dangerous to transport. Moreover, batteries are regulated both as hazardous waste and dangerous goods. Canada needs a simple set of standards and regulations.

The system design needs to take this into account. For example, shredding and separating close to disposal sites will make the material safe and enable longer distance travel. The next ten years, as recycling volumes from spent vehicle batteries slowly increase, is the time to study these system designs and establish hubs. Hub locations should be co-designed by government and industry.

TARGETS

Mandated Benchmark

Recycling capacity needed per year	2030	2035	2040
GWh of battery material	13	27	71
Total ktpa of lithium, nickel, cobalt, and manganese	7	14.5	38

Leader Scenario: 20% of the North American market

Recycling capacity needed per year	2030	2035	2040
GWh of battery material	25	50	140
Total ktpa of lithium, nickel, cobalt, and manganese	14	30	90

KEY ACTION AREAS 2022-2025

4.1 Create Extended Producer Responsibility (EPR) policies to incentivize the market

An EPR rule mandates that battery and vehicle manufacturers ensure their materials are recycled. EPR rules would help catalyze the investment needed to kick start the recycling market here in Canada. It would also create early incentives to ensure that batteries are designed for ease of recycling. This would catalyze collaboration between recyclers and OEMs which would help drive an integrated supply chain in EV batteries. Some may argue that Canada does not need an EPR because the batteries are so valuable that the industry will figure it out. But other jurisdictions are setting high environmental and technical standards, so Canada needs to set itself a high bar if it wants to compete.[64] An EPR will create the kind of communication up and down the supply chain that helps build innovation ecosystems.

Early action on recycling in Canada would give companies and processes a first mover advantage. Putting strong rules and processes in place now will help Canadian firms secure a position in the future industry.

Early action on recycling in Canada would give companies and processes a first mover advantage. Putting strong rules and processes in place now will help Canadian firms secure a position in the future industry.

But some care and creativity is needed in designing an EPR for EV batteries. EPRs can raise costs, which will be passed on to consumers (such as in a battery recycling fee charged by car dealers). So supply-side policies that help control or reduce costs should be considered.

There is a broader strategic consideration here: mandates generally deliver power to upstream and midstream firms in supply chains. If downstream firms have to offload the product, but there is limited capacity, then recycling firms can name their price. However, there is enough upstream competition in the recycling industry today to handle the added push of an EPR. An EPR scheduled to take effect in 2025 or a bit later would not likely be too onerous.

In any event, OEMs will not like the added responsibility. So, as the government negotiates with OEMs for support on other aspects of the battery strategy, they should consider building this obligation in.

How can we advance this action area?

4.1.1 The federal government should work with British Columbia, which has developed expertise on battery EPR as part of its five-year action plan.

4.1.2 The first task should be to identify high priority metals. For these metals, we must set technical standards and determine the recovery rate.

4.1.3 The government and industry should work together on policy proposals. We need to convene the whole supply chain from chemicals to vehicle and other OEMs in order to get the EPR right. Strong communication up and down the supply chain is key.

4.1.4 The industry should work with civil society organizations to conduct a communications and GR campaign to press for a strong EPR.

4.2 Develop harmonized federal rules on the transportation of recycled battery materials

Spent batteries are flammable, hazardous materials. As such, they are subject to a variety of complex rules. In many instances, battery metals are regulated both as hazardous waste and dangerous goods.

Canada needs to rationalize cross-provincial rules for the transportation of battery materials. This means a shift from the existing patchwork of provincial regulations to a harmonized federal system.

Local shredding could reduce the toxicity of the product and enable transport to regional hubs for reprocessing.How can we advance this action area?

4.2.1 Canada needs a Recycling Task Force that brings together industry and governments to study the current system of regulations and design a federal policy.

4.2.2 In the absence of near-term federal action, coordination among provinces to harmonize and simplify the regulations would be beneficial.

Recycling is not just about collection and shredding. It is a chemical intensive process. R&D should focus on recovery techniques, environmental impact reduction, the chemical processing necessary to make an integrated supply chain, techno-economics, and policy.

4.3 Design an efficient long-term ecosystem around 2-3 regional recycling hubs

Canada must to use this time before major volumes come online to design an efficient long-term system that will keep costs low for OEMs while meeting a high environmental standard. There are important system-level considerations that should be examined (e.g., should facilities be located near OEMs or elsewhere?)

How can we advance this action area?

4.3.1 Canada needs to design a hub and spoke system map that outlines how materials move through the country.

4.3.1.1 This needs to take into consideration the regulations just discussed, and the associated safety recommendations.

4.3.1.2 It also needs to take into account efficient materials flows, green transportation corridors to cathode manufacturing, and access to chemistry expertise.

4.3.2 As soon as the plan is formulated, Canada should begin siting the hubs. The goal should be, roughly three sites, one in the West and one or two in the East, linking into the emerging EV corridor from Bécancour to Tennessee.

4.3.3 Study the ReCell centre in the US and European initiatives to distill best practices for these hubs.

4.3.4 Medium-term the goal must be to secure FDI from OEMs in Canada's recycling ecosystem.

4.4 Research, development and deployment on refining techniques

To lead over the long-run, Canada needs to build research and development capacity in recycling. As this report has pointed out, recycling is not just about collection and shredding. It is a chemical intensive process. R&D should focus on recovery techniques, environmental impact reduction, the chemical processing necessary to make an integrated supply chain, techno-economics, and policy.

How can we advance this action area?

4.4.1 The Recycling Task Force needs to have a representative in the Battery Metals Research Network and needs to play a role in any future Centre for Excellence.

4.4.2 The near-term goal should be to establish 2-3 research centres alongside recycling hubs. Universities should be contacted and integrated into the work. Researchers will need funding which should be budgeted in network applications.

4.4.3 The research agenda should include:

- 4.4.3.1 Documenting the cost of compliance with current regulations.
- 4.4.3.2 Research on chemical conversion to high value-add products.
- 4.4.3.3 Recycling processes for different battery chemistries.
- 4.4.3.4 Identify process inputs and related constraints on facilities.
- 4.4.3.5 Setting minimum recycling content requirements and targets.

Metals Strategies

In addition to an overall roadmap and strategy, Canada needs individual strategies for each metal. Each metal has its own global market, Canadian footprint, flowsheet and facilities. To illustrate what this looks like, this section presents draft strategies for lithium, nickel, graphite, and rare earth elements. Full, detailed strategies for all the metals in the EV supply chain are needed.

This level of detail is needed to create realistic scenarios that convert the "10% of North American supply chains" into specific targets for each metal. That is, in the real world, an overall contribution of 10% will be achieved by producing more than 10% in some areas and less than that in others.

Therefore, individual metals strategies should be benchmarked to more specific goals that may be higher or lower than the 10% of North America benchmark or the 20% world leader scenario. For example, Canada should push hard to capture North American market share in nickel and graphite. Lithium and rare earths are likely to be more competitive so setting more moderate goals there is pragmatic.

Lithium


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TARGETS

Mandated Benchmark

	2030	2035
Lithium (ktpa LCE)	57	114
Projects needed	2-3	2-6

THE SUPPLY CHAIN

Lithium is plentiful in geologic terms. There are large reserves throughout the world. Lithium for batteries occurs in two main forms: as brine and in


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spodumene ore. In the salars, the famous South American salt flats, brine is pumped into large evaporation ponds. Spodumene is mined as ore.

Both brines and ores can be processed into lithium carbonate or lithium hydroxide. Cathode can be made with both, and by 2030 the global market is likely to be evenly split between the two products. However, the market standard is to report volumes in lithium carbonate equivalent (LCE).

Though most lithium in EVs goes into the cathode, lithium is also needed for electrolytes. The figures above only include lithium for cathode. Adding electrolytes would increase these targets by about 12%.

THE CANADIAN LANDSCAPE

Canada has large lithium reserves and is home to both brine (in the west) and spodumene (in Québec and Ontario). It also has significant lithium in brines historically associated with oil and gas reservoirs. There is a long history of spodumene exploration and development in Québec. With demand skyrocketing, this is the time to reinvigorate the spodumene industry in Québec.

The opportunity for brine Lithium in Canada has been revolutionized by direct lithium extraction (DLE). In DLE, raw brine goes straight to chemical production, instead of going into large evaporation ponds. DLE is faster and has lower environmental impact than conventional extraction methods. Canada has a variety of DLE startups and is well-positioned to produce volumes by 2025-2027. Even if DLE is not immediately competitive, investing in DLE now will help drive the cost reductions needed.

THE STRATEGY

Lithium will be needed over the entire energy transition and escalating demand is driving price increases globally. But due to the wide availability of lithium geologically, it will be a competitive space dominated by the big players. The US has a number of startups and will be using the Defense Production Act to drive action in this area.

Nonetheless, Canada has an opportunity to build homegrown capacity in DLE and to produce local spodumene feed for cathode manufacturing in Ontario and Québec.

But due to the competitive landscape in North American, our initial targets here should be modest: 10% of the North American market as a baseline rising to 12.5% as a stretch goal.

Canada has the expertise and experience to develop spodumene deposits in Québec to feed new cathode plants. Advanced projects there should be brought on line to feed domestic CAM production by 2025.

Canada should focus on innovative strategies that leverage chemical expertise in order to compete with lithium industries in other countries. DLE provides a great opportunity for a demonstration fund on the model of the Alberta Oil Sands Technology and Research Authority (AOSTRA). AOSTRA was a public-private partnership that pioneered research and development for new technologies that unlocked the oil sands. A similar partnership could be used to develop DLE in Western Canada. In addition to help perfecting DLE techniques, demonstrations would also provide demand-pull on innovative start-ups like Mangrove Lithium, E3 Lithium, and Conductive who are innovating and developing IP in this space.

However, DLE requires lots of power, because you need to move large volumes of brine through the facility to yield lithium concentrate. **So Canada needs a clean energy strategy for lithium.**

Direct lithium processing to lithium carbonate or hydroxide can be done in one fully integrated facility owned and operated by one firm. However, there may be benefits to incentivizing firms to work together in a hub-and-spoke system that shares key stages in the chemical processing of lithium.

Canada's lithium firms need support to get pilot lines up and running. A tax credit or other form of grant for pilot lines up to 3000 t/y would catalyze demonstration and investments.

Integrating the firms into a national R&D strategy is needed to ensure the competitiveness of the industry over the long-run. Canada should establish a research hub for brines in Alberta and a spodumene hub in Québec.

Nickel

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TARGETS

Mandated Benchmark

	2030	2035
Nickel (ktpa elemental)	37	74
New mines	1	3
New refining facilities	1	2

Leader Scenario: 35% of 2030 North American Market

	2030	2035
Nickel (ktpa elemental)	130	175
New mines	1	3
New refining facilities	1	2

On the mandated benchmark for this roadmap, Canada needs an additional 37 ktpa of nickel in 2030 and 74 ktpa by 2040. But we can and should push for maximum production. Trytten Consulting estimates that with concerted effort we could develop 130 ktpa of mining capacity by 2030—35% of the market. Given current reserves, we can produce 165 ktpa by 2040, though exploration and further development of existing sites should add a little to that. Still, by 2040 Canadian onshore feed could only provide about 20% of the North American market.[65]

THE SUPPLY CHAIN

Nickel is mined as ore and physically processed (primarily by froth flotation) to concentrate at the mine site. It can then be refined and purified by either pyrometallurgical (smelting) or hydrometallurgical processes into metal or other intermediates. Class 2 nickel-iron alloys produced by smelting laterite ores in the tropics dominate the market for stainless steel. Class 1 nickel metal produced by electrowinning is an important input for stainless steel and a

Canada should maximize production to capture as much of the North American market as possible. Current projects could bring 130,000 tpa online by 2030 and Canada should strive to achieve this goal. But government and industry must invest in refining and processing capacity at the same time so that an integrated supply chain is ready when new mines start to come on line in 2026-2027.

critical feed for high-nickel alloys. These intermediates need further processing before they can go to a cathode manufacturer. Battery-grade nickel can be produced from dissolving Class 1 metal, or by direct processing eliminating the metal production stage. The result is a high purity sulfate or hydroxide that is combined with, most often, cobalt and manganese in cathode production.

THE CANADIAN LANDSCAPE

Canada is a leading supplier of nickel, producing 6.7% of the world's nickel in 2020. This amounts to 170 ktpa. But at present Canada does not process any battery grade nickel. There are a number of pathways from Canada's sulfidic ore deposits to battery grade material.

Currently, Canadian nickel from Vale's Long Harbour facility in Newfoundland is mined and refined to Class 1 nickel metal. The metal is shipped to Europe where it can be further processed into battery grade material via a number of routes. Vale recently announced that its low-carbon nickel will be used to supply Northvolt's new cathode facilities in Europe.[66] This is exciting news that demonstrates the power of Canada's ESG advantage in nickel. Elsewhere, Vale's Ontario and Manitoba operations produce nickel concentrate that is smelted to matte and refined to Class 1 nickel in Ontario, and Glencore's Ontario and Québec operations produce nickel concentrate that is smelted to matte in Ontario and shipped to Europe for refining to Class 1 metal. Sherritt International produces Class 1 nickel in Alberta from imported joint-venture feed materials.

However, producing Class 1 metal may not be the most efficient route from mine to battery. Sherritt pioneered the use of hydrometallurgy for treating nickel concentrates from Manitoba in the 1950s, and Long Harbour has adopted a different hydrometallurgical route in Newfoundland. Modern hydrometallurgy can be a low-carbon alternative to traditional fossil fuel smelting. But transforming nickel into matte before converting it to nickel powder or sulfate suitable for batteries creates a complex flowsheet.

Canada could build a strategy around converting nickel concentrate into mixed hydroxide precipitate (MHP) which can be efficiently converted to battery-grade nickel chemicals. MHP is the emerging focal point of the global battery grade nickel market.[67] The route via MHP is lower cost than routes through metal. However, metal is better for long distance transportation.

Thus, if the hydromet facility is close to cathode production, then MHP is an effective basis for a low-cost, low-carbon strategy. An integrated Canadian supply chain should be built on MHP.

THE STRATEGY

Canada should maximize production to capture as much of the North American market as possible. Current projects could bring 130,000 tpa online by 2030 and Canada should strive to achieve this goal. But government and industry must invest in refining and processing capacity at the same time so that an integrated supply chain is ready when new mines start to come on line in 2026-2027.

To develop processing capacity, Canada should build an integrated battery nickel supply chain centered on hydrometallurgy. This can be achieved with an efficient hub and spoke model where concentrate is produced at the mine and then further refined to MHP in central hubs. That MHP can then be transported easily or converted to battery grade materials for local CAM production.

Graphite

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TARGETS

Mandated Baseline

	2030	2035
Graphite (ktpa CPSG)	111	223
Anode active material plants needed	3	5
New refining facilities	1	2

Leader Scenario: 35% of North American Market

	2030	2035
Graphite (ktpa CPSG)	350	750
Anode active material plants needed	3	5

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Graphite will be needed in anodes for at least 10 years, more likely up to 20 years. There are strong reserves and an innovative group of juniors in Canada but they need support to create two centralized refining hubs (East and West) to achieve economies of scale. R&D on shaping, purification, and coating is needed to secure long-term advantages.

An investment in graphite is smart because all the major chemistries rely on a graphite anode. Roughly the same amount of graphite anode is required regardless of the relative market shares of NCA, NCM, LFP, and so on. So the targets offered here can be relied on.

Graphite will be needed in anodes for at least 10 years, more likely up to 20 years. There are strong reserves and an innovative group of juniors in Canada but they need support to create two centralized refining hubs (East and West) to achieve economies of scale.

THE SUPPLY CHAIN

Battery grade graphite is referred to as CSPG: coated spherical purified graphite. Producing CSPG is a complex process that is currently done completely in Asia.

Like transition metals, graphite ore is mined and then floated to produce a concentrate. Then the secondary or chemical processing begins. The first stages here are purification and shaping (the technical term is spheronization, and it also involves milling or micronization). Some firms do purification first; some do shaping first. Currently, China has a 100% global share on these stages.[68] Once purified and spheronized, graphite is coated. While China also dominates coating, some is done in South Korea and Japan. There is IP and battery-grade projects in the US (Alabama Graphite Corp) and Canada (Nouveau Monde and Mason Graphite). The Australian firm Syrah is also expanding its North American footprint.[69]

Up to 50% or even 60% of the material is lost to shaping, though this loss rate is likely to come down slightly over time. So in terms of transportation costs, there is a logistical advantage to processing close to the mine site.

The residual particles that do not go into the battery, "micronized graphite," are an additional source of value. Work on product development is needed to use the large volumes of waste effectively. Graphite is a good source of crystallized carbon, which could be used for a wide variety of materials and products.

THE CANADIAN LANDSCAPE

In 2022, Nouveau Monde will begin demonstration at a coating facility with 2,000 t/y.[70] Nouveau Monde's phase 2 plans include a facility to produce 42,000 t/y of CSPG at its site in Bécancour, Québec (to begin operations in 2025). This would provide roughly half of Canada's graphite needs on this roadmap. This or another Québec or Ontario graphite facility should be developed.

There is an urgent need to site and develop a second coating facility with BC the likely ideal location. Graphite is already mined in BC, but has not been developed for the battery market. A second facility with 45-50ktpa capacity could cost $200-300m. Graphite coating is fairly well understood and there are a number of options for developing the technology. There are a number of processes in the public domain that could be adapted. There is also American IP for coating that could be licensed if necessary. Either way, we need to set up a piloting lab and get experts to create a process that works for Western graphite supplies.

THE STRATEGY

Canada should seek to be the main North American supplier of coated spherical purified graphite for EV batteries. An achievable leader goal is 1.5 million tpa of raw graphite by 2040, generating 750,000 tpa of anode active material—25% of the North American market.

In short, Canada should target far more than 10% of the North American market. Canadian graphite reserves could easily produce 1.5 million tpa. At an accelerated rate designed to deplete reserves in 10 or 15 rather than 20 years, which would be desirable if alternative anode products are likely to come online early, the target could be as much as 2-3 million tpa of raw graphite.

We should start aggressive piloting and scaling now. A two-year pilot on a second facility will be enough to plan and site a larger plant starting in 2024-2025.

Large coating facilities in Québec or BC could be vertically integrated within a mining firm or could be separately owned and operated. Either way, a large facility could serve as a central node in a hub and spoke system. One potential hub and spoke system would locate smaller milling and shaping facilities closer to mine sites. Those smaller pieces would feed into these two facilities for coating.

Canada should seek to be the main North American supplier of coated spherical purified graphite for EV batteries. An achievable leader goal is 1.5 million tpa of raw graphite by 2040, generating 750,000 tpa of anode active material—25% of the North American market.

Rare Earth Elements

Rare earths are not used in batteries, but they are an essential part of electric vehicles. Rare earth magnets are essential to motors and can be used in lightweight alloys. Neodymium and praseodymium (NdPr) power strong magnets that help electric vehicles achieve the necessary torque.

The global rare earths mining and processing market is dominated by China. Over the last few years, automotive manufacturers have been looking to secure rare earths supply from North American suppliers.[71] As the EV supply chain ramps up, there will be opportunities for Canada's REE sector.

THE SUPPLY CHAIN

Praseodymium

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Neodymium

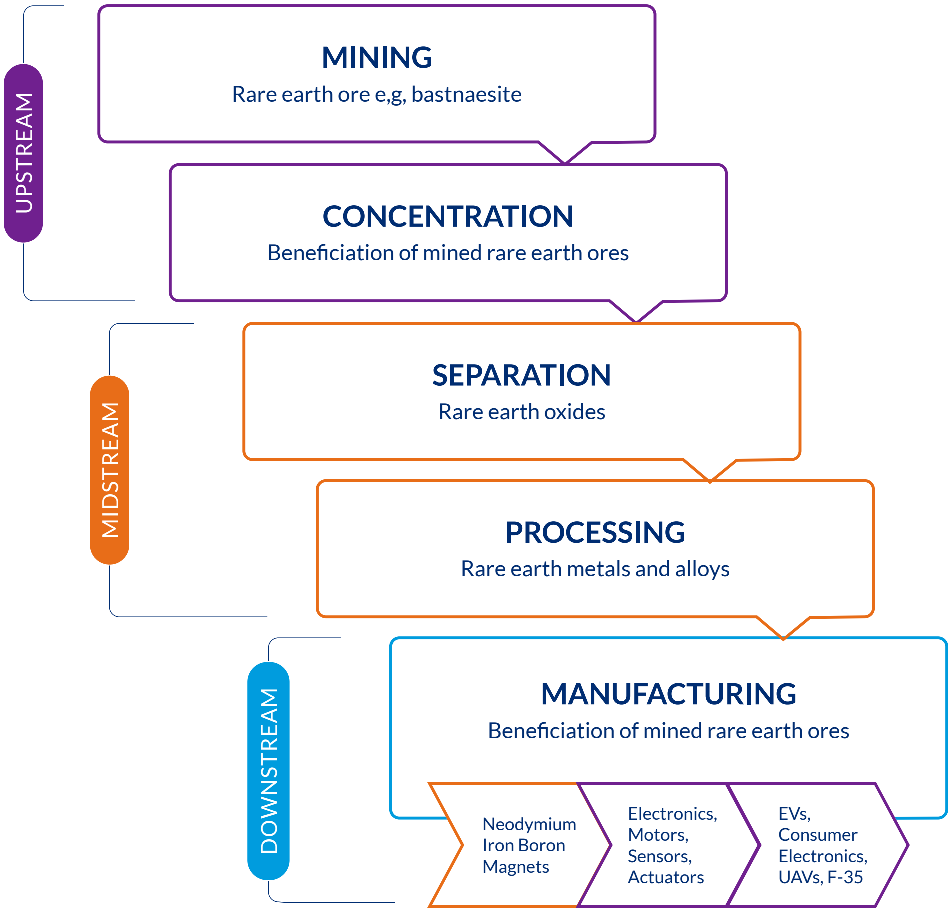
RHJPhtotos/Shutterstock.com

Rare earths elements are mined as ore and floated to concentrate, like most metals. Then rare earths must be separated from other minerals in the concentrate. Rare earths are not actually rare but they are found in small quantities that are difficult to separate from other minerals. Rare earths are also often co-located with small amounts of radioactive material. This means that REE separation and processing is science-intensive and requires a lot of expertise.

Rare earths can be separated and prepared as oxides by environmentally-friendly hydrometallurgical processes, such as solvent extraction.[72] Once separated into oxides, rare earths are processed into metals and alloys. This is the most energy-intensive step of the chain, and one where Canada's clean power could create a long-term advantage.

THE CANADIAN LANDSCAPE

Canada is well stocked with REEs with promising demonstrations for mining, processing, and recycling. In 2022, Avalon's Nechalacho deposit in the Northwest Territories began production under Australian miners, Cheetah Resources[74]The project mines material from the Nechalacho deposit and transports it to Saskatchewan for further processing. Search Minerals has deposits in Labrador and is piloting a hydrometallurgical process for refining rare earths into oxides. Rio Tinto has a project to produce scandium in Northern Québec. GeoMega is advancing REE magnet recycling/processing facilities, hence contributing to circular economy objectives.



Source: Department of Energy 2020[73]

In short, Canada has all the elements of the rare earths supply chain.

The Government of Saskatchewan has also invested in the supply chain through the $35m Rare Earths Processing Facility. In Phase 1 the facility will begin processing monazite ores. In phase II, it will refine these into oxides and, ultimately, into neodymium and praseodymium metal.

Canada is also home to Neo Performance Materials which processes rare earths in China and Estonia, and manufactures REE powders and magnets in Thailand. Neo could replicate facilities and attract downstream parts production to Canada.

In short, Canada has all the elements of the rare earths supply chain.

THE STRATEGY

Canada should position itself as a world leader in rare earths production by creating a mines-to-motors supply chain. This could be up and running in as little as three years.

The key is to eliminate investment risk with a clear downstream demand. There are a number of ways to achieve this, but as discussed above, the simplest way is to build a rare earths public-private partnership to mobilize capital. One promising strategy is to work with a downstream OEM to develop a commitment to building the upstream supply chain here in Canada. That downstream commitment alongside a clear strategy with achievable targets should be able to bring the supply chain online.

Rare earth elements processing is even more science-intensive than other metals. We need to establish regional hubs for processing and innovation that will lower processing and refining costs over time.

We need to build the Saskatchewan Rare Earths Facility into a hub for rare earths processing. This requires all the hallmarks of classic cluster development: investment in R&D, partnerships with universities and technical institutes, bringing in local financial partners, and more.

The Saskatchewan Rare Earths Facility can then be a key node in a national hub and spoke system. Since rare earths are low volume, shipping to central locations for processing is beneficial.

Other Metals

We need full strategies for the other metals in the battery supply chain as well. A crucial task for the critical minerals task force is to forge public-private-indigenous partnerships for each metal.

Cobalt is a by-product of nickel and copper mining. As nickel and copper production expand, more cobalt will be produced. Cobalt refining processes are well understood and there is no need to use R&D to drive further innovation. A number of firms are seeking to expand Canada's processing capacity to produce the cobalt hydroxide and sulphate needed for the battery supply chain. There is a particular opportunity in cobalt sulphate, which is best sourced close to battery factories. But the global

Cobalt

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market is competitive and dominated by big players. Investment in the sector is critical if Canada truly wants to gain a foothold in the global landscape.

Manganese has not been developed in Canada but Canada is likely home to the largest deposits in North America. Two junior miners, Manganese X and Canadian Manganese, have explored large deposits. We also have Canadian expertise in manganese mining through Euro Manganese, headquartered in Vancouver, but their deposit is in the Czech Republic.

Iron for batteries is readily available as the volumes needed for batteries are only a fraction of existing Canadian production.

Phosphate is not currently mined in Canada, but there are large reserves in Québec, Ontario, and BC. These could be developed and fed into an LFP supply chain. Nutrien has mined phosphate ores in Canada, but has closed its Canadian phosphate operations and now produces phosphoric acid in the United States at integrated facilities. Arianne is seeking to mine and process phosphate to produce high purity phosphoric acid. There is an opportunity here and with market certainty the feed will come on line easily.

Copper is home to significant copper production in Québec, Newfoundland, Ontario, and British Columbia. High prices and bankable demand-pull would be needed to push development for the EV market. Teck, a homegrown Canadian firm with a significant global footprint, can supply Canadian needs in the near-term from its new Chilean project. Canadian development, especially with an eye to export opportunities, is a possibility but the government and downstream industries need to work closely to model copper needs and define a strategy.

Strategies for **aluminum, vanadium** and **silicon** should also be pursued.

Manganese

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Iron

Aleksandr Pobedimskiy/Shutterstock.com

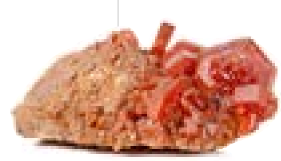
Phosphate

Copper

Ique Perez/Shutterstock.com

Silicon

bonchan/Shutterstock.com



Vanadium

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Aluminum

RHJPhtotos/Shutterstock.com

Summary and Path Forward

A call to build an integrated supply chain with homegrown capacity

This report provides a call to action: Canada needs a national battery metals strategy with clear targets, timelines, and priority actions to catalyze the development of the supply chain. That strategy should, this report argues, include three things.

First, it should have a critical role for the midstream chemical processing stage as the core of an integrated supply chain. An integrated supply chain built on chemical processing capacity will pay dividends over the transition. A strong midstream allows Canada adapt to changing metals needs, feed Canadian battery firms, and develop export opportunities.

The midstream is critical to what this report calls catalytic investments: investments that connect elements of the supply chain and unlock value.

Second, the strategy must build a whole battery ecosystem with significant homegrown capacity. If we want to deliver real value-added over the long-run, Canadian firms need to contribute to mining, chemical processing, and battery assembly. We cannot rely solely on investments by large foreign OEMs to drive value. We need a plan to develop capacity and leverage Canadian firms. These firms can act as force multipliers if they invest in R&D and participate in the kinds of interaction that create long-term innovation.

Third, the strategy needs roadmaps and metals strategies that can be used to align existing and new funds. It must identify the catalytic investments we need to unlock Canada's potential in global value chains.

Getting started

This report contains almost a hundred concrete actions. Where can Canada focus? The BMAC members identified a priority action for each workstream, as well as cross-cutting priorities.

In mining, the strategy should focus on unlocking nickel, lithium, and graphite development by developing creative financial mechanisms to drive investment.

In chemical production, Canada must design a national integrated supply chain with a highly efficient mine-to-battery materials flowsheet.

In cell manufacturing, government, indigenous groups and industry need to strategize about how to translate the new foreign direct investments in battery manufacturing into a Canadian battery ecosystem.

In recycling, strong extended producer responsibility requirements would catalyze the recycling market and harmonize regulations and standards to activate the ecosystem.

To unite and pull these together, government and industry must work together to co-deliver on a national strategy.

The easiest way to get started today is by forming the Critical Minerals, Midstream, Battery Components, and Recycling Task Forces that this report calls for. In convening these, government, indigenous communities, and industry should take an expansive view of who should be at the table. The goal should be to forge true alliances for an industry that does not yet exist. We cannot be beholden to the status quo. We have to convene for the future we want and build processes for creative, catalytic collaboration across societal and national lines.

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