CANADIAN BATTERY INNOVATION ROADMAP

accelerate

Authorship Team

Moe Kabbara
Vice President,
The Transition Accelerator
Senior Advisor, Accelerate

Bentley Allan
Transition Pathway Principal,
The Transition Accelerator
Senior Advisor, Accelerate

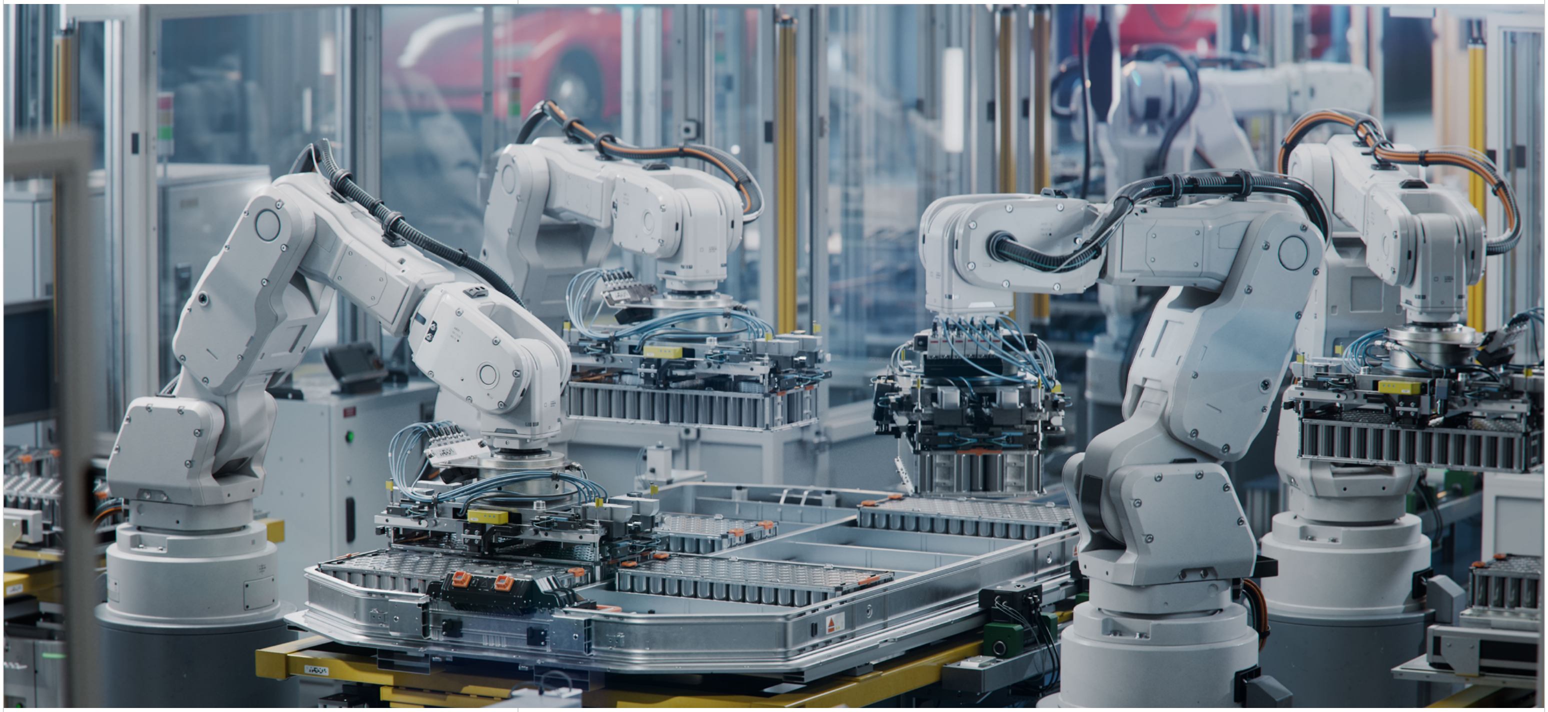
Travis Southin
Future Economy Lead,
The Transition Accelerator

About This Roadmap

This Battery Innovation Roadmap outlines a strategy to establish Canada as a global leader in battery technology by 2035. It offers an in-depth analysis of Canada's current position in the global battery landscape and details key actions needed to build a thriving battery ecosystem. The roadmap addresses critical areas including innovation infrastructure, industrial policy, and skills development. It is designed to guide policymakers, industry leaders, and researchers in collaborative efforts to maximize Canada's potential in the rapidly evolving battery sector. This document serves as a blueprint for enhancing Canada's competitiveness, fostering innovation, and contributing to the global clean energy transition.

Acknowledgments

This Canadian Battery Innovation Roadmap was funded by Natural Resources Canada and the Ivey Foundation. The roadmap was authored by Moe Kabbara, Bentley Allan, and Travis Southin. We also would like to acknowledge the valuable input provided by numerous stakeholders across Canada's battery ecosystem, including industry leaders, researchers, policymakers, and innovators. Their insights and expertise have significantly contributed to shaping this strategy for Canada's battery sector.



About Accelerate

Accelerate is Canada's ZEV industrial alliance. Our members and collaborators work together and with the public sector to develop the tools, relationships, and policy and investment priorities that will build and integrate a world-class zero emission vehicle supply chain and industry.

We activate key industry, public sector, Indigenous, labour and research stakeholders and build off Canada's advantages in mining, cleantech, finance, skill development, clean energy, and vehicle parts and assembly, to shape effective action that will result in a competitive, integrated ZEV sector.

Together, we are building Canada's Zero Emission Vehicle supply chain so that it becomes a central part of Canada's future wealth and prosperity.

EXECUTIVE SUMMARY

Introduction

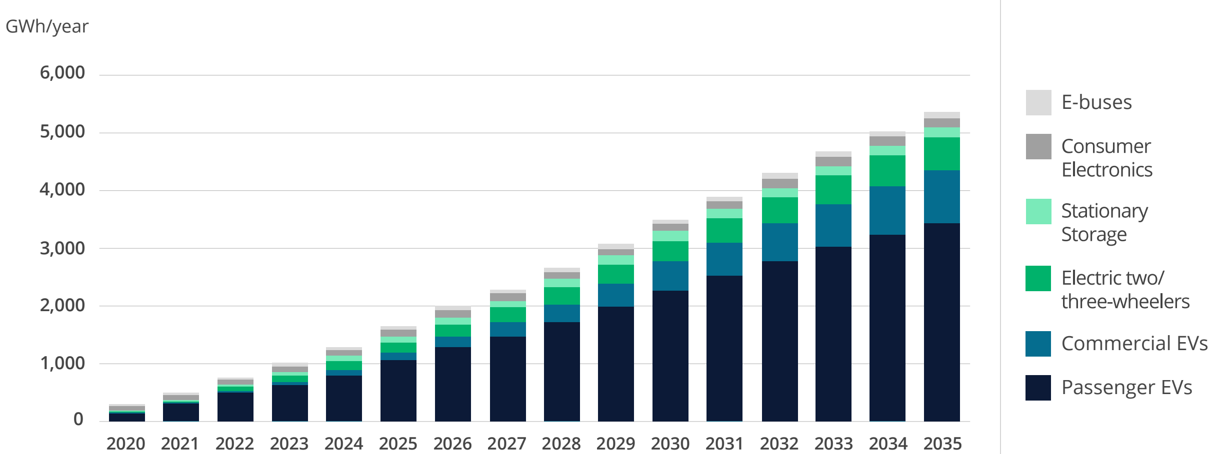
Batteries are a critical platform technology in the energy transition. They will enable cheap and deep decarbonization of the power and transportation sectors. As battery technology improves and supply chains scale, batteries will be used in even wider applications than they are already, enabling a clean, wireless, and connected future.

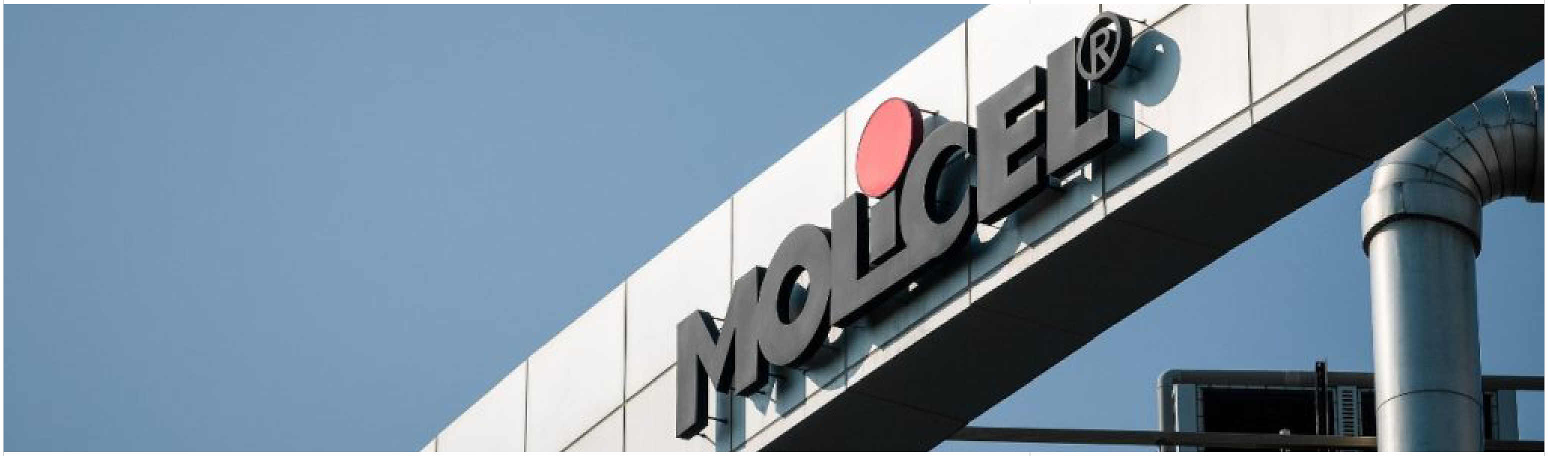
There is a global competitive race to create innovative technologies that will shape this future. The countries that benefit economically will be those that make strategic, focused investments in battery technology and supply chains. The countries that fail to take advantage of this moment will be consumers of batteries, taking on considerable economic and geopolitical risk in the process.

Canada finds itself at a pivotal juncture in this global competition. With a rich legacy of battery innovation and significant recent investments in battery production, Canada has the potential to establish itself as a world leader. This roadmap presents an ambitious vision for Canada to become a global leader in clean, innovative battery technology and a hub for sustainable battery production in North America by 2035. To realize this vision, we must leverage our strengths, address the challenges, and implement a comprehensive strategy that aligns government, industry, and academic efforts.

The countries that benefit economically will be those that make strategic, focused investments in battery technology and supply chains.

Forecast of Global Battery Demand by End-Use Application (GWh) 2020-2035





Canada's Battery Legacy and Current Landscape

Canada was an early mover in lithium-ion battery innovation. Vancouver-based Moli Energy was a leading lithium-ion battery maker in the 1980s, leading the charge to commercialize the lithium-ion battery. Moli was the first manufacturer of lithium-ion batteries in North America. But Canada lost its critical edge because it failed to see the economic, geopolitical, and environmental value of this technology at the right moment. After a Moli-made cell caught fire, the Province of British Columbia called in a loan and forced its sale to a Japanese consortium for $5M. The company had assets worth $58M and had received $120M in government support.

Despite this setback, Canada's legacy of battery innovation persists. We continue to produce world-class researchers, exemplified by figures like Jeff Dahn, whose work at Dalhousie University has kept us at the forefront of battery technology. Building on this foundation, a new generation of firms has emerged, developing innovative processing techniques, advanced materials, control systems, and precision testing equipment. These companies represent the potential for Canada to reclaim its position as a battery innovation leader.

> *"Canada's battery research community has always been at the cutting edge. With the right support and investment, we can translate this scientific excellence into homegrown industrial capacity."*
>
> - Jeff Dahn, Professor Emeritus, Principal Investigator – NSERC/Tesla Canada/Dalhousie Alliance Grant

Battery innovation presents an enormous opportunity for Canada. Canada has made a huge bet on batteries with strategic investments in up to 195 GWh of battery production across three facilities. The task now is to maximize the value of these factories by building the production networks around them into an innovative ecosystem that increases efficiency and advances the core technology. In doing so, Canada can add value to its local economy, build homegrown firms, and lead the way in clean battery innovation.

History of Canadian Battery Innovation

For more than 40 years, Canadian innovators have made groundbreaking contributions to the advancement of battery technology. Below is a selection of Canadian contributions across academia, industry, and government.

1978

The World's First Commercial Li Battery

Moli Energy is formed in 1979 in Burnaby BC and goes on to produce the world's first commercial rechargeable Li battery in the following decade.

1990

Ethylene Carbonate Jump Starts Li-ion Batteries

Researchers at Moli Energy Ltd. report on the role of ethylene carbonate (EC) in making Li-ion batteries viable. Every commercial battery cell today includes some ethylene carbonate in the electrolyte.

1999

FEC Boosts Battery Life

Researchers from Canada's National Research Council (NRC) discover and patent fluoroethylene carbonate (FEC) as a small addition to the electrolyte that dramatically increases the cycle life of lithium-ion batteries.

2000

Carbon Coating Revolutionizes LFP Batteries

Université de Montréal / Hydro-Québec researchers report on carbon coating of lithium iron phosphate batteries, which was critical to making LFPs work. BASF, Sony, Mitsui licensed the technology soon after.

2000

High Power Potential of Li-ion Batteries Revealed

E-One Moli researchers show for the first time that Li-ion cells designed for power can outperform other battery chemistries. E-One Moli is now the main supplier of battery cells to Dyson.

2001

NMC Changes the Battery Future

Researchers from Dalhousie University in partnership with 3M develop and patent certain grades of lithium nickel-manganese-cobalt (NMC) oxide compounds. NMC material is now being used around the world in power tools and electric vehicles.

2007

Advancing Solid-State Batteries

Researchers from the University of Calgary discover a new garnet-type material that would enable solid-state batteries which offer the promise of higher energy storage, improved safety and longer lifespan.

2009

Renewed Promise of Lithium-Sulfur Batteries

Researchers at the University of Waterloo improved the lifespan and capacity of lithium-sulfur batteries. They're now made with cheaper, easy-to-find materials, making them a promising option for the future.

RECENT INVESTMENTS IN CANADA IN CRITICAL MINERALS, BATTERIES AND ELECTRIC VEHICLES

In 2019, the federal government launched the Mines to Mobility initiative to establish a passenger EV battery value chain in Canada. Working in close collaboration with provinces and territories, Mines to Mobility had catalyzed over $46B in announced investments by mid-2024.

UPSTREAM	• Rio Tinto: $737M to decarbonize Rio Tinto Iron and Titanium operations, including a large-scale demonstration plant for a new spodumene concentration process
	• Anglo American: $24M into Canadian Nickel to develop Crawford nickel project
MIDSTREAM	• Umicore: $1.5B to produce cathode active materials (CAM) and precursor chemicals (PCAM)
	• Ultium CAM (GM/POSCO): $500M to produce CAM
	• Vale Canada: Providing a long-term supply of battery grade nickel sulfate to Ultium CAM
	• Nouveau Monde Graphite: $923M to produce anodes
	• Electra: $80M raised to produce cobalt sulfate in Canada
	• BASF: $692M to produce CAM
	• Ford, EcoProBM, and SK On Co consortium: $1.2B for battery materials production in Quebec
DOWNSTREAM	• NextStar (Stellantis/LG Energy Solutions): $4.9B to produce battery cells
	• Stellantis: $3.6B to produce EVs and fund automotive innovation
	• GM Canada: $2.0B to produce EVs
	• Ford Canada: $1.8B to produce EVs
	• Lion Electric: $185M to assemble battery packs for e-buses (and build a battery innovation centre)
	• Honda: $15B for comprehensive EV supply chain in Ontario (EV assembly, battery manufacturing, materials processing)
	• Northvolt: $7B for EV battery manufacturing in Quebec
	• Volkswagen: $7B for EV battery manufacturing in Ontario
INNOVATION	• Nano One: $66M spent in Canada on innovative approach to CAM production
	• E3 Lithium: $59M raised to produce battery-grade lithium products
	• NOVONIX: $36M spent in Canada on innovations related to advanced battery testing systems and electrode materials development
	• Flex'N'Gate: $20M to create a battery research facility

The Global Battery Innovation Landscape

The global battery innovation landscape is characterized by intense competition from jurisdictions who have secured technological leadership through deliberate strategies, including China, the United States, the European Union, Korea, and Japan. Canada's industrial policy for battery innovation can be improved by learning from these examples.

These jurisdictions have successfully practiced 'networked industrial policy' to align public and private investments to capture leadership in value-added niches in global supply chains by scaling up the technological capabilities of domestic firms. Scaling up domestic firms is the primary goal of their industrial policy efforts. This overarching goal animates their approach to related policy domains, such as trade policy, foreign direct investment attraction, labour market policy, etc.

This approach conceptualizes a more active role for the state in driving innovation, moving beyond simply fixing market failures with non-targeted, market framework interventions (tax credits for R&D underspending, regulations for environmental harm, and education spending for skills shortages). Instead, networked industrial policy takes a technology-specific, targeted approach to catalyzing and de-risking collaboration among a cohort of innovative battery firms over time. This mobilizes a broad policy mix, including supply-side inputs to innovation (ex: R&D support and infrastructure, skilled labour, upstream materials) and demand-side market pull for innovative products (ex: procurement, consumer incentives, regulations). The state's emphasis shifts from ad-hoc support for individual projects to a holistic approach that strengthens systems, creates networks, develops institutions, and aligns strategic priorities.

Battery-specific coordination forums facilitate private-public information sharing, enabling collaborative goal setting and optimal policy design. While the main focus of many of these organizations is facilitating cooperative R&D projects (ex: Japan's NEDO or the EU's Batt4EU), the collaborative space opened up by these public-private forums also enables information sharing and dialogue to coordinate how the broader mix of demand-side and supply-side policy instruments can be optimized to enable the scaling up of innovative battery firms and the achievement of innovation targets.

For Canada to compete effectively in this landscape, it must adopt a similarly strategic and collaborative approach, tailored to its unique strengths and challenges.

The state's emphasis shifts from ad-hoc support for individual projects to a holistic approach that strengthens systems, creates networks, develops institutions, and aligns strategic priorities.

Global Best Practices

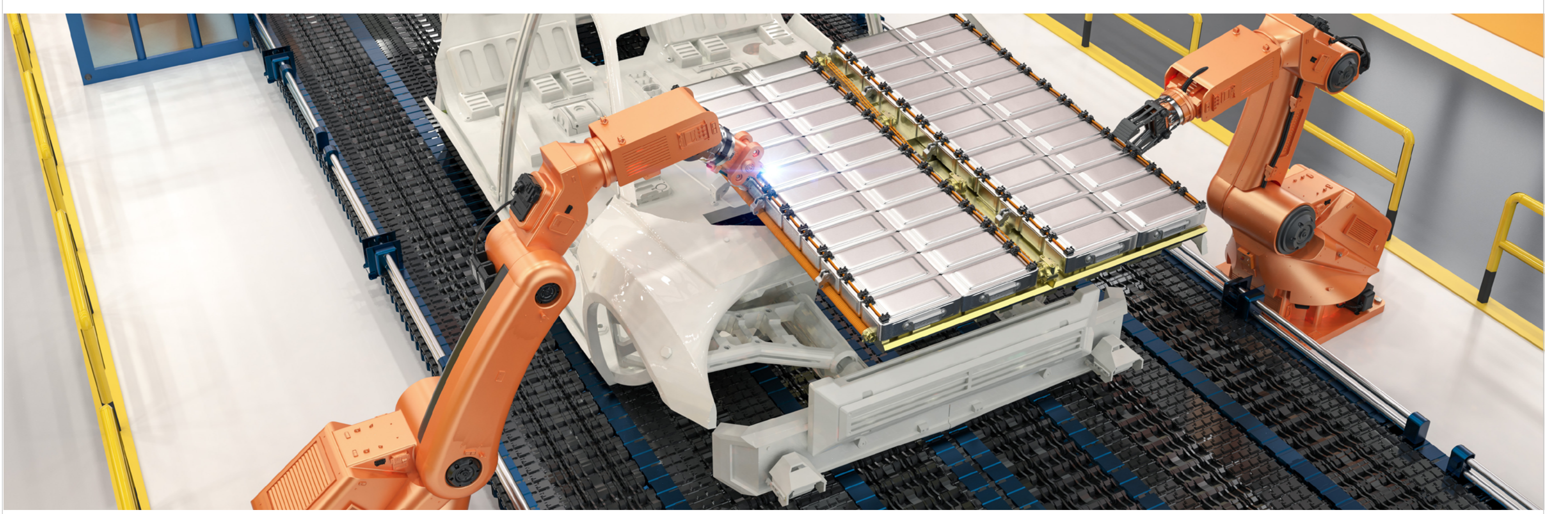
The global landscape of battery innovation is shaped by the strategic efforts of leading nations to advance their battery technologies and secure a dominant position in the market. Countries like China, the United States, the European Union, South Korea, and Japan have set ambitious production and innovation targets to drive their battery industries forward. These nations have implemented comprehensive policies and investments to enhance their capabilities across the entire battery supply chain. Understanding these global best practices provides valuable insights for Canada as it seeks to develop and implement its own strategic roadmap. The following table highlights the key production and innovation targets of these leading countries, illustrating their commitment to advancing battery technology and securing a competitive edge in the global market.

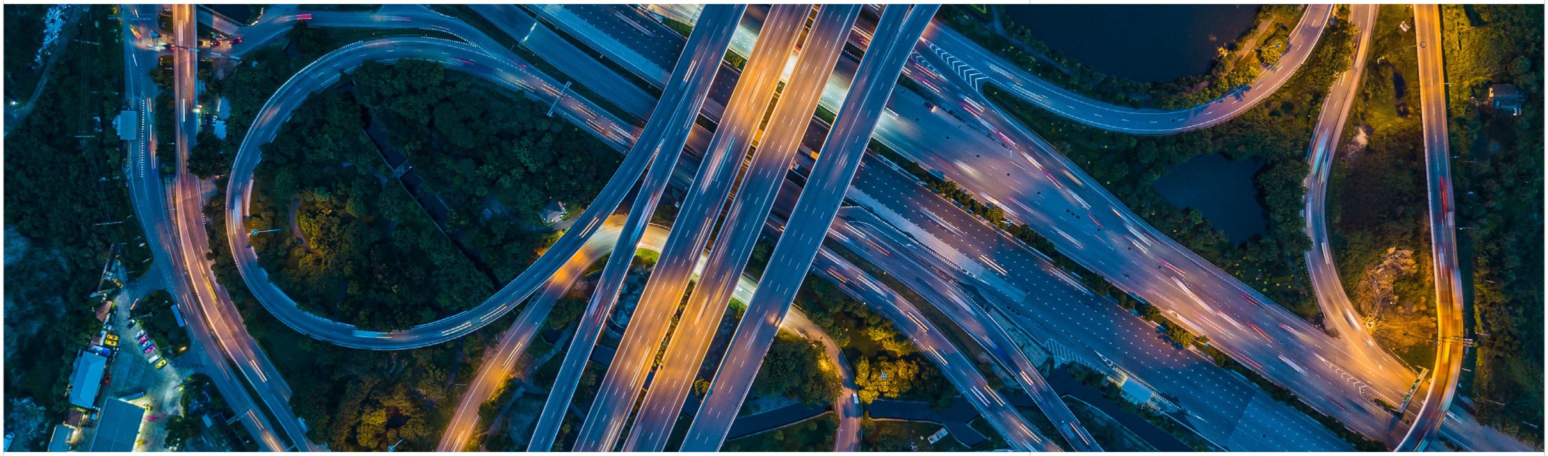
Global Battery Strategies

China	United States	European Union	South Korea	Japan
SETTING TARGETS				
Production Targets				
Raise domestic content of core components and materials to 40% by 2020 and 70% by 2025	Capture 60% of domestic demand by 2030	• Capture 90% of domestic demand (550 GWh) by 2030 • 2030 targets for domestic critical mineral extraction (10%), processing (40%), recycling (25%)	• 40% of global battery market and 20% of materials/parts/equipment market by 2030 • 4x cathode production capacity and triple exports of battery-making equipment the next five years	• 600 GWh (or 20% share of the global battery market) by 2030 • 150GWh domestic production by 2030
Innovation Targets				
Next-gen battery energy density of 500 Wh/kg by 2025	Solid-state and Li-metal production cost <60 $/kWh, 500 Wh/kg, cobalt/ nickel-free by 2030	• Increase energy density (+60% compared to 2019 values) • Reduce cost by 60% compared to 2019 values • Improve cycle lifetime (at least by a factor of 2 compared to 2019)	• 800 km single charge by 2026 • Lithium-sulfur batteries commercialized by 2025, solid-state by 2027, and lithium-metal by 2028 • Recycling 100% domestic secondary battery closed-loop by 2030	Full commercialization of solid-state batteries by 2030
BATTERY ROADMAPS				
• Made in China 2025 (2015) • Action Plan towards the Development of Automotive Power Battery Industry (2017) • NEV Industry Development Plan (2020) • The 14th Five-Year Plan > National Key R&D Program (2021)	• Energy Storage Grand Challenge Roadmap (2020) • National Blueprint for Lithium Batteries (2021)	• Strategic Action Plan for Batteries (2018) • Batteries Europe: SRA (2020) • BEPA Batt4EU: SRIA (2021) • Green Deal Industrial Plan (2023) • EU Batteries Regulation (2023) • Update of the SRIA (2024)	• K-Battery Development Strategy (2021) • Innovation Strategy on Secondary Battery Industry (2022) • Post-IRA Public-Private Joint Strategy for Battery Industry Development (2023)	• Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (revised in 2021) • Battery Industry Strategy (2022)

Global Battery Strategies

China	United States	European Union	South Korea	Japan
INDUSTRIAL POLICY MIXES AND COORDINATION FORUMS				
Supply Push				
• Joint Venture FDI requirements • R&D investments • Loans for mineral supply chain	• DoE R&D funds • DoE Loan Program • IRA tax credits	• Horizon Europe R&D • European Investment Bank • Important Projects of Common European Interest	• Public-private 'battery alliance' R&D fund • Loans & guarantees for critical minerals • Battery-specific tax credit bonuses	NEDO R&D consortiums
Demand Pull				
• Transit procurement • Purchase subsidies • EV mandate & credit system	IRA EV consumer incentive thresholds for domestic supply chains	• Procurement thresholds for domestic supply chains • Fit-for-55 2035 ICE phase out • EU Batteries Regulation	EV purchase incentive technical eligibility criteria	EV infrastructure investment
Public-Private Coordination				
China EV100	Li-bridge	• European Battery Alliance • InnoEnergy • BATT4EU	Korean Battery Alliance	Storage Battery Industry Strategy Council





Roadmap Vision and Strategy

The Canadian Battery Innovation Roadmap sets forth a bold vision for 2035: to establish Canada as a global leader in clean, innovative battery technology and a hub for sustainable battery production in North America. This vision recognizes the transformative potential of batteries in driving the clean energy transition and positions Canada to capture a significant share of the economic and environmental benefits this transition will bring.

There are considerable challenges to realizing this vision. While Canada is a leader in early-stage innovation, in part due to strong government expenditure on research and development, these innovators often fail to scale at home. Too often, they are bought by foreign firms, or they stall along the commercialization pathway.

To realize this vision in a competitive global landscape, Canada needs a new approach premised on active, targeted collaboration between government and industry. Such a collaboration is the core of modern industrial policy as practiced in all jurisdictions seeking to build innovative battery ecosystems. **Canada simply cannot be competitive without a strategic approach.**

The first element of this approach is to set the right targets and metrics. Doing this in the context of a shifting technological space can be daunting. This roadmap begins by laying out three kinds of drivers that are shaping the battery technological frontier. By focusing on market, environmental, and geopolitical drivers we can understand where the puck is going and design a strategy that mitigates uncertainty.

Market drivers include improving energy density to increase range, reducing charging time, enhancing cold-weather performance, extending cycle life, lowering costs, and ensuring safety. These factors are crucial for the widespread adoption of battery technologies across various applications, from electric vehicles to grid-scale energy storage.

Environmental drivers emphasize the need for sustainable materials, efficient recycling processes, low-emissions production methods, and second-life applications for batteries. By prioritizing these factors, Canada can position itself as a leader in sustainable battery technology, aligning with global efforts to combat climate change and reduce environmental impacts.

Where Is the Puck Going?

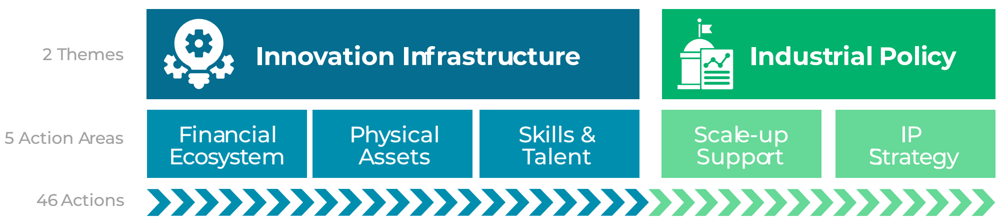
Geopolitical drivers focus on reducing dependency on critical materials like cobalt, ensuring ethical sourcing practices, and building resilient supply chains. These factors are essential for Canada's economic security and its ability to maintain a stable, domestic battery industry.

By focusing on technological advancements, best practices in policy, and a thorough assessment of the current Canadian landscape, the Battery Innovation Roadmap articulates key actions needed to achieve these ambitious targets.

Roadmap Actions

Canada's battery sector is at a critical juncture. Without ambitious structural changes to policy and industry, we risk losing our most promising companies and technologies. This roadmap outlines essential steps to create an environment where Canadian battery innovators can thrive and scale. Our strategy centers on two themes: Innovation Infrastructure and Industrial Policy.

Without ambitious structural changes to policy and industry, we risk losing our most promising companies and technologies.



Online Battery Innovation Roadmap

Make sure to explore our comprehensive online roadmap, designed to help navigate key battery innovation policies. This interactive tool empowers policymakers with actionable insights and strategic guidance to drive Canada's leadership in battery technology.

Innovation Infrastructure

Financial Ecosystem:

Enhance funding mechanisms and align existing programs to support battery innovation across all stages of development.

Goal: $3B invested in battery innovation through public and private funding.

Physical Assets:

Expand research centers, establish demonstration facilities, and build out national labs to support cutting-edge battery research and development.

Goal: Canada's battery R&D centers and national labs contribute significantly to achieving the innovation metrics goals laid out in the roadmap.

Skills & Talent:

Develop specialized training programs, enhance partnerships with educational institutions, and create a skilled workforce to drive battery innovation.

Goal: By 2035, train and integrate over 10,000 skilled professionals into Canada's battery industry, with at least 500 graduates annually from specialized training programs.

Industrial Policy

Scale-up Support:

Implement targeted policies and programs to help innovative firms grow and remain in Canada, capturing more value within our domestic economy.

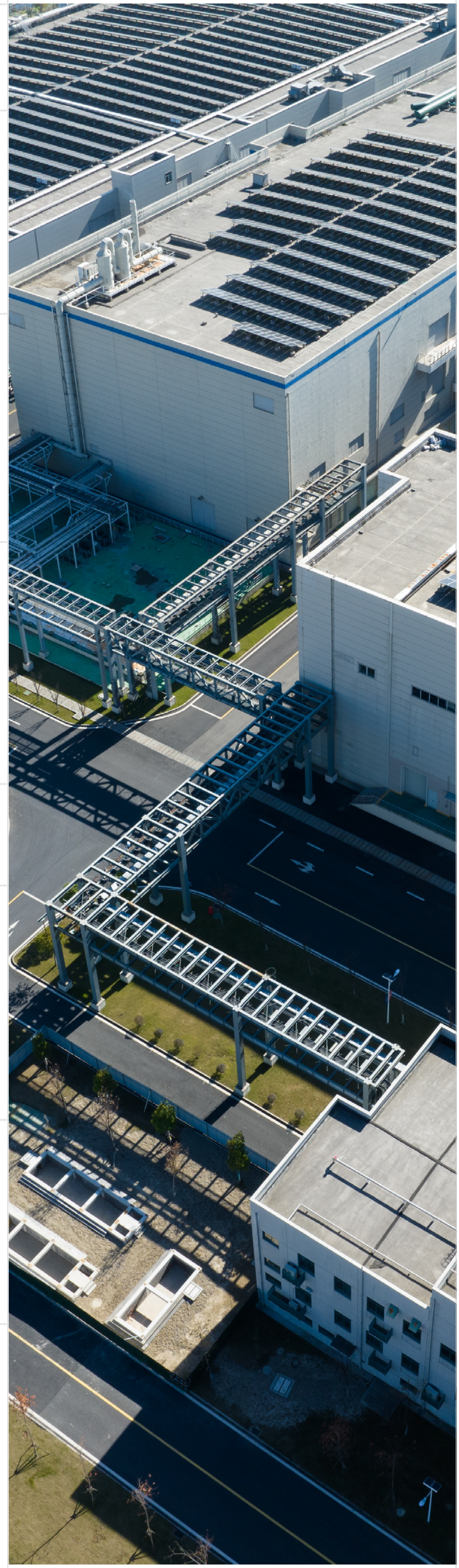
Goal: By 2035, increase the number of Canadian-owned firms in the battery sector tenfold, contributing to 20% of the North American battery value chain.

IP Strategy:

Strengthen intellectual property protection and development strategies to ensure Canadian innovations benefit our economy and global competitiveness.

Goal: Secure 1,000 patents in battery technology by 2035.

Across these five areas, we have identified 50 high-impact actions to transform Canada's battery innovation landscape. These actions include establishing new funding mechanisms, creating research facilities, implementing targeted industrial policies, and forming a national battery alliance. By executing these initiatives, we can build a robust, world-leading battery ecosystem, capturing value at every stage and positioning Canada as a global leader in battery technology.



Innovation Infrastructure

Building a world-class battery innovation ecosystem requires a strong foundation of innovation infrastructure. The roadmap identifies three critical components of this infrastructure: the financial ecosystem, physical assets, and human capital. Each of these areas requires targeted interventions and investments to support Canada's battery ambitions.

The financial ecosystem is crucial for supporting innovation at all stages, from early-stage research to commercialization and scale-up. The roadmap proposes several key actions to enhance Canada's financial support for battery innovation. These include aligning and focusing existing funding mechanisms to better support the battery sector, establishing a dedicated Battery Innovation Venture Fund to provide crucial early-stage capital, and expanding the Office of Energy Research and Development's (OERD) funding program to offer larger grants for growth-stage companies. Additionally, the roadmap recommends implementing R&D minimums for public support to ensure that companies receiving government assistance contribute to Canada's innovation ecosystem.

Physical assets form the backbone of any innovation ecosystem, providing the facilities and equipment necessary for cutting-edge research and development. The roadmap calls for significant investments in this area, including enhancing existing research centers at institutions like Dalhousie University and the University of Waterloo, launching new battery research centers across Canada to promote regional diversity, and establishing state-of-the-art demonstration facilities for testing large-scale battery technologies. Furthermore, it proposes the creation of regional production clusters that bring together R&D centers, firms, and other stakeholders to foster collaboration and knowledge sharing along the entire battery value chain.

Human capital is the driving force behind innovation, and developing a skilled workforce is essential for Canada's success in the battery sector. The roadmap outlines a comprehensive approach to skills and talent development, starting with a thorough mapping of the skills required by Canada's battery industrial and innovation ecosystem over different time horizons. It proposes developing international partnerships with leading organizations focused on battery training, enhancing collaboration between universities, technical schools, and battery companies to co-create relevant curricula, and launching specialized training programs and apprenticeships. Additionally, the roadmap recommends creating a fellowship program to support advanced research in battery technologies, ensuring a pipeline of high-level expertise to drive innovation.

By investing in these three pillars of innovation infrastructure, Canada can create a fertile ground for battery innovation, supporting the growth of domestic companies and attracting international investment and talent.

> *"Building world-class research facilities and demonstration centers is crucial. These assets will not only advance our technology but also attract global talent and investment to Canada."*
>
> –Karim Zaghib, CEO of Volt-Age Electrifying Society (CFREF) and Professor at Concordia University

Industrial Policy

To fully capitalize on its innovation potential and compete on the global stage, Canada needs a robust industrial policy tailored to the unique challenges and opportunities of the battery sector. The roadmap proposes a two-pronged approach to industrial policy, focusing on scale-up support and intellectual property (IP) strategy.

Scale-up support is critical for helping innovative Canadian firms grow and remain in the country, capturing more value within the domestic economy. A centerpiece of this effort is the establishment of a National Battery Alliance, a central coordinating body that will drive the implementation of the roadmap and foster collaboration across the ecosystem. This alliance will bring together key stakeholders from government, industry, and academia to align efforts, share information, and develop strategies to overcome challenges in the battery innovation landscape.

To complement the alliance, the roadmap proposes creating a dedicated government problem-solving team to address specific issues and opportunities in the battery sector. This agile team will work across departments to implement reforms and coordinate policies effectively. Another key initiative is the development of a Battery Ecosystem Intelligence Dashboard to track progress, analyze the current state of the ecosystem, and inform decision-making.

The roadmap also emphasizes the need to streamline regulatory processes for new battery technologies, reducing barriers to innovation and commercialization. It recommends integrating industrial policy goals into existing programs, such as structuring EV incentives to benefit Canadian firms and technologies.

Intellectual property is a crucial asset in the innovation economy, and the roadmap proposes a comprehensive IP strategy to ensure that Canadian innovations translate into economic benefits for the country. This includes implementing comprehensive IP education for researchers and entrepreneurs, providing financial support for start-ups to secure IP services, and formulating a National IP Strategy for Batteries to guide efforts in this critical area.

To accelerate innovation in key areas, the roadmap suggests implementing a fast-track patent processing system for technologies deemed critical to national interests. Additionally, it proposes developing programs for sharing and pooling non-core patents among Canadian battery companies, fostering collaboration and reducing duplication of efforts.

By implementing these industrial policy measures, Canada can create an environment that not only fosters innovation but also supports the growth and retention of innovative firms, ensuring that Canadian battery technology translates into domestic economic prosperity.

> *"As a Canadian company scaling up in this competitive global market, we've seen firsthand the importance of supportive industrial policies. They can make the difference between success and stagnation."*
>
> –Chris Burns, CEO and Co-Founder of NOVONIX™

Key Findings & Next Steps

This roadmap envisions Canada as a global leader in clean, innovative battery technology and a hub for sustainable battery production in North America by 2035. Achieving this vision requires addressing key challenges and leveraging Canada's strengths through a coordinated, strategic approach involving government, industry, and academia.

Key Findings

- Untapped Potential: Canada has significant strengths in raw materials and research capabilities within the battery supply chain.
- Current Gaps: Challenges exist in scaling up innovative firms, providing continuous financial support, and retaining high-value assets within Canada.
- Strategic Coordination: A coordinated approach involving government, industry, and academia is essential for success.

Next Steps: Establishing the National Battery Alliance

The immediate priority is to establish the National Battery Alliance, a central coordinating body essential for implementing this roadmap. This alliance will unite key players from government, industry, and academia to drive the realization of our vision.

Key Functions of the National Battery Alliance

- Strategic Coordination: Align efforts across the battery value chain.
- Policy Advocacy: Champion supportive policies and regulations.
- Innovation Catalyst: Foster collaboration in research and development.
- Skills Development: Coordinate training and education initiatives.
- Investment Attraction: Promote Canada as a destination for battery investments.
- International Partnerships: Facilitate global collaborations and knowledge exchange.

Near-Term Priorities for the Alliance

- Formalize its structure and governance.
- Develop a detailed implementation plan for the roadmap.
- Initiate the Battery Ecosystem Intelligence Dashboard.
- Launch working groups on critical issues (e.g., financing, skills, R&D).
- Begin outreach to international partners.

By taking these steps, the National Battery Alliance will play a pivotal role in translating this roadmap from vision to reality. It will be the driving force behind Canada's ascent to becoming a global battery powerhouse, fostering innovation, creating high-value jobs, and contributing significantly to the country's clean energy future.

> "The proposed National Battery Alliance is exactly what Canada needs. It will help align our efforts, share knowledge, and accelerate our path to becoming a global battery powerhouse."
>
> — Dan Blondal, CEO of Nano One Materials Corp

TECHNICAL REPORT

Introduction

Canada has world-leading potential in the battery supply chain. But to take advantage of this potential in a highly competitive world, it needs a focused industrial strategy to support scale-up, attract investment, and retain assets. The Government of Canada has provided unprecedented support for downstream manufacturing and has worked hard to support its fledgling ecosystem. Furthermore, demand-side policies such as consumer purchase incentives have helped Canada achieve a higher rate of EV sales as a proportion of new vehicles in 2023 (11%) than the US (10%).[1] However, while progress on downstream manufacturing and EV adoption are important, these actions fall short of what is needed to build a full battery innovation ecosystem.

Canada has made a $46B bet on the battery industry. But these investments in assembly could result only in a thin industry: high-value components and intellectual property from other countries is simple assembled in Canada. To maximize the return on investment, Canada needs to build a vibrant innovation ecosystem to lead in the technologies and components that create high value batteries.

Canada's battery ecosystem still suffers from three main problems that require industrial policy solutions. First, Canada has produced key battery technologies and innovative firms, but these firms do not scale up into strong, scaled homegrown firms. Second, innovative firms struggle to secure the financial capital that they need to survive and expand through the pipeline from discovery to commercialization. Third, firms that do thrive often leave, or manufacture their products elsewhere.

Canada needs a focused strategy to support the scale-up of firms from startups to mature global competitors, the development of a financial ecosystem, and policy packages that attract and retain globally competitive firms.

This strategy requires setting clear metrics, making targeted investments, and creating a strong process for collaboration between industry, government, universities, and other stakeholders. Canada needs to do this in a strategic, focused way because there is a global competition on to position firms in the emerging battery innovation value chain.

Canada has world-leading potential in the battery supply chain. But to take advantage of this potential in a highly competitive world, it needs a focused industrial strategy to support scale-up, attract investment, and retain assets.

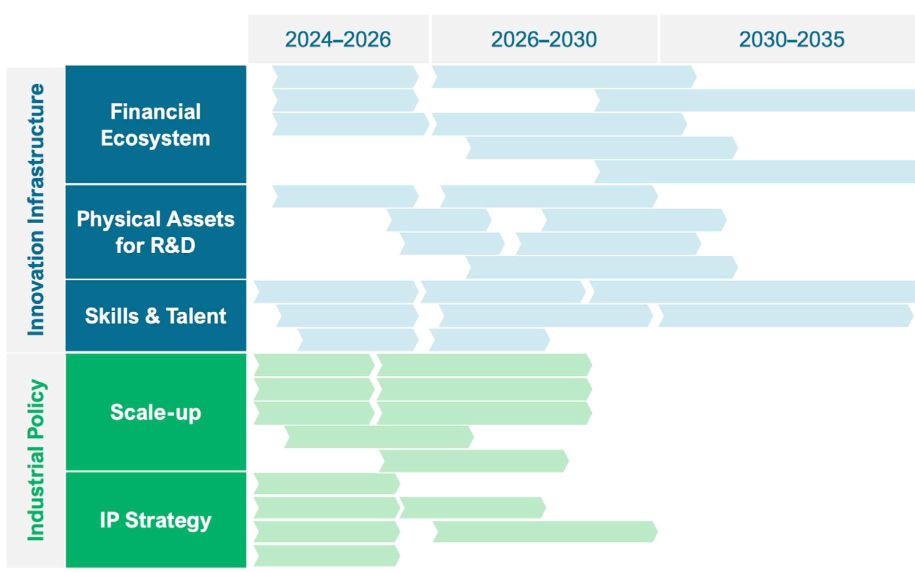
1 https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2024/market-snapshot-zero-emission-vehicles-now-account-for-over-10-percent-of-all-new-vehicles-in-canada.html

Developing a Battery Innovation Roadmap

In 2022, the Canadian Battery Task Force co-chaired by Accelerate launched a Battery Blueprint which aimed to establish a starting point for developing a national battery strategy. One of the goals highlighted was to establish Canada as a center for North American clean battery innovation, cell design, and manufacturing. This includes building homegrown cell manufacturing capacity, leveraging transformative investments, and supporting Canadian companies in scaling up and commercializing their innovations. The Battery Innovation Roadmap builds on this foundation by outlining specific strategies and actions to achieve these objectives, ensuring that Canada not only attracts and retains high-value battery manufacturing but also becomes a global leader in battery technology and innovation.

The Battery Innovation Roadmap is anchored in modern industrial policy, informed by an understanding of the technological frontier, and incorporates best practices from other jurisdictions. This roadmap was developed through consultations with stakeholders from industry, academia, government, and global experts to ensure a comprehensive and actionable plan. It starts by examining where battery technology is headed, identifying trends in chemistry, energy density, charging capabilities, and sustainability. This understanding sets the foundation for realistic and ambitious targets. It then identifies the best trends and practices in policy, assesses the current Canadian landscape, and articulates the key actions needed to achieve our goals.

The roadmap is built around two primary themes: Innovation Infrastructure and Industrial Policy. These themes are further divided into five critical action areas: Financial Ecosystem, Physical Assets, Skills & Talent, Scale-up, IP Strategy. Each area outlines specific actions, such as establishing a national Battery Technology Incubator Program, enhancing research centers, creating targeted training programs, streamlining regulatory processes, and fostering public-private partnerships. By integrating these elements, the roadmap aims to create a vibrant innovation ecosystem that supports the scale-up of Canadian firms, secures financial capital, and retains high-value manufacturing and intellectual property within Canada. This strategic, focused approach helps us clearly define what success looks like and measure our progress, ensuring that Canada can cash in on its promise of becoming a global leader in battery innovation.

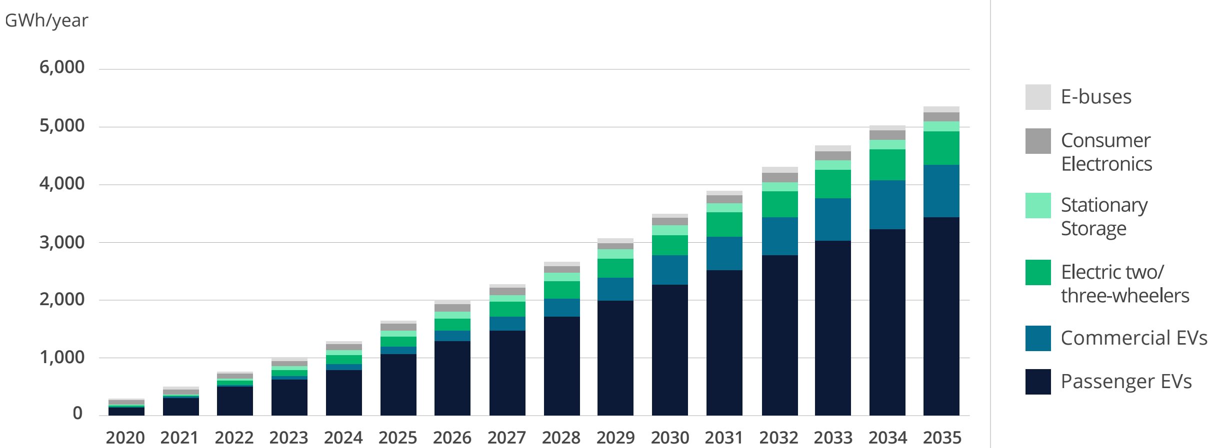


The Three Whys: Batteries, Innovation, and Canada

Why Batteries?

As global economies move towards decarbonization, the focus on sustainable practices has intensified, with batteries emerging as a cornerstone in this transition. Batteries are critical for the electrification of key industries, providing the foundation for harnessing clean energy technologies such as wind, solar, and hydrogen. Lithium-ion batteries, in particular, are essential for the electrification of vehicles, driving the rapid transformation of the automotive sector. Beyond electric vehicles (EVs), batteries facilitate access to clean, affordable, and reliable electricity, supporting the Canadian economy's transition to net-zero emissions by 2050. This pivotal role underscores the necessity for continued innovation and investment in battery technology, as demand is expected to increase sixfold by 2035.

Forecast of Global Battery Demand by End-Use Application (GWh) 2020-2035



Source: Bloomberg New Energy Finance (2024)

Why Innovation?

Why should we be enhancing battery technology? What new opportunities are driving us to innovate further? How can we improve upon the batteries we have today? The answers to these questions lie at the heart of a rapidly evolving global market driven by urgent environmental needs, shifting geopolitical landscapes, and ever-increasing consumer demands. Understanding where battery technology is headed is crucial for meeting these evolving demands. As the world transitions towards net-zero, it's essential to grasp the key innovation drivers, metrics, targets, and enabling technologies shaping the future of batteries.

Why Canada?

Canada's battery technology innovations span over 40 years, driving down costs and increasing adoption. Examples across academia, industry, and government showcase Canada's significant contributions to battery technology advancements. From the world's first commercial lithium battery in British Columbia to groundbreaking research in Ontario and Quebec, Canada's history in battery innovation is rich and impactful. This history positions Canada as a leader in the global battery industry, with the expertise and experience necessary to drive future advancements.

Moreover, Canada has untapped potential in the battery supply chain. We have significant advantage in raw material supply, with plans for long-term growth in battery metals markets The BNEF Lithium-ion battery supply chain ranking emphasizes Canada's competitive edge and the potential to become a global hub for sustainable battery production. By leveraging these strengths, Canada can maximize its value-added production, capture domestic opportunities, and lead the way in clean battery innovation.

Charting a Path to Success

Looking forward, the vision for 2035 is for Canada to become a global leader in clean, innovative battery technology and a hub for sustainable battery production in North America. This strategic approach involves setting clear goals and actions to build a robust battery ecosystem. By focusing on technological advancements, best practices in policy, and a thorough assessment of the current Canadian landscape, the Battery Innovation Roadmap articulates key actions needed to achieve these ambitious targets.

2035 Vision

Canada is a global leader in clean innovation battery technology, and hub for sustainable battery production in North America.

History of Canadian Battery Innovation

For more than 40 years, Canadian innovators have made several groundbreaking contributions to the advancement of battery technology. Below are a handful of Canadian contributions across academia, industry, and government.

1978

The World's First Commercial Li Battery

Moli Energy is formed in 1979 in Burnaby BC and goes on to produce the world's first commercial rechargeable Li battery in the following decade.

1990

Ethylene Carbonate Jump Starts Li-ion Batteries

Researchers at Moli Energy Ltd. report on the role of ethylene carbonate (EC) in making Li-ion batteries viable. Every commercial battery cell today includes some ethylene carbonate in the electrolyte.

1999

FEC Boosts Battery Life

Researchers from Canada's National Research Council (NRC) discover and patent fluoroethylene carbonate (FEC) as a small addition to the electrolyte that dramatically increases the cycle life of lithium-ion batteries.

2000

Carbon Coating Revolutionizes LFP Batteries

Université de Montréal / Hydro-Québec researchers report on carbon coating of lithium iron phosphate batteries, which was critical to making LFPs work. BASF, Sony, Mitsui licensed the technology soon after.

2000

High Power Potential of Li-ion Batteries Revealed

E-One Moli researchers show for the first time, that Li-ion cells designed for power can outperform other battery chemistries. E-One Moli is now the main supplier of battery cells to Dyson.

2001

NMC Changes the Battery Future

Researchers from Dalhousie University in partnership with 3M develop and patent certain grades of lithium nickel-manganese-cobalt (NMC) oxide compounds. MC material is now being used around the world in power tools and electric vehicles.

2007

Advancing Solid-State Batteries

Researchers from the University of Calgary discover a new garnet-type material that would enable solid-state batteries which offer the promise of higher energy storage, improved safety and longer lifespan.

2009

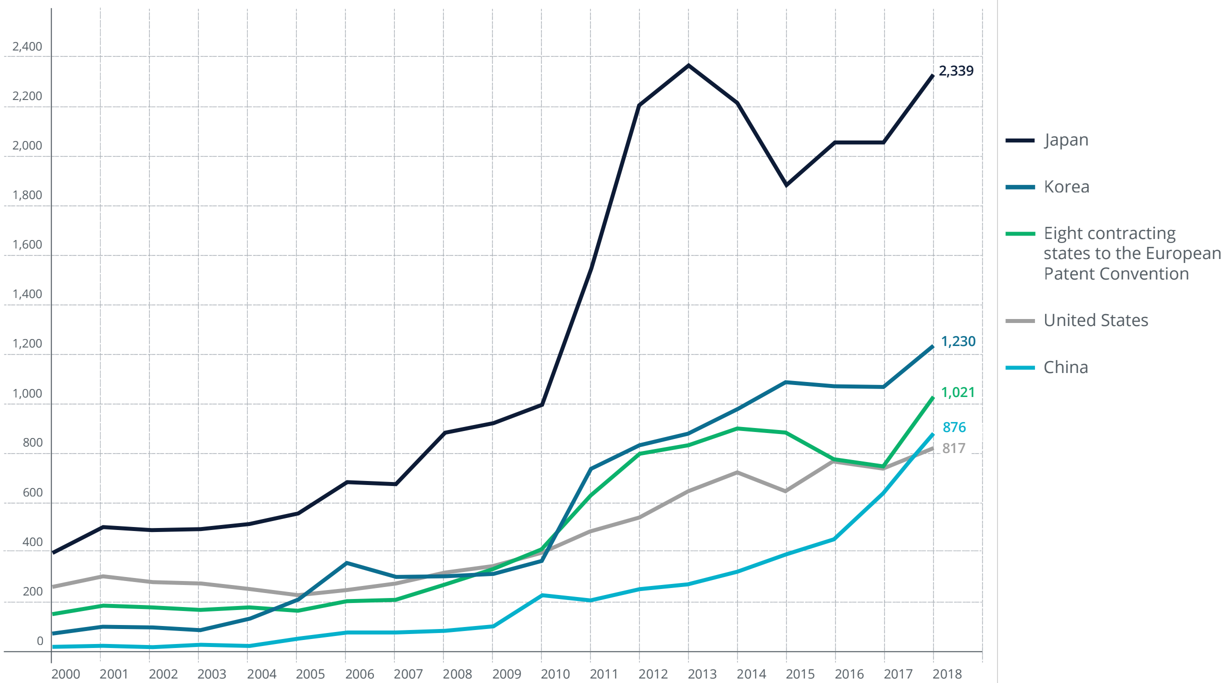
Renewed Promise of Lithium-Sulfur Batteries

Researchers at the University of Waterloo improved the lifespan and capacity of lithium-sulfur batteries. They're now made with cheaper, easy-to-find materials, making them a promising option for the future.

Global Battery Innovation Landscape

The global innovation landscape for batteries is dominated by a select few countries whose outsized market share and leadership in battery-related patents and publications is a result of decades of public R&D investment.

Battery technology patenting trends by main world regions
(international patent families 2000-2018)



Source: (IEA, 2020)[2]

Fraunhofer ISI have recently analyzed the innovation outputs (publications from 2017-2021 and patents from 2016-2020) of leading countries and firms. Japan has the lowest share of publications but has consistently had the highest share of patents (40-55% from 2001 to 2019).[3] Conversely, China has the highest share of publications, but is outranked by Japan and/or the US across all battery types (ranking second in lithium ion, sodium-sulfur, sodium-ion, and aluminum-ion). However, the results show that innovation outputs (patents and publications) are not necessarily determinative of a countries' ability to capture an outsized share of the battery market. For example, despite South Korea's status as the second largest industrial share of batteries in the global market, the country shows "a low to moderate performance in patents and publications."[4] Similarly, while China is the top producer of liquid electrolyte-based lithium-ion batteries, "its share of Li-ion battery patents is 17%, less than half that of Japan and comparable to the U.S. (15%) and the EU28 (15%)."[5]

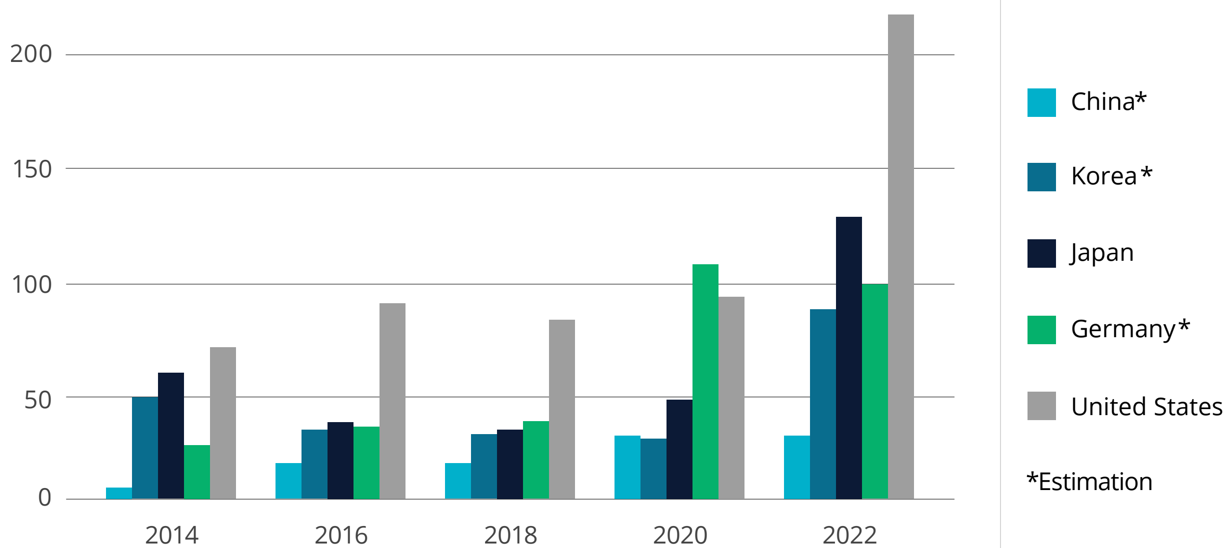
While total patent count for all battery technologies may not be the optimal measure of

2 https://link.epo.org/web/battery_study_en.pdf
3 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 93
4 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 92
5 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 92

a country's industrial success, Patent data for technology-specific subcategories signal potential leaders in next-generation batteries. For example, while Japan has the highest patent share across almost all battery types, their lead over their competitor countries is particularly pronounced (over 40% share) for lithium-ion, aluminum-ion, and solid-state batteries. Similarly, the US is the leader in lithium-air, lithium-sulfur, and sodium-sulfur battery patents. Finally, progress towards Korea's goal of commercializing lithium-sulfur batteries by 2025 can be confirmed by its strength in patenting in this area.

Increased competition is also reflected in R&D investment, as the leading patent holding countries have doubled (and in some cases tripled) their battery-related public R&D spending since 2020.[6] R&D investment in battery technologies for leading countries has recently been analyzed by Fraunhofer ISI. These figures were calculated by the authors based on announced public direct R&D funding, mainly focusing on specific public funding bodies (U.S.: DOE, DE: BMBF, JP: NEDO, KR: MOTIE and CN: MoST).[7] However, the authors also note that their estimate likely undervalues China's battery R&D expenditures.[8] It should be noted that other authors have noted that direct R&D funding is less prominent in China's policy mix of supports for the EV sector than in other countries. Instead, consumer purchase subsidies make up a significant portion: "in 2022, purchase subsidies amounting to about €4.2B (RMB 30B) were allocated to almost 3.2M NEV, up from €0.9B (RMB 6.5B) for about 427,000 NEV in 2021, and a total of €0.2B (RMB 1.4B) for about 75,000 NEV for the aggregate period 2010 to 2020."[9] China is unique from most other countries in that purchase subsidies for BEVs are paid out directly to manufacturers rather than consumers.

Estimated annual public funding on battery R&D from 2014 to 2022 (Million € per year)



Source: Fraunhofer ISI (2024)[10]

6 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p.96

7 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 96; The authors summarize the methodology as follows: "First, it might be, that especially for the case of China and South Korea - not all funding sums are made public or explicit. Often much of the funding for batteries is more indirect through demand side policies - that is to say tax incentives or exemptions and other subsidies. The amount of these indirect investments is difficult to capture without the direct internal data from the governments, although we integrated some data that was available. Furthermore, the information gathered on funding budgets sometimes cannot really be assigned to years and exact funding purposes. This is another reason, why it is not easy to simply compare the sum of the funding budgets. Because of these challenges, we compare only direct R&D funding, mainly focusing on specific public funding bodies (U.S.: DOE, DE: BMBF, JP: NEDO, KR: MOTIE and CN: MoST). Considering the limited availability of information on a yearly base (especially for DE, KR and CN), we compare the budget per year including estimated figures based on several assumptions" p. 95

8 The authors note: "The public funding on battery R&D in China has slightly risen from 2014 based on our estimation. The project budget under the guideline of National Key R&D Funding in 2021 was 29M euros. It is worth noting that the R&D funding program in China often does not count personnel cost support and it is difficult to compare with other countries in the same condition. The real public funding is estimated to be much higher and notice should be given rather to the changes in funding over time." p. 95

9 https://www.ifw-kiel.de/fileadmin/Dateiverwaltung/IfW-Publications/fis-import/bc6aff38-abfc-424a-b631-6d789e992cf9-KPB173_en.pdf p. 12

10 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.p.96

The global industrial policy race has intensified competition for technological leadership in batteries. Crucially, leading countries' R&D investments are deployed strategically as part of larger industrial policy packages containing other types of demand-side and supply-side supports. For example, Chinese firms like CATL and BYD were able to finance their early scaling up of battery technologies through steady revenue from municipal procurement contracts and consumer incentives that required Chinese-made batteries.[11] Jurisdictions that have successfully implemented industrial strategies make efforts to coordinate public and private actions through the establishment of institutionalized mechanisms for ongoing information sharing, dialogue and collaboration (e.g. the European Battery Alliance, or Li-Bridge in the United States). The industrial policy approaches of China, the US, the EU, Korea, Japan and Australia are analyzed in more detail below in this report's section on international best practices.

Canadian Battery Innovation Landscape

Canada's battery innovation landscape is vibrant and evolving, bolstered by investments, advanced research, and strategic initiatives. Over the years, Canada has made notable strides in battery technology, leveraging its rich history of innovation and strategic investments to enhance its presence in the global market.

Recently, Canada achieved a significant milestone by topping BloombergNEF's global lithium-ion battery supply chain ranking, surpassing major players like China. This ranking reflects the country's robust manufacturing capabilities, strong environmental and social governance credentials, and substantial investments from industry giants such as Umicore, Volkswagen, Ford, Stellantis, and LG Energy Solutions.[12] These accomplishments highlight Canada's competitive edge in the battery sector and its commitment to sustainability and innovation. However, while these are significant wins on the FDI side, we need to ask the question: how do we leverage these investments to strengthen Canadian homegrown companies?

Also, Canada's homegrown battery sector to name a few include companies like Nano One, Electrovaya, Novonix, Lion Electric, and Li-Cycle who have secured substantial funding to drive their innovative projects. These investments are crucial for advancing battery technology and ensuring Canada remains a strong contender in the global market.

11 Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press.
12 "From October 8, 2020 to April 25, 2024, a total of $46.1B in investments across the EV supply chain has been announced across thirteen project groupings."

RECENT INVESTMENTS IN CANADA IN CRITICAL MINERALS, BATTERIES AND ELECTRIC VEHICLES

In 2019, the federal government launched the Mines to Mobility initiative to establish a passenger EV battery value chain in Canada. Working in close collaboration with provinces and territories, Mines to Mobility had catalyzed over $46B in announced investments by mid-2024.

UPSTREAM	• Rio Tinto: $737M to decarbonize Rio Tinto Fer et Titane operations, including a large-scale demonstration plant for a new spodumene concentration process
	• Anglo American: $24M into Canadian Nickel to develop Crawford nickel project
MIDSTREAM	• Umicore: $1.5B to produce cathode active materials (CAM) and precursor chemicals (PCAM)
	• Ultium CAM (GM/POSCO): $500M to produce CAM
	• Vale Canada: Providing a long-term supply of battery grade nickel sulfate to Ultium CAM
	• Nouveau Monde Graphite: $923M to produce anodes
	• Electra: $80M raised to produce cobalt sulfate in Canada
	• BASF: $692M to produce CAM
	• Ford, EcoProBM, and SK On Co consortium: $1.2B for battery materials production in Quebec
DOWNSTREAM	• NextStar (Stellantis/LG Energy Solutions): $4.9B to produce battery cells
	• Stellantis: $3.6B to produce EVs and fund automotive innovation
	• GM Canada: $2.0B to produce EVs
	• Ford Canada: $1.8B to produce EVs
	• Lion Electric: $185M to assemble battery packs for e-buses (and build a battery innovation centre)
	• Honda: $15B for comprehensive EV supply chain in Ontario (EV assembly, battery manufacturing, materials processing)
	• Northvolt: $7B for EV battery manufacturing in Quebec
	• Volkswagen: $7B for EV battery manufacturing in Ontario
INNOVATION	• Nano One: $66M spent in Canada on innovative approach to CAM production
	• E3 Lithium: $59M raised to produce battery-grade lithium products
	• NOVONIX: $36M spent in Canada on innovations related to advanced battery testing systems and electrode materials development
	• Flex'N'Gate: $20M to create a battery research facility

Highlights from Canadian Battery Firms

Nano One, based in Burnaby, British Columbia, focuses on developing advanced materials for lithium-ion batteries. The company has developed a patented One-Pot process that simplifies the production of high-performance cathode materials, reducing costs and environmental impact. Nano One has partnered with various industry leaders to commercialize and scale its technology. In May 2024, Nano One entered into a 20-year license agreement with Worley for the development, marketing, and deployment of cathode plant designs, which will help in scaling up their innovative One-Pot Process technology.[13]

Electrovaya, located in Mississauga, Ontario, specializes in lithium-ion battery systems for electric vehicles, utility-scale energy storage, and portable power applications. Known for its proprietary Lithium Ion SuperPolymer® technology, Electrovaya offers significant advantages in safety, longevity, and energy density. Their innovative approach includes a solvent-free production process and a flexible ceramic separator enhancing battery safety. They have over 100 patents related to electrode and electrolyte materials, battery architectures, and battery management systems.

NOVONIX Battery Technology Solutions Inc., a battery materials and technology company with operations in Canada, focuses on developing high-performance materials for lithium-ion batteries, including synthetic graphite anode materials. Novonix's innovations aim to improve battery life, performance, and cost-effectiveness, supporting the growing demand for electric vehicles and renewable energy storage.

Lion Electric, a Canadian manufacturer of electric buses and trucks, has developed its own battery technology. The company recently inaugurated its Mirabel battery manufacturing factory, which will produce lithium batteries for medium- and heavy-duty vehicles. Lion Electric's proprietary battery systems are designed to be efficient, reliable, and competitive.

Li-Cycle is a Toronto-based company, specializing in recycling spent lithium batteries. The company's unique process recovers over 95% of all materials from discarded batteries, supporting sustainable production practices and the circular economy. Li-Cycle's technology reduces environmental impact and contributes to the lifecycle management of lithium-based products.

E-One Moli Energy, based in British Columbia, manufactures high-performance lithium-ion batteries for various applications, including power tools, medical devices, and electric vehicles. E-One Moli Energy focuses on producing reliable and high-capacity lithium-ion batteries.

Lithion Technologies, based in Quebec, specializes in recycling lithium-ion batteries. Their process allows for the recovery of up to 95% of battery components. Lithion's recycling technology is designed to be efficient and environmentally friendly, contributing to a circular economy. Lithion Recycling has been expanding its operations and forming strategic partnerships to enhance its capabilities.

Calogy Solutions, based in Sherbrooke, Quebec, develops advanced thermal management solutions for electric vehicle batteries. Calogy's thermal management technology improves battery safety, performance, and longevity by optimizing temperature control.

Salient Energy, based in Nova Scotia, develops zinc-ion batteries as a safer and more sustainable alternative to lithium-ion batteries. Salient's zinc-ion batteries are designed for stationary energy storage applications, offering a safer and more environmentally friendly option. Salient Energy has been advancing its zinc-ion battery technology and securing funding for further development.

13 https://www.marketscreener.com/quote/stock/NANO-ONE-MATERIALS-CORP-49477318/company/

E-Zinc, based in Toronto, Ontario, develops zinc-air batteries for long-duration energy storage. E-Zinc's technology stores electrical energy within zinc metal, offering a cost-effective and sustainable solution for grid energy storage. In May 2022, e-Zinc secured over $31M CAD in Series A financing to establish production capabilities for its zinc-based long-duration energy storage technology. This funding round was led by Anzu Partners, BDC Capital, Toyota Ventures, and Eni Next.

VoltaXplore is a joint venture between Martinrea International Inc. and NanoXplore Inc., focused on developing graphene-enhanced lithium-ion batteries. VoltaXplore's graphene-enhanced batteries aim to improve performance and reduce costs. VoltaXplore has been working on scaling up its production capabilities.

AlumaPower, based in Toronto, Ontario, develops aluminum-air batteries, which offer high energy density and are suitable for various applications, including backup power and electric vehicles. AlumaPower's aluminum-air batteries use recycled aluminum to produce electricity through oxidation, offering a lightweight and high-density energy solution. AlumaPower envisions a future system where melted down engines and other scrap vehicle parts could be used to create aluminum-air batteries.

Calumix is a Canadian company specializing in the development of advanced materials for battery applications. Calumix focuses on enhancing battery performance and sustainability through innovative material technologies. Calumix has been working on new material technologies for batteries.

Battery Research Centers

Canadian Battery Innovation Centre (CBIC):

Located at Dalhousie University, the CBIC is set to open in Fall 2025. It will be the first university-based battery prototyping and testing facility in Canada, providing open access to researchers and industry partners. The center aims to accelerate battery innovation by enabling rapid prototyping and testing of new battery designs.[14]

Western Canada Battery Consortium (WCBC) and Battery Innovation Hub:

The University of Calgary hosts the WCBC which focuses on developing advanced battery technologies with higher energy density, faster charging times, and improved safety. The Battery Innovation Hub supports this initiative by providing facilities for battery materials development, cell assembly, and safety assessments, fostering partnerships with industry and academia.[15]

Waterloo Institute for Nanotechnology (WIN):

Located at the University of Waterloo, WIN conducts cutting-edge research in nanotechnology, including advancements in battery technology. The institute collaborates with industry partners to develop next-generation battery materials and designs, contributing to Canada's leadership in battery innovation.[16]

National Research Council of Canada (NRC):

The NRC's Advanced Clean Energy program includes a focus on battery energy storage. The NRC operates several facilities across Canada, including in Vancouver, Ottawa, Boucherville, and Edmonton. These facilities offer capabilities in battery performance and safety evaluation, pilot-scale battery manufacturing, and materials synthesis, among others. The NRC collaborates with industry and academia to develop next-generation energy storage materials and devices.

14 https://www.dal.ca/news/2024/03/13/battery-centre-dalhousie.html
15 https://science.ucalgary.ca/research-innovation/institutes-centres-facilities/battery-innovation-hub
16 https://uwaterloo.ca/institute-nanotechnology/

Ontario Battery and Electrochemistry Research Centre (OBEC):

Located at the University of Waterloo, OBEC is a hub for electrochemical energy storage research. It collaborates with industry and government agencies to develop cleaner and more efficient energy technologies for various applications, including portable electronics, electric vehicles, and smart grid systems. OBEC aims to attract industrial battery manufacturers and cleantech companies to Ontario.[17]

University of British Columbia (UBC) - Next Generation Battery Research and Training Centre:

UBC Okanagan is home to the Next Generation Battery Research and Training Centre. This center focuses on training and research in advanced battery technologies, aiming to develop innovative solutions for energy storage challenges. It supports both academic research and industry collaborations to advance battery technology and training.

These centers collectively contribute to Canada's leadership in battery research and development, supporting the transition to cleaner energy technologies and fostering innovation in the battery industry.[18]

Hydro-Québec's Center of Excellence in Transportation Electrification and Energy Storage:

A leading battery research facility in Canada, the center focuses on developing solid-state batteries, advanced battery materials, and energy storage systems for transportation and grid applications. It collaborates with industry leaders like Mercedes-Benz AG and research institutions such as Berkeley Lab and the U.S. Army Research Laboratory. Hydro-Québec's research aims to create ultra-high-performance battery technologies that will accelerate transportation electrification and enhance renewable energy integration. This work positions Canada at the forefront of battery innovation, contributing to sustainable energy solutions and the growth of the country's battery industry ecosystem.[19]

17 https://uwaterloo.ca/ontario-battery-electrochemistry-research-centre/
18 https://give.ubc.ca/projects/next-generation-battery-research-and-training-centre/
19 https://www.hydroquebec.com/ce-transportation-electrification-energy-storage/research-areas.html

Dalhousie University: Powering Canada's Battery Innovation[20]

Canadian Battery Innovation Centre (CBIC)

- $13.5M R&D prototyping facility
- First university-based battery prototyping and fabrication facility in Canada
- $5M grant from Canadian Foundation for Innovation
- Partnerships with Tesla, Novonix, Emera Inc., and others

Master of Battery Technology Program

- Launching Fall 2025
- Addressing growing demand for battery expertise in Canada

World-Leading Research

- Long-standing partnership with Tesla for lithium-ion battery R&D
- Focus on new electrode materials, improved energy density, and battery safety
- Recent breakthrough: 70% decrease in self-discharge using polypropylene tape

Industry Collaboration

- Training highly qualified personnel for the battery industry
- Supporting Canada's growing EV and energy storage sectors

Dalhousie University is at the forefront of battery innovation, driving Canada's position in the global battery market through cutting-edge research, industry partnerships, and workforce development.

Funding Programs

Canada's federal and provincial governments have established several programs to bolster battery innovation, providing financial support and fostering a conducive environment for technological advancement.

Strategic Innovation Fund (SIF):

Provides financial backing for projects that drive innovation in key sectors, including the battery industry.[21] The SIF has invested $9.5B in 129 projects.[22] While the majority of SIF battery projects are foreign direct investment,[23] a prominent Canadian recipient was Saint-Jérôme-based electric bus and truck maker Lion Electric, who received support for a battery manufacturing operation.[24]

20 https://www.dal.ca/news/2024/03/13/battery-centre-dalhousie.html
21 https://ised-isde.canada.ca/site/strategic-innovation-fund/en
22 https://ised-isde.canada.ca/site/strategic-innovation-fund/en/investments
23 https://ised-isde.canada.ca/site/strategic-innovation-fund/en/investments/projects#819817
24 https://www.pm.gc.ca/en/news/news-releases/2021/03/15/major-investments-canada-and-quebec-electric-vehicle-battery-assembly

Canada Growth Fund:

Supports high-growth companies in critical sectors, providing necessary capital for scaling innovative solutions.[25] The fund deploys a wide range of instruments (ex: concessional debt, price assurance mechanisms such as contracts for difference, anchor equity, and offtake contracts). The fund targets three areas of focus:

1. "Projects that use less mature technologies and processes (proven in pilots but not yet widely adopted) to reduce emissions across the Canadian economy. These could include but are not limited to carbon capture, utilization, and storage; hydrogen; and biofuels.
2. Technology companies, including small and medium enterprises (SMEs), which are scaling less mature technologies that are currently in the demonstration or commercialization stages of development; and
3. Companies, including SMEs, and projects across low-carbon or climate tech value chains, including low-carbon natural resource development."[26] The fund has recently invested $50M in Montreal-based Idealist Capital, whose cleantech investment fund includes investments in battery companies such as Montreal-based bidirectional EV-charging technology firm Dcbel.[27]

Smart Renewables and Electrification Pathways Program:

Advances renewable energy technologies and grid modernization, indirectly benefiting the battery sector.[28]

Energy Innovation Program:

This Natural Resources Canada program funds research, development, and demonstration projects to accelerate clean energy innovation. The recent Battery Industry Acceleration Call specifically targets battery innovation, emphasizing the importance of advancing battery technologies in Canada's clean energy future.[29] The program also has a long history of supporting battery innovation, such as the 2011 investment in Mississauga-based battery firm Electrovaya for its project titled Utility Scale Electricity Storage Demonstration Using New and Re-purposed Lithium-Ion Automotive Batteries.[30]

The Office of Energy Research and Development (OERD):

Natural Resources Canada's OERD leads the Government of Canada's efforts in delivering energy research, development, and demonstration (RD&D) funding, accelerating efforts in energy innovation and cleantech programming. Since 2016, OERD has invested over $1B in more than 850 energy innovation research, development, and demonstration projects.[31] As shown in the diagram below, OERD has a long history of supporting battery-related R&D through R&D programs (ex: Energy Innovation Program), as well as through challenge-based programs such as the Impact Canada Cleantech Challenge – Charging the Future.[32] Toronto-based e-Zinc won the top prize for its project focused on a zinc-based energy storage system can be significantly less expensive than comparable lithium-ion systems for long-duration applications.[33]

25 https://www.cgf-fcc.ca/
26 https://www.budget.canada.ca/fes-eea/2022/doc/gf-fc-en.pdf p. 5
27 https://betakit.com/idealist-capital-receives-50-million-from-canada-growth-fund/
28 https://natural-resources.canada.ca/climate-change/green-infrastructure-programs/sreps/23566
29 https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/grants-incentives/energy-innovation-program/18876; https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/grants-incentives/energy-innovation-program/energy-innovation-program-battery-industry-acceleration-call/25713
30 https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/current-investments/utility-scale-electricity-storage-demonstration-using-new-and-re-purposed-lithium-ion/4973
31 https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/oerd/5711
32 https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/grants-incentives/cleantech-challenges/impact-canada-cleantech-challenge-charging-the-future/24456
33 https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/current-investments/commercialization-lowest-cost-long-duration-energy-storage-systems/24477

OERD's Battery Innovation Investments

2012

- High Energy Density Energy Storage for Automotive Applications
- Improved Fluxless Aluminum Brazing Materials and Process Technology for Manufacturing of Advanced Battery Cooling Heat Exchangers

2017

- Development of Thick Film Electric Heaters for Thermal Modulation of Battery Systems
- Electric Vehicle Infrastructure Demonstration Program:
- Repurposing Used Large-Format Heavy-Duty Transit Bus Batteries for Electric Vehicle Rapid Charging
- Vehicle to Grid Demand Response (V2G-DR)
- Nova Scotia Vehicle Grid Integration Pilot
- EV Charging Infrastructure in Apartment, Commercial/Office and Retail Store Environments
- Arctic Charging and Heating Stations for EV's Tethered to Islanded Hybrid Diesel-Renewable SmartGrid
- Sky Smart Electric Vehicle Charging Station
- Electric Vehicle Automatic Parking
- Decreasing Transactional EV Charging Costs and Enhancing Grid Efficiency

2018

- Women in Cleantech challenge: Amanda Hall of Summit Nanotech awarded the $1M grand prize
- Green Infrastructure Smart Grid Program:
- West 5 Smart Grid Project
- Lac Mégantic Microgrid
- Slemon Park Microgrid Project
- Collaborative Grid Innovation for Atlantic Smart Energy Communities
- Waterton Energy Storage Project

2019

- Charging the Future, challenge: Toronto-based e-Zinc was awarded the $1-million prize for Commercialization of Lowest-Cost, Long Duration Energy Storage Systems. Runners-up include:
- Salient Energy: Safe and Long-Lasting Zinc-Ion Batteries for Energy Storage
- Agora Energy Technologies: Metal-Free Rechargeable CO2 Flow Battery
- Calogy Solutions: Nordic Battery Pack with Advanced Thermal Management and Data-Driven Battery Management System
- GBatteries: Reducing the Cost of Lithium-Ion Battery Manufacturing
- Power Forward Challenge: Alba Nova Project: A Smart Grid Pilot Using Advanced Battery Storage

2020

- Energy Innovation Program:
- Ultra-fast charging of lithium-ion cells for the mass global adoption of electric vehicles

Source: Natural Resources Canada[34]

NRC Advanced Clean Energy Program:

Focuses on advancing clean energy technologies, providing funding and expertise.[35]

NRC Clean and Energy Efficient Transportation Program:

Aims to improve energy efficiency and reduce environmental impact in transportation technologies.

Critical Minerals Research Development and Demonstration Program:

Supports R&D for technologies related to critical minerals essential for battery production. [36]

Critical Minerals Infrastructure Fund:

Provides up to $1.5B in federal funding over seven years for clean energy and transportation infrastructure projects necessary to enable the sustainable development and expansion of critical minerals in Canada.[37]

34 https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/oerd/battery-innovation/25734
35 https://nrc.canada.ca/en/research-development/research-collaboration/programs/advanced-clean-energy-program
36 https://www.canada.ca/en/campaign/critical-minerals-in-canada/federal-support-for-critical-mineral-projects-and-value-chains/critical-minerals-research-development-and-demonstration-program.html
37 https://www.canada.ca/en/campaign/critical-minerals-in-canada/federal-support-for-critical-mineral-projects-and-value-chains..

Tax Incentives

Critical Mineral Exploration Tax Credit:

Encourages the exploration of critical minerals necessary for battery production.[38]

Scientific Research and Experimental Development (SR&ED) Incentives:

Offers tax credits for companies conducting R&D in Canada.[39]

Zero Emission Technologies Manufacturing Tax Credit:

Supports the manufacturing of zero-emission technologies, including batteries.[40]

The Clean Economy Investment Tax Credits:

Announced in 2022-2023, The Clean Economy Investment Tax Credits (ITCs), represent $93B in federal incentives by 2034–35 for clean technologies, including battery storage and hydrogen production. On June 21, 2024, the following four ITCs officially were signed into law: the Clean Technology ITC, the Carbon Capture, Utilization and Storage (CCUS) ITC, the Clean Technology Manufacturing ITC, and the Clean Hydrogen ITC.[41] Of particular relevance for batteries is the Clean Technology Manufacturing ITC, which will "provide support to Canadian companies that are manufacturing or processing clean technologies and their precursors, providing support for 30% of the cost of investments in new machinery and equipment used to manufacture or process key clean technologies, and extract, process, or recycle key critical minerals."[42]

The EV supply chain ITC:

Budget 2024 introduced an additional ITC covering 10% of the costs of buildings at various stages of the supply chain: EV assembly, battery production, and cathode active material (CAM) production. This comes in addition to the Clean Technology Manufacturing ITC of 30% for machinery and equipment.[43] To qualify, a manufacturer must also be claiming the Clean Technology Manufacturing ITC in all three of the segments of the supply chain. One of these segments may be through another company in which the manufacturer is at least a part owner. The ITC is valued at approximately $80M over the next five years and $1B from 2029-2034. The Centre For Net-Zero Industrial Policy commended this policy as a strategic approach to incentivize coordinated investments upstream the value chain, where Canada is well-positioned to capture significant value.[44]

Financial Supports from Agencies

Canada Innovation Corporation:

Provides funding and support to innovative companies, helping them scale and commercialize new technologies.[45] This organization will be established by 2026-27.

Business Development Bank of Canada (BDC):

Offers financial and advisory services to businesses developing battery technologies.[46]

38 https://www.canada.ca/en/department-finance/news/2024/03/government-extending-support-for-mineral-exploration-in-canada.html
39 https://www.canada.ca/en/revenue-agency/services/scientific-research-experimental-development-tax-incentive-program.html
40 https://www.canada.ca/en/department-finance/programs/consultations/2021/tax-reduction-zero-emission-technology-manufacturing.html
41 https://www.canada.ca/en/natural-resources-canada/news/2024/06/government-of-canada-launches-the-first-clean-economy-investment-tax-credits.html
42 https://www.canada.ca/en/natural-resources-canada/news/2024/06/government-of-canada-launches-the-first-clean-economy-investment-tax-credits.html
43 https://netzeroindustrialpolicy.ca/reports/canadas-innovative-tax-credits
44 https://netzeroindustrialpolicy.ca/reports/canadas-innovative-tax-credits
45 https://www.canada.ca/en/department-finance/services/publications/canada-innovation-corporation-blueprint.html
46 https://www.bdc.ca/en

Export Development Canada (EDC):

Provides financing, insurance, and bonding solutions to help companies export their products and expand internationally.[47]

Canada Infrastructure Bank:

Invests in projects that support sustainable infrastructure, including energy storage solutions.[48]

Sustainable Development Technology Canada (SDTC):

Awards funding for development and demonstration of clean technology. Battery-related projects include funding for Ottawa-based smart battery management technology company GBatteries.[49] SDTC programming is transitioning to the National Research Council of Canada (NRC) following the establishment of a reinforced contribution agreement with ISED.[50] This change seeks to address governance issues detailed in a report by Canada's Auditor General Karen Hogan.[51] SDTC will ultimately transition (alongside NRC's IRAP) to the Canada Innovation Corporation (CIC) upon its formation by 2026-27.

Path Forward

While Canada's support for battery innovation has laid a strong foundation and fostered significant advancements, there remains untapped potential that requires a more targeted strategic approach. Canada's existing suite of innovation programs do not take a targeted approach to focusing on battery innovation. Instead, programs like the Strategic Innovation Fund's Net-Zero Accelerator, Canada Growth Fund, and SDTC focus more generally on net-zero technologies and cleantech. Furthermore, battery-specific R&D programs such as OERD's Charging the Future and the Energy Innovation Program's Battery Industry Acceleration Call are impermanent and smaller scale than larger funds (ex: SIF, CGF). For example, the Energy Innovation Program's Battery Industry Acceleration Call supports "R&D projects that request between $500K and $3M (comprising up to 75% of total project cost) and demonstration projects that request between $1M and $5M (comprising up to 50% of total project cost)."[52] Battery projects funded by larger programs such as the SIF are primarily foreign investment attraction, rather than scaling up technology of Canadian firms.

Focusing on filling gaps in seed funding, demonstration funding in the tens of millions, and scaling up funding of Canadian innovation in the hundreds of millions is essential. These programs need to be part of a strategic roadmap to scale up Canadian firms who are pushing the technological frontier in key innovation metrics that are essential for next-generation batteries. This requires taking a firm-level and technology-level perspective over time, rather than a project-by-project approach that spreads R&D funding across a variety of sectors without coordinating all public-private innovation efforts to reach critical mass in specific strategic areas. By addressing these gaps, Canada can ensure its battery innovation sector continues to thrive, fully capturing the opportunities ahead and solidifying its position in this critical field. We need clear metrics, targeted investments, and a strong process for collaboration between industry, government, universities, and other stakeholders.

We need clear metrics, targeted investments, and a strong process for collaboration between industry, government, universities, and other stakeholders.

47 https://www.edc.ca/
48 https://cib-bic.ca/en/
49 https://www.sdtc.ca/en/companies/gbatteries-energy-canada-inc/; https://www.gbatteries.com/about
50 https://www.canada.ca/en/innovation-science-economic-development/news/2024/06/minister-champagne-announces-a-new-governance-framework-for-cleantech-funding.html
51 https://www.oag-bvg.gc.ca/internet/docs/parl_oag_202406_06_e.pdf
52 https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/grants-incentives/energy-innovation-program/battery-industry-acceleration-call-for-proposals-applicant-guide/battery-industry-acceleration-call-for

Battery Technological Frontier

Why should we be enhancing battery technology? What new opportunities are driving us to innovate further? How can we improve upon the batteries we have today? The answers to these questions lie at the heart of a rapidly evolving global market driven by urgent environmental needs, shifting geopolitical landscapes, and ever-increasing consumer demands. Understanding where battery technology is headed is crucial for meeting these evolving demands. As the world transitions towards a net-zero, it's essential to grasp the key innovation drivers, metrics, targets, and enabling technologies shaping the future of batteries. This section explores how addressing market needs, geopolitical pressures, and ensuring environmental sustainability are vital for advancing battery technology to help unlock pathways to net zero.

The global market for batteries is expanding rapidly, driven by the increasing adoption of electric vehicles (EVs), the integration of renewable energy sources into power grids, and the growing demand for portable electronic devices.[53] Meeting these demands requires significant improvements in battery performance, cost, safety, and sustainability. Understanding the innovation drivers, such as market requirements for higher energy density and faster charging times, is critical for guiding research and development efforts. Additionally, addressing geopolitical concerns, such as reducing reliance on conflict minerals and ensuring ethical sourcing of materials, is essential for creating a stable and responsible supply chain. Environmental sustainability also plays a crucial role, with a focus on reducing the carbon footprint of battery production and improving recycling rates to minimize waste.

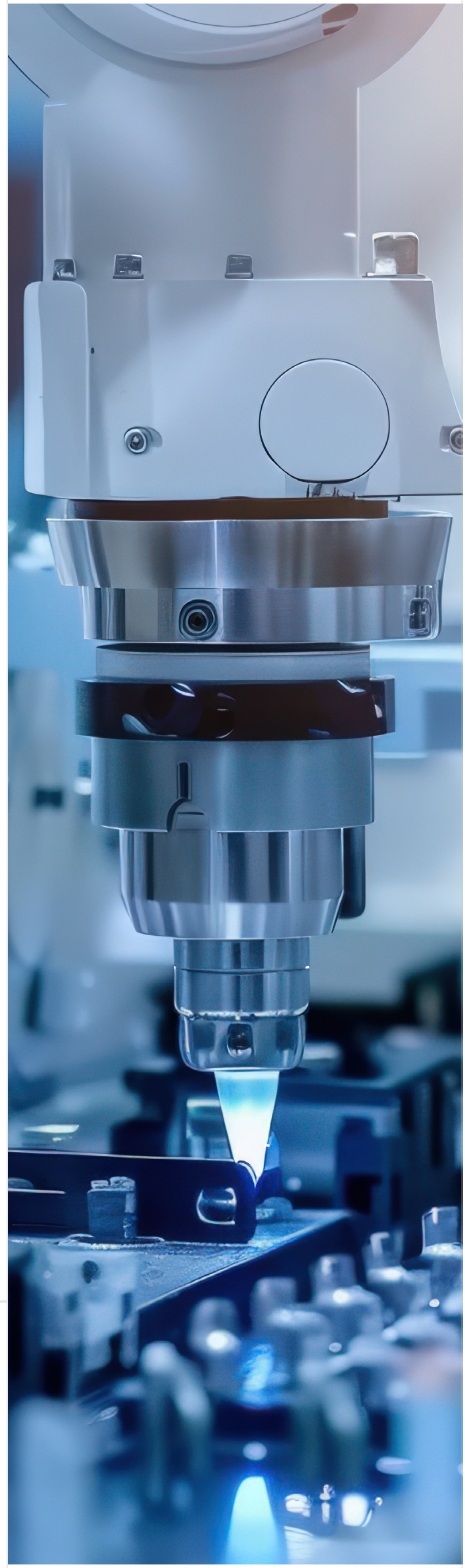
This comprehensive understanding of the battery technological frontier will enable stakeholders, including governments, researchers, manufacturers, policymakers, and investors, to make informed decisions that drive innovation and promote the widespread adoption of advanced battery technologies. By aligning technological advancements with market needs, geopolitical realities, and environmental goals, the industry can achieve sustainable growth and make significant contributions to global efforts to combat climate change and promote energy security in a net-zero world.

Market Drivers

In the rapidly evolving battery technology landscape, market drivers are key economic and consumer-oriented factors that shape the development and adoption of new innovations. These drivers focus on meeting specific consumer needs and improving product performance to make battery technology more attractive and practical for widespread use. By addressing these market drivers, manufacturers and researchers can align battery advancements with consumer expectations and market demands, promoting greater adoption of sustainable energy solutions. This section explores the major market drivers, outlining the innovation metrics, goals, and enabling technologies that fall into the following categories:

Affordability

Cost-effective battery solutions are crucial to making advanced technologies accessible to a broader market. Affordable batteries enable more consumers to adopt EVs and other battery-powered devices, driving overall market growth. Efforts are focused on reducing production costs through innovation and economies of scale, making sustainable technologies financially viable for a wider audience.



53 BNEF estimates that lithium-ion battery demand across EVs and stationary storage reached approximately 950 gigawatt-hours (GWh) in 2023, with global battery manufacturing capacity exceeding this demand at around 2,600 GWh.

Range

Ensuring that electric vehicles (EVs) have sufficient range is essential for alleviating range anxiety among consumers. Longer battery ranges increase the practicality and convenience of EVs, making them a more viable alternative to traditional combustion engine vehicles. The goal is to develop batteries that support extended driving distances on a single charge, enhancing consumer confidence and adoption.

Space Efficiency

Space efficiency is critical in both consumer electronics and electric vehicles. Compact and lightweight batteries allow for better design flexibility, enabling manufacturers to produce sleeker, more efficient products without compromising performance. The focus is on creating batteries that maximize energy density while minimizing physical size and weight, thereby improving overall product utility and appeal.

Charging Convenience

Faster charging times are vital for improving the convenience of EV ownership. Quick turnaround times reduce downtime, making EVs more practical for everyday use and long-distance travel. By developing technologies that enable rapid charging, the industry can enhance user experience and encourage more consumers to switch to electric vehicles.

Climate Adaptability

Batteries need to perform reliably in various climates, including cold weather. Ensuring that batteries can operate efficiently in low temperatures is critical for their widespread adoption, particularly in regions with harsh winters. Innovations in battery chemistry and thermal management are key to maintaining performance and longevity in cold conditions.

Longevity/Durability

Long-lasting and durable batteries reduce the need for frequent replacements, lowering the total cost of ownership and enhancing the sustainability of battery-powered devices. Durability is especially important for applications in harsh or demanding environments. The aim is to develop batteries that maintain high performance over longer periods, thereby increasing their value and reliability.

Safety

Ensuring the safety of battery technology is paramount. Advances in battery safety help prevent issues such as overheating, short-circuiting, and other potential hazards, providing consumers with peace of mind and fostering trust in battery-powered products. The industry prioritizes the development of safer battery chemistries and robust safety mechanisms to protect users and enhance product credibility.

Enabling Technologies

To meet the ambitious targets for advancing battery technology and addressing key market drivers, a range of innovative approaches and cutting-edge technologies are being developed. These enabling technologies focus on enhancing the core components and systems of batteries to significantly improve their performance, safety, and efficiency.

Battery Chemistry

Advancements in solid-state batteries, lithium-sulfur batteries, sodium-ion batteries, and

Where Is the Puck Going?

lithium iron phosphate (LFP) batteries are expected to significantly enhance energy density and safety. Solid-state batteries, for example, offer higher energy density and improved safety by using solid electrolytes instead of liquid ones, reducing the risk of leaks and fires.

Improved Processes & Advanced Lithium-Ion Batteries

Innovations in advanced electrode materials (e.g., silicon or graphene) and nanotechnology applications are crucial for increasing capacity and efficiency. Enhanced electrolyte formulations and improved manufacturing processes are also vital. Using materials like silicon in electrodes can increase capacity, while nanotechnology can improve the interface for ion transport, boosting energy density.

Battery Management Systems (BMS)

Advanced BMS technologies, including sophisticated charging algorithms, thermal management systems, and state of health monitoring, are essential for optimizing battery performance and longevity. BMS can dynamically adjust charging rates based on battery conditions, manage heat generation, and monitor battery health to extend lifespan and maintain efficiency.

Innovation Metrics

How do we know if we're effectively addressing these market drivers? Innovation metrics provide the answer. By establishing clear, quantifiable benchmarks, we can measure progress in battery technology development. Metrics such as energy density, charge/discharge cycles, and cost per kilowatt-hour help gauge improvements in vehicle range and charging convenience. Space efficiency can be evaluated through volumetric and gravimetric energy density, ensuring batteries are becoming more compact and lightweight without compromising performance. Affordability is tracked through production costs and market prices, aiming for reductions that make advanced battery technologies more accessible to consumers. By consistently measuring these metrics, we can ensure that advancements in battery technology align with market needs and drive the industry toward achieving net-zero goals.

The following table provides a summary of the market drivers, relevant applications, and the innovation metrics that can be used to evaluate progress towards addressing market needs. Each metric is then analyzed in detail to illustrate the drivers it addresses, the specific targets for various applications, and the enabling technologies that are instrumental in achieving these targets, highlighting contributions from specific Canadian innovators working in these areas.

INNOVATION METRIC	DRIVERS	APPLICATIONS
Energy Density (Wh/kg)	**Range**	Transportation
	Space efficiency	Electronics/Storage
Charging Time (minutes to full charge)	**Charging Convenience**	Transportation/ Electronics/
Low Temp Performance (operational efficiency at low temperatures)	**Climate Adaptability**	All Markets
Cycle Life (number of charge/discharge cycles with <20% fade)	**Longevity/Durability**	All Markets
Cost per kWh	**Affordability**	All Markets
Incident Rate	**Safety**	All Markets

Energy Density (Wh/kg)

Measures the amount of energy stored in a battery relative to its weight, directly impacting the range of electric vehicles (EVs) and the efficiency of portable electronic devices. Higher energy density allows for longer driving ranges for EVs and longer usage times for consumer electronics without the need for frequent recharging.

Drivers

Range, Space Efficiency

Targets

Varies by application: EVs (>350 Wh/kg), Consumer Electronics (300-400 Wh/kg), Energy Storage (200-250 Wh/kg)

Enabling Technologies:

- **Solid-State Batteries:** These batteries replace the liquid or gel-form electrolyte with a solid electrolyte, allowing for higher energy densities and improved safety. Solid-state batteries can potentially double the energy density compared to current lithium-ion batteries, making them ideal for EVs and portable electronics. Researchers at the **University of Waterloo**[54] are developing advanced solid-state batteries that could lead to higher energy densities and safer battery systems. In addition **Hydro-Québec's** Center of Excellence in Transportation Electrification and Energy Storage is a global leader in developing solid-state battery technologies, achieving promising results that enhance battery performance, range, and safety, and partnering with companies like Mercedes-Benz to accelerate the development and commercialization of these advanced batteries.[55]
- **Lithium-Sulfur (Li-S) Batteries:** Li-S batteries offer a higher energy density than traditional lithium-ion batteries by utilizing sulfur as the cathode material. This technology promises to reduce battery weight and cost while increasing capacity, which is crucial for applications requiring long ranges. **The National Research Council of Canada** has an in-house research group that is working on solid-state battery alternatives, including lithium-sulfur technology.[56] In addition, **The University of British Columbia** is working on a project called "Solid-State Lithium Tellurium-Sulfur Battery for Clean Transportation. This initiative aims to create a battery cell that is twice as powerful, smaller, safer, and cheaper to manufacture compared to current lithium-ion batteries.[57] Linda Nazar's research at **the University of Waterloo** has made significant contributions to lithium-sulfur battery technology, including the development of highly ordered interwoven composites that allow these batteries to approach their theoretical energy density of approximately 2,600 Wh/kg, a substantial improvement over current lithium-ion technology.[58]
- **Metal-Air Batteries:** These batteries use metal (such as lithium or zinc) and oxygen from the air as reactants. Metal-air batteries have a very high theoretical energy density, which could lead to significant advancements in the range and efficiency of EVs and energy storage systems. **Abound Energy** (formerly known as Zinc8 Energy),

54 https://electricautonomy.ca/special-reports/2024-05-28/waterloo-ontario-battery-electrochemistry-research-centre/
55 https://news.hydroquebec.com/en/press-releases/1580/hydro-quebec-partners-with-mercedes-benz-on-development-of-solid-state-battery-technologies/
56 https://www.theglobeandmail.com/business/article-charged-up-canadian-scientists-are-in-a-race-to-make-the-next/
57 https://pics.uvic.ca/projects/developing-the-next-generation-of-lithium-batteries/
58 https://uwaterloo.ca/nazar-group/research

a Canadian company, has developed rechargeable zinc-air batteries for grid energy storage. Their technology uses zinc and air to store energy, offering a potentially low-cost solution for long-duration energy storage.[59]

- **Advanced Electrode Materials:** Incorporating materials like silicon or graphene into battery electrodes can significantly increase energy capacity. These materials can store more lithium ions, leading to higher energy densities and improved battery performance. Canadian researchers are leading innovations in this space, particularly in developing silicon-based anodes with higher capacities. At the **University of Waterloo**, researchers are developing silicon-based anodes using a novel chemical vapor deposition process, aiming to create more stable and efficient lithium-ion batteries.[60] **The National Research Council of Canada** is collaborating with industry partners to scale up the production of silicon nanowires for next-generation battery anodes, addressing key challenges in manufacturability and performance.[61]
- **Nanotechnology:** The application of nanostructures in battery electrodes can enhance the surface area, improve conductivity, and increase the overall energy density. Nanotechnology enables more efficient ion transport and greater electrode stability. Researchers at the **University of Calgary** are pioneering the use of nanostructured materials to enhance the performance and stability of battery electrodes, focusing on applications such as lithium-ion and redox flow batteries.[62] **Nanode Battery Technologies** in Alberta is designing high-performance nanostructured electrodes for lithium and sodium-ion batteries, aiming to significantly boost energy storage capabilities.[63]
- **Enhanced Electrolyte Formulations:** Developing new electrolyte formulations that are more stable and efficient can improve the overall energy density of batteries. These formulations can enhance ion conductivity and thermal stability, crucial for high-performance applications. Innovations in this area by Canadian researchers are paving the way for more robust and energy-efficient batteries. Researchers at the National Research Council of Canada have developed new electrolyte formulations based on dinitrile solvents, which enhance ion conductivity and thermal stability for high-voltage lithium-ion batteries.[64] **The Western Canada Battery Consortium at the University of Calgary** is actively working on innovative electrolyte materials to improve the performance and safety of next-generation batteries, focusing on applications in electric vehicles and renewable energy storage.[65]

Charging Time (minutes to full charge)

Crucial for the practicality and user convenience of battery-powered devices, particularly for EVs and consumer electronics. Faster charging times reduce the downtime required for recharging, making EVs more convenient for users and enabling quicker turnaround times for devices.

Drivers

Charging Convenience, Cold Weather Performance

59 https://www.popsci.com/science/metal-air-batteries/
60 https://www.greencarcongress.com/2021/05/20210527-silicon.html
61 https://hpqsilicon.com/press-release/hpq-silicon-a-project-for-the-development-of-silicon-based-anode-materials-for-lithium-ion-batteries/
62 https://science.ucalgary.ca/research-innovation/institutes-centres-facilities/battery-innovation-hub
63 https://www.sdtc.ca/en/companies/nanode-battery-technologies/
64 https://nrc-publications.canada.ca/eng/view/accepted/?id=431ad01c-3fb7-4610-923b-99d08c6a4c16
65 https://science.ucalgary.ca/research-innovation/institutes-centres-facilities/battery-innovation-hub

Target

Varies by application: EVs66 (<15 mins), Consumer Electronics (30-60 mins), Energy Storage (1-2 hours)

Enabling Technologies:

- **Lithium Titanate Oxide (LTO) Batteries:** LTO batteries have a faster charging capability compared to traditional lithium-ion batteries due to their unique anode material, which allows for rapid ion exchange and high-rate charging.
- **High Nickel Content Cathodes:** Batteries with high nickel content cathodes can achieve faster charging times while maintaining high energy density and stability. Nickel-rich cathodes reduce the overall resistance and enhance the charging efficiency. Canada is at the forefront of developing advanced cathode materials that balance performance and cost. In 2019, **Dr. Jeff Dahn and his team, in collaboration with Tesla**, published a landmark paper in the Journal of The Electrochemical Society. This research focused on a novel lithium-ion battery chemistry using a high nickel content cathode material. The high nickel content allowed for faster charging capabilities compared to traditional lithium-ion batteries.[67]
- **Electrode Design:** Thinner electrodes or those with increased surface area can facilitate faster ion transport, reducing charging times. Optimized electrode designs improve the overall charging rate without compromising battery capacity. Canadian researchers are making significant advancements in optimizing electrode designs to enhance battery performance. **Dr. Zhongwei Chen and his team at the University of Waterloo** have developed a novel silicon-based anode material and flash heat treatment process, resulting in thinner, lighter electrodes with significantly improved energy capacity and cycle life, which facilitate faster ion transport and reduced charging times.[68]
- **Improved Conductivity:** Enhancing the conductivity of battery materials can lead to quicker charging by reducing internal resistance. Conductive additives and advanced material processing techniques can achieve this improvement. Canadian efforts in this area include developing materials with superior conductivity to speed up the charging process. Similar, **Dr. Dahn** has made significant advancements in battery conductivity, which could lead to faster charging times for lithium-ion batteries.
- **Advanced Charging Algorithms:** Developing sophisticated algorithms to manage the charging process can optimize charging times and extend battery life. These algorithms ensure efficient energy transfer and prevent overheating or overcharging. Canadian tech companies are developing cutting-edge charging algorithms that maximize battery performance while reducing charge times. **Canadian tech company GBatteries**[69] has developed advanced charging algorithms that significantly reduce charging times for lithium-ion batteries while extending their lifespan.
- **Active Balancing:** Implementing active balancing systems can ensure that all cells within a battery pack charge uniformly, preventing bottlenecks and speeding up the overall charging process. Canadian innovations in battery management systems are leading to more efficient and faster charging solutions. **Canadian company e-Zinc** has developed an advanced active balancing system for zinc-air batteries, which ensures uniform charging of all cells within a battery pack, thereby reducing bottlenecks

66 Longer range EVs may require more time
67 https://www.dal.ca/diff/dahn.html
68 https://uwaterloo.ca/institute-nanotechnology/profiles/zhongwei-chen
69 Their AI-powered ActiveBMS technology uses pulse charging and machine learning to optimize the charging process, allowing electric vehicle batteries to charge up to 50% faster without degrading the battery. https://www.gbatteries.com/

and speeding up the overall charging process. Their technology enhances battery performance and efficiency, making it a promising solution for faster and more reliable energy storage.[70]

- **Enhanced Thermal Management:** Effective thermal management systems can dissipate heat more efficiently during fast charging, ensuring the battery remains within safe temperature limits and improving charging speed. Canadian researchers are developing advanced thermal management technologies to support rapid charging capabilities. **Calogy Solutions**, a Canadian company, is developing advanced thermal management technologies that enhance heat dissipation during fast charging, ensuring batteries remain within safe temperature limits and improving charging speed. Their innovative solutions help maintain optimal battery performance and safety, supporting rapid charging capabilities.[71]

Low-Temperature Performance

Evaluates the operational efficiency of batteries at low temperatures, ensuring reliability in various climates. Batteries that perform well in cold conditions are essential for markets in regions with harsh winters, ensuring that EVs and energy storage systems remain functional and efficient.

Drivers

Cold Weather Performance

Target

Varies by application: EVs under typical usage (80% battery capacity at -20°C), Energy Storage (more than 85% capacity at -20°C)

Enabling Technologies

- **Electrolyte Additives:** Adding specific compounds to electrolytes can improve battery performance at low temperatures by enhancing ion transport and preventing electrolyte freezing.
- **Advanced Electrolyte Formulations:** Developing electrolytes that remain stable and conductive at low temperatures is crucial for battery performance in cold weather.
- **LFP Batteries:** Lithium iron phosphate (LFP) batteries are known for their excellent thermal stability and performance at low temperatures. **Electrovaya Inc.,** based in Mississauga, Ontario, specializes in developing and manufacturing advanced lithium iron phosphate (LFP) batteries known for their excellent thermal stability and low-temperature performance. **Nano One Materials Corp**., headquartered in Vancouver, is pioneering innovative processes to produce high-performance LFP battery materials, aiming at nhancing efficiency and reliability in cold climate applications.
- **Enhanced Separator Design:** Improving the design of separators, which keep the anode and cathode apart, can help maintain battery efficiency at low temperatures.
- **Electrode Optimization:** Optimizing the materials and structure of electrodes can enhance battery performance in low temperatures.
- **Thermal Insulation:** Incorporating effective thermal insulation within battery packs

70 https://e-zinc.ca/
71 https://www.calogysolutions.com/en/

can help maintain operational temperatures and improve performance in cold climates.

- **Temperature Monitoring and Control:** Implementing precise temperature monitoring and control systems can ensure batteries operate efficiently in cold conditions. Canadian companies are developing state-of-the-art monitoring systems that enhance battery performance in low temperatures. **Calogy Solutions Inc.,** based in Sherbrooke, Quebec, is developing advanced thermal management systems, including precise temperature monitoring and control, to enhance battery performance in cold climates. **The University of Calgary's Western Canada Battery Consortium** is also engaged in developing innovative battery technologies, including temperature control systems, to ensure efficient battery operation in harsh winter conditions

Cycle Life

Measures the number of charge-discharge cycles a battery can endure before significant capacity degradation, impacting the long-term viability and cost-effectiveness of the battery. Longer cycle life translates to longer-lasting batteries, reducing the need for frequent replacements and lowering the total cost of ownership.

Drivers

Longevity/Durability

Target

Varies by application: EVs (2000+ cycles), EVs with Vehicle to Grid Requirements (10,000 cycles), Energy Storage (5,000-10,000 cycles)

Enabling Technologies

- **High Stability Electrolytes:** Developing electrolytes that remain stable over many charge-discharge cycles can significantly extend battery life.
- **Durable Cathode Materials (NMC or LFP):** Using materials like nickel manganese cobalt (NMC) or lithium iron phosphate (LFP) for cathodes can improve the durability and longevity of batteries.
- **Coating and Doping of Electrodes:** Applying coatings and doping electrodes with specific elements can enhance their stability and extend battery life.
- Cell Form Factor: Optimizing the size and shape of battery cells can improve packing efficiency and reduce mechanical stress, enhancing the overall performance and longevity of the battery pack. Employing modular designs and advanced manufacturing techniques can further ensure consistent quality.
- **State of Charge Management:** Effective management of the battery's state of charge can prevent overcharging and deep discharging, both of which can shorten battery life.
- **Thermal Regulation:** Proper thermal regulation can prevent overheating and thermal degradation, extending battery life.
- **Adaptive Charging Algorithm:** Adaptive algorithms that optimize charging rates and patterns based on usage and environmental conditions can extend battery life.

Cost per kWh

Economic metric determining the affordability of battery technologies, influencing their adoption across different markets. Lowering the cost per kilowatt-hour makes batteries more accessible for a wider range of applications, from EVs to grid storage.

Drivers

Affordability

Target

Varies by application: EVs (<$100/kWh), Energy Storage (short duration < $100) long duration < $50/kWh)

Enabling Technologies

- **LFP Batteries:** Lithium iron phosphate (LFP) batteries are cost-effective alternatives to traditional lithium-ion batteries. They offer a balance of performance and affordability, making them an attractive option for reducing battery costs. Canadian companies are advancing LFP technology to provide cheaper and more efficient battery solutions.
- **Sodium-ion Batteries:** Sodium-ion batteries are emerging as a low-cost alternative to lithium-ion batteries, leveraging the abundance of sodium to reduce costs. Michael Metzger is an Assistant Professor and Herzberg-Dahn Chair for Advanced Battery Research at Dalhousie University, focusing on lithium-ion and sodium-ion battery research.[72]

Safety Incident Rate

Tracks the occurrence of safety incidents, crucial for maintaining user trust and regulatory compliance. Ensuring a low incidence rate of safety issues, such as thermal runaway or battery fires, is essential for widespread adoption and user confidence.

Drivers

Safety

Targets

Varies by application: EVs (Less than 0.001 incidents per million hours), Energy Storage (0.0001 safety incidents per gigawatt-hour (GWh) of energy stored and discharged.)

Enabling Technologies:

- **Non-flammable Electrolytes:** These electrolytes reduce the risk of fire and explosions, enhancing the safety of batteries, especially in EVs and large-scale energy storage systems.
- **Stable Cathode and Anode Materials:** Utilizing materials that are less likely to degrade or cause thermal runaway can significantly improve battery safety.
- **Robust Cell & Pack Design:** Designing battery cells with enhanced structural integrity can prevent mechanical failures and improve overall safety. Moreover, a

72 https://www.dal.ca/faculty/science/physics/faculty-staff/Faculty/Michael_Metzger.html

well-engineered pack design can significantly reduce the risk of thermal runaway propagation. By incorporating advanced cooling systems, robust physical barriers, and optimized cell arrangements, a good pack design can isolate potential issues within individual cells, preventing them from affecting the entire battery pack. This comprehensive approach ensures higher safety standards and reliability for battery systems.

- **Precise Manufacturing Controls:** Implementing stringent manufacturing controls ensures that batteries are produced consistently and meet high safety standards.
- **Advanced Thermal Management:** Effective thermal management systems prevent batteries from overheating, which is critical to maintaining safety during operation and charging.
- **State-of-Health Monitoring:** Continuous monitoring of battery health can detect potential issues before they lead to failures, enhancing the safety and reliability of battery systems.
- **Fault Detection and Response Mechanisms:** Advanced systems for detecting faults and responding appropriately can mitigate safety risks, ensuring that batteries operate safely under all conditions.

Environmental Drivers

As the world moves towards a more sustainable future, the environmental impact of battery production and usage has become a critical concern. Batteries play a pivotal role in the transition to clean energy, but their lifecycle from production to disposal can have significant ecological consequences. Addressing these challenges requires a focus on key environmental drivers that can transform the battery industry into a model of sustainability. This section delves into the major environmental drivers, highlighting the innovation metrics, target, and enabling technologies essential for achieving a greener battery ecosystem.

Eco-Friendly Materials

The shift towards eco-friendly materials is driven by the urgent need to reduce the environmental impact of battery production. Traditional battery materials often involve significant environmental costs, including resource extraction, energy-intensive processing, and the use of hazardous chemicals. By focusing on biodegradable electrolytes, green synthesis methods, and the substitution of rare materials, the industry aims to minimize these impacts. Eco-friendly materials can significantly reduce the ecological footprint of batteries, making them more sustainable and aligning with broader environmental goals. The goal is to achieve near 100% utilization of such materials, ensuring that the entire lifecycle of battery production is as green as possible.

Recyclability

Recyclability is a crucial driver in the battery industry, addressing the challenge of waste and resource efficiency. With the increasing number of batteries reaching the end of their life, it is essential to develop efficient recycling processes to recover valuable materials and reduce landfill waste. Advanced sorting techniques and direct recycling processes, coupled with standardized battery designs, can enhance the recycling rate and ensure that a high percentage of materials are recovered and reused. The target is to achieve a 90% recovery rate for valuable battery components, thereby supporting a circular economy and reducing the need for new raw materials.

Carbon Footprint

Reducing the carbon footprint of batteries is vital for their contribution to a net-zero future. The entire lifecycle of a battery, from raw material extraction to manufacturing, usage, and disposal, can generate significant greenhouse gas emissions. By integrating renewable energy sources into manufacturing processes, improving efficiency, and utilizing lifecycle management software, the industry aims to lower the carbon emissions associated with battery production and use. The goal is to reduce the carbon footprint to less than 50 kg CO2eq/kWh, ensuring that batteries contribute positively to climate goals.

Second Life Adaptability

Second life adaptability refers to the ability to repurpose batteries for secondary applications after their initial use. This driver is important because it extends the useful life of batteries, reduces waste, and maximizes the value extracted from the materials and energy invested in their production. Technologies such as improved design for disassembly, smart battery management systems, and cell balancing techniques can facilitate the repurposing of batteries without the need for complete disassembly. The development of an Ease of Repurposing Index (ERI) will help measure and enhance the adaptability of batteries for second-life applications, ensuring they can be effectively reused in various contexts, such as energy storage systems.

By focusing on these areas, the battery industry can significantly reduce its environmental impact and support a sustainable future.

Technologies such as improved design for disassembly, smart battery management systems, and cell balancing techniques can facilitate the repurposing of batteries without the need for complete disassembly.

Innovation Metrics

Environmental drivers focus on the sustainability and ecological impact of battery technologies. Key metrics include:

- **Percentage of Sustainable Materials**: Evaluates the proportion of eco-friendly materials used in battery production. Using sustainable materials helps reduce the environmental impact of battery production and disposal.
- **Recycling Rate (%)**: Measures the effectiveness of recycling processes, aiming to recover valuable battery components. High recycling rates reduce waste and the need for raw material extraction, promoting a circular economy.
- **Carbon Footprint (CO2eq/kWh)**: Assesses the total greenhouse gas emissions produced throughout the battery's lifecycle. Lower carbon footprints are crucial for reducing the environmental impact of batteries and contributing to climate goals.
- **Lifecycle Management**: Measures the average lifespan of a battery before its capacity degrades to a specified threshold, such as 80% of its initial capacity. Effective lifecycle management ensures that batteries are used efficiently and disposed of responsibly.

Targets

- **Eco-Friendly Materials**: Achieving near 100% utilization of sustainable materials in battery production.
- **Recycling**: Targeting a high recovery rate of 90% for valuable battery components.
- **Carbon Footprint**: Reducing the carbon footprint to less than 50 kg CO2e/kWh for the entire lifecycle of the battery.
- **Second Life Adaptability**: Enhancing the Ease of Repurposing Index (ERI)[73] to enable efficient reuse of batteries in second-life applications.

73 Ease of Repurposing Index (ERI) refers to a metric designed to evaluate how easily a battery can be repurposed for secondary applications after its initial use. The index considers factors such as the battery's design for disassembly, the efficiency of its battery management systems, and the effectiveness of its cell balancing techniques, ultimately aiming to maximize the battery's utility and lifespan while minimizing waste.

Enabling Technologies

Several technologies are crucial for meeting these environmental goals:

- **Biodegradable Electrolytes**: Development of electrolytes that break down easily without releasing harmful chemicals. These electrolytes reduce the environmental impact of battery disposal.
- **Advanced Sorting Techniques**: Technologies that efficiently separate battery materials to improve the purity and quality of recycled components. Advanced sorting improves recycling efficiency and material recovery rates.
- **Direct Recycling Processes**: Processes that can directly recycle cathode materials back into new cathode materials. Direct recycling reduces the energy and resources needed for recycling, making it more sustainable.
- **Green Synthesis Methods**: Techniques that reduce environmental harm during battery material synthesis. Green synthesis methods use less toxic precursors and lower energy production methods, minimizing environmental impact.
- **Standardized Battery Designs**: Designs that facilitate easier recycling and second-life applications. Standardized designs make it easier to disassemble and repurpose batteries, promoting a circular economy.
- **Lifecycle Management Software**: Tools that manage the entire lifecycle of batteries, ensuring optimal use and recycling. Lifecycle management software tracks battery health and usage, optimizing performance and extending lifespan.

Geopolitical Drivers

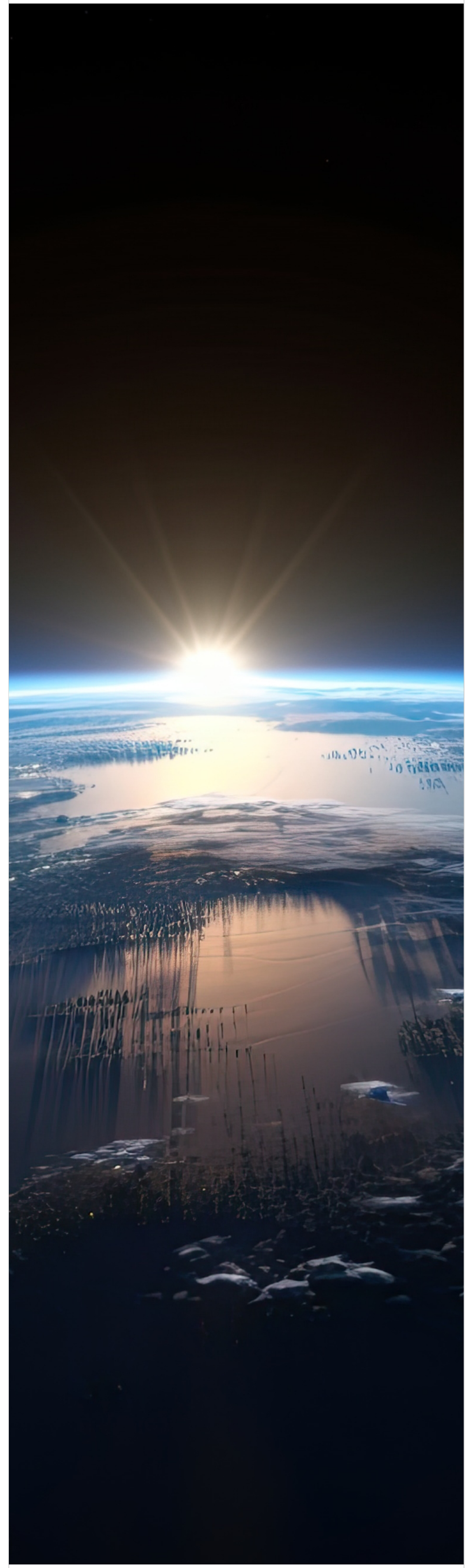
Innovation Metrics

Geopolitical drivers focus on the ethical and secure sourcing of battery materials. Key metrics include:

- **Reduction in Conflict Minerals Usage**: Measures the percentage reduction in cobalt content per battery unit, aiming to minimize reliance on conflict minerals. Reducing conflict mineral usage helps ensure ethical sourcing and avoid supporting unethical mining practices.
- **Ethical Sourcing**: Ensures that all materials are sourced in an environmentally and socially responsible manner. Ethical sourcing ensures that materials are obtained without exploiting workers or harming the environment.
- **Geopolitical Independence:** Avoids overreliance on technologies and materials from foreign adversaries.

Targets

- **Cobalt Reduction**: Reducing cobalt content by 50% in the next five years and working towards cobalt-free battery technologies by 2035.
- **Ethical Sourcing**: Establishing robust supply chains that ensure all materials are sourced ethically.
- **Maximize the Use of Locally-Sourced and Friendshored Resources**: Creating geopolitically resilient supply chains, free from dependence on foreign adversaries.



Enabling Technologies

To achieve these goals, several technologies are being developed:

- **Cobalt-Free Chemistries**: Development of lithium iron phosphate (LFP) batteries and other cobalt-free battery chemistries. LFP batteries provide a safer and more sustainable alternative to traditional lithium-ion batteries. Also in 2021, **Dr. Jeff Dahn and his team** published research on a single crystal nickel-rich cathode material that could potentially replace cobalt-containing cathodes in lithium-ion batteries. This work demonstrated high energy density and long cycle life without the use of cobalt, addressing both performance and sustainability concerns in battery technology.[74]
- **High Nickel Battery Chemistries**: High nickel battery chemistries with low cobalt content (2-3%) are being developed to increase the energy density of batteries while reducing reliance on cobalt. Nickel-rich cathodes, such as Nickel-Cobalt-Manganese (NCM) and Nickel-Cobalt-Aluminum (NCA), have been shown to provide higher energy densities compared to traditional chemistries. These high nickel batteries offer improved performance in terms of energy storage and power output, making them suitable for applications requiring high energy density, such as electric vehicles. By optimizing the proportion of nickel and minimizing cobalt content, these chemistries aim to balance performance, cost, and sustainability.
- **Recycling Technologies**: Advanced recycling technologies for cobalt and other critical materials. Effective recycling technologies help reclaim valuable materials and reduce dependence on new raw material extraction.
- **Solid-State Batteries**: Development of solid-state batteries that have lower or no cobalt content. Solid-state batteries offer higher energy density and improved safety without relying on cobalt.
- **Supply Chain Transparency Tools**: Technologies that enhance transparency and traceability in the supply chain, ensuring ethical sourcing. Supply chain transparency tools help verify the origin and ethical status of materials, ensuring compliance with ethical standards

MARKET	ENVIRONMENTAL	GEOPOLITICAL
• Vehicule Range • Space Efficiency • Charging Convenience • Cold Weather Performance • Longevity/Durability • Affordability • Safety	• Eco-Friendly Materials • Recyclability • Carbon footprint • Second Life Adaptability	• Reduction in the Use of Conflict Minerals

74 Y. Liu, H. Wu, Y. Wang, K. Li, S. Yin and J.R. Dahn. Impact of Shell Composition, Thickness and Heating Temperature on the Performance of Nickel-Rich Cobalt-Free Core-Shell Materials. J. Electrochem. Soc. 167 (16), 160556 (2021).

Building Innovation Ecosystems with Industrial Policy

The goal of an industrial policy for battery innovation is to establish innovation ecosystems at key nodes along the battery supply chain.[75]

What is an innovation ecosystem? Innovation is often conflated with novelty—the creation of new technologies. But as Dan Breznitz has argued, "Canadian politicians and policymakers have always confused innovation with invention," ignoring the fact that the real impact of innovation comes from the continuous improvement of existing products.[76] This emphasis is mirrored in the gap between Canada's strong performance in higher education expenditure on R&D (0.6% of GDP in 2022 versus the OECD average of 0.43%) versus business expenditure on R&D (1% of GDP in 2022 versus the OECD average of 2%).[77] It is important to distinguish between invention, creating a truly new thing, and innovation, which is the process of using ideas to improve products and services.

On this vision, building an innovation economy cannot be equated with chasing investment or building a startup culture. Knowledge creation should be integrated with manufacturing and upstream commodity supply chains into a dynamic system of R&D, commercialization, and production. This is an innovation ecosystem.

Innovation ecosystems have a number of critical elements:

- Geographical location (place-based).
- "Triple-helix" interactions between government, industry, and universities.
- Communication up and down the value chain.

The goal is to create places where innovators with diverse ideas can engage in meaningful exchange.[78] These places must have strong connections to the global community so that they can play strategic roles in global production networks.[79] The provision of public goods, physical and financial assets is critical to the development of these ecosystems.

Having battery manufacturing in Canada is a strong asset for a battery innovation ecosystem, but on its own it is a thin value-added segment of the supply chain. The real value comes in its anchoring function for dynamic production networks around the battery supply chain. Battery manufacturing provides a platform and knowledge base upon which learning-by-doing and commercialization can take place. Maximizing the investment in VW, Nortvolt, and Stellantis' factories means embedding them in a local ecosystem. But firms alone do not necessarily integrate into a cohesive battery innovation ecosystem.

75 Bramwell, A., Hepburn, N., & Wolfe, D. A. (2012). Growing innovation ecosystems: University-industry knowledge transfer and regional economic development in Canada. Final Report to the Social Sciences and Humanities Research Council of Canada, 62; Breznitz, Dan. 2021. Innovation in Real Places: Strategies for Prosperity in an Unforgiving World. Oxford University Press, Ch. 5.
76 Breznitz, Dan. 2021. Innovation in Real Places: Strategies for Prosperity in an Unforgiving World. Oxford University Press, Introduction, p. 62
77 https://www.oecd.org/sti/scoreboard.htm
78 Piore, Michael J. and Charles F. Sabel. 1984. The Second Industrial Divide: Possibilities for Prosperity. Basic Books; Berger, Suzanne. 2013. Making in America: From Innovation to Market. MIT Press; Breznitz, Dan. 2021. Innovation in Real Places: Strategies for Prosperity in an Unforgiving World. Oxford University Press.
79 Harald Bathelt, Anders Malmberg, and Peter Maskell, "Clusters and Knowledge: Local Buzz, Global Pipelines and the Process of Knowledge Creation," Progress in Human Geography 28, no. 1 (2004): 45–47; Neil M Coe, Peter Dicken, and Martin Hess, "Global Production Networks: Realizing the Potential," Journal of Economic Geography 8, no. 3 (2008): 272–274.

The Need for a Government Role In Building Innovation Ecosystems

Successful ecosystems are built on exchanges of information between firms, governments, and universities. Investment in the excellence of all three is necessary over the long-run. These three groups need to work together to get to the technology horizon and put in place the innovation infrastructure needed. There is a crucial role for government in providing a vision, coordinating firms, and investing in the public goods that create innovation ecosystems.

We need to consider both innovation and industrial policy and how they fit together.[80]

Innovation policy is largely comprised of supply-side academic research funding and R&D tax credits/grants for early stage start-ups. In this vein, innovation policy is usually conflated with support for research and development (R&D) and foreign direct investment (FDI). These core lessons came out of the OECD's programming on innovation in the 1990s and 2000s. Monumental changes in global political economy over the last five years mean we need to take a broader industrial policy frame.

Industrial policy is an intentional effort to change the structure of the economy for public aims.[81] In this instance, an industrial policy is any set of investments, incentives, regulations, and policy supports with the explicit goal of building an innovative battery industry. To build that industry, we need to do more than empower entrepreneurs or attract foreign firms. We need a focused strategy for building supply chains, innovation architecture, and scaling successful firms.

Industrial policy provides a strong policy and strategic environment for innovation policy. Innovation policy should focus on how knowledge creation will contribute to the aims of industrial policy. But the aims of industrial policy are broader because innovation for innovation's sake does not build prosperity. Knowledge could be created, but never translated into broad-based economic impacts. Knowledge could be created, but bought by foreign companies and taken overseas. Industrial policy harnesses knowledge for structural transformation in the economy.[82] It seeks to retain firms as part of a national strategy to build capabilities for production and innovation at home.

Good industrial policy combines supply-push and demand-pull instruments to scale firms and technologies into markets.[83] Without these, markets can get caught in chicken and egg problems in which producers cannot get going because there is no secure demand and potential users cannot begin because there is nothing available at cost. Supply-push policies support the creation, commercialization, and scaling of technologies. They are essential to lower the costs of new technologies and ease the costs of transition. Demand-pull measures create secure downstream markets. Secure demand is often needed to obtain the financing necessary to build production facilities. Procurement, carbon pricing, and other regulations can serve as demand-side policies for the green transition. When new products are trying to displace already cheap incumbents, they create markets for alternatives.

Green industrial policy poses special challenges because the technologies are nascent and incumbent technologies can be hard to displace. This is in part because of the underlying political-economy: legacy firms want to maintain market share and extract as much

80 Borrás, S., & Edquist, C. (2019). Holistic innovation policy: Theoretical foundations, policy problems, and instrument choices. Oxford University Press; Schot, J., & Steinmueller, W. E. (2018). Three frames for innovation policy: R&D, systems of innovation and transformative change. Research policy, 47(9), 1554-1567.

81 Juhász, Réka, Nathan Lane, and Dani Rodrik. The New Economics of Industrial Policy; Allan, Bentley, Joanna Lewis, and Thomas Oatley. 2021. Green Industrial Policy and the Global Transformation of Climate Politics. Global Environmental Politics 21:4, November 2021, https://doi.org/10.1162/glep_a_00640

82 Rodrik, Dani and Joseph E. Stiglitz. 2024. A New Growth Strategy for Developing Nations.

83 Brownlee, M., Elgie, S., and Scott, W. (2018). "Canada's next Edge: Why Clean Innovation Is Critical to Canada's Economy and How We Get It Right." Discussion Paper. Smart Prosperity Institute, https://institute.smartprosperity.ca/library/publications/canada-s-next-edge-why-clean-innovation-critical-canada-s-economy-and-how-we; Nemet, G. F. (2019). How solar energy became cheap: A model for low-carbon innovation. Routledge; Sivaram, V., Cunliff, C., Hart, D., Friedmann, J., Sandalow, D. (2020). Energizing America: A roadmap to launch a national energy innovation mission.

value as possible from existing assets. Green transitions require capex and entail risk. Incumbents try to carefully manage these, so they are often tepid participants in processes of transformation.

Having battery manufacturing in Canada is a strong asset for a battery innovation ecosystem, but on its own it is a thin value-added segment. The real value comes in its anchoring function for dynamic production networks around the battery supply chain. However, firms alone do not necessarily integrate into a cohesive battery innovation ecosystem. In the case of batteries, the mission is to support technology innovation from the supply-side, but ensure that local manufacturing will provide a proving ground and early demand-side market for scaling innovations.

Having battery manufacturing in Canada is a strong asset for a battery innovation ecosystem, but on its own it is a thin value-added segment.

Losing Winners: Cautionary Tales

Canada has a strong battery innovation ecosystem but it has lost some significant assets over the years. Far too many promising technologies pioneered by Canadian start-ups (oftentimes with public R&D support) are acquired by larger foreign firms who ultimately reap the economic rewards at scale.[84]

LFP Patent: The Lithium-iron-phosphate (LFP) battery was invented at the University of Texas, Austin by John Goodenough. The battery suffered from low conductivity until a Québec-based consortium led by Michael Armand developed a special coating procedure. The consortium, which included the Université de Montreal and Hydro Québec, then held the intellectual property that was critical to commercializing LFP technology. In a major industrial policy failure, Hydro Québec allowed its patent to be used in China without licensing fees so long as the batteries were not sold outside of China.[85] Chinese industrial policy then supported the development of LFP at Contemporary Amperex Technology Limited (CATL), which is now the world's largest battery producer.[86] CATL now makes the world's cheapest batteries and LFP comprises 40% of the domestic market in China.[87]

The Québec-based consortium's patent expired in 2022. CATL is now free to export its technology and production capabilities around the world. LFP is an example of free north-to-south technology transfer, which in the early 2000s was likely regarded as beneficent aid to a developing country. It constitutes a major failure of industrial policy in retrospect.

Springpower international: Springpower was initially set up as a northern branch of the Chinese company Highpower.[88] It was designed to help transfer knowledge from Western scientific communities to Chinese battery makers. However, Highpower walked away from its $100K investment. James Sbrolla, an "entrepreneur in residence" in the Business Accelerator Program funded by Ontario's Ministry of Research and Innovation, stepped in to support the young firm. He helped them secure a $3.6M grant from SDTC for a project running from September 2017 to January 2022 to advance cathode production efficiency technology.[89] The company also received $753K from Ontario's Low Carbon Innovation fund, as well as roughly half a million in other federal contributions.[90]

84 Denney, S., Southin, T., & Wolfe, D. A. (2023). Do winners pick government? How scale-up experience shapes entrepreneurs' assessments of innovation policy mixes. Science and Public Policy
85 https://www.mitrachem.com/post/the-iron-age-for-evs-finally-arrives-with-a-rush-of-companies-in-the-u-s-and-europe
86 For the full story, see Sanderson, Henry. 2022. Volt Rush. Simon & Schuster.
87 https://www.isi.fraunhofer.de/en/blog/themen/batterie-update/globale-batterieproduktion-analyse-standorte-mengen-zellen-lfp-nmc-nca-kathoden.html
88 https://techcrunch.com/2021/05/04/tesla-taps-tiny-startups-tech-to-build-cheaper-cleaner-batteries/
89 SDTC project description: "With their superior storage capacity, lithium ion batteries have become the preferred form of electrochemical energy storage; they are widely used in automotive, energy storage and portable electronics markets, with global demand continuing to grow rapidly. Springpower International Inc. (SPI) has created a new way to create the materials required for lithium ion batteries; the SPI technology is both environmentally friendlier and costs less than traditional technologies. SPI's innovative production technology completely eliminates the generation of liquid waste produced by traditional technologies. The SPI process is simpler—it has fewer steps, consumes less re-agents and eliminates the creation of byproducts that require disposal. The whole process is less energy intensive and leads to lower production costs, which could be passed down to consumers and promote the wider adoption of clean technologies such as electric vehicles and renewable energy."
90 https://search.open.canada.ca/grants/?sort=agreement_value+desc&search_text=springpower&page=1

Despite this support, Springpower's patents were purchased by Tesla deal for $3, according to public records.[91] A number of Springpower's staff then became Tesla employees. Springpower's technology seems to be crucial to Tesla's plan to switch from a wasteful dry cathode process to a wet cathode.[92] Tesla hopes the technology will cut cathode production costs in half.[93]

Hibar Systems: Hibar was founded in the early 1970s and became a world-leading provider of precision mechanized pumps.[94] Hibar began with a prototype that dispensed an extremely small volume of electrolyte into watch batteries.[95] Hibar now makes a range of pumps that can dispense liquids for use in batteries, cosmetics, and foods in automated production lines. This is an excellent example of technological spillover and learning. These are the fundamentals of innovation ecosystems in which firms like Hibar provide the capital goods for other manufacturers, enhancing their productivity and fueling cycles of co-learning. Europe has built its world leading manufacturing industry on capital goods firms like Hibar.

In 2019, it received $2M in Industrial Research Assistance Program (IRAP) support from the Ministry of Innovation, Science, and Economic Development (ISED). This project was "to support the development of a high-speed Lithium-ion battery manufacturing system to meet growing market demand for mass electric energy storage solutions."[96] Later in 2019, Tesla quietly acquired Hibar, listing it as a subsidiary in Canadian filings. Hibar's technology has wide applicability outside of the battery industry, and Tesla is now licensing Hibar Pumps to a Japanese firm, Unicontrols.[97] Further evidence of the economic and geopolitical significance of this Canadian-developed technology is seen in recent developments, where the United States charged two former Hibar Systems employees (now owners of a China-based company) with conspiracy to send trade secrets about the technology.[98] Assistant Attorney General Matthew G. Olsen of the US Justice Department's National Security Division emphasized that "this blatant theft of advanced trade secrets relating to battery components and assembly blunts America's technological edge, and the Justice Department will hold accountable those who would try to cheat our country of its economic potential and threaten our national security."[99] Losing winners poses economic and geopolitical risks.

The end-result is that US-based Tesla has become the beneficiary of industry-leading Canadian technologies developed with the assistance of approximately $7M in R&D support allocated to these two companies from both federal and provincial governments.[100]

Capturing more of the prosperity associated with the mass market adoption of Canadian-invented battery technologies requires that Canada employ an industrial policy that is centred on intentionally mobilizing a whole-of-government policy mix towards the scaling up of a portfolio of domestic champions. This overarching goal should be the lens through which policymakers view all battery-related innovation policy, procurement policy, regulatory policy, infrastructure policy, trade policy, etc. Implementing this coordinated industrial policy would help to achieve the Net-Zero Advisory Body's recommended 'net-zero competitiveness goal' of Canada producing 30% of upstream materials and 10% of batteries and vehicles needed to meet North America's vehicle mandates.[101]

91 https://www.documentcloud.org/documents/20692829-2021-1-26-spi-to-tesla-6-properties
92 https://www.tesmanian.com/blogs/tesmanian-blog/tesla-uses-springpower-international-technology-to-produce-batteries-economically-and-environmentally
93 https://techcrunch.com/2021/05/04/tesla-taps-tiny-startups-tech-to-build-cheaper-cleaner-batteries/
94 https://electricautonomy.ca/2019/10/04/tesla-acquires-canadian-battery-specialist-hibar-systems/
95 https://businessinfocusmagazine.com/2015/04/a-powerhouse-of-precision/
96 https://www.newswire.ca/news-releases/government-of-canada-invests-in-the-success-of-canadian-innovators-827397347.html
97 https://unicontrols-inc.com/hibarpump/
98 https://thelogic.co/briefing/canadian-pleads-guilty-to-conspiring-to-sell-tesla-secrets-in-u-s-doj/
99 https://www.justice.gov/opa/pr/owners-china-based-company-charged-conspiracy-send-trade-secrets-belonging-leading-us-based#:~:text=Klaus%20Pflugbeil%2C%2058%2C%20a%20Canadian,a%20leading%20U.S.%2Dbased%20electric
100 https://search.open.canada.ca/grants/?sort=agreement_value+desc&search_text=springpower&page=1
101 Net-Zero Advisory Body (NZAB). (2023). Compete and Succeed in a Net-Zero Future. Annual report to the Minister of Environment and Climate Change

Best Practices

Countries who have secured battery innovation leadership have industrial policy lessons to offer Canada. These countries have successfully practiced 'networked industrial policy' to align public and private efforts at each stage of the supply chain.[102] This approach prioritizes innovation investments to scale up the technological capabilities of domestic firms to capture leadership in value-added niches in global supply chains. This involves public-private collaboration in designing supports, as well as long-term investment and planning to align policy measures impacting both supply-side inputs to innovation and demand-side market pull for innovative products.[103] This approach conceptualizes a more active role for the state in driving innovation, moving beyond simply fixing market failures with non-targeted market framework interventions (tax credits for R&D underspending, regulations for environmental harm, and education spending for skills shortages). Networked industrial policy involves targeted, technology-specific efforts to strengthen systems, create networks, develop institutions and align strategic priorities.[104] This reflects the networked character of innovation in modern supply chains, where firms must source and build innovative capabilities through long-term coordination within their supply-chain and with public research bodies, rather than solely through traditional, short-term contracting or complete vertical integration.[105]

The networked approach to industrial policy involves the government creating "bridging organizations that bring together network participants, including government and higher education institutions, to strategize about what kinds of investments and what new initiatives might be useful to strengthen the networks for the future."[106] While the main focus of many of these organizations is facilitating cooperative R&D projects (ex: Japan's NEDO or the EU's Batt4EU), the collaborative space opened up by these public-private forums also enable information sharing and dialogue to coordinate how the broader mix of demand-side and supply-side policy instruments can be optimized to enable the scaling up of innovative battery firms and the achievement of innovation targets. The roadmap key actions below deliver on that networked approach.

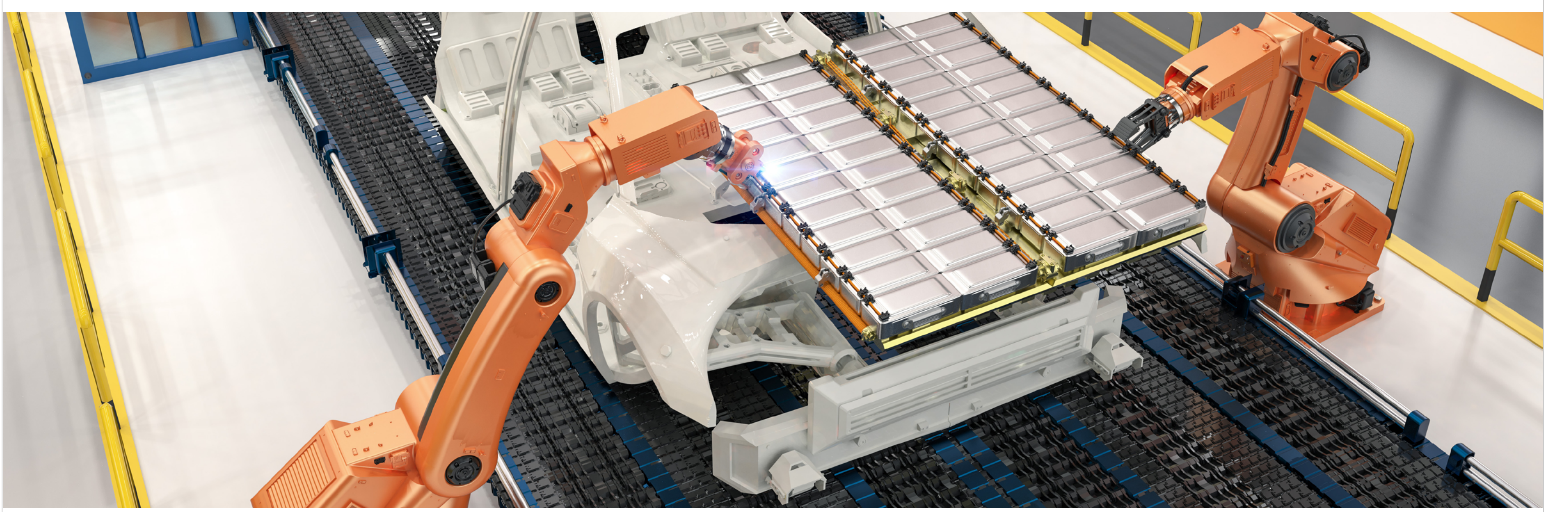
102 Keller, M. R., & Negoita, M. (2013). Correcting network failures: the evolution of US innovation policy in the wind and advanced battery industries. Competition & Change, 17(4), 319-338.
103 Elena Goracinova, Patrick Galvin and David A. Wolfe. Emerging models of networked industrial policy: recent trends in automotive policy in the USA and Germany. Int. J. Automotive Technology and Management, Vol. 22, No. 1, 2022.
104 Elena Goracinova, Patrick Galvin and David A. Wolfe. Emerging models of networked industrial policy: recent trends in automotive policy in the USA and Germany. Int. J. Automotive Technology and Management, Vol. 22, No. 1, 2022.
105 Block, F., Keller, M. R., & Negoita, M. (2020). Network failure and the evolution of the US innovation system. Journal of Industry, Competition and Trade, 20(2), 235-247, p. 239
106 Block, F., Keller, M. R., & Negoita, M. (2020). Network failure and the evolution of the US innovation system. Journal of Industry, Competition and Trade, 20(2), 235-247, p. 239

Global Battery Strategies

China	United States	European Union	South Korea	Japan
SETTING TARGETS				
Production Targets				
• Raise domestic content of core components and materials to 40% by 2020 and 70% by 2025	• Capture 60% of domestic demand by 2030	• Capture 90% of domestic demand (550 GWh) by 2030 • 2030 targets for domestic critical mineral extraction (10%), processing (40%), recycling (25%)	• 40% of global battery market and 20% of materials/parts/equipment market by 2030 • 4x cathode production capacity and triple exports of battery-making equipment the next five years	• 600 GWh (or 20% share of the global battery market) by 2030 • 150GWh domestic production by 2030
Innovation Targets				
• Next-gen battery energy density of 500 Wh/kg by 2025	• Solid-state and Li-metal production cost <60 $/kWh, 500 Wh/kg, cobalt/nickel-free by 2030	• Increase energy density (+60% compared to 2019 values) • Reduce cost by 60% compared to 2019 values • Improve cycle lifetime (at least by a factor of 2 compared to 2019)	• 800 km single charge by 2026 • Lithium-sulfur batteries commercialized by 2025, solid-state by 2027, and lithium-metal by 2028 • Recycling 100% domestic secondary battery closed-loop by 2030	• Full commercialization of solid-state batteries by 2030
BATTERY ROADMAPS				
• Made in China 2025 (2015) • Action Plan towards the Development of Automotive Power Battery Industry (2017) • NEV Industry Development Plan (2020) • The 14th Five-Year Plan > National Key R&D Program (2021)	• Energy Storage Grand Challenge Roadmap (2020) • National Blueprint for Lithium Batteries (2021)	• Strategic Action Plan for Batteries (2018) • Batteries Europe: SRA (2020) • BEPA Batt4EU: SRIA (2021) • Green Deal Industrial Plan (2023) • EU Batteries Regulation (2023) • Update of the SRIA (2024)	• K-Battery Development Strategy (2021) • Innovation Strategy on Secondary Battery Industry (2022) • Post-IRA Public-Private Joint Strategy for Battery Industry Development (2023)	• Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (revised in 2021) • Battery Industry Strategy (2022)

Global Battery Strategies

	China	United States	European Union	South Korea	Japan
INDUSTRIAL POLICY MIXES AND COORDINATION FORUMS					
Supply Push	• Joint Venture FDI requirements • R&D investments • Loans for mineral supply chain	• DoE R&D funds • DoE Loan Program • IRA tax credits	• Horizon Europe R&D • European Investment Bank • Important Projects of Common European Interest	• Public-private ‘battery alliance’ R&D fund • Loans & guarantees for critical minerals • Battery-specific tax credit bonuses	• NEDO R&D consortiums
Demand Pull	• Transit procurement • Purchase subsidies • EV mandate & credit system	• IRA EV consumer incentive thresholds for domestic supply chains	• Procurement thresholds for domestic supply chains • Fit-for-55 2035 ICE phase out • EU Batteries Regulation	• EV purchase incentive technical eligibility criteria	• EV infrastructure investment
Public-Private Coordination	• China EV100	• Li-bridge	• European Battery Alliance • InnoEnergy • BATT4EU	• Korean Battery Alliance	• Storage Battery Industry Strategy Council



China

Targets

China's ascent to EV battery dominance illustrates the importance of setting clearly articulated targets. For example, 2015's "Made in China 2025" plan called for reaching 80% EV share in total Chinese car sales and 20% share in the total vehicle stock by 2025.[107] Importantly, domestic production ambitions animated these consumer adoption goals, as seen by the "Made in China 2025" plan declaring "New Energy Vehicles" (NEV) as one of seven "strategic emerging industries" targeted by China's industrial policy where domestic content of core components and materials should rise to 40% by 2020 and 70% by 2025. Consumer adoption targets were updated in 2020's NEV Industry Development Plan such that by 2035, NEVs shall account for more than 50% of total vehicle sales, with pure electric vehicles accounting for more than 95% of NEVs and vehicles in public sector will be fully electrified.[108] Technology-specific goals include achieving by 2025 energy density on cell level reaching 500 Wh/kg in next generation batteries (ex: lithium-sulfur batteries, metal-air batteries, and solid-state batteries).[109] This goal was articulated in 2017's Action Plan towards the Development of Automotive Power Battery Industry.

Policy Mix

China's approach to supporting innovative battery firms as they scale illustrates the power of an industrial policy that utilizes a wide range of supply and demand-side instruments in a coordinated fashion. Supply-side measures included upstream subsidies for critical minerals to foster strategic alignment of the whole value chain, R&D grants to facilitate triple helix innovation collaboration, and joint venture requirements for foreign direct investment to enable technology transfer to Chinese firms.[110] Demand-side measures provided steady revenue to Chinese battery firms like BYD[111] and CATL[112] as they scaled their technologies, including local content requirements for purchase incentives and for EV procurement (municipal transit). Particularly influential were the eligibility requirements for subsidies requiring batteries from approved (non-foreign) suppliers via 2015's 'Battery Whitelist', which were subsequently ratcheted up via technology-specific performance requirements to further stimulate innovative competition among domestic suppliers.[113] As consumer incentives were gradually replaced by regulations forcing producers to produce a percentage of EVs, domestic firms continued to be favoured, as only domestic firms could trade EV production compliance credits.[114] This combination of subsidizing the supply-side inputs to battery innovation while stimulating the demand-pull for Chinese-made batteries enabled firms to bridge the commercialization 'valley of death.' Finally, these firms also benefitted from access to patient capital in the form of loans from state-owned banks and equity investment from public funds, such as the government of Hefei mobilizing 11.26B yuan to acquire a 24.1% stake in NIO, a now prominent EV maker who, at the time, was facing financial issues five years into its life.[115]

107 Gong, H., & Hansen, T. (2023). The rise of China's new energy vehicle lithium-ion battery industry: The coevolution of battery technological innovation systems and policies. Environmental Innovation and Societal Transitions, 46, 100689.
108 https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2024/benchmarking-international-battery-policies_2024.pdf p. 76
109 https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2024/benchmarking-international-battery-policies_2024.pdf p. 76
110 http://docs.dpaq.de/12007-european_chamber_cm2025-en.pdf p. 43
111 Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press; Altenburg, T., Corrocher, N., & Malerba, F. (2022). China's leapfrogging in electromobility. A story of green transformation driving catch-up and competitive advantage. Technological Forecasting and Social Change, 183, 121914.
112 https://www.wardsauto.com/technology/battery-supplier-catl-riding-crest-ev-wave
113 Gong, H., & Hansen, T. (2023). The rise of China's new energy vehicle lithium-ion battery industry: The coevolution of battery technological innovation systems and policies. Environmental Innovation and Societal Transitions, 46, 100689.
114 http://docs.dpaq.de/12007-european_chamber_cm2025-en.pdf p. 43
115 Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press.

Coordination

Public-private forums and independent intermediaries for information exchange are an essential element of China's industrial policy approach for battery innovation. China EV100[116] was created in 2014 to unite supply chain actors, including 178 domestic and 37 foreign members from government, upstream and downstream producers, and academia. Headed by the former deputy director of the Development Research Centre of the State Council, the organization coordinates roadmaps for technology development and diffusion, such as a report in 2019 to spearhead the policy discussion on the timetable of full electrification of vehicles.[117]

United States

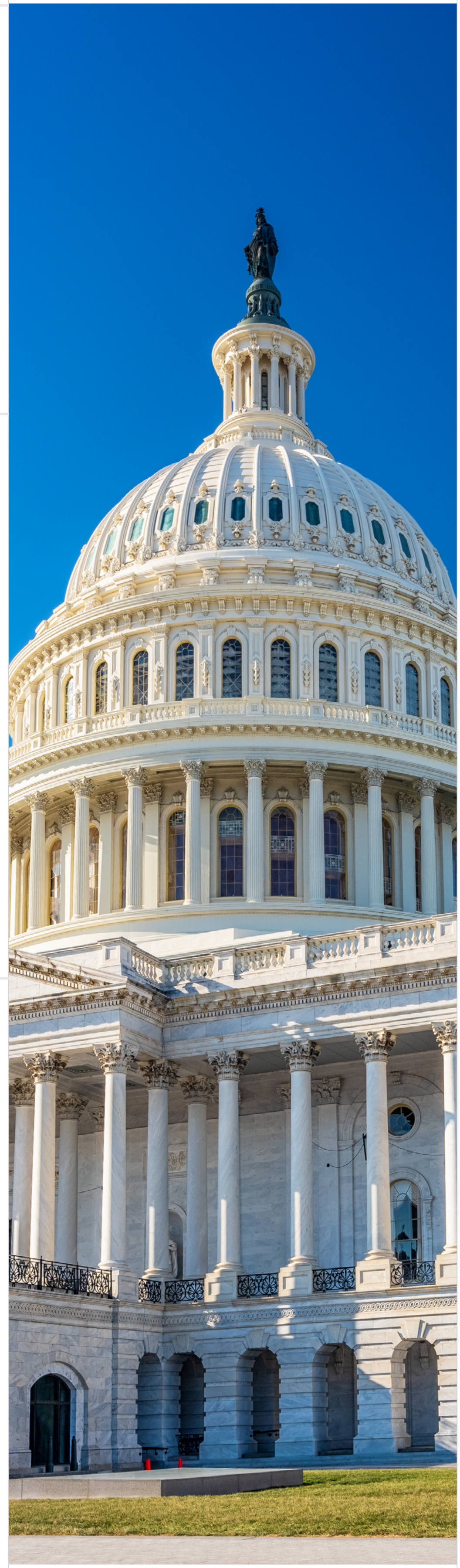
Targets

Following President Biden's 100-day executive order on February 2021, the Departments of Energy, State, Commerce and Defense set battery targets via the Federal Consortium for Advanced Batteries' (FCAB) National Blueprint for Lithium Batteries, 2021 – 2030 (June 2021). The document set a goal that "by 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term U.S. economic competitiveness and equitable job creation, enables decarbonization, advances social justice, and meets national security requirements."[118] This goal was subsequently refined in consultation with industry via Li-Bridge (discussed below): "by 2030 the United States can capture 60% of the economic value consumed by U.S. domestic demand for lithium batteries ($33B value-added; 100,000 direct jobs), up from the 30% domestic value-added most likely to result from doing business as usual."[119] Finally, the 2021 FCAB National Blueprint for Lithium Batteries also laid out technology specific goals, aiming by 2030 to "accelerate R&D to enable the demonstration and at-scale production of revolutionary battery technologies including solid-state and Li-metal, that achieve a production cost of less than $60/kWh, a specific energy of 500 Wh/kg, and are cobalt- and nickel-free" and to achieve 90% recycling of consumer content by 2030.[120]

Policy Mix

Contrary to its reputation as a purely free market economy, the US government's longstanding active support of innovation is recognized by industrial policy scholars as the archetypal networked industrial policy.[121] Supply-side inputs to innovation are coordinated amongst private and public actors through programs such as the US Department of Energy's (DOE) Advanced Research Projects Agency - Energy (ARPA-E) to commercialize early stage R&D in targeted fields of strategic importance.[122]

ARPA-E battery programming has included 2010's Batteries for Electrical Energy Storage in Transportation (BEEST) initiative. Firms were brought together by the government to do collaborative R&D towards the goal of EV/ plug-in hybrid EVs equaling or exceeding



116 http://www.chinaev100.com/
117 Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press.
118 https://www.energy.gov/sites/default/files/2021 p. 5
119 https://www.anl.gov/sites/www/files/2023-02/Li-Bridge%20Industry%20Report_2.pdf p. 7
120 https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf p.22; https://www.energy.gov/eere/vehicles/funding-selections-bipartisan-infrastructure-law-battery-recycling-reprocessing-and; https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html
121 Block, F. L., & Keller, M. R. (2011). State of innovation: the US government's role in technology development. Routledge.
122 Sabel, C. F., & Victor, D. G. (2022). Fixing the Climate: Strategies for an Uncertain World. Princeton University Press.

the price/performance of internal combustion engine cars.[123] For example, solid state battery innovator QuantumScape (850 employees and an initial public offering in 2020) originated from a BEEST- funded ($1.5M USD) project at Stanford University. The DOE's labs also provide American firms access to R&D facilities and over 10,000 in-house engineers/scientists. For example, the DOE's Battery 500 Consortium, founded in 2016, is led by Pacific Northwest National Laboratory, with partners from national labs, universities and industry.[124] The project aims to increase the specific energy (up to 500 Wh kg-1) of battery technology, achieve 1,000 charge/discharge cycles, and reduce the cost of cells to significantly less than $100 kWh-1.

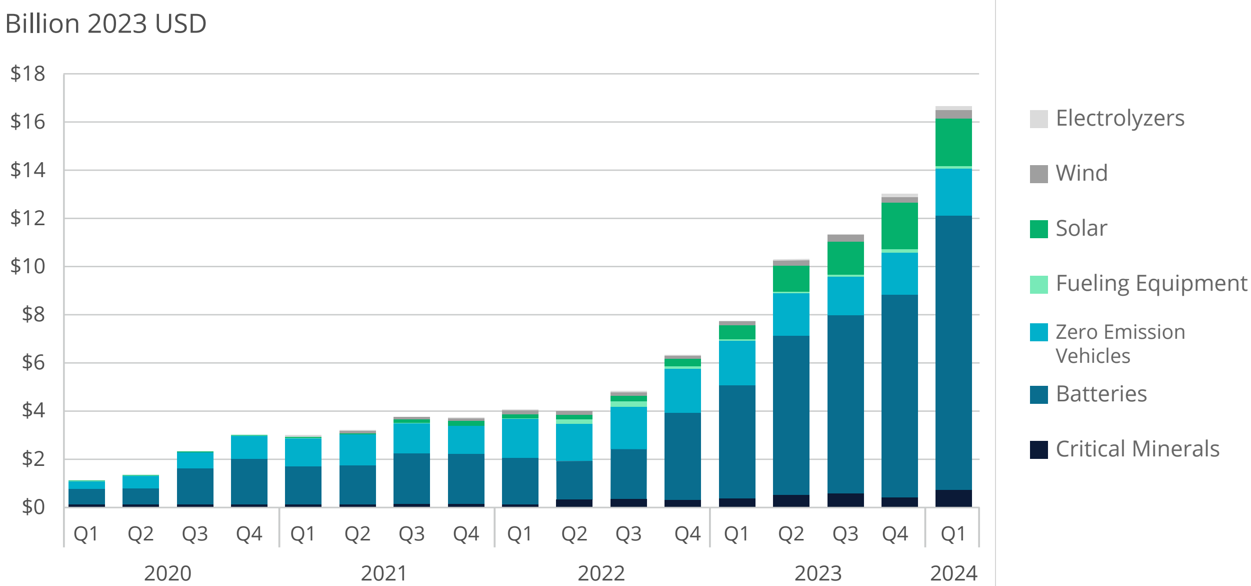
The Bipartisan Infrastructure Law (BIL) further bolstered supply-side R&D via nearly $7BUSD of battery-related grants. For example, the DOE's Office of Manufacturing and Energy Supply Chains (MESC), established in 2022 allocates R&D and demonstration award sizes of $50M USD to $300M USD, requiring at least 50% private sector cost share.[125] The grants are targeted towards commercial-scale domestic production in specific areas of interest in Battery Materials Processing Grants (Lithium Separation from Domestic Sources; Recovery of Battery Critical Minerals (non-Lithium); Processing of Battery Material Precursors), as well as Battery Manufacturing (Battery Cathodes and Anodes; Electrolyte Salts and Electrolyte Solvents; Cell Manufacturing for Small and Specialized Markets; Non-Lithium Based Battery Cell and Systems).[126] The first allocation in October 2022 of $2.8B USD yielded $6.2B USD of private investment from 20 companies, catalyzing the creation of "commercial-scale facilities in 12 states to extract and process lithium, graphite and other battery materials, manufacture components, and demonstrate new approaches, including manufacturing components from recycled materials."[127] The BIL grants for battery recycling allocated from the DOE's Vehicles Technology Office also exhibit principles of networked industrial policy, de-risking innovation via shared R&D investment between multiple companies, universities, and federal labs.[128] This thickens innovation networks, catalyzing the formation long-term alliances between partners with mutually beneficial capabilities. The BIL also bolstered investment in later stage technology readiness level (TRL) deployment via the $26B USD Department of Energy Office of Clean Energy Demonstrations (OCED). The BIL's funding for large scale demonstrations helps transition private-public energy R&D between early-stage technology readiness levels (ex: ARPA-E) to later stage deployment programs (ex: DOE Loan Programs Office, whose budget was increased tenfold by the Inflation Reduction Act, from $40B USD to $400B USD).

Demand-side instruments such as consumer incentives, regulations, and standards are also used to drive domestic battery innovation.

Demand-side instruments such as consumer incentives, regulations, and standards are also used to drive domestic battery innovation. The Inflation Reduction Act (IRA) introduced consumer tax credits for the purchase of EVs and production tax credits for producers of EV components, with the eligibility requirements for both tied to domestic production thresholds for battery and critical mineral components. Eligibility for the $3750 USD credit requires that at least 40% of the value of critical minerals for batteries be from the United States or an American free-trade partner, rising to 80% in 2027.[129] Eligibility for another $3750 USD credit requires 50% of the value of the battery components to be manufactured or assembled in North America, rising to 100% by 2029.[130] This demand-signal for American-made batteries has sparked a dramatic increase in clean energy manufacturing.

123 Goracinova, E., Galvin, P., & Wolfe, D. A. (2022). Emerging models of networked industrial policy: recent trends in automotive policy in the USA and Germany. International Journal of Automotive Technology and Management, 22(1), 29-51, p. 40.
124 https://www.pnnl.gov/innovation-center-battery500-consortium
125 https://www.energy.gov/mesc/battery-manufacturing-and-recycling-grants
126 https://www.energy.gov/mesc/battery-manufacturing-and-recycling-grants
127 https://www.energy.gov/articles/biden-harris-administration-awards-28-billion-supercharge-us-manufacturing-batteries
128 https://www.energy.gov/eere/vehicles/funding-selections-bipartisan-infrastructure-law-battery-recycling-reprocessing-and
129 https://home.treasury.gov/news/press-releases/jy1379
130 https://home.treasury.gov/news/press-releases/jy1379

Manufacturing investment by technology, actual investment



Source: Rhodium Group/ MIT-CEEPR Clean Investment Monitor (2024)[131]

As this figure illustrates, the majority of investment has been in the battery supply chain (ex: $14B or 85% in Q1 2024). Regulations such as treasury guidance on eligibility for production tax credits and consumer EV tax credits (i.e. defining 'foreign entities of concern' for domestic content eligibility) both favour domestic production.[132] Regarding standards, the Critical and Emerging Technology Standards Strategy (May 2023) works to influence international standards-setting to create markets for American made technology developed through federal R&D in 'critical and emerging technologies' (such as batteries).[133]

Coordination

The Biden-Harris administration has created new forums for public-private coordination of industrial policy for batteries. Whole of government coordination is facilitated though the American Battery Material Initiative (AMBI). Created in 2022, AMBI is "a dedicated effort to align Federal investments and activities, domestic and international, to accelerate the development of the full end-to-end battery supply chain."[134] DOE leads the initiative with support from the Department of State, the Department of the Interior, and the Partnership on Global Infrastructure. AMBI seeks "to align and leverage dozens of programs and efforts across the Federal government to support and grow the battery supply chain, including resources through the Bipartisan Infrastructure Law and Inflation Reduction Act...[and] coordinate domestic and international efforts to accelerate permitting for critical minerals projects."[135]

Industry-government coordination is pursued through Li-Bridge. Created in October 2021, Li-Bridge brings together the battery expertise of DOE Argonne National Laboratory (ANL) and three U.S. trade associations to "convene leading experts in lithium battery technology from throughout the North American industry in order to provide their advice to the U.S. government."[136] Participating firms represented upstream (i.e.: minerals), midstream (i.e.:

131 https://www.cleaninvestmentmonitor.org/reports/clean-investment-monitor-q1-2024-update p. 6
132 https://home.treasury.gov/news/press-releases/jy1939
133 https://www.whitehouse.gov/wp-content/uploads/2023/05/US-Gov-National-Standards-Strategy-2023.pdf
134 https://www.energy.gov/articles/biden-harris-administration-awards-28-billion-supercharge-us-manufacturing-batteries
135 https://www.energy.gov/articles/biden-harris-administration-awards-28-billion-supercharge-us-manufacturing-batteries
136 https://www.anl.gov/sites/www/files/2023-02/Li-Bridge%20Industry%20Report_2.pdf p. 5

cathode and anode), and downstream (i.e.: cell manufacturers, utilities) segments of the supply chain who collectively had over $900B USD in annual revenue and 1M employees. The resulting battery roadmap (Feb. 2023) had 26 recommendations that were formulated via numerous forums where thematic committees prepared analysis in advance and afterwards. The focus areas included the following: Technology, Innovation & Transparency; Manufacturing & Infrastructure; Demand, Supply and Availability; Workforce & Communities; Economic Competitiveness & Differentiation; and Go-Forward Operating Model. The committees met over a 6-month period and "consisted of six to eight members drawn from companies selected by the Boston Consulting Group with the goal of including on each committee companies representing a cross section of the entire lithium battery supply chain."[137]

European Union

Targets

The Net-Zero Industry Act sets overall goals for domestic manufacturing capacity of net-zero technologies (such as solar photovoltaic panels, wind turbines, batteries and heat pumps) of reaching 40% of the EU's deployment needs, as well as a target for an increased Union share for these technologies with a view to reaching 15% of world production by 2040.[138] The Act also contains a battery specific target: "aim to meet almost 90% of the Union's battery annual demand by the Union's battery manufacturers, meaning a Union manufacturing capacity of at least 550 GWh by 2030."[139] Other targets include the EU Batteries Regulation (2023) setting mandatory recycling targets (collection of waste, minimum percentage share of recovered materials from waste, recycling efficiency, recovery of materials) and carbon footprint declaration requirements for specific battery types.[140] Finally, the Critical Raw Materials Act aims to diversify critical raw materials by setting 2030 benchmarks for domestic critical mineral extraction (10%), processing (40%), recycling (25%), and no more than 65% of the EU's annual consumption from a single third country.[141]

Policy Mix

The EU's approach to industrial policy for batteries includes both supply-side and demand-side policies to secure resilient domestic supply chains. On the supply-side, the battery industry received at least €1.7B in EU grants and loan guarantees between 2014 and 2020, on top of state aid of up to €6B authorized between 2019 and 2021.[142] Battery R&D is primarily funded by Horizon Europe. This funding is coordinated along the battery supply chain via the public-private body Batteries European Partnership (Batt4EU). Formed in 2021, Batt4EU is a public-private partnership between the European Commission, the battery industry, research organizations and related associations. Batt4EU published the Strategic Research and Innovation Agenda (SRIA) in June 2021 (updated in 2024) to identify promising areas for battery innovation investment and to coordinate research and commercialization efforts along the industrial value chain over different Technology Readiness Levels (TRLs).[143] These priorities inform the allocation of up to €925M earmarked in Horizon Europe calls for battery research projects.

137 https://naatbatt.org/li-bridge-and-the-age-of-electricity/
138 https://www.consilium.europa.eu/en/press/press-releases/2024/05/27/industrial-policy-council-gives-final-approval-to-the-net-zero-industry-act/
139 https://data.consilium.europa.eu/doc/document/ST-9218-2024-INIT/en/pdf p. 18
140 https://environment.ec.europa.eu/news/new-law-more-sustainable-circular-and-safe-batteries-enters-force-2023-08-17_en
141 https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en
142 https://www.euractiv.com/section/energy-environment/opinion/europes-strategy-on-battery-innovation-is-more-relevant-than-ever/
143 https://bepassociation.eu/our-work/sria/

The EU has also created various supply-side programs for later stage demonstration and large-scale deployment. For example, the Important Projects of Common European Interest (IPCEIs) instrument gives EU Member States the opportunity to support large-volume production facilities for innovative products. The EU Commission sets the framework conditions and monitors compliance. The Member States must notify EU Commission for approval to use state aid to fund these projects. There have been two battery production IPCEIs (in 2019 and 2021) accounting for €6.1B in total support by paid by the 12 participating Member States to more than 50 companies who are pledging €14B in private investment. The EU also expanded the scope and size of the Innovation Fund from €450M to approximately €530M.[144] The Innovation Fund is financed through the revenues of the European Emissions Trading System (ETS) and targets scale-up and deployment of innovative technology. For example, in the third call for large projects saw 4 battery projects (out of 41 in total) receive financing by the Innovation Fund. On December 6th 2023, the European Commission announced a dedicated instrument for the battery value chain under the Innovation Fund, potentially offering up to €3B.[145]

Further upstream on the supply-side, the EU's The Critical Raw Materials Act sets 2030 targets for domestic production of critical mineral extraction (10%), processing (40%), recycling (25%), and no more than 65% of the EU's annual consumption from a single third country.[146] Streamlining Permitting is also targeted under the Act, with timeframes for extraction permits capped at 27 months, and processing and recycling permits capped at 15 months. Other supply-side policies provide financing for scaling up of battery production, such as the European Investment Bank (EIB). For example, EIB's early loans to Northvolt (€52.5M in 2018 and €350M in 2019) supported its Vasteras factory, unlocking follow-on investments from the Ikea Foundation, Goldman Sachs, and VW. The company also secured an additional €942.6M loan in 2024 for its gigafactory in Northern Sweden.[147]

Demand-side instruments also aim to create markets for domestic producers. For example, the EU Batteries Regulation (July 2023) aims to establish minimum sustainability standards and extended producer responsibility for batteries.[148] This would introduce circular economy principles (ex: minimum recycled content) and mandatory sustainability requirements (carbon footprint rules, performance, safety and durability criteria). For example, targets for recycling efficiency, material recovery and recycled content will be introduced gradually from 2025 onwards. The act will also create a battery passport to inform consumer choices. This builds on the Circular Economy Action Plan's (2020) identification of "batteries and vehicles" as one of the seven key product value chains.[149] Procurement is another demand-side tool that the EU is utilizing to stimulate a market for battery technology. The Net-Zero Industry Act contains provisions expanding the ability to add sustainability and mandatory domestic sourcing thresholds in procurement contracting.[150] There are also provisions to create penalties for contractors in the event of non-observance of those resilience requirements.

Coordination

Early public-private coordination occurred through the European Commission's creation of the European Battery Alliance (EBA) in 2018. The EBA worked closely with InnoEnergy, an independent investment vehicle and research house, to create a battery strategy. The

144 https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/what-innovation-fund_en
145 https://bepassociation.eu/our-work/sria/ p. 25
146 https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en
147 https://www.eib.org/en/press/all/2024-011-eib-finances-northvolt-s-battery-factory-with-over-usd1-billion
148 https://environment.ec.europa.eu/news/new-law-more-sustainable-circular-and-safe-batteries-enters-force-2023-08-17_en
149 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html
150 https://data.consilium.europa.eu/doc/document/ST-9218-2024-INIT/en/pdf

pathbreaking work highlighted six strategic action areas all along the value chain: Securing the sustainable supply of raw materials; Supporting European projects covering different segments of the battery value chain, including cells manufacturing; Strengthening industrial leadership through stepped-up EU research and innovation support covering the full value chain; Developing and strengthening a highly skilled workforce in all parts of the value- chain; Supporting a sustainable battery value chain – ie requirements for safe and sustainable batteries production - as a key driver for EU competitiveness; and Ensuring consistency with the broader enabling and regulatory framework.[151] The research and innovation parts of the European Battery Alliance were organized under Batteries Europe,[152] which includes over 700 research (37%), industry (46%), and academic/other (17%) members. Batteries Europe is the European Technology & Innovation Platform (ETIP) on batteries in charge of implementing the battery related research and innovation priorities identified by the EU's Strategic Energy Technology (SET) Plan, the 2007 strategy that structured joint research and innovation actions among Member States for clean energy.[153]

Research and innovation funding in the EU is organized under Horizon Europe, passed in December 2020 with a €95.5B budget for the 2020-2027 period.[154] Batteries European Partnership (Batt4EU) was created in June 2021 to guide the allocation of up to €925M earmarked in Horizon Europe for calls for battery research projects. Batt4EU is a Co-programmed Partnership established between the European Commission and Batteries European Partnership Association (BEPA) under Horizon Europe – the Framework Programme for Research and Innovation of the European Union.[155] BATT4EU is governed by the Partnership Board, which is made up of private (BEPA's Association Delegation) and public (European Commission) delegates. BEPA was launched in 2020 by industry to group together all relevant firms along the battery supply chain. The expert working groups of Batteries Europe and BEPA have been replaced by a single set of joint working groups in coordination with Batt4EU. To create a continuous workflow between the road mapping exercises by Batteries Europe and the preparation of the Horizon Europe Work Programme by BATT4EU, the expert working groups of BEPA and Batteries Europe have been integrated with a joint governance structure and shared strategy to gain efficiency and synergies among the initiatives."[156]

BATT4EU serves as an important information flow channel for industry (BEPA) to provide input to help identify R&D priorities and call topics for the Horizon Europe Work Programs.[157] This input is conveyed via the 2021 and 2024 versions of the Strategic Research and Innovation Agenda (SRIA), which is the result of input collected by the Batteries European Partnership Association (BEPA) and Batteries Europe from hundreds of European battery experts organized in six Working Groups, each covering different battery topics.[158] BATT4EU's Strategic Research and Innovation Agenda (Feb. 2024) "builds heavily" on the Roadmaps that have been published by the Batteries Europe[159] and Battery 2030+[160] projects.[161] The working groups include: New and Emerging Technologies; Raw materials and Recycling; Advanced Materials; Cell Design and Manufacturing; Mobility Applications and Integration;

151 European Commission. 2018. EUROPE ON THE MOVE Sustainable Mobility for Europe: safe, connected and clean. Annex 2 – Strategic Action Plan on Batteries. https://www.eumonitor.eu/9353000/1/j4nvhdfcs8bljza_j9vvik7m1c3gyxp/vkofgxoczgwu
152 https://batterieseurope.eu/
153 https://research-and-innovation.ec.europa.eu/document/download/e86c56bb-fd23-485e-9ee5-3b3031f32d12_en?filename=com_2023_634_1_en_act_part1.pdf
154 https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/how-horizon-europe-was-developed_en
155 https://pr.euractiv.com/pr/batt4eu-new-milestone-more-competitive-and-sustainable-eu-battery-value-chain-218839
156 https://bepassociation.eu/our-work/sria/ p. 25
157 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html
158 https://bepassociation.eu/our-work/sria/
159 https://batterieseurope.eu/results/technology-roadmap/researchandinnovationroadmap-2023/
160 https://battery2030.eu/
161 https://bepassociation.eu/our-work/sria/

and Stationary Applications and Integration.[162] These working groups identified the strategic priority areas identified in the Strategic Research and Innovation Agenda (SRIA): Raw Materials, Advanced Materials, Design, Manufacturing, Mobility, Stationary storage, and Dismantling and Recycling.[163] The SRIA lays out a multi-year agenda and implementation plan for each priority area identified, which is an assessment on which research projects will benefit from funding under the BATT4EU umbrella. This is complemented with an annex that provides a full set of Key Performance Indicators that quantify the current state- of-art of battery research in Europe and that sets the targets for the short and midterm.

The BATT4EU Partnership cooperates with other partnerships to cover the whole value chain, such as raw materials extraction and production with the European Raw Materials Alliance or with application-oriented initiatives, namely 2Zero (road transport), ZEWT (waterborne), Clean Aviation and Europe's Rail. While Batt4EU R&D projects cover the whole battery supply chain, "advanced materials and battery cell design and manufacturing are seen as the key activities of the partnership."[164] In terms of TRLs, BATT4EU projects focus on both of close-to-market Li-ion technologies (TRL 5-8), as well as new promising and longer-term breakthrough technological solutions (TRL 2-4).[165] Batt4EU extends beyond the primary task of guiding battery research funding (discussed above). The organization also serves as a coordination mechanism to support "standardisation efforts and the development of the battery regulation, ensuring a wide dissemination of the research results and contributions to the education and upskilling of the workforce."[166]

Finally, Batt4EU's SRIA document also articulates coordination activities that Batt4EU will undertake to strengthen the battery innovation ecosystem.[167] First, Batt4EU will build an information observatory to provide accurate and up-date information on key metric and the state-of-art concerning various key technologies. Second, it will utilize the information observatory to build strategic roadmaps that foster exchanges between experts in different parts value chain to "understand causal relationships between the different research needs in the different sectors, including on cross-cutting activities such as safety, digitization and sustainability."[168] Third, concrete actions for 'broadening and deepening Europe's excellent R&I community' include organizing clustering events for projects to learn from each other sharing best practices with the community and push for adoption of common data standards and reporting methodologies, organizing high-level events where researchers, industrial developers and policy makers meet to discuss the most pressing research needs, and creating benchmarks of the European battery innovation ecosystem with ecosystems elsewhere in the world and draft recommendations for improvement. Fourth, promoting innovation uptake includes informing Partnership projects of funding mechanisms for technology scale up, providing training and mentoring to early-stage research projects on IP management and business cases, creating research-to-business matchmaking events with other EU battery funding programs (ex: IPCEIs) and investors. Fifth, education and skills building activities include promoting information sharing across projects on skills gaps, developing European-wide curricula and standards for providing access to research infrastructures, and programs to foster geographic mobility of researchers across the EU. Finally, engagement with NGOs and civil society will enable public education on batteries by sharing access to the information observatory, and the development of an educational toolkit on existing myths around battery performance, sustainability and safety.

162 https://bepassociation.eu/our-work/technical-working-groups/
163 https://bepassociation.eu/our-work/sria/
164 https://bepassociation.eu/our-work/sria/ p. 86
165 https://bepassociation.eu/our-work/sria/ p. 86
166 https://bepassociation.eu/our-work/sria/ p. 25
167 https://bepassociation.eu/our-work/sria/ p. 69
168 https://bepassociation.eu/our-work/sria/ p. 69

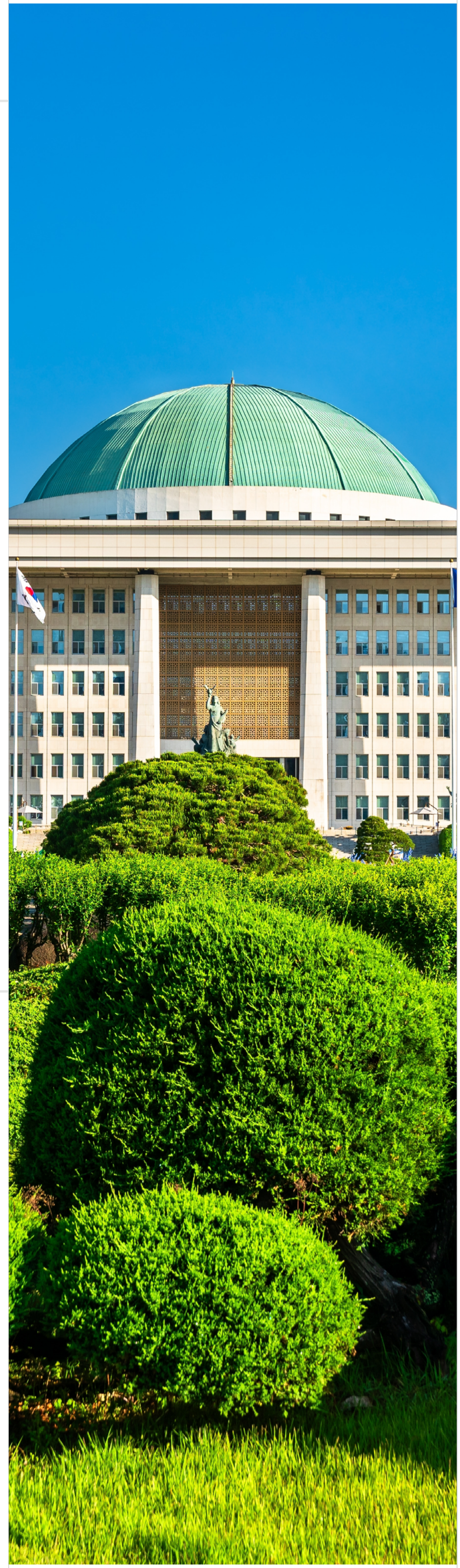
South Korea

Targets

South Korea's longstanding commitment to achieving technological leadership in batteries has positioned its firms to benefit from global demand growth, as well as industrial policy investments in other countries (ex: the US IRA). This commitment to technological leadership is encapsulated by President Lee Myung-bak's 2012 comments on the launch of an early Korean-made EV: "if this electric vehicle is of higher quality than the one from Japan, it is a great achievement. However, in the Green Growth era, it is important for us to have original technology [as] there is not much competitiveness to manufacturing products with others' technology."[169] This innovation emphasis continues to animate Korean battery investments, as evident in President Yoon Suk Yeol's 2023 comments while announcing 20T won ($15B USD) in battery R&D by 2030: "their importance cannot be stressed enough [as] batteries are at the center of the global competition for technological supremacy.. securing core next-generational technology will determine our fate in the future.. we have to maintain our competitiveness and 'super gap' with technological innovation."[170] Korea's K-Battery Development Strategy (2021) similarly emphasized innovation and export leadership, rather than merely domestic production. Specifically, the strategy aims by 2030 for battery sales of 166T won ($120B USD) (40% of the global market) and materials/parts/equipment sales of 60T won ($43B USD).[171] In terms of technology specific targets, the strategy aims to commercialize lithium-sulfur batteries by 2025, solid-state batteries by 2027, and lithium-metal batteries by 2028. Importantly, the strategy also sets targets for private sector investment of 20.1T won ($14.5B USD)[172] in R&D by 2030. This complements the 13.5T won ($9.8B USD) of public R&D investment committed for the same period. The goal of increasing the distance of an EV on a single charge up to 800 kilometers by 2026 was set in 2022 by the Secondary Battery Industry Innovation Strategy.[173] Upstream targets were set in 2023 via the government's new national strategy for strengthening the competitiveness of the secondary battery industry. This goal aims to quadruple the domestic production capacity of cathode materials (to 1.58 million metric tons) and triple the export of battery production-related equipment (3.5B won) over the next five years.[174]

Policy Mix

Korea's policy mix for battery innovation encourages the global expansion of innovative Korean battery firms via both supply-side and demand-side policies. On the supply-side, Korea's K-Battery Development Strategy (2021) built on Korea's long track record of deploying public R&D funds to leverage private investment via R&D consortiums. The strategy funds several large-scale R&D projects worth over 500B won ($360M USD) for early commercialization of next-generation batteries. R&D projects include leading battery firms such as LG Energy Solution (lithium-sulfur batteries, all-solid-state batteries), Samsung SDI (cobalt-free nickel-manganese batteries), and SK Innovation.[175] The strategy also connects large firms with innovative SMEs specializing in materials/parts/equipment for batteries in a manner that is consistent with networked industrial policy principles. The 80B won ($58M



169 Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press.
170 https://www.koreaherald.com/view.php?ud=20230420000698
171 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 66
172 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 69
173 https://www.kedglobal.com/batteries/newsView/ked202211020008
174 https://www.koreaherald.com/view.php?ud=20230420000698
175 https://batterieseurope.eu/wp-content/uploads/2023/06/Battery-Innovation-South-Korea_rev6.pdf

USD) program is partially funded (30B won) from the government (MOTIE), and partially funded (20B won) from three major battery firms (LG Energy Solution, Samsung SDI, and SK Innovation), in addition to 30B won from a private asset management company.[176] R&D funding was boosted in 2022 after a change in government via the Innovation Strategy on Secondary Battery Industry. The strategy will provide 1T won (approx. $723M USD) in R&D funding by 2030 to extend Korea's 'super-gap' in next-generation battery innovation. This funding is intended to leverage approximately 19.5T won (approx. $14.1B USD) from private companies. Finally, in 2023, MOTIE's new national strategy for strengthening the competitiveness of the secondary battery industry announced public-private joint R&D investment of 20T won ($14.5B USD) by 2030 for the development of technology to commercialize the world's first all solid-state battery for EVs, as well as 5 year investments of 150B won ($108M USD) of R&D for NCM batteries, 50B won ($36.2M USD) for LFP batteries, and 150B won ($108M USD) for ESS.[177]

Korea's supply-side programs go beyond direct R&D funding to include other policy tools. For example, the K-battery strategy also introduced higher tax credit rates (up to 50% for R&D expenditures and up to 20% for facility investment) for battery technology by adding it to the list of "National Strategic Technologies."[178] The bonus credits are tiered to favour SMEs and scale-ups (like the general R&D base credit), with SMEs receiving a higher percentage of eligible expenses than 'middle market enterprises' and 'major companies.'[179] Supply-side programs announced in April 2023's Post-IRA Public-Private Joint Strategy for Battery Industry Development support North American expansion of battery manufacturing and upstream battery materials through 7T won ($5B USD) worth of loans and guarantees as well as higher credit lines, interest rate cuts, lower insurance premiums and other financial incentives.[180] This includes tax credits, as well as lowering lending rates and insurance premiums by as much as 20%.[181] Demand-side instruments are also strategically deployed to support domestic firms. For example, EV purchase incentive eligibility requirements (cost, vehicle performance, after-sales service infrastructure and battery energy density) have been repeatedly adjusted to strategically favour domestic firms.[182]

Coordination

Industrial policy scholars have long pointed to Korea as a leader in utilizing public-private bodies to effectively exchange information and coordinate innovation investments.[183] The government has a long history of effectively leveraging public investment to catalyze private sector network formation, cooperation, and commitment to ambitious industrial policy targets. These coordination bodies have been termed 'hybridized industrial ecosystems' due to their bringing together of all the major public and private players in the production and innovation value chain.[184] For example, Korea Smart Grid Association

176 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 66
177 https://www.koreaherald.com/view.php?ud=20230420000698
178 https://batterieseurope.eu/wp-content/uploads/2023/06/Battery-Innovation-South-Korea_rev6.pdf
179 https://taxsummaries.pwc.com/republic-of-korea/corporate/tax-credits-and-incentives; https://english.moef.go.kr/pc/selectTbPressCenterDtl.do?boardCd=N0001&seq=5759
180 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 65
181 https://www.reuters.com/business/autos-transportation/south-korea-offer-53-bln-financing-support-battery-investment-north-america-2023-04-07/
182 Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press.
183 Evans P. 1995. Embedded Autonomy: States and Industrial Transformation. Princeton, NJ: Princeton Univ. Press; Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press
184 Kim, Sung-Young. "Hybridized industrial ecosystems and the makings of a new developmental infrastructure in East Asia's green energy sector." Review of international political economy 26.1 (2019): 158-182; Thurbon, E., Kim, S. Y., Tan, H., & Mathews, J. A. (2023). Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition. Oxford University Press.

(KSGA) was created in 2009 by the government, comprised of leading firms, and given official responsibility for formulating and implementing all national policies including technology roadmaps and commercialization for smart microgrids.

This coordination model is also employed in more recent battery industrial policy. For example, the Korean Battery Alliance announced in November 2022 as part of the Secondary Battery Industry Innovation Strategy serves as a forum to align public and private investments. The strategy includes an R&D spending commitment of 20.5T won ($14.8B USD) by 2030, with 1T won from the government and 19.5T won from leading Korean firms such as Samsung SDI Co., SK On, LG Energy Solutions Ltd.[185] This R&D will focus on the development of core battery technologies that help to increase the driving distance of an EV on a single charge up to 800 kilometers.[186]

Joint action goes beyond R&D to include other inputs to the innovation process, such as skilled labour. For example, the alliance aims to add an additional 16,000 employees to the Korean battery sector by 2030 by establishing an academy where the government will provide the infrastructure and the private sector will shape the curriculum. The alliance aligns the broader policy mix to fill upstream gaps in the supply chain, such as mapping and securing critical minerals, assisting the refining and smelting businesses, and mobilizing 3T won ($2.2B USD) in loans and guarantees for five year from the Korea Trade Insurance Corp. and the Export-Import Bank of Korea.[187] This complements the recent strengthening of broader S&T advisory mechanisms, such as the Special committee on the National Strategic Technology within the National Science and Technology Advisory Council. Created in 2023 by the Ministry of Science and ICT (MSIT), the Special Committee is a joint public-private deliberative body established to "closely communicate with government sectors involved in the development of national strategic technologies as well as experts from industry, academia, and research institutions in each technology field."[188]

Japan

Targets

Japan's Green Growth Strategy (2020) set the goal of domestic production capacity for in-vehicle batteries to 100GWh by 2030 and aiming to achieve a cumulative installation of approximately 24GWh for home-use and business/industrial-use storage batteries by 2030.[189] The Battery Industry Strategy (2022) increased this to achieving domestic capacity of 150GWh and global production by Japanese firms reaching 600 GWh (or 20% share of the global battery market) by 2030.[190] Importantly, this document also set technology-specific goals, such as achieving "full-scale commercialization of all-solid-state batteries around 2030 [while] Japan maintains and secures technology leader position even after 2030" via commercialization by 2035 of other new-generation high-performance battery chemistries (ex: fluoride batteries, zinc batteries and polyvalent ion batteries).[191] Finally, The Basic Plan for the GX: Green Transformation Policy (February 2023) set a goal of $44.5B USD (7T yen) of public-private investment in battery R&D and production and R&D over 10 years as part of a larger aspiration to achieve $935B USD (150T yen) of public-private investment in green transformation.[192]

185 https://www.reuters.com/article/idUSL4N31X27P/; https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2024/benchmarking-international-battery-policies_2024.pdf p. 67
186 https://www.koreatimes.co.kr/www/tech/2023/07/129_338997.html
187 https://www.kedglobal.com/batteries/newsView/ked202211020008
188 https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=&bbsSeqNo=42&nttSeqNo=787&searchOpt=ALL&searchTxt=
189 https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/index.html
190 https://batterieseurope.eu/wp-content/uploads/2023/06/Battery-Innovation-JAPAN_release.pdf; https://www.meti.go.jp/english/report/pdf/0520_001a.pdf
191 https://batterieseurope.eu/wp-content/uploads/2023/06/Battery-Innovation-JAPAN_release.pdf; https://www.meti.go.jp/english/report/pdf/0520_001a.pdf
192 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender...

Policy Mix

Japan's technology leadership in batteries is a result of both supply and demand-side industrial policy. Since the 1990s, Japanese firms gained access to a steady supply of innovative technology through the New Energy and Industrial Technology Development Organization (NEDO), the unit within the Ministry of International Trade and Industry (MITI) that coordinated collaborative energy R&D. Total battery R&D funding by NEDO between 2009–2022 is approximately $584M USD (92B yen).[193] Roughly $800M USD was budgeted to NEDO in 2021 from the Green Innovation Fund for collaborative R&D (TRL 4 to 7) in high-performance batteries.[194] NEDO's public R&D grants leverage private investment and in-kind secondments of experts from consortium members, including many of Japan's leading battery firms, alongside national research institutions and universities. NEDO's in-house technical expertise and 'relational skills' proved "instrumental in fostering information-sharing among companies which were simultaneously competing with one another."[195] For example, Toyota built a nickel–hydride battery with Matsushita while scientists from its subsidiary, Toyoda Automatic Loom, were developing a similar battery with Yuasa, one of Matsushita's competitors. More recently, the 2018-2022 solid-state battery project included collaborative R&D projects involving 23 companies, including Panasonic, Toyota, Nissan and Honda. The project's goals are to develop core solid-state technologies to reduce charging time to 10 minutes while lowering the battery pack cost to $90 per kWh by around 2030.[196] Scholars of networked industrial policy highlight NEDO as illustrating the importance of fostering consortium partners from separate yet intersecting industry verticals (ex: automotive firms learned from Sony's early use of batteries in consumer electronics), as well as the importance of geographic clustering, as "collaborative learning is difficult when relevant competencies are spatially isolated."[197] In some instances, foreign firms implementing a project must agree that NEDO holds more than a 50% share in the resulting intellectual property.[198]

Finally, an early demand-side instrument included the Japan Development Bank stimulating consumer adoption of EVs via infrastructure investment by creating a public-private consortia in 2014 to co-finance charging infrastructure. Public funds were leveraged to crowd in investment from leading automakers (Toyota Honda, Nissan, and Mitsubishi).[199] This program was followed up by METI's Promoting the Introduction of Clean Energy Vehicles and Infrastructure subsidies in 2021.[200]

Coordination

In addition to NEDO's coordination role discussed above, the Ministry of Economy, Trade and Industry (METI) created the Public-Private Storage Battery Industry Strategy Council in 2021.[201] The council's thirty members include: Government officials, such as the METI and the Agency for Natural Resources and Energy (ANRE); eight storage battery manufacturers

193 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 55
194 https://green-innovation.nedo.go.jp/en/about/; https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html
195 Keller, M. R., & Negoita, M. (2013). Correcting network failures: the evolution of US innovation policy in the wind and advanced battery industries. Competition & Change, 17(4), 319-338, p. 30.
196 https://chargedevs.com/newswire/toyota-nissan-honda-panasonic-partner-to-develop-solid-state-batteries/
197 Keller, M. R., & Negoita, M. (2013). Correcting network failures: the evolution of US innovation policy in the wind and advanced battery industries. Competition & Change, 17(4), 319-338, p. 30.
198 https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.allenovery.com/global/-/media/allenovery/2_documents/news_and_insights/publications/2021/06/nedo_green_innovation_funds_for_hydrogen_june_2021.pdf&ved=2ahUKEwjd77iHn9uGAxVjD1kFHUYICHQQFnoECBwQAQ&usg=AOvVaw1rKs9s5lCc1I3iI9uFyHDD
199 https://www.dbj.jp/en/topics/dbj_news/2014/files/0000016072_file1.pdf
200 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html p. 56
201 https://static1.squarespace.com/static/5988d560579fb39f04f76482/t/61d4a551f62803517bc14b29/1641325905214/JEPIC-USA+Newsletter+December+2021.pdf

(ex: Kyocera and Panasonic Energy); five battery component suppliers (ex: Nichia & Sumitomo Metal Mining); four industry experts and professors; four industry groups, including Battery Association of Japan (BAJ), Japan Electrical Manufacturers' Association (JEMA), Japan Automobile Manufacturers Association (JAMA), Battery Association for Supply Chain (BASC); and five observers.[202] A strategy document was prepared along four work themes: securing upstream resources; expanding and strengthening the production base of the supply chain; establishing rules for supply chain management; and commercializing the next-generation batteries and skills development.

202 https://static1.squarespace.com/static/5988d560579fb39f04f76482/t/61d4a551f62803517bc14b29/1641325905214/JEPIC-USA+Newsletter+December+2021.pdf

Roadmap Key Actions

CANADA - ROADMAP KEY ACTIONS	
EXISTING POLICIES	**PROPOSED POLICIES**
Targets	
NRCan & ISED Mandate Letters (2021) • "Develop a sustainable battery innovation and industrial ecosystem in Canada, including to establish Canada as a global leader in battery manufacturing, recycling and reuse"	**Scale-ups** • By 2035, increase the number of Canadian-owned firms in the battery sector by 10x who will contribute 20% of the North American battery value chain which includes materials, components, and technology
Roadmap	
• Mines to Mobility Strategy (2021, via Mandate Letters) • Critical Minerals Strategy (2023)	• This Battery Innovation Roadmap • More work is needed to map R&D priorities to the targets identified in this report
Supply-Push	
Financial Ecosystem • OERD R&D programs • SDTC • NRC IRAP • BDC/EDC • SIF • CGF • CIB • Global Innovation Clusters • Regional Development Agencies • Venture Capital Catalyst Initiative • Poloz Working Group (Budget 2024) **Innovation Infrastructure** • NRCan CANMET Labs • NRC labs • CFI funding for university labs	**Financial Ecosystem** • Establish a financial working group • Focus and align existing funding mechanisms • Launch a national Battery Technology Incubator Program • Expand OERD's funding program • Recommend that BDC develop and implement a strategic investment initiative • Ramp up investments by CIC and CGF • Create a network of regional green development banks **Innovation Infrastructure** • Build existing research centres • Launch three new battery research centres • Establish regional production clusters • Demonstration facilities • Build the national labs **Solve the scaling problem with smart, ambitious programs** • Scaling Fund at OERD • Large Demonstration Fund • Promote partnerships between start-ups and established firms

CANADA - ROADMAP KEY ACTIONS	
EXISTING POLICIES	**PROPOSED POLICIES**
Demand-Pull	
Regulations • ZEV Sales Target **Taxes** • Carbon Pricing **Procurement** • Greening Government Strategy **Consumer Incentives** • Federal and provincial ZEV purchase incentives	Nail the details and facilitate supply chain integration • Streamline regulatory processes for new battery technologies • International partnerships for standards and training. • Skills mapping • Integrate programs into industrial policy (incentives for local production in credit programs like iMHZEV) • Develop new standards for next generation battery materials Build Canadian exports • Recommend that EDC further tailor its programs to help companies navigate international markets
Public-Private Coordination	
• ZEV Council (Transport Canada)	**Get Canada's industrial policy process right** • National Battery Alliance • Small, nimble, government problem-solving team • Regional production clusters • Develop a Battery Ecosystem Intelligence Dashboard

Innovation Infrastructure

To compete in battery innovation, Canada needs to build its physical, financial, and human infrastructure. Physical infrastructure includes the laboratories, demonstration facilities, and production plants necessary to develop, improve, and commercialize technologies. Physical assets are the backbone of an innovation system. They provide the means by which researchers and firms advance technology. But they also create a focal point for knowledge formation and collaboration.

That knowledge formation and collaboration is the core of human infrastructure. Building skills and talent is an essential part of regional cluster development. Industries tend to cluster because they can share physical assets and pools of knowledge. That knowledge is formed through physical interactions between individuals.

Battery innovation does not just happen in the lab. Innovation also happens in commercialization and manufacturing, so having a skilled workforce all along the production pipeline supports a battery innovation ecosystem. Training for innovation in both basic research and process engineering is needed.

The financial infrastructure includes creating an ecosystem with a variety of types of grants, loans, and equity financing. The needs and pathways of each firm in the battery space is different and each will need a unique mix of financial elements in order to survive the valleys of death and reach scale. This funding infrastructure is as much a part of a firm's strategic landscape as physical assets are.

All these assets are underdeveloped due to the problems of Canada's scale-up infrastructure. Physical and human infrastructure tends to be built by homegrown firms, which co-locate R&D assets with their headquarters. Financial infrastructure helps to build such firms, but the profits from growth also helps build that infrastructure for others in the sector. Without a good financial ecosystem, Canada loses winners, which weakens the physical infrastructure.

Financial Ecosystem

Goal

$3B invested in battery innovation through public and private funding with the following breakdown; $500m for advanced manufacturing $1B for emerging technologies $1.5B for demonstrations and pre-commercialization projects (TRL6-9).

Actions

- Focus and enhance finance along the innovation to commercialization path
- Support increases in Business Expenditure in R&D (BERD) and early stage growth (5-8)
- Build funds to support demonstration and commercialization (TRL 7-11)
- Design smart policies and programs to support innovation

Focus and Enhance Finance Along the Innovation to Commercialization Path

2024–2026: Establish a financial working group to look at how the financial ecosystem is structured and understand barriers for private capital participation in the battery ecosystem.

With the goal of understanding why so many promising winners are lost, and why innovative firms in Canada struggle to scale, a public-private working group should be established to rigorously assess how the financial ecosystem works and doesn't work for battery companies. Establishing a financial working group is essential to address the persistent challenges that innovative battery firms in Canada face in scaling their operations due to limited access to private capital.

This group should assess the financial ecosystem to identify why so many promising companies struggle to secure necessary funding and scale effectively. By understanding the barriers that hinder private capital participation, the working group can develop targeted interventions and policies that encourage greater investment in the battery sector. Enhanced collaboration between public and private stakeholders will foster knowledge sharing and create a cohesive strategy to support financial growth and stability. Ultimately, this action will contribute to the sustainable growth and global competitiveness of Canada's battery industry.

2024–2026: Focus and align existing funding mechanisms to bolster Canadian homegrown innovation in the whole battery-automotive cluster. Funding agencies should have dedicated battery specialists, and NRCan's Office of Energy Research and Development (OERD) should play a central role.

To effectively bolster Canadian homegrown innovation in the battery-automotive cluster, it is essential to align existing funding mechanisms. Funding agencies, such as Business Development Canada (BDC), the Canada Innovation Corp (CIC), and the Canada Growth Fund (CGF), should have dedicated battery specialists to map the entire battery innovation ecosystem and make targeted interventions, ensuring alignment and connectivity across firms, government agencies, and research labs. NRCan's Office of Energy Research and Development (OERD) should play a central role, empowered to make strategic grants to innovative firms ready to scale. Additionally, agencies like CGF should offer equity and concessional debt to firms aiming to create first-of-a-kind (FOAK) facilities or scale their operations. A new, large demonstration fund should be established to provide dedicated grants to innovative battery processing and advanced materials firms. Agencies such as BDC

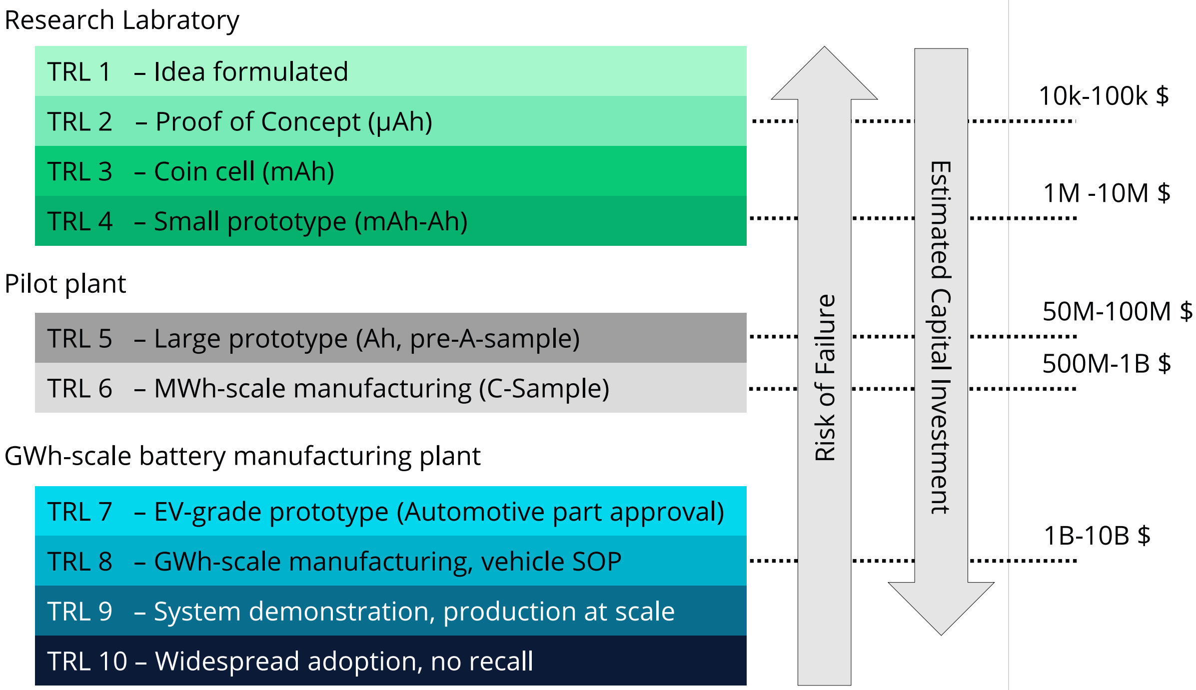
▾ Financial Ecosystem

Actions:

- » Focus and enhance finance along the innovation to commercialization path
- » Support increases in Business Expenditure in R&D (BERD) and early stage growth (5-8)
- » Build funds to support demonstration and commercialization (TRL 7-11)
- » Design smart policies and programs to support innovation.

should focus on their core strengths in helping firms mature and scale through concessional finance, ensuring businesses have access to the financial support they need at every stage of their growth.

Fig. 2: Technology readiness level scale for EV battery application



Source: Nature Communications[203]

The "Risk of Failure" arrow indicates risks of project failure or technology not transitioning to the next level. The scale starts with lab innovation and considers keymilestones in cellmanufacturing to reach EV qualification and vehicle Start-of-Production (SOP). The definitions of A- and C-samples are discussed later in the "Challenges in scaling up" paragraph. Risk increases with decreasing TRL number. US dollar figures are ballpark estimates of the minimum investment required per project based on industrial data or publicly available press releases.

203 Frith, J.T., Lacey, M.J. & Ulissi, U. A non-academic perspective on the future of lithium-based batteries. Nat Commun 14, 420 (2023). https://doi.org/10.1038/s41467-023-35933-2

Actions:

- Focus and enhance finance along the innovation to commercialization path
- Support increases in Business Expenditure in R&D (BERD) and early stage growth (5-8)
- Build funds to support demonstration and commercialization (TRL 7-11)
- Design smart policies and programs to support innovation

Support Increases in Business Expenditure in R&D (BERD) and Early Stage Growth (5-8)

2026–2030: **Launch a national Battery Technology Incubator Program** to seed and support the development of numerous start-ups in the battery sector, offering seed funding, mentorship, and shared R&D resources.

Launching a national Battery Technology Incubator Program is critical to fostering the development and growth of start-ups in the battery sector. This initiative will provide essential support through seed funding, mentorship, and shared R&D resources, helping new companies overcome initial barriers and accelerate their progress.

Such a program can emulate the success of initiatives like the ChargeUp Accelerator in New York, which offers early-stage battery innovators $25,000 for participation, connections to investors, and opportunities for follow-on investment up to $100,000 for technical development. By providing a comprehensive curriculum and access to a rich ecosystem of resources, ChargeUp has significantly improved the commercialization prospects for participating companies.[204]

Establishing a similar incubator program would ensure that innovative battery technologies are developed domestically. This program would help address the financing gap that many start-ups face, provide strategic mentorship from industry veterans, and facilitate critical connections within the battery innovation ecosystem.

2026–2030: **Establish a Battery Innovation Venture Fund** through a public-private partnership where government funding provides initial seed funding to encourage private investment from Canadian venture capital firms.

Establishing a Battery Innovation Venture Fund through a public-private partnership is vital to stimulating investment in the Canadian battery sector. This initiative can draw inspiration from successful precedents such as Volta Energy Technologies in the United States. Volta Energy Technologies leverages a model where government funding acts as a catalyst to attract substantial private investment. In its case, partnerships with Argonne National Laboratory and private investors have been instrumental in advancing cutting-edge energy storage technologies by providing critical capital and resources.

Creating a similar fund would involve initial seed funding from the government to reduce risks for private investors, encouraging venture capital firms to invest in early-stage battery technology companies. This approach not only provides the necessary financial support for startups to scale but also fosters innovation by integrating public sector insights with private sector efficiency and expertise. By leveraging government funds to attract private investment, Canada can accelerate the commercialization of breakthrough battery technologies, ensuring the country remains at the forefront of the global energy transition.

204 https://newenergynewyork.com/programs/chargeup-accelerator/

Build Funds to Support Demonstration & Commercialization (TRL 7-11)

2026–2030: Expand OERD's funding program to offer up to $50M per project for growth-stage battery technology companies including rigorous evaluation and milestone-based disbursements.

Expanding the Office of Energy Research and Development's (OERD) funding program to offer up to $50M per project for growth-stage battery technology companies is essential for bridging the valleys between lab-scale innovations and commercial viability. This funding size addresses a critical gap in the battery innovation ecosystem, enabling technologies to transition from prototype to market-ready products. A critical stage of the valley of death falls in technology readiness levels 5-8, which cover prototyping and validation, including creating robust front-end engineering and design plans for full commercial facilities. Since the suspension of Sustainable Development Technologies Canada in October, Canada has lacked a funder in this segment of the technology pipeline.[205] A purpose-built fund able to make grants up to $50M per project would fill this gap and create the basis for strategic investment.

The fund should be operated on industrial policy best principles: guided by rigorous supply chain targets in multiple segments of the battery sector, aiming to build homegrown capacity, creating a focused but balanced portfolio of investments, and evaluating technology outcomes in the aggregate rather than at the project level. OERD, with its history of catalytic finance in the innovation space, possesses the expertise to make strategic investments that propel growth. By incorporating rigorous evaluation and milestone-based disbursements, this program ensures that investments are both impactful and accountable. Similar programs, like the U.S. Department of Energy's ARPA-E, have demonstrated the success of substantial, strategic funding in advancing energy technologies. Since 2009, ARPA-E has provided approximately $3.84B in R&D funding for more than 1,590 potentially transformational energy technology projects, leading to significant private-sector follow-on funding and commercial advancements.[206]

2026–2030: Recommend that BDC develop and implement a strategic investment initiative to build a diversified portfolio focusing on growth-stage Canadian battery startups.

The business support services and financial expertise that BDC provides are crucial as startups transition from early-stage development to market-ready companies. By focusing on growth-stage startups, BDC can offer the necessary support to navigate financial challenges and achieve sustainable growth. This approach mirrors successful models like the strategic investments by Volta Energy Technologies, which combine funding with deep industry expertise to accelerate the commercialization of energy technologies. Volta Energy Technologies has demonstrated the effectiveness of strategic investments in driving innovation and supporting startups through critical growth phases.

INNOVATION INFRASTRUCTURE

▾ Financial Ecosystem

Actions:

- » Focus and enhance finance along the innovation to commercialization path
- » Support increases in Business Expenditure in R&D (BERD) and early stage growth (5-8)
- » Build funds to support demonstration and commercialization (TRL 7-11)
- » Design smart policies and programs to support innovation

205 https://www.cbc.ca/news/politics/sustainable-development-technologies-canada-champagne-1.6985847
206 https://arpa-e.energy.gov/about/our-impact

▾ Financial Ecosystem

Actions:

- » Focus and enhance finance along the innovation to commercialization path
- » Support increases in Business Expenditure in R&D (BERD) and early stage growth (5-8)
- » Build funds to support demonstration and commercialization (TRL 7-11)
- » Design smart policies and programs to support innovation

Design Smart Policies and Programs to Support Innovation

2024–2026: Add a battery-specific bonus credit to SR&ED. Canada's R&D credit program should include specific incentives for batteries justified by the critical role of the battery ecosystem in Canada's economic future.

Korea's K-Battery Development Strategy (2021) exemplifies the benefits of such targeted incentives. Korea added higher R&D tax credit rates for battery technology to their list of "National Strategic Technologies," providing tiered bonus credits that favor SMEs and scale-ups. This approach ensures that smaller and medium-sized enterprises receive a higher percentage of eligible expenses compared to larger companies, thereby fostering innovation and growth at all levels of the industry.[207]

2024–2026: Introduce R&D minimums for public support. R&D minimums ensure that companies invest in Canada's innovation ecosystem, rather than simply harnessing Canada's world-leading energy resources, human capital, and public infrastructure.

The Government of Canada has provided strong public support for assets in the battery supply chain. The government should attach a condition to such support going forward: a minimum level of R&D spending to support the facility in Canada. This will connect downstream assets to the broader ecosystem and build business expenditure on R&D (BERD) in the battery industry. Such investments support long-term prosperity and create further value-added opportunities.

2024–2026: Structure existing tax credits so that cash is made available to firms up front. Tax credits on capital expenditure can be boosted by allowing firms to claim the value of the credit when expenditures are made, rather than on their amortization schedule. Restructuring existing tax credits to provide cash upfront can significantly enhance the value of these incentives by helping firms avoid interest payments and lowering their cost of capital. This approach is crucial for accelerating the energy transition, as it addresses key financial barriers for early-stage companies that may not yet have significant taxable income.

2024–2026: Dedicated Battery R&D. Support battery innovation strategy with $1B earmarked for the development of critical emerging technologies in battery production, electrical control systems, battery chemistry, and battery materials.

Supporting a dedicated battery R&D strategy with $1B earmarked for the development of critical emerging technologies in battery production, electrical control systems, battery chemistry, and battery materials is essential for maintaining Canada's competitive edge. Currently, Canada has many innovation funds and programs, but these are unfocused and must cover a wide range of activities and firms. A dedicated fund for strategic R&D that brings together national labs, firms, and academia into triple helix research programs is needed. These programs should be benchmarked to the metrics laid out in this roadmap, ensuring that the research is targeted and effective in addressing the most pressing technological challenges and opportunities in the battery sector.

207 https://taxsummaries.pwc.com/republic-of-korea/corporate/tax-credits-and-incentives; https://english.moef.go.kr/pc/selectTbPressCenterDtl.do?boardCd=N0001&seq=5759

Physical Assets

Goal

Canada's battery R&D centres and national labs to contribute to accomplish the innovation metrics goals laid out in the roadmap

Actions

- » Build out Canada's physical innovation infrastructure
- » Focus and target research and collaboration
- » Provide active support to industry with effective policy

Build Out Canada's physical innovation infrastructure

2024–2026: Build existing research centres. Enhance the capabilities of current battery research centres (e.g. Dalhousie and Waterloo), doubling their research capacity and technological resources.

Enhancing the capabilities of current battery research centres, such as those at Dalhousie University and the University of Waterloo, is vital for Canada to achieve global leadership in battery technology. Additional investment in these centres for training programs and advanced physical equipment will significantly bolster their research capacity and technological resources.

Advanced testing and validation equipment can support firms and startups by providing access to cutting-edge facilities, fostering quicker innovation, and enabling direct collaboration with top researchers. For example, Battery Innovation Centre in Indiana[208] exemplifies this approach, where increased funding and resource allocation have turned it into a hub of battery innovation, supporting both academic research and industry needs. By following a similar model, Canada's research centres can become pivotal in driving advancements and commercialization in the battery sector.

208 https://bicindiana.com/

2026–2030: Launch three new battery research centres across Canada to promote regional diversity and access to specialized facilities.

Launching three new battery research centres across Canada will significantly enhance regional diversity and provide greater access to specialized facilities, fostering nationwide innovation. The automotive industry is heavily concentrated in Southern Ontario, and establishing an additional centre there would further support this sector. New research assets in the western provinces would open up new avenues for manufacturing and industrial growth, spreading economic benefits more evenly. Existing laboratories in Alberta and British Columbia can serve as foundational bases for these regional hubs, diversifying and strengthening Canada's battery research landscape. This approach mirrors successful models in other regions, such as Indiana's Battery Innovation Center, which drives regional innovation through strategically distributed facilities.

2026–2035: Establish regional production clusters. Connect R&D centres with firms into regional production clusters that bring together the whole supply chain. E.g. encourage interaction between powertrain manufacturers and battery design.

The triple helix model, which emphasizes dense interactions between network of scientists, firms, and policymakers, is critical for driving innovation. Co-locating industrial assets, university research centres, and government agencies provides a basis for collective knowledge formation. These clusters ensure robust collaboration and efficient knowledge transfer, driving advancements in battery technology and production while generating returns on investment and cultivating skilled communities.

2026–2030: Demonstration facilities. Build state-of-the-art demonstration facilities for testing large-scale battery technologies and systems.

These facilities enable new battery chemistries, electrolytes, and processes to be rigorously tested at both lab and demonstration scales, ensuring that theoretical research can transition effectively to practical applications. Demonstration-scale pouch facilities provide a critical environment for validating large-scale battery technologies. This infrastructure not only reduces costs for innovators but also accelerates development timelines by offering a controlled setting to refine and perfect new battery solutions before full-scale production.

2024–2026: Build the national labs. Increase funding the NRC's Energy storage integration and battery testing facilities to expand their capacity for additional research and development in battery cell production, battery cell assembly and battery testing.

National research labs have driven innovation in Japan, Korea, and the United States. Canada has excellent researchers in its national labs, but these labs need to play a key role in innovation processes. Increasing funding for the NRC's Energy Storage Integration and Battery Testing facilities will expand their capacity for additional research and development in battery cell production, battery cell assembly, and battery testing. By enhancing these labs, Canada can leverage its existing research talent and infrastructure to drive significant advancements in battery technology and maintain global competitiveness.

Actions:

- Build out Canada's physical innovation infrastructure
- Focus and target research and collaboration
- Provide active support to industry with effective policy

Focus and Target Research and Collaboration

2024–2026: Focus and target collaboration. Align battery research centres with national labs and firms into collaborative public-private working groups to achieve the market and environmental targets laid out in this roadmap.

To enhance Canada's battery research capabilities, it is essential to focus and target collaboration by aligning battery research centers with national labs and firms into collaborative public-private working groups. These groups should aim to achieve the laid out in this roadmap. Research centers and regional clusters must be incentivized to meet these targets through creative programs or challenges, channeling their efforts toward lowering costs and improving performance.

The Strategic Research and Innovation Agenda (SRIA) by the Batteries European Partnership (Batt4EU) exemplifies successful collaboration.[209] This agenda, developed with input from hundreds of European battery experts and industry actors, organizes efforts into six working groups covering various battery topics. These groups focus on strategic priority areas such as raw materials, advanced materials, cell design, manufacturing, mobility applications, stationary applications, and recycling. Similarly, Canada's approach can draw on such collaborative frameworks to ensure that research and innovation are aligned with its targets.

2026–2035: Invest in recycling. Build battery recycling innovation centres alongside existing research hubs to improve recycling rates and efficiencies long-term.

Recycling is a key component of the battery ecosystem, presenting opportunities for developing new processes and business models over time. Research centers focused on recycling could encompass areas such as chemical processing, end-of-life design, second-use applications, and increasing recycling rates. For example, focusing on graphite recomposition ensures that metals which currently cannot be recycled are integrated into the system. These centers will drive innovation in recycling technologies, making the battery industry more sustainable and efficient.

2026–2030: Develop advanced materials, next-gen chemistries, and new processes first. Initiate focused research programs at R&D centres targeting advanced battery materials and next-generation battery chemistries.

Investing in the development of advanced materials, next-generation chemistries, and new processes is essential for pushing the boundaries of battery technology. Initiating focused research programs at R&D centers to target these areas is a critical step. Nickel-rich and iron-phosphate lithium-ion batteries are poised to be the commercial workhorses of the next decade, while sodium-ion and solid-state batteries are reaching commercial stages without radically altering chemistries. The innovation frontier lies in simplifying processing and enabling the reconfiguration of chemistry within existing assets. For instance, Mitra Chem provides a process that allows OEMs to change and tailor battery chemistry quickly and easily. Similarly, Xerion Technologies manufactures solid-state batteries directly from precursors through plating, eliminating the need to make cathodes entirely. These advancements can drive the next wave of innovation, making battery technologies more adaptable and efficient.

209 https://bepassociation.eu/our-work/sria/

Provide Active Support to Industry with Effective Policy

2024–2026: A proactive technology transfer plan. Canada must develop a comprehensive technology transfer plan to maximize spill-overs from its battery factories. The goal is to form linkages between the battery factories and the broader economy, so that a wide range of firms can benefit from the knowledge represented in the factories.

Developing a proactive technology transfer plan is essential for Canada to maximize spillovers from its battery factories and integrate them into the broader economy. This plan should cover the entire value chain, from R&D to production, ensuring that best practices from other jurisdictions are incorporated. For instance, methods on licensing technologies and fostering innovation through close coordination with various institutions and firms should be included. Such a plan helps prevent the battery plants from becoming isolated enclaves and maximizes the return on investment by creating linkages that benefit a wide range of firms. Agencies such as the Canada Innovation Corp or the Office of Energy Research and Development could lead this initiative, feeding it into the tiger team and the National Battery Alliance. This approach ensures that the knowledge and advancements generated within battery factories are disseminated widely, promoting broader economic growth and innovation.

2026–2030: International outreach. Forge partnerships with leading international battery research institutions to exchange knowledge, share resources, and co-develop technologies.

Launching an international outreach initiative to forge partnerships with leading battery research institutions worldwide will significantly enhance Canada's position in the global battery industry. By facilitating the exchange of cutting-edge knowledge and best practices, this initiative ensures that Canada remains at the forefront of battery technology innovation. Collaborating with international experts and sharing resources reduces duplication of efforts and accelerates technological advancements. These partnerships provide access to a broader network of research and development opportunities, fostering global collaboration. Strengthening Canada's international connections promotes its reputation as a leader in innovation and sustainable technology development. For example, initiatives like InnoEnergy in Europe demonstrate the benefits of international collaboration, offering valuable insights into how such partnerships can be structured and managed effectively.

2024–2030: Create a network of organizations to support manufacturing innovation. This would be a network that funds public-private institutions to bring together universities, colleges, SMEs, and government agencies into concrete research projects.

This network could be modeled after successful initiatives like the Fraunhofer Institutes in Germany or the National Network for Manufacturing Innovation (NNMI) in the United States. A Canadian example is NGEN, the manufacturing supercluster, which provides a useful model. However, smaller, battery-focused institutes would offer significant advantages. These institutes aim to support SMEs in commercializing and scaling by imparting advanced manufacturing capabilities, thereby enhancing innovation and competitiveness in the battery manufacturing sector.

▾ Physical Assets

Actions:

- Build out Canada's physical innovation infrastructure
- Focus and target research and collaboration
- Provide active support to industry with effective policy

Skills & Talent

Goal

By 2035, aim to have trained and integrated over 10,000 skilled professionals into Canada's battery industry, with at least 500 graduates annually from specialized training programs

Actions

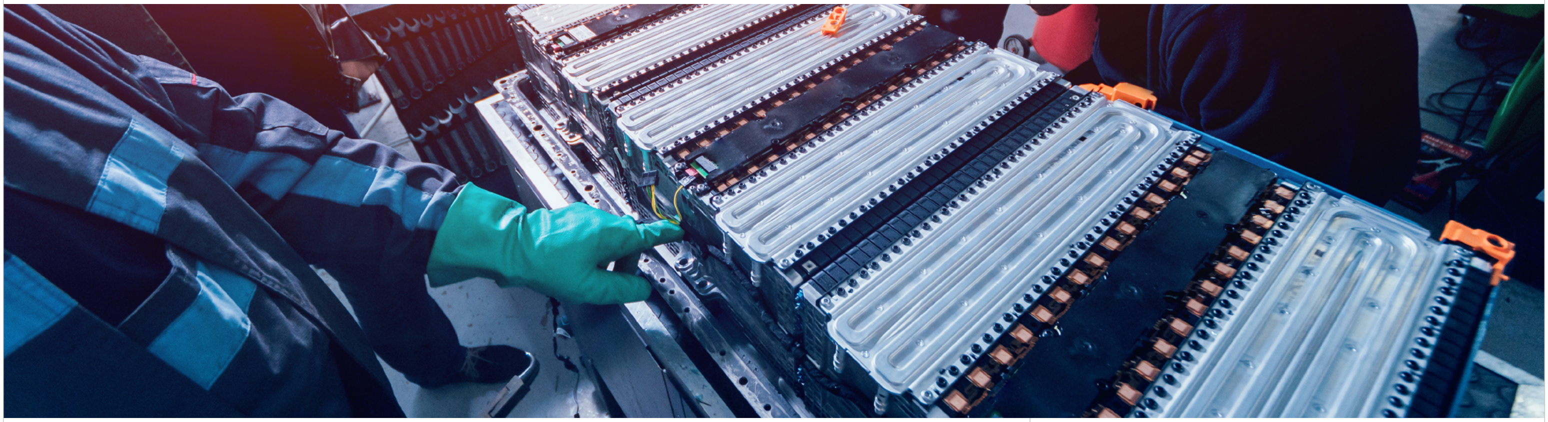
- Map the skills needed
- Develop collaborative partnerships to support the workforce
- Create programs with the right advanced content

Map the Skills Needed

2024–2026: Complete, in close collaboration with provinces and territories, a **comprehensive mapping of the skills (and related training)** that will be required by Canada's battery industrial and innovation ecosystem over different time horizons.

Workers in the automotive sector will be significantly impacted by the transition from internal combustion engines (ICE) to battery electric vehicles (BEV). Existing work on automotive skills has shown that changes in training must be anticipated and planned for throughout the battery innovation lifecycle. The transition will require a broad range of new skills, including battery process engineers who need mechanical knowledge, production and processing expertise, critical thinking, and communication skills. Additionally, battery management expertise is crucial, with a focus on thermal and electrical management.

Electrical equipment technicians, classified under NAICS 3359, will be essential to the evolving battery industry. Chemical and metallurgical experts, alongside material scientists, will also be needed to support advancements in battery technology. To prepare workers with these skills, a comprehensive mapping exercise is necessary to guide course and certification development. Skills and retraining programs should follow directly from this mapping exercise, ensuring workers are equipped to meet the demands of the evolving battery ecosystem.



Develop Collaborative Partnerships to Support the Workforce

2024–2026: Develop international partnerships with organizations that are focused on battery training (e.g. InnoEnergy).

Developing international partnerships with organizations focused on battery training, such as InnoEnergy, integrates Canada into the global cutting edge by exposing Canadian stakeholders to the global conversation on skills and innovation. These partnerships link Canada to leading international agencies, ensuring that Canadian professionals stay abreast of the latest developments and best practices. InnoEnergy, for instance, is spearheading battery training initiatives in Europe and represents an essential touchpoint for advancing Canadian skills development. By forging these connections, Canada can leverage global expertise to enhance its battery industry training programs, ensuring a well-equipped workforce ready to meet the evolving demands of the sector.

2024–2026: Enhance partnerships between universities, technical schools, and battery companies to co-create curriculum that meets the evolving needs of the industry.

This approach strengthens the triple helix model, which emphasizes collaboration among academia, industry, and government for innovation. Extending this model to skills development ensures a seamless integration of academic knowledge and industry requirements. Course development at leading universities must reflect the current and future demands of the battery sector. Achieving this depends on properly incentivizing professors and instructors; providing fellowships and course releases can motivate faculty members to develop new, relevant courses and train their colleagues on necessary industry-specific content. This collaborative effort ensures that educational institutions produce graduates equipped with the skills and knowledge required to drive innovation and growth in the battery industry.

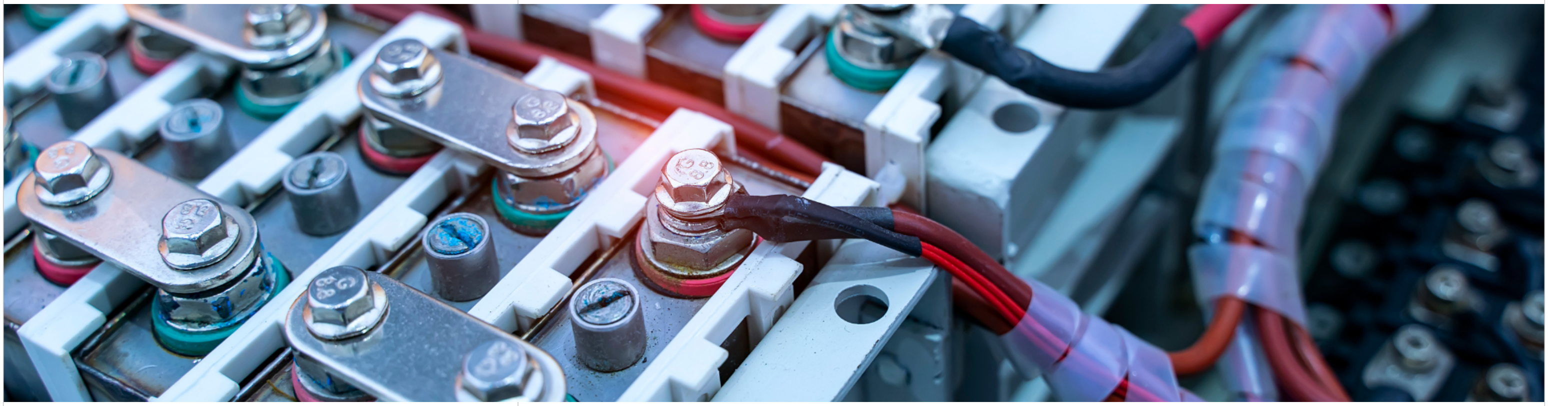
▾ Skills & Talent

Actions:

» Map the skills needed

» Develop collaborative partnerships to support the workforce

» Create programs with the right advanced content



INNOVATION INFRASTRUCTURE

▾ Skills & Talent

Actions:

- » Map the skills needed
- » Develop collaborative partnerships to support the workforce
- » Create programs with the right advanced content

Create Programs with the Right Advanced Content

2026–2030: Introduce online courses and certifications focused on battery technology and innovation, accessible to a wide audience across Canada.

Such courses aim to ensure future widespread accessibility to specialized knowledge across Canada, regardless of geographical location. They propose offering flexible learning options tailored for individuals aspiring to enter or advance within the battery sector. Additionally, these programs would help address the anticipated growth in demand for skilled professionals in the rapidly evolving battery industry. For current employees, they would facilitate ongoing education and professional development opportunities, ensuring they stay current with industry advancements.

2026–2030: Develop specialized training programs in partnership with educational institutions and industry leaders to provide skills necessary for the battery sector.

This will ensure that we are aligning future educational content with industry needs to ensure that graduates acquire relevant and up-to-date skills necessary for the battery sector. They advocate for fostering collaboration between academia and industry, encouraging innovation and practical application in educational curricula. Additionally, these initiatives aim to prepare students for immediate employment in the battery sector, thereby reducing the skills gap and meeting industry demands. By offering cutting-edge programs, educational institutions would enhance their reputation and attract top talent interested in pursuing careers in this rapidly advancing field.

2026–2035: Launch apprenticeship programs that focus on hands-on training and real-world application in battery manufacturing and R&D.

Such programs will provide essential practical experience, bridging the gap between theoretical knowledge and real-world application in battery manufacturing and research. They aim to prepare individuals for the specific challenges inherent in these fields, thereby supporting workforce development by creating a pipeline of skilled workers prepared for immediate employment. Also, these programs would encourage industry participation in training programs, ensuring that apprentices receive education aligned with current and future industry needs.

2026–2035: Create a fellowship program to support postgraduate and doctoral research in battery technologies and their applications.

The program would promote advanced research and innovation in battery technologies, aiming to foster the development of new solutions and continuous improvements. It'll support the growth of a highly skilled research community dedicated to advancing battery technology, aiming to attract top-tier talent to Canada and enhancing the country's position as a global leader in battery innovation.

Industrial policy

The second cluster of key actions falls under the umbrella of industrial policy. These actions include intentional efforts to integrate targets, investments, and policy mixes to generate intellectual property and scale up firms. These goals cannot be achieved with piecemeal or one-off efforts. They must be part of a coherent strategy that is pursued across government.

IP Strategy

Goal

By 2035, aim for Canada to secure 1000 patents in battery technology, focusing on enhancing energy density, reducing costs, improving weather performance, safety, and recyclability, thus establishing Canadian leadership in global battery innovation and intellectual property development.

Actions

- Education & Resources for Canadian Start-ups
- Strategic Acceleration and Prioritization of Critical IP
- Encourage Collaborative & Efficient IP Development

Education & Resources for Canadian Start-ups

2024–2026: **Implement comprehensive intellectual property education** for researchers and entrepreneurs in the battery sector to enhance their understanding of IP issues and strategies.

This education will equip innovators with essential knowledge to protect and monetize their inventions, reducing the risk of IP infringement and legal disputes, and fostering a secure innovation environment. Additionally, it will enhance the ability of researchers and entrepreneurs to strategically navigate the patent landscape, increasing the likelihood of securing valuable patents and promoting a culture of innovation and IP awareness within the battery industry.

2024–2035: **Provide financial support for start-ups to secure IP legal services,** ensuring proper patent filing, protection, and litigation management.

This support will ensure that promising technologies are adequately protected, preventing potential IP theft or infringement. Moreover, it will aid the growth and sustainability of start-ups by safeguarding their intellectual assets, ensuring they can focus on innovation and development without the constant threat of legal challenges. This proactive measure will foster a more robust and secure environment for emerging companies in the battery industry.

INDUSTRIAL POLICY

▾ IP Strategy

Actions:

- » Education & Resources for Canadian Start-ups
- » Strategic Acceleration and Prioritization of Critical IP
- » Encourage Collaborative & Efficient IP Developmentadvanced content

Strategic Acceleration and Prioritization of Critical IP

2024–2026: **Formulate a National IP Strategy for Batteries** with strategic framework that outlines key areas for IP development, focusing on increased energy density, cost reduction, improved weather performance, safety, and recyclability.

This strategy will provide a clear direction and focus for IP development efforts, aligning them with national priorities. This strategy will facilitate coordinated and strategic investment in key areas of battery technology, enhancing overall innovation efficiency. Additionally, it will help identify and prioritize high-impact areas for patent development, driving targeted research and innovation.

2026–2030: **Implement a fast-track system for patent processing** for technologies deemed critical to national interests, such as those improving battery safety and recyclability.

A fast-track system will accelerate the time-to-market for crucial technologies, ensuring timely access to innovative solutions. This expedited process will provide a competitive edge to Canadian firms by reducing bureaucratic delays in securing patents. Additionally, it will encourage the rapid development and deployment of technologies that address urgent national and global challenges, fostering a more dynamic and responsive innovation ecosystem in Canada.

Encourage Collaborative & Efficient IP Development

2026–2030: **Establish partnerships with global entities to share best practices**, co-develop IP, and access new markets, thereby strengthening the international presence of Canadian battery technology.

This approach will enable the sharing of expertise and resources, accelerating the development of cutting-edge technologies. It will open new market opportunities for Canadian innovations, enhancing global competitiveness. Additionally, it will foster international collaboration and cross-border innovation, promoting knowledge transfer and the co-development of IP, ultimately contributing to a robust and dynamic battery technology ecosystem in Canada.

2026–2035: **Develop a program to encourage sharing and pooling of non-core patents** among Canadian battery companies to facilitate faster and more cost-effective innovation.

This program will promote collaborative innovation, enabling companies to build on each other's non-core technologies. It will reduce duplication of efforts and associated costs, increasing overall R&D efficiency. Additionally, it will foster a cooperative ecosystem where companies can focus on their core competencies while leveraging shared IP assets for broader innovation. This collaborative approach will enhance the competitive edge of the Canadian battery industry.

▾ IP Strategy

Actions:

- » Education & Resources for Canadian Start-ups
- » Strategic Acceleration and Prioritization of Critical IP
- » Encourage Collaborative & Efficient IP Developmentadvanced content

Scale-up

Goal

By 2035, increase the number of Canadian-owned firms in the battery sector by 10x who will contribute 20% of the North American battery value chain which includes materials, components, and technology.

Actions

- Get Canada's industrial policy process right
- Solve the scaling problem with smart, ambitious programs
- Nail the details and facilitate supply chain integration
- Build Canadian exports

Get Canada's Industrial Policy Process Right

2024–2026: **National Battery Alliance.** Establish a National Battery Alliance through a public-private partnership model to synchronize scale-up efforts and support ongoing strategy development and collaboration (e.g. the European Battery Alliance, or Li-Bridge in the US).

Best practices for industrial policy include robust mechanisms for public-private collaboration, which facilitate the exchange of high-quality information. This collaboration is essential to industrial policy, understood as collaborative problem-solving, uncovering problems and solutions in markets and innovation processes. A critical role for the Alliance would be to work closely with funding agencies such as the Canada Innovation Corp (CIC) and the Office of Energy Research and Development (OERD) to coordinate R&D across the ecosystem. The Alliance should manage expert and industry groups to provide inputs into R&D needs, similar to the approach of BATT4EU.[210]

2024–2026: **Small, nimble, government problem-solving team.** Create a small (8-10 people) cross-departmental tiger team for battery innovation. 2 representatives each from Finance, NRCan, and ISED, with 1 each from CIC, CGF, PMO, and PCO.

The National Battery Alliance (NBA) will generate crucial insights into the battery sector's problems and opportunities in Canada. However, implementing the necessary reforms and programs can become diluted in the complex governmental process. Evidence shows that small teams can significantly support industrial policy by effecting change and coordinating policy across departments and mandates.[211] These teams must also be empowered to

210 https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-02-internationale-batteriepolitik-strategien-der-fuehrenden-laender.html
211 https://www.hks.harvard.edu/centers/wiener/programs/economy/events/global-experiences-industrial-policy..

▼ Scale Up

Actions:

- » Get Canada's industrial policy process right
- » Solve the scaling problem with smart, ambitious programs
- » Nail the details and facilitate supply chain integration
- » Build Canadian exports

proactively communicate with firms and civil society partners, ensuring that innovation and reform efforts are efficiently and effectively implemented. In the United States, a small interagency team led by the DOE works to leverage and align all existing programs domestically and internationally to bolster the battery supply chain.[212]

2024–2035: **Regional production clusters.** Connect R&D centres with firms into regional production clusters that bring together the whole supply chain. E.g. encourage interaction between powertrain manufacturers and battery design.

These clusters create shared knowledge and logistical assets that enhance comparative advantage.[213] Globally, technology and innovation naturally cluster in specific geographies due to the dynamic problem-solving networks formed by dense interactions among experts and manufacturers. Canada's battery ecosystem should be anchored in locations that facilitate interaction and knowledge exchange, spurring new ideas, partnerships, and efficiencies through shared human and logistical infrastructure.

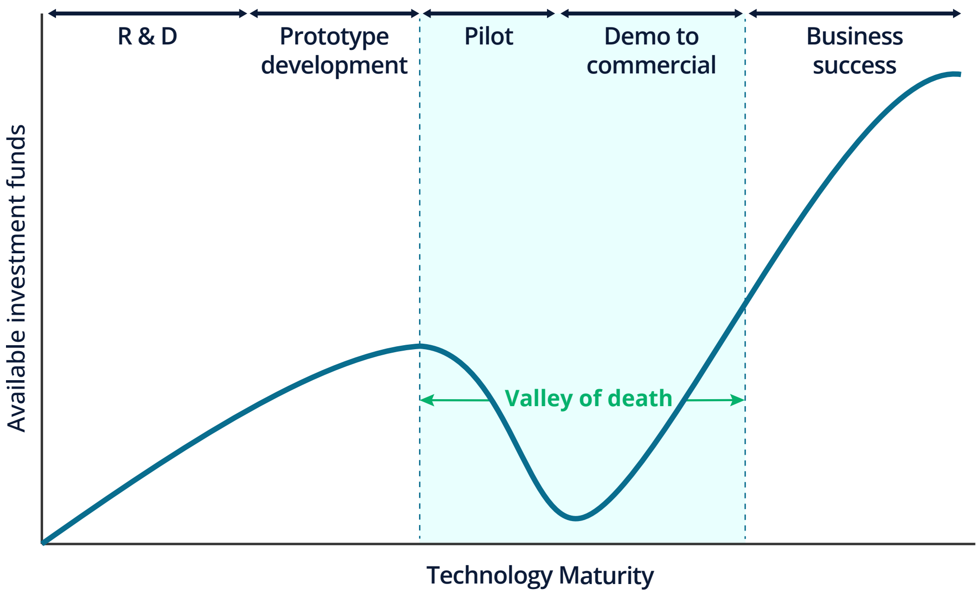
2024–2026: **Develop a Battery Ecosystem Intelligence Dashboard** to track progress and analyze the current state of the ecosystem.

This tool will provide policymakers, industry stakeholders, and researchers with real-time data and insights, enabling informed decision-making and strategic planning. Continuous monitoring of key performance indicators will ensure the roadmap's goals and targets are being met. By identifying gaps in the ecosystem, such as areas needing additional investment or policy support, the dashboard will uncover new opportunities for innovation and collaboration. Additionally, it will foster transparency and communication among stakeholders, creating a collaborative environment aligned with strategic objectives.

An example of this approach can be seen in Batt4EU's information observatory. Batt4EU provides accurate and up-to-date information on key metrics and state-of-the-art technologies. By building strategic roadmaps, Batt4EU fosters exchanges between experts in different parts of the value chain, enhancing the understanding of causal relationships and promoting cross-cutting activities such as safety, digitization, and sustainability. Implementing a similar system will help prioritize high-impact areas and drive significant progress towards achieving the roadmap's goals.

212 See above, but also https://www.energy.gov/articles/biden-harris-administration-awards-28-billion-supercharge-us-manufacturing-batteries
213 https://www.inderscienceonline.com/doi/abs/10.1504/IJATM.2022.122096

Solve the Scaling Problem with Smart, Ambitious Programs



2024–2030: **Large Demonstration Fund.** Create a response program to the U.S. Bipartisan Infrastructure Law (BIL) by establishing a Canadian initiative that funds large-scale battery projects with $100M to $200M, aimed at scaling up Canadian innovation and bridging supply chain gaps.

The BIL and the Inflation Reduction Act (IRA) committed over $26B USD to create the Department of Energy's (DOE) Office of Clean Energy Demonstrations (OCED), addressing the need for first-of-a-kind (FOAK) demonstrations at scale. This initiative complements existing programs for early technology readiness levels (such as DOE ARPA-E) and later-stage deployment (such as DOE Loans Program Office).[214]

The BIL included a fund for battery material extraction and processing grants, allocating $2.8B in 2022. [215] These investments focused on first-of-a-kind facilities for innovative firms, with the first round of grants awarding between $100M to $200M USD to firms building demonstration plants for innovative processing. Demonstration projects often fall into the valley of death due to their high-risk nature, making them hard to finance. Programs to support the best technologies through technology readiness levels 8-11 (demonstration and commercialization) are crucial.

Canada should create a fund to support first-of-a-kind commercial facilities in the battery space, ensuring the country remains competitive and innovative in the global battery industry.

214 https://www.energy.gov/sites/default/files/2023-08/OCED%202023%20Multi-Year%20Program%20Plan.pdf
215 https://www.energy.gov/mesc/battery-materials-processing-grants

INDUSTRIAL POLICY

▾ Scale Up

Actions:

- Get Canada's industrial policy process right
- Solve the scaling problem with smart, ambitious programs
- Nail the details and facilitate supply chain integration
- Build Canadian exports

2024–2026: **Promote partnerships between start-ups and established firms** to leverage expertise and infrastructure for scaling operations.

Promoting partnerships between start-ups and established firms is essential for leveraging expertise and infrastructure to scale operations. This approach allows start-ups to access the advanced resources, facilities, and networks of established companies, which are often critical for accelerating development and commercialization. Such partnerships can provide start-ups with mentorship and guidance from industry veterans, fostering innovation and improving their chances of success. Established firms benefit by gaining access to cutting-edge technologies and innovative solutions, enhancing their competitive edge. By facilitating these collaborations, Canada can create a synergistic ecosystem where both start-ups and established companies thrive, driving forward the battery industry's growth and innovation. For example, initiatives like New York's Charge Up Accelerator demonstrate the effectiveness of such partnerships in fostering innovation and scaling operations.

INDUSTRIAL POLICY

▾ Scale Up

Actions:

- » Get Canada's industrial policy process right
- » Solve the scaling problem with smart, ambitious programs
- » Nail the details and facilitate supply chain integration
- » Build Canadian exports

Nail the Details and Facilitate Supply Chain Integration

2024–2026: **Streamline regulatory processes for new battery technologies** to accelerate the path from prototype to production.

Streamlining regulatory processes for new battery technologies is crucial to accelerate the transition from prototype to production. Simplified regulations can significantly reduce the time and cost involved in bringing innovative battery solutions to market. This approach ensures that promising technologies are not delayed by bureaucratic hurdles, allowing faster commercialization and wider adoption. By establishing clear and efficient regulatory pathways, Canada can foster an environment where innovation thrives, ensuring that new battery technologies reach consumers and industries more swiftly. This will enhance the country's competitive edge in the global battery market and support the overall growth of the sector. For example, the European Union's streamlined regulatory processes for advanced battery technologies have effectively accelerated market entry for new innovations, setting a precedent for how such frameworks can benefit technological advancement.[216]

2024–2026: **International partnerships for standards and training.** Develop partnerships with organizations that are focused on battery training (e.g. InnoEnergy) to create international learning platforms and align its battery strategy with global best practices.

These partnerships offer valuable insights and resources that can accelerate innovation and enhance skill development. Additionally, given the significant investment by Northvolt, Canada can position itself as an integral part of a dynamic transatlantic ecosystem, benefiting from shared knowledge and standards. This approach ensures Canada remains competitive and at the forefront of battery technology advancements.

2024–2026: **Integrate programs into industrial policy.** Ensure policies and programs provide demand-pull on Canadian battery technology.

For instance, consumer credits like the EV incentive or the iMHZEV should be structured to benefit Canadian firms. This can be achieved without explicit local content requirements by indexing incentives to ESG standards or providing additional benefits to technologies developed through programs like the SR&ED. Such measures would promote the use of Canadian-developed technologies, supporting domestic innovation while maintaining compliance with international trade regulations. This approach ensures that Canadian firms gain a competitive edge and the country's technological advancements are prioritized in the development of local supply chains.

2026–2035: **Develop new standards for next generation battery materials** to facilitate integration along the whole supply chain and reduce costs.

Technological innovation in battery materials will inevitably outpace current regulations, creating barriers to efficient implementation. By proactively establishing updated standards, Canada can streamline the adoption of innovative materials, ensuring regulatory frameworks support rather than hinder progress. This approach will accelerate technological advancements and cost reductions, providing a competitive edge in the rapidly evolving global battery market. Staying ahead of regulatory needs will help Canada maintain a leadership position in battery innovation.

216 https://www.dlapiper.com/en/insights/blogs/environment-health-safety-and-product-compliance/2023/new-regulatory-framework-for-batteries-in-the-european-union

Build Canadian Exports

2024–2026: **Recommend that EDC further tailor its programs to help companies navigate international markets** and export regulations, enhancing the global competitiveness of Canadian battery products.

By tailoring its services to address the unique challenges of the battery industry, EDC can help firms overcome regulatory hurdles, secure international partnerships, and access new markets. This approach will enable Canadian companies to expand their global footprint, leverage international demand, and contribute to the country's reputation as a leader in battery innovation and sustainable technology development.

2024–2026: **Support overseas scale-up of Canadian technology leaders.** The long-term goal here is to help build exports in the battery sector. This is essential to replace oil and gas exports long-term.

Export Development Canada is already doing excellent work supporting Canadian cleantech firms. However, Canada could benefit from taking a cue from South Korea and Japan by developing a targeted battery strategy. The aim? To promote the global expansion and export of homegrown technology by leading domestic companies. Japan and Korea are setting the bar high. Their battery strategies include specific targets for both exports and R&D. By pooling research investments, these countries are propelling their firms to the forefront of technological innovation. This collaborative approach allows these nations to combine resources and bolster the entire sector.

Actions:

- » Get Canada's industrial policy process right
- » Solve the scaling problem with smart, ambitious programs
- » Nail the details and facilitate supply chain integration
- » Build Canadian exports

> "The proposed National Battery Alliance is exactly what Canada needs. It will help alignt our efforts, share knowledge, and accelerate our path to becoming a global battery powerhouse."
>
> — Dan Blondal, CEO of Nano One Materials Corp

Key Findings & Next Steps

This roadmap envisions **Canada as a global leader in clean, innovative battery technology and a hub for sustainable battery production in North America by 2035**. Achieving this vision requires addressing key challenges and leveraging Canada's strengths through a coordinated, strategic approach involving government, industry, and academia.

Key Findings

- Canada has significant untapped potential in the battery supply chain, with strengths in raw materials and research capabilities.
- Current gaps exist in scaling up innovative firms, providing continuous financial support, and retaining high-value assets within Canada.
- A coordinated, strategic approach involving government, industry, and academia is essential for success.

This roadmap is structured around two primary clusters: Innovation Infrastructure and Industrial Policy. These clusters encompass five critical action areas that form the backbone of our strategy to build a robust battery innovation ecosystem in Canada.

Innovation Infrastructure focuses on creating the physical, financial, and human capital necessary to support battery innovation:

- **Financial Ecosystem:** Enhance funding mechanisms and align existing programs to support battery innovation across all stages of development
  - Goal: $3B invested in battery innovation through public and private funding with the following breakdown;
- **Physical Assets:** Expand research centers, establish demonstration facilities, and build out national labs to support cutting-edge battery research and development.
  - Goal: Canada's battery R&D centres and national labs contribute to achieving the innovation metrics goals laid out in the roadmap
- **Skills & Talent:** Develop specialized training programs, enhance partnerships with educational institutions, and create a skilled workforce to drive battery innovation.
  - Goal: By 2035, aim to have trained and integrated over 10,000 skilled professionals into Canada's battery industry, with at least 500 graduates annually from specialized training programs

Industrial Policy aims to integrate targets, investments, and policy mixes to generate intellectual property and scale up firms:

- **Scale-up Support:** Implement targeted policies and programs to help innovative firms grow and remain in Canada, capturing more value within our domestic economy.
  - Goal: By 2035, increase the number of Canadian-owned firms in the battery sector by 10x who will contribute 20% of the North American battery value chain which includes materials, components, and technology.

» **IP Strategy:** Strengthen intellectual property protection and development strategies to ensure Canadian innovations benefit our economy and global competitiveness.

   » Goal: By 2035, aim for Canada to secure 1,000 patents in battery technology

The path forward requires a concerted effort from all stakeholders to transform these recommendations into reality.

Next Steps: Establishing the National Battery Alliance

The immediate priority is to establish the National Battery Alliance as a cornerstone for implementing this roadmap. This alliance will serve as a central coordinating body, bringing together key players from government, industry, and academia.

Key Functions of the National Battery Alliance:

» **Strategic Coordination:** Align efforts across the battery value chain

» **Policy Advocacy:** Champion supportive policies and regulations

» **Innovation Catalyst:** Foster collaboration in research and development

» **Skills Development:** Coordinate training and education initiatives

» **Investment Attraction:** Promote Canada as a destination for battery investments

» **International Partnerships:** Facilitate global collaborations and knowledge exchange

Near-term Priorities for the Alliance:

» Formalize its structure and governance

» Develop a detailed implementation plan for the roadmap

» Initiate the Battery Ecosystem Intelligence Dashboard

» Launch working groups on critical issues (e.g., financing, skills, R&D)

» Begin outreach to international partners

By taking these steps, the National Battery Alliance will play a pivotal role in translating this roadmap from vision to reality. It will serve as the driving force behind Canada's ascent to becoming a global battery powerhouse, fostering innovation, creating high-value jobs, and contributing significantly to the country's clean energy future.

The journey ahead is challenging but filled with immense opportunity. With commitment, collaboration, and strategic action, Canada is poised to lead in the battery technology revolution, shaping a sustainable and prosperous future for generations to come.