Lithium-ion Battery Sector

Developing a promising sector for Quebec's economy

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propulsion Québec

Cluster for Electric and Smart Transportation

About Propulsion Québec

Propulsion Québec rallies the entire sector around joint projects aimed at positioning Quebec as a global leader in developing and implementing smart and electric modes of ground transportation.

The organization represents some 130 member businesses, associations, and public and parapublic organizations that are helping to develop Quebec's smart and electric transportation industry.

By 2026, the cluster's aim is for Quebec to :

- **Be recognized as a global leader in the business segments tied to electric and smart transportation;**
- **Have a solid core of worldclass businesses that span the entire electric and smart transportation value chain;**
- **Become a hub for electric and smart vehicle trials and use.**

About this report

Propulsion Québec asked KPMG to assess the development potential of the lithium-ion battery industry in Quebec, and, more specifically, to identify strategies that Quebec can use to gain a foothold in this booming market.

Propulsion Québec would like to thank KPMG and its partner Globerpro, the pilot project committee members, and all of the experts consulted for this report for their vital contributions.

This study was made possible thanks to the financial support of the Government of Quebec, Société de développement de Shawinigan, and many other public and private partners.

THE TRANSPORTATION INDUSTRY IS ENTERING A NEW ERA marked by electric and autonomous vehicles. As a way to address climate change, many countries and municipalities around the world are setting ambitious goals for electrification, spurring demand for electric vehicles. The number of electric vehicles is expected to grow exponentially in the next decade—and with it, demand for lithium-ion batteries.

The industry is changing at a phenomenal pace, but growth of the global electric vehicle market hinges on battery production—a fact that has not escaped the notice of many governments and innovative companies. Announcements of support and investment have been made at a furious pace, as everyone looks to secure their place in the lithium-ion battery value chain.

Quebec has some remarkable competitive advantages for tapping into this promising sector's extraordinary opportunities for growth and wealth creation. Given our access to a variety of strategic minerals and our proximity to U.S. and Ontario automobile manufacturers, there is a very positive outlook for developing this key sector. We also already have a handful of companies specializing in different parts of the lithium-ion battery value chain, expertise in the development and assembly of specialized electric vehicles, and research expertise—major factors that make us all the more attractive.

But global competition is fierce, and the window of opportunity to establish a foothold in this industry of the future is relatively short. In Europe, Asia and North America, many governments are taking concrete measures to actively support local development of this industry.

Quebec will have to take quick action to carve out a place for itself in this growing industry. Industry stakeholders and all levels of government will need to agree on an ambitious collective vision and together lay the groundwork for developing a successful industry. This study identifies strategies that Quebec can use to establish a foothold in this market. Collectively, we have an opportunity to build on extraordinary momentum toward energy independence and regional development. It's up to us to seize this opportunity.

Sarah Houde
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Summary

The global lithium-ion battery industry is transforming at an accelerated pace. From fall 2018 when KPMG started this study, to winter 2019 when the study was completed, planned global lithium-ion battery production capacity for 2028 rose from 1,102 to 1,559 GWh—a 40% jump in five months! The reason for this race to add cell production capacity? A major transformation of the entire automotive industry. And, although the scope and pace of the change are hard to predict, one thing is certain: Electric vehicles will account for a significant portion of all passenger vehicles in the coming decade. Many countries, federated states, and regions of the world recently announced measures to support local development of the lithium-ion battery sector. Their decision-makers have rightly identified strong potential for creating wealth and growth.

In Quebec, the lithium-ion battery industry currently has a number of players representing the various links in the value chain.

In Quebec, the lithium-ion battery industry currently has a number of players representing the various links in the value chain. The province can draw on its mineral resources, which some players are now seeking to develop by transforming them into battery-grade materials. Quebec also has expertise in developing and assembling specialized electric vehicles such as buses, utility vehicles, trucks, and snowmobiles, as well as recognized research expertise. However, outside certain very specific subsectors, few Quebec players that manufacture components and cells for electric vehicles are well known.

The growing popularity of electric vehicles—sales of which could increase by a factor of 26 by 2030—will also disrupt the structure of the recycling industry. Lithium-ion battery recycling is currently underdeveloped and mainly carried out in centralized facilities so that volumes are high enough to be profitable. But, there are convincing strategic, ecological, and economic reasons to consider recycling end-of-life batteries locally. In particular, local battery recycling would provide access to raw materials contained in batteries, address the need to recycle responsibly, mitigate the costs of collecting and transporting batteries and recover economic value from batteries. We can therefore expect that players from across the globe will want to get in on this market.

This report presents the development potential of the lithium-ion battery industry in Quebec and, more specifically, assesses the potential for a battery cell or component manufacturing plant and a lithium-ion battery recycling plant.

Five main findings emerge from the study

1. **Quebec has a unique set of competitive advantages.**
Quebec can build on its strengths to establish a foothold in this strategic market. Quebec already has the raw materials required for battery production, readily available technological and industrial expertise, access to clean and abundant energy, relatively low operating costs for North America, and proximity to automobile manufacturers.

2. **Quebec's most promising options for development:**
a) Implementing stronger vertical integration of the sector by strengthening the capacities of resource and material producers. **b)** Working to attract strategic partners and establish partnerships with them to develop a lithium-ion battery-cell or component manufacturing plant. **c)** Developing a lithium-ion battery recycling industry based on reliable hydrometallurgical processes (as yet undeveloped). **d)** Adapting current recycling facilities so they can handle end-of-life lithium-ion batteries (e.g., adapt recycling facilities that treat industrial waste using pyrometallurgy).

3. **These strategies can be carried out separately or at the same time,** as they reinforce each other.

4. **Speed of action is crucial, and the window of opportunity is short,** given the rapid transformation of the global industry.

5. **For each development strategy, specific conditions will need to be in place in order to achieve success.** But from a wider perspective, Quebec will need to adopt a collective vision for developing this industry, achieve greater cooperation among industry stakeholders, and offer government support for key projects.

1-

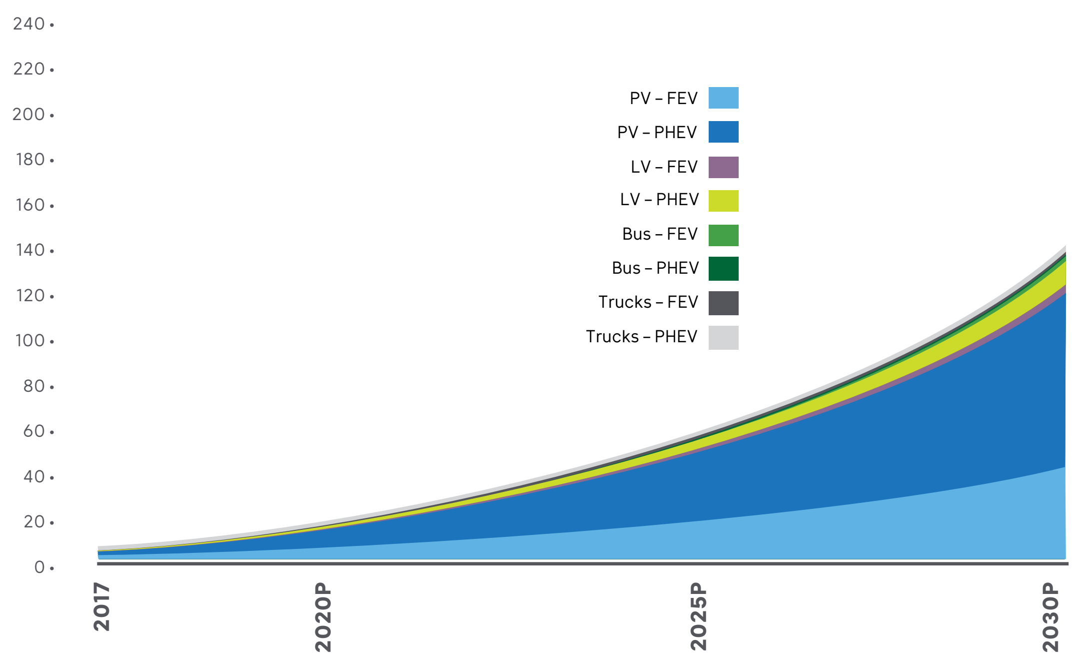
The fast-growing North American ***and global market, shaped by electric transportation growth***

1.1 Growth in demand for lithium-ion batteries

Since the 1990s the lithium-ion battery market has developed mainly in line with the rapidly increasing number of personal electronic devices, such as laptops, cellphones, tablets, and so on. According to experts, future demand for lithium-ion batteries will be largely determined by the development of the electric vehicle market, which is expected to skyrocket over the next decade.

Growth in the global electric vehicle fleet

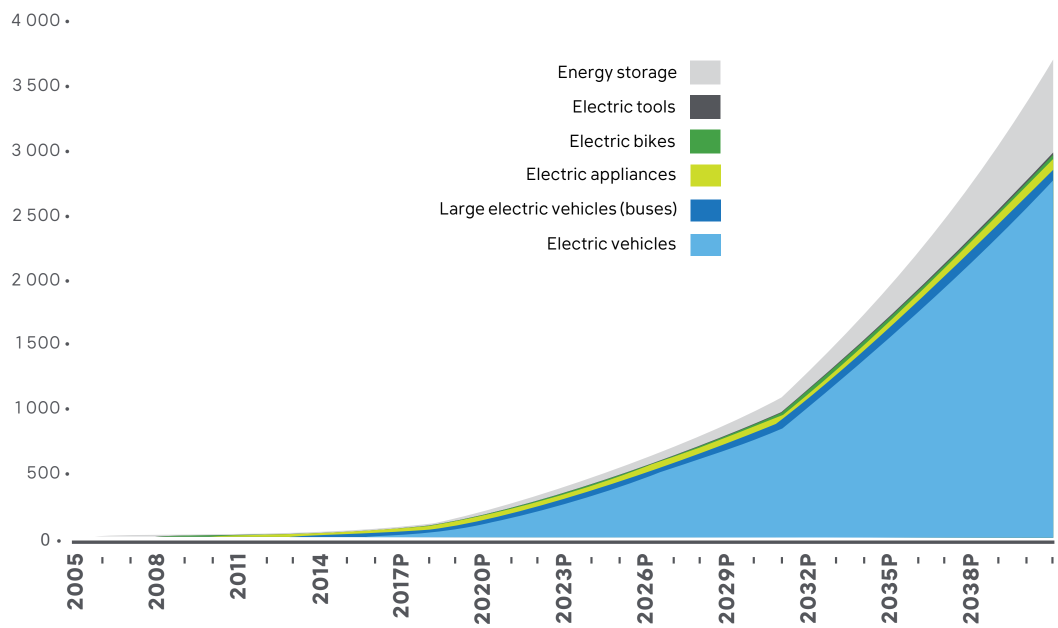
2017–2030E, per vehicle type, in millions



Demand for batteries for energy storage is also expected to increase, and over time should account for a significant portion of the final demand for lithium-ion batteries. These new uses are completely reshaping the lithium-ion battery market.

Global demand for lithium-ion batteries

2005–2040P, by end use, GWh



Note: Illustration of relative market share. Final demand for lithium-ion batteries is unpredictable.

Source: Credit Suisse, 2018

Factors that could accelerate or slow the pace of electric vehicle adoption:

- **Changes in battery production costs and their effect on the final sale price of electric vehicles;**
- **Technological improvements to lithium-ion batteries, particularly for longer range or faster charging;**
- **Policies that may or may not be adopted by governments around the world, such as financial incentives for the purchase of electric vehicles, industrial development policies supporting growth in the sector, regulations, taxation based on carbon emissions, etc.;**
- **The development of alternative technologies;**
- **The pace at which autonomous vehicles are introduced and the impact on the total number of vehicles on the road;**
- **Changes in oil prices;**
- **The pace at which charging facilities are rolled out.**

It should be noted that the ten countries leading the way in the adoption of electric vehicles have all introduced measures to make them more appealing to buyers or to encourage development within the sector by supporting battery manufacturers or car manufacturers. The objectives of government policies to protect the environment and reduce pollution levels also play an important role in demand trends[1].

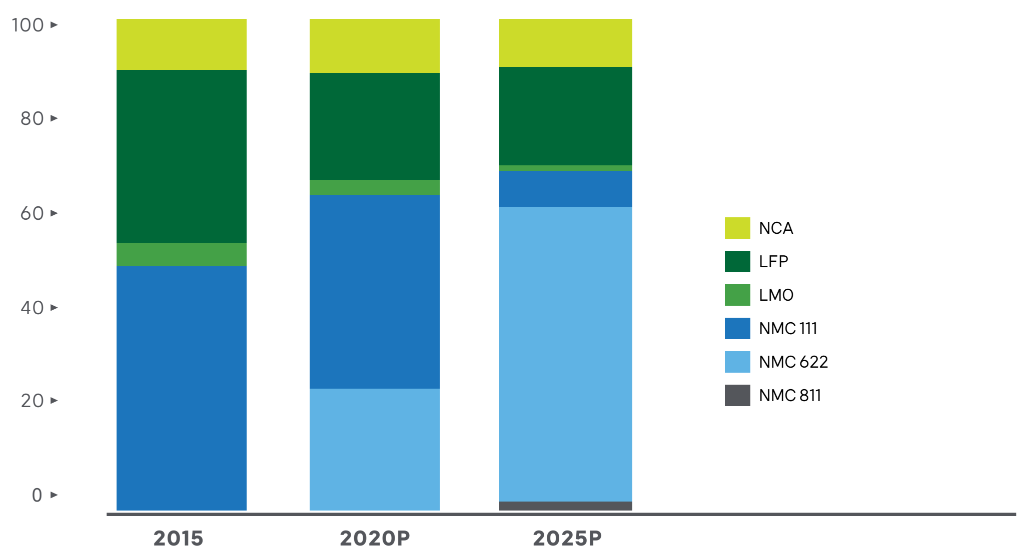
1 International Energy Agency, *Global EV Outlook 2018*, 2018, p. 22.

1.2 Lithium-ion batteries: Solid and sustainable technology

The battery industry initially concentrated on the production of cobalt and lithium oxide (LCO) batteries that power electronic devices but is now turning to battery chemistry for electric vehicles. As shown in the diagram below, lithium nickel manganese cobalt oxide (NMC) chemistry is currently the most widespread in the automotive sector, followed by lithium iron phosphate chemistry (LFP, more common on the Chinese market and used to power buses) and aluminum oxide, lithium, nickel, and cobalt. According to the experts, the market share of NMC chemicals is expected to increase from 50% in 2015 to nearly 70% in 2025[2], partly because of their energy density, which allows for a higher range compared to LFP technology and reduces the need to use rare and costly raw materials, like cobalt.

Change in market share of the main chemistries used in lithium-ion batteries for electric vehicles

2015–2025E, %



Source: BMO Capital Markets, 2018

Looking further ahead, the interviews conducted suggest that technology could shift toward (safer) solid batteries, with ceramic electrolytes, lithium-sulfur or lithium-air batteries. While some certainly have potential, a number of steps remain before this technology can be brought to market.

Despite significant momentum in research and development, the potential for major technology upheavals in the short and medium term remains limited, given the length of time it takes to develop and then mass commercialize new technology. It can take between 13 and 26 years to develop and commercialize new technology, at which point an auto manufacturer can then integrate new battery chemistry into a vehicle fleet.[3]

2 BMO Capital Markets, *The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See 2018*, p. 53.
3 Yole Développement, 2016.

Comparison of lithium-ion battery technologies in development

NAME	OBJECTIVE	DESCRIPTION
Improved NMCs	Replace the NMC chemistries used at the moment	Improved NMC layered cathodes use less cobalt and more nickel, so they are cheaper. NMC 622, already in commercialization, and NMC 811 are expected to eventually replace older NMC chemistries.
eLNO – Lithium nickel oxide	Improved energy density and power	eLNO cathodes are developed by Johnson Matthey and belong to the same category as NMC cathodes. They contain less cobalt and would have higher energy density, more power, and a longer life span and would be safer than NMC or NCA batteries. Although an initial commercial launch is planned for 2022, doubts remain as to the viability of this technology, particularly in terms of the electrolyte's compatibility with the materials used in eLNO.[4]
Solid batteries	Replace batteries that have liquid electrolytes	Solid batteries replace the liquid electrolyte used today with a solid, non-flammable electrolyte. This significantly reduces the risks associated with lithium-ion batteries, and possibly doubles their energy density. However, they are not ready for large-scale commercialization because their energy capacity is still too low. It is estimated that solid batteries will only become competitive in terms of price around 2030, in the electronics market. What's more, solid batteries have other technological issues, and all materials and processes developed for existing batteries will have to be adapted to these new ones.
Lithium-air batteries	Improved energy density	This technology uses the oxygen in the air to interact with lithium ions and power the electric vehicle. Energy density is ten times higher than the batteries currently in use. Research on lithium-air batteries is in its infancy, however.[5]
Lithium-sulfur batteries	Improved energy density	This type of chemistry uses cathodes containing lithium anodes and sulfur, resulting in a low-cost, high energy-density battery. However, there are plenty of technological obstacles to overcome before these types of batteries could be commercialized.
Lithium-metal batteries	Improved capacity	These metal-anode batteries have a potential capacity ten times higher than the anodes currently in use. There are still many challenges to overcome before commercialization, particularly in terms of how the metal reacts with the electrolyte.[6] Quebec has made numerous strides forward with this technology.

Source: KPMG analysis

4 Redburn, Umicore Power *Play*, 2018, p. 87.
5 RBC Capital Markets, *RBC Electric Vehicle Forecast Through 2050 & Primer*, 2018, p. 30.
6 European Commission's Joint Research Center, *Lithium ion battery value chain and related opportunities for Europe*, 2016, p. 23.

1.3 Global value chain facing transportation and supply challenges

The lithium-ion battery value chain is global and involves many players. Some are well established, including the major Asian groups that helped develop lithium-ion batteries in the 1990s such as Panasonic, LG Chem, and Samsung, automobile manufacturers (BMW, Mercedes), and mining giants such as Glencore, Vale, Anglo, and Rio Tinto. Other players have come onto the scene more recently. Some have experienced significant growth in recent years (e.g., Tesla) while others are currently trying to break into the market (e.g., Northvolt).

The raw materials part of the chain is dominated by several large players—mainly from the United Kingdom, Australia, Chile, the United States, and China. Manufacturers of components and active materials are mainly concentrated in Asia, as are cell manufacturers. With the exception of a few players, they are poorly integrated. Automobile manufacturers tend to assemble battery packs themselves or subcontract battery pack assembly in or near vehicle assembly plants. This is understandable because battery packs are hard to transport (due to size and safety issues) and must meet the manufacturer's specific requirements. Manufacturers generally have supply agreements or even partnerships with their suppliers.

Companies in the chain generally manufacture both certain components (in particular the cathode, to ensure quality) and cells, such as LG Chem, SK Innovation, and Samsung SDI. Sometimes companies go so far as to manufacture vehicles, such as BYD and Tesla. Other players such as Northvolt and Umicore are also integrating the recycling phase into their activities.

However, increased pressure from car manufacturers to reduce lithium-ion battery production costs could persuade current players to increase their vertical integration in order to secure supply, control manufacturing resources, recover margins paid to suppliers, and ensure better control over the quality of the end product.

Main players in the global value chain for lithium-ion batteries for electric vehicles

Raw materials | Refined and precursor materials | Components and active materials | Cell production | Module production | Battery pack assembly | Integration in the vehicle | Recycling and reuse

Raw materials / Refined and precursor materials

LITHIUM
SQM
Albemarle
Livent
Galaxy Resources
Jiangxi Ganfeng
Tianqi
Orocobre

COBALT
Glencore
ChinaMolybdenum
Vale
Norilsk

COPPER
Anglo
Kaz Minerals
Rio Tinto
Codelco
Freeport
BHP
Glencore
Antofagasta
Southern Copper

MANGANESE
Anglo
American BHP
Eramet
Consolidated Minerals
Vale

GRAPHITE
AMG N.V.
Bass Metals Ltd.
Imerys SA

NICKEL
Anglo American
Glencore
Vale
Norilsk
BHP
Sumitomo Mining

ALUMINIUM
Rusal
Chalco
Rio Tinto
Alcoa
China Hongqiao Group

Components and active materials

CATHODES
Sumitomo
Umicore
ShanShan
Nichia
Beijing
Easpring
BASF
3M
L&F
Johnson Matthey

ANODES
Shanshan
BTR New Energy
Jiangxi ZiChen
Hitachi Chem
Mitsubishi Chem

SEPARATORS
Shenzhen Senior TechCo.
Jinhui Hi-Tech
Asahi Kasei

ELECTROLYTES
Capchem Tech
Shanshan
Mitsubishi Chem
Ube Industries

Cell production / Module production / Battery pack assembly

AESC
CATL
SAFT (Total)
Lishen
Leclanché
Murata
Foxconn
Boston Power
NEC
Sanyo
Continental AG
GS Yuasa
Guoxuan
Bosch

Integration in the vehicle

Volkswagen (Panasonic, Samsung SDI, CATL, SK Innovation)
Nissan (AESC, CATL)
Ford (LG Chem)
Hyundai (LG Chem, CATL)
Mercedes (Panasonic, SK Innovation, A123)
Renault (LG Chem, CATL)
Volvo (LG Chem)
BMW (Samsung SDI, CATL, *A123)*
Fiat (Samsung SDI)
BAIC (CATL)
PSA (CATL)
Daimler (CATL)
Honda (CATL)
Toyota (Panasonic)
Chevrolet (A123, LG Chem)

Recycling and reuse

Glencore
Retriev Technologies
Umicore
Valdi (Eramet)

Players often involved in the production of modules and packs, near automobile manufacturers

A123, Panasonic, LG Chem, Samsung SDI, SK Innovation, Northvolt (in development)

Tesla (Panasonic), BYD, Bolloré/Blue Solutions

*Some players can also assemble battery packs

Source: KPMG analysis

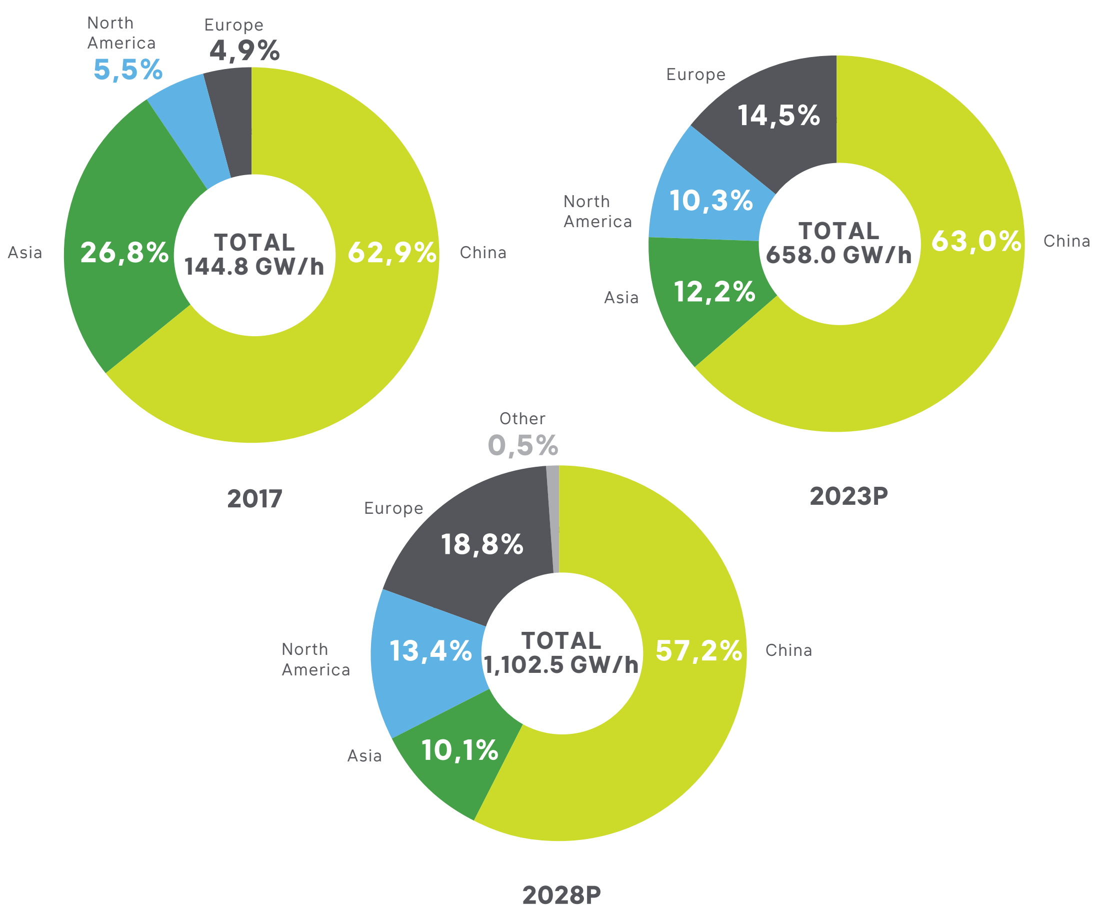
A global race to add lithium-ion battery cell production capacity

In several regions of the world, the production of electric vehicles tends to be consistent with sales of lithium-ion batteries. This is particularly true in China and Europe, while in the United States the connection is less obvious. Lithium-ion battery production in China is roughly equivalent to electric vehicle production and sales (accounting for just over 40% of cumulative global sales until 2017), whereas in Europe and the United States lithium-ion cell production capacity is currently not high enough to meet the needs of auto manufacturers. Together, Europe and the United States account for about 40% of electric vehicle production (cumulatively until 2017)[7], but only about 10% of global cell production capacity. Therefore they are net importers of lithium-ion battery cells.

To meet the expected very strong growth in demand for lithium-ion batteries and to quickly position themselves in the market, several industry players have entered the race to add cell production capacity. This involves both building new plants and increasing the production capacity of existing facilities. As shown in the diagrams on the next page, recent announcements suggest that global cell production capacity could increase tenfold between 2017 and 2028.

Current and planned lithium-ion battery production capacity in megafactories, September 2018

2017 to 2028, by region, in GWh



Source: Benchmark Mineral Intelligence, 2018

7 International Council on Clean Transportation, *Power Play: How Governments Are Spurring The Electric Vehicle Industry*, 2018, p. 25.

The industry is developing at breakneck speed, and the strong interest of existing players is clear: between fall 2018, when KPMG started work on this study, and February 2019, planned production capacity for 2028 rose from 1,102 GWh to 1,549 GWh. This is a 40% jump in five months. With the major additions to cell production capacity already announced, the supply of anode and cathode materials will be a considerable challenge for cell manufacturers. Production capacity for lithium, cobalt, nickel, manganese, and graphite will also need to be stepped up.

Five factories announced or operating in North America

At the end of January 2019, three lithium-ion cell production plants for the electric vehicle market, with a production capacity greater than 1 GWh, were operating in North America, and two construction projects were announced, as shown on the map on the following page. Two of the factories were built in the early 2010s and have since increased their production capacity. For example, LG Chem's plant in Michigan, which produces batteries for the Chevy Bolt, stepped up capacity from 1.5 GWh in 2016 to 3 GWh in 2018.[8 9]

These five factories have each received very substantial government support. For example, the Tesla plant (which also manufactures vehicles) was awarded tax incentives valued at US$1.3 billion. Tax incentives are often spread over a number of years to ensure companies actually deliver on the investment promises they have made.

Government-granted tax incentives (non-exhaustive list):

- **Sales tax abatements**
- **Tax abatements**
- **Business tax abatements**
- **Tax credits**
- **Discounted electricity rates**

There are also a few plants in the United States with capacity of less than 1 GWh, including the 200 MWh EnerDel facility in Indiana. EnerDel is the only completely independent U.S. player, since it does not rely on foreign capital or technology.[10]

8 CleanTechnica, *LG Chem Battery Production Ramps Up In Holland, Michigan*, https://cleantechnica.com/2015/10/28/lg-chem-battery-production-ramps-up-in-holland-michigan/, accessed February 1, 2019.
9 Electrive, *LG to augment capacities of its U.S. battery plant*, https://www.electrive.com/2018/01/06/lg-augment-capacities-u-s-battery-plant/, consulté le 1er février 2019.
10 Wards Auto, *U.S. EV Battery Capacity Lacking, Expert Warns*, https://www.wardsauto.com/alternative-propulsion/us-ev-battery-capacity-lacking-expert-warns, accessed February 4, 2019.

Battery cell megafactories in the United States – government aid (US$)

TESLA – NEVADA

Aid allocated
$1.3 billion in federal tax incentives

Capacity
20 GWh in 2018, rising to 105 GWh

Jobs
6,500

LG CHEM – MICHIGAN

Aid allocated
$325 million ($150 million under the *Recovery Act* and $175 million in federal and local tax incentives)

Capacity
3 GWh

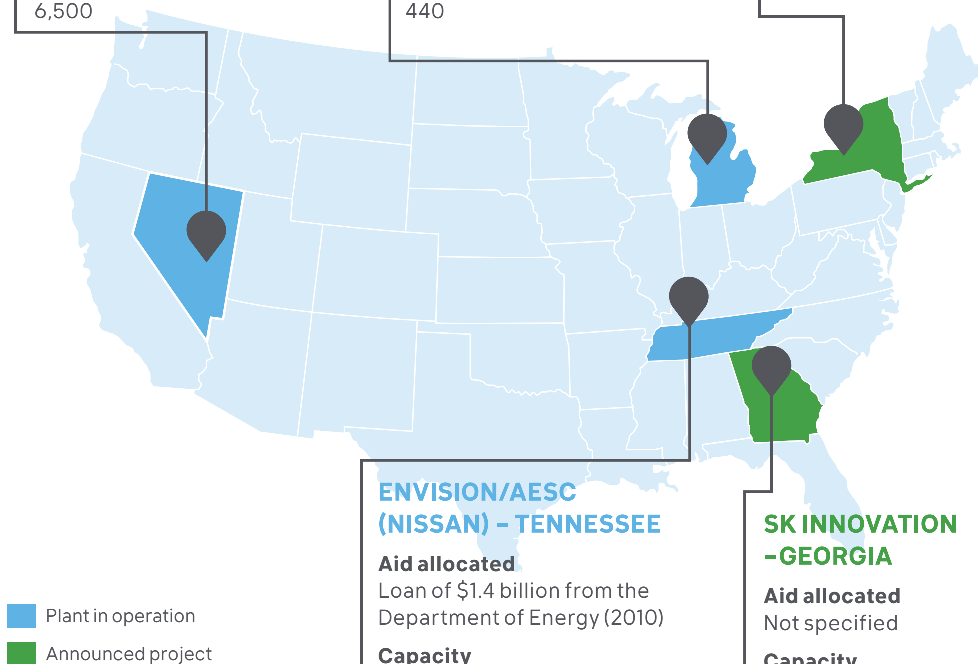
Jobs
440

IMPERIUM3 – NEW YORK

Aid allocated
$13.5 million ($4 million in loans and $9.5 million in tax incentives)

Capacity
3 GWh initially (2019)

Jobs
230



ENVISION/AESC (NISSAN) – TENNESSEE

Aid allocated
Loan of $1.4 billion from the Department of Energy (2010)

Capacity
Battery cells and packs for 150,000 electric vehicles

Jobs
400 (2018)

SK INNOVATION –GEORGIA

Aid allocated
Not specified

Capacity
Ultimately 9.8 GWh (construction in 2019)

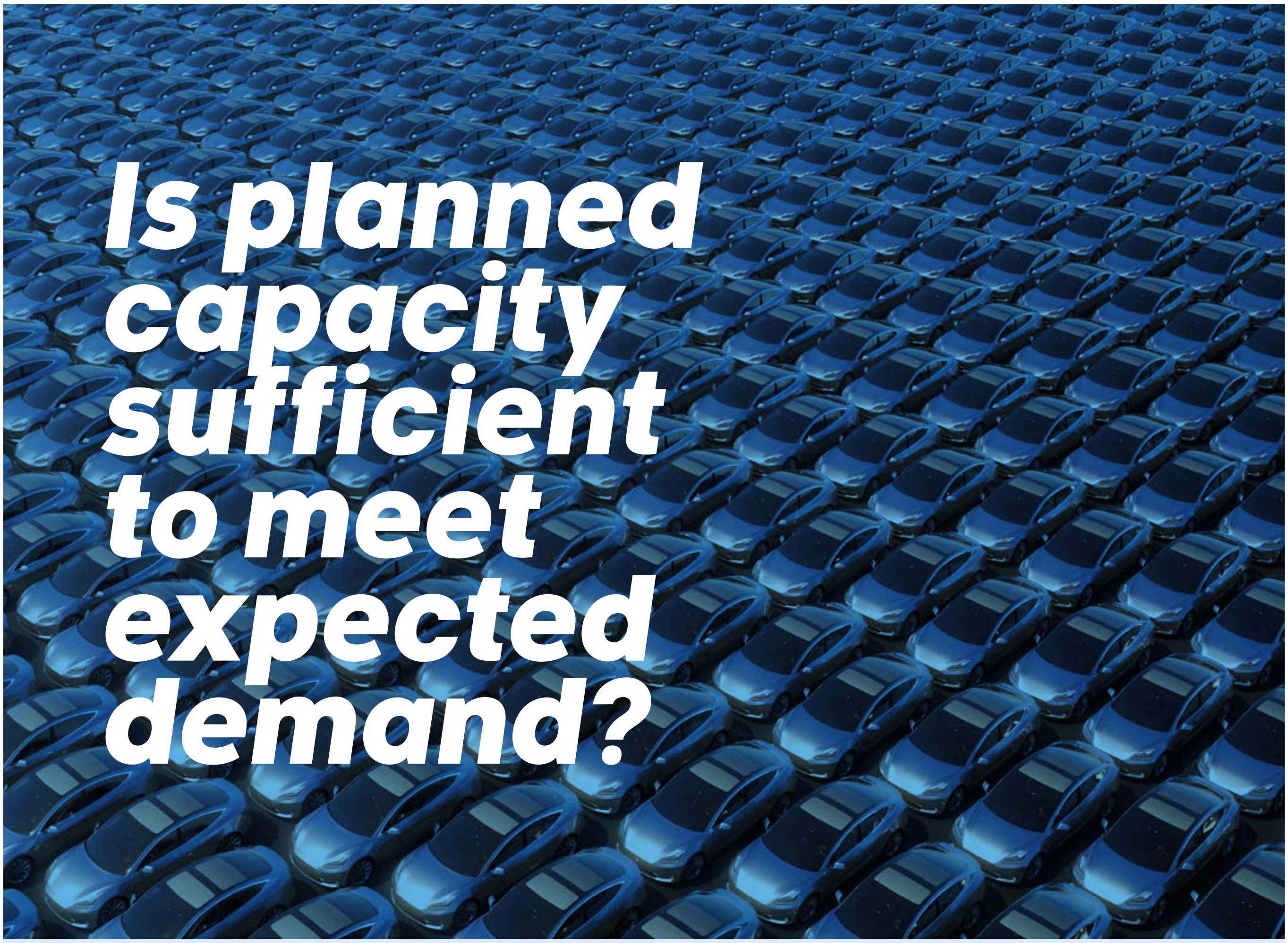
Jobs
2,000

Source: KPMG analysis

A trend towards higher production capacity per plant

Globally, there is a trend towards increasing the average production capacity of cell plants in order to achieve efficiency gains. However, optimal plant size varies depending on the source consulted. Some sources state that optimal gains are achieved at around 20 GWh[11], while others say between 8 GWh and 10 GWh[12].

11 L.E.K., *Fast-Moving EV Battery Market: How to Win Against the Competition?*, https://www.lek.com/insights/fast-moving-ev-battery-market-how-win-against-competition, accessed February 2, 2019.
12 Electreck, *Northvolt starts construction on first phase of its planned battery gigafactory*, https://electrek.co/2018/04/27/northvolt-construction-first-phase-planned-battery-gigafactory/, accessed January 15, 2019.



Is planned capacity sufficient to meet expected demand?

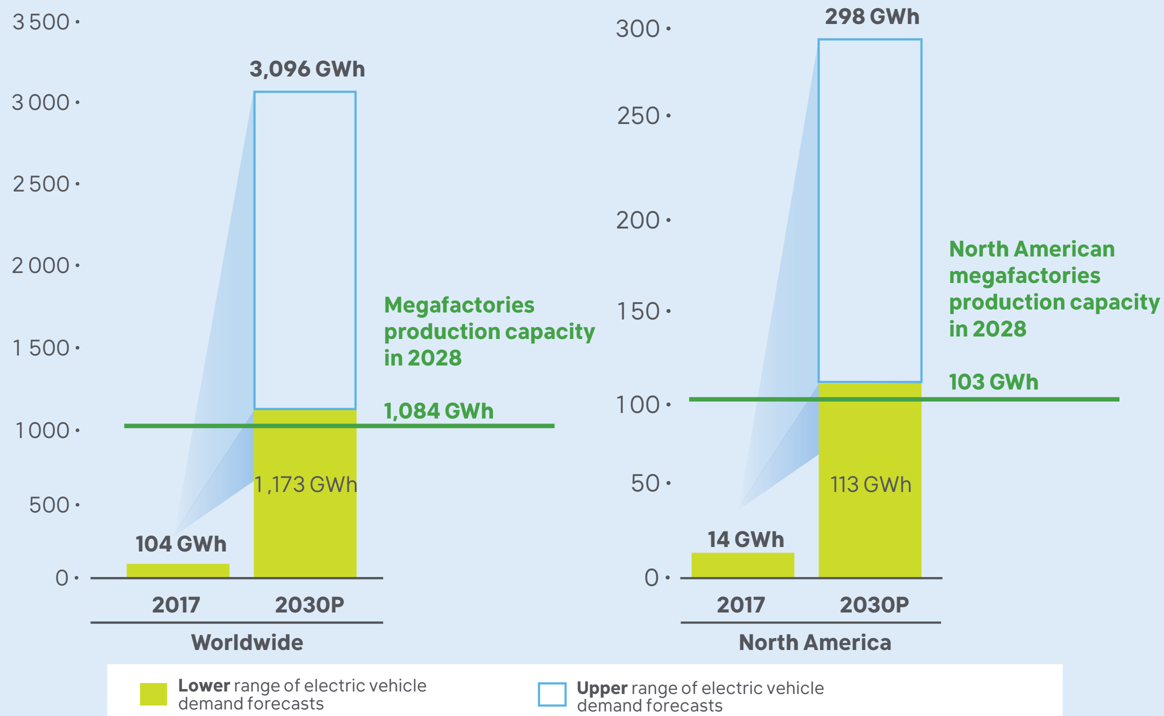
Assuming that on a global scale (i) 70% of the announced factories will be built and completed on time (a figure considered realistic) and (ii) they will produce 100% of planned capacity, the planned production capacity of 1,085 GWh in 2028 would meet the lower end of the range of global lithium-ion battery demand estimated by KPMG for the electric vehicle market only (which does not take into account demand from other uses, including energy storage).

For 2030, global sales of various types of electric vehicles (hybrids, PHEVs, FEVs) are expected to be between 40 and 60 million units (respectively the low and high end of the range estimated by KPMG). The energy requirement of this fleet of vehicles will depend on the average battery size, which is estimated at between 30 kWh (hybrids and PHEVs) and 55 kWh (long-range FEVs). For example, in 2018, fully electric passenger vehicle battery packs sold in the United States averaged 55 kWh.

The situation is similar in the North American market, where the planned production capacity of 103 GWh in 2028 would also meet the lower end of the demand range (diagram on the following page). The North American market (excluding Mexico) for fully electric vehicles is expected to increase from about 250,000 vehicles in 2018 to about 2 million in 2030.

Current and expected lithium-ion battery demand and production capacity worldwide and in North America

2017 and 2030E



Source: Benchmark Mineral Intelligence, 2018; KPMG analysis

The frenetic pace of plant construction announcements is explained by the expected market size in 2030. ***Even if all these factories were built, there would still be a significant undercapacity compared to expected demand.*** *There is still time for new, high-producing players to get on board. The market offers an opportunity for growth and wealth creation that are virtually unprecedented in terms of scope and sustainability.*

2- *The lithium-ion* **battery recycling market**

2.1 Growth in demand for recycled raw materials

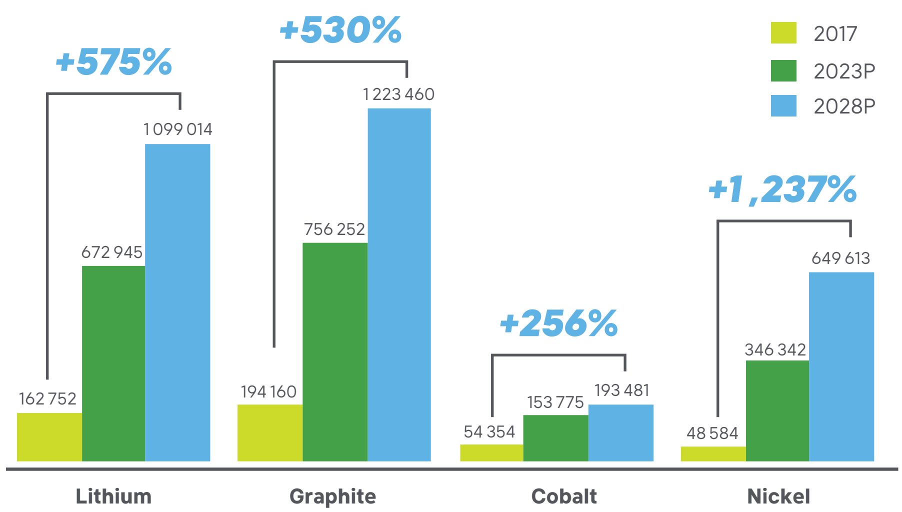
Vigorous growth in demand for base materials expected

Demand for lithium-ion battery raw materials should remain strong over the next ten years, given the robust growth in demand for electric vehicles.

Demand for raw and other materials used to produce lithium-ion batteries is expected to skyrocket over the next decade (between 500% and 1,200% in ten years for some materials). Because of this, cell and component manufacturers will find it difficult to secure an adequate, stable, ethical, and high-quality supply. Global production capacity will not be great enough to fill needs for electric vehicles, storage, and electronic devices.

Expected worldwide demand for raw materials

By material, in metric tons



Note : Assuming 70% of planned megafactories are built (at a capacity usage rate of 100%)

Source: Benchmark Mineral Intelligence, 2019; KPMG analysis

With this expected spike in demand for raw materials, recycling and recovered materials could play an important role in the lithium-ion battery supply chain and be a key source of battery materials. The growth in sales of electric vehicles and the huge quantity of end-of-life batteries to follow a few years later will help provide a critical mass of material for this recycling industry.

Recycled raw materials: Geostrategic, economic, and environmental considerations to support demand[13]

Geostrategic, economic, and environmental considerations are expected to support the demand for recycled raw materials over the long term, opening the door to a wealth of business opportunities.

In terms of environmental considerations, end-of-life batteries will need to be recycled on a massive scale to reduce the environmental impact of the electric car industry. Lithium-ion batteries are considered hazardous materials that will cause major public health and environmental problems if not processed in a clean and appropriate manner. Because of this, car manufacturers and all stakeholders in the electric battery industry will be keen to make sure batteries are properly managed at the end of their useful life.

At the geostrategic level, as a way to prevent overdependence on mineral resources, resource-poor countries or regions could promote recycling to create their own alternative «deposits» of materials and reduce the risk of dependence on certain regions.

2.2 Developing innovative recycling technology

Lithium-ion batteries are tricky to recycle because of the wide variety of chemistries and formats available on the market, the risks associated with dismantling them, and the lack of information (i.e., labelling). Having robust recycling processes that can handle a variety of chemistries is critical to maximizing the volumes recycled and increasing profitability. However, the recycling technology in widespread use today does not recover all of the various raw materials contained in batteries.

The biggest players in the industry, such as Umicore in Belgium and Valdi in France, use pyrometallurgical processes that recover only some of the materials and a portion of their value. Hydrometallurgical processes give better results in terms of recovery and could make a meaningful difference in recycling efforts if materials are reused to make new batteries. However, such processes are still under development and are being tested as pilot projects, while some are ineffective.

Clear classification of batteries and their components would make recycling safer and more cost-effective. It's easier to determine the value of a battery's materials if they can be properly identified.[14] However, this will require a concerted effort by car manufacturers and/or tighter regulations.

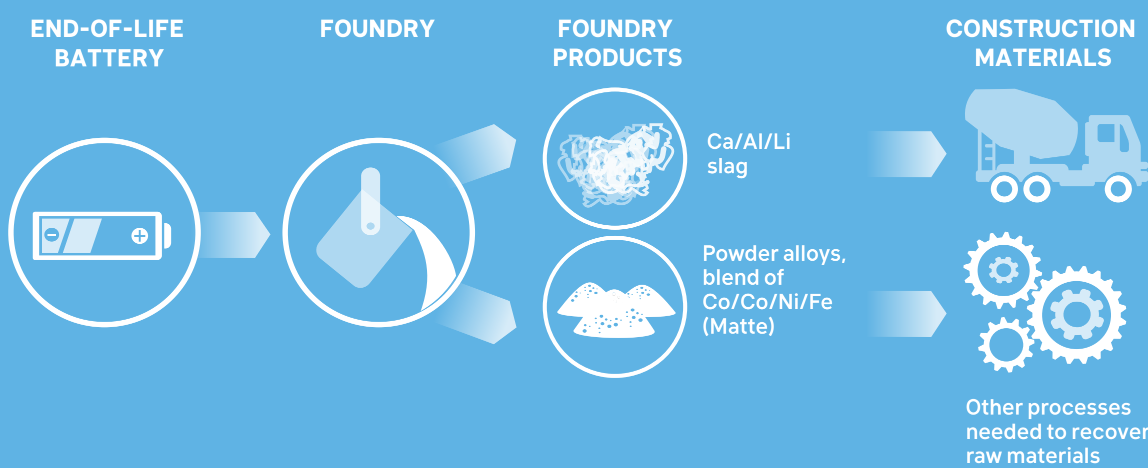
13 Berenberg, 2018.
14 CEC, *Environmentally Sound Management of End-of-Life Batteries from Electric-Drive Vehicles in North America*, 2015, p. 62.

Lithium-ion battery recycling processes

Pyrometallurgical recycling

In this process, battery components are melted at high temperature in a foundry to extract precious metals such as cobalt. Pyrometallurgy does not require any special adjustment or sorting according to technology. It's a fairly simple operation. But it takes a lot of energy, emits pollutants, and does not recover a number of materials, including lithium. The product that leaves the foundry is called "matte", a mixture of metals and sulfide often in the form of a fine powder that requires further processing to obtain purer metals.

Source: KPMG analysis

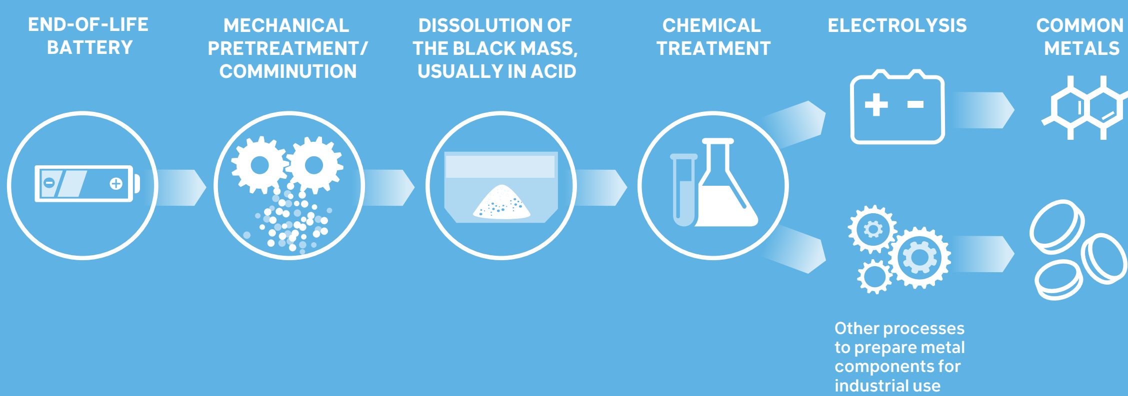


Mechanical/physical recycling

This process consists of physically dismantling and separating the battery components to collect a mixture of metals (nickel, lithium, etc.). It's risky due to the residual energy in the battery and is more difficult to implement on a large scale, but the environmental impact is lower than other recycling techniques. Black mass, a coarse powder containing all electrode materials, is one of the products of mechanical/physical recycling. Additional processing is needed in order to obtain materials that are purer and more valuable. Mechanical/physical treatment often precedes hydrometallurgical processes.

Hydrometallurgical recycling

When combined with manual battery pre-treatment, hydrometallurgy can recover most metals and non-metallic components from a battery. Batteries are treated with an aqueous chemical solution to separate dissolved metals. Although it produces wastewater, this process is more environmentally friendly and uses less energy than pyrometallurgy.



Source: KPMG analysis

Other processes in development

Other recycling processes exist, such as recycling based on biometallurgical processes (using biological solvents), but they are rarely used in the industry. They are often still in the development stage and will not be commercially available for several years.

Sources: Berenberg, Umicore, Retrieve, Glencore

Lithium-ion battery recycling: An emerging industry and a golden opportunity for Quebec

The lithium-ion battery recycling sector is currently underdeveloped. But the growing popularity of electric vehicles and the increase in the number of end-of-life batteries will fundamentally change the structure of the industry because of the amount of recoverable materials they contain—that is, as long as efficient and profitable recycling processes are used.

Few active players have been identified in the northeastern United States and Canada. According to information compiled by KPMG, there are only two battery recycling plants in Canada (only one of which mainly recycles batteries). In the northeastern United States, Korean recycling company SungEel and U.S. company Metallica Commodities Group announced a new joint venture for lithium-ion battery recycling with an expected capacity of 5,000 metric tons per year. The facility will be located in the state of New York[15] on the same technology campus as a new cell plant that the Imperium3 consortium plans to build.[16]

According to our interviews, in Canada only Retriev (British Columbia) appears to be able to recover raw materials efficiently through its recycling process. Its current capacity is 4,500 metric tons per year.[17] In the case of Glencore in Sudbury, Ontario, the recycling plant is a foundry designed to refine mining products such as nickel and cobalt. Lithium-ion batteries from electric vehicles are only a marginal source of supply. Most of the final recovery of raw materials recycled by Retriev or Glencore in Canada is done outside North America, in Norway.[18]

The amount of batteries to be recycled could increase rapidly in the coming years, to as much as 1.7 million metric tons in 2025. Existing or planned processing capacity could then be substantially exceeded.

15 Waste 360, *SungEel MCC Unveils Lithium-Ion Battery Recycling Plant*, https://www.waste360.com/e-waste/sungeel-mcc-unveils-lithium-ion-battery-recycling-plant.
16 Koffman Southern Tier Incubator, *Imperium3's Battery Factory Is Coming To Endicott Earlier Than Expected*, https://southerntierincubator.com/imperium3s-battery-factory-is-coming-to-endicott-in-2019/.
17 Retriev, 2017.
18 Glencore, 2018.

Like its counterparts around the world, the Quebec lithium-ion battery recycling industry lacks structure. According to interviews conducted by KPMG, the majority of batteries (especially from damaged vehicles) are scrapped. The few batteries that are recycled are handled by Retriev, in British Columbia, with high transportation costs due to current regulations and the size of the batteries. What's more, vehicle manufacturers and car dealers don't seem to have a recycling system in place in Canada, given the small volume of end-of-life batteries from electric vehicles.

However, battery recycling plants are being developed in Quebec, and the growing number of electric vehicles on Quebec's roads could provide a critical mass of material for those plants.

If new regulations require a higher recycling rate for batteries from electric vehicles, the amount of batteries to be recycled could increase rapidly in the coming years, to as much as 1.7 million metric tons in 2025. Existing or planned processing capacity could then be substantially exceeded. The industry could transition from an economic model based on processing costs to a model based on the recovery and reuse of raw materials. This will largely depend on reaching a high enough volume of end-of-life batteries to make operations profitable. Once this critical mass is reached, ecological and economic considerations (collection and transport costs) could favor local recycling of end-of-life lithium-ion batteries.

Regulations that promote the adoption of electric vehicles (resulting in a large fleet), efficient recycling of end-of-life batteries (as well as a robust collection ecosystem), and the proximity of a sufficiently large battery pool (to minimize transportation costs) are key factors in the location of facilities where electric vehicle lithium-ion batteries will be recycled. And finally, battery manufacturers could agree on standards for identifying battery components, to make recycling more efficient.

2.3 Emergence of the recycling market: A matter of battery life and supply

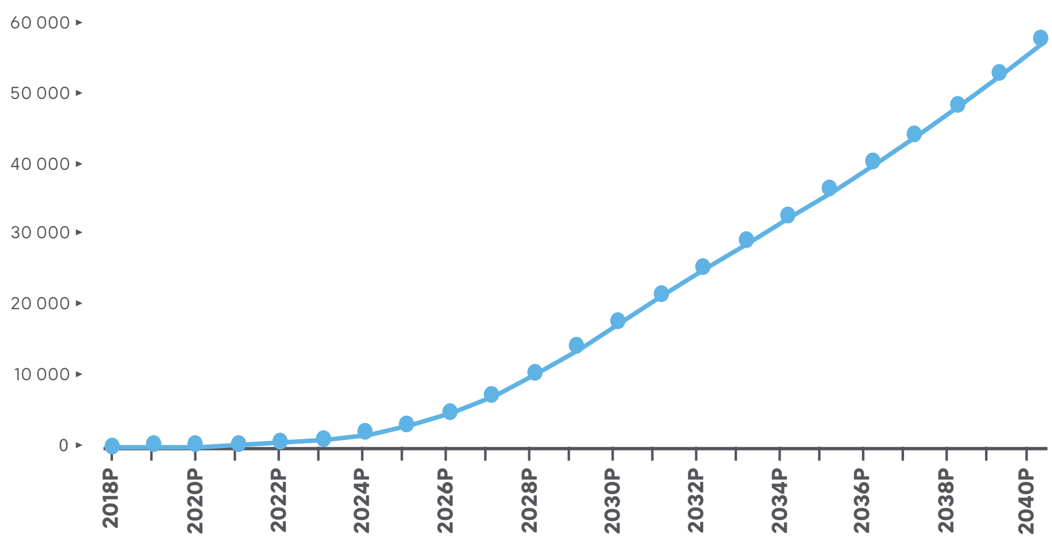
A significant future supply

The growth in lithium-ion battery recycling activities is expected to be driven mainly by the volume of end-of-life batteries from electric vehicles (from 2025–2030, energy storage needs could also be a significant driver of growth in the battery pool). Ultimately, once the sector is well established two key factors will determine the size of the recycling market: growth in sales of electric vehicles (and, later on, of batteries for energy storage) and actual battery life. However, there is plenty of uncertainty about how these two parameters will evolve over the next decade.[19]

For Canada, analyses suggest that the number of end-of-life batteries could rise to between 140,000 and 210,000 by 2030. In terms of recycling capacity, Canada alone would need facilities capable of handling between 40,000 and 63,000 metric tons in 2030. The number of end-of-life batteries in Quebec could reach between 58,000 and 88,000 in 2030. To recycle all these end-of-life batteries locally, Quebec would need recycling facilities with capacity of between 17,500 and 26,400 metric tons in 2030.

Estimated growth in the number of end-of-life batteries – Quebec market

2018E–2040E, end-of-life batteries, in metric tons



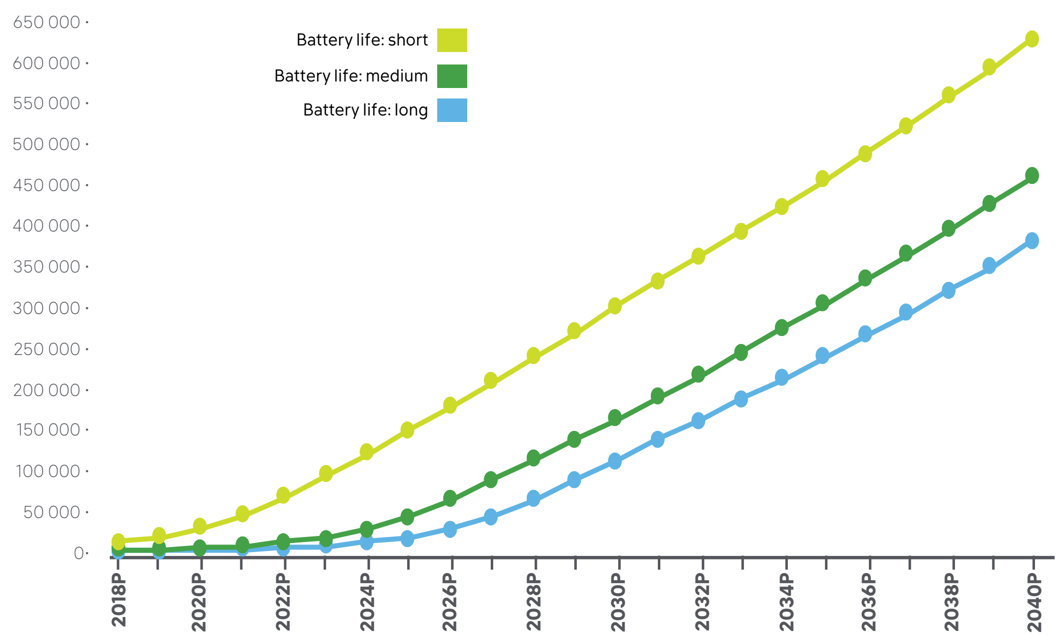
Sources: RBC, FleetCarma, EVadoption, IEA; KPMG analysis

19 The life of lithium-ion vehicle batteries is generally estimated at between eight and ten years. But that hasn't been proven because of the limited number of electric vehicles on the market before 2015. A survey of Tesla owners suggests that actual battery life could be significantly higher than estimated. According to Tesla's projections (based on actual usage data from a group of more than 250 Tesla drivers), a Tesla battery still has 80% of its capacity after the car has logged 800,000 km. This equates to a battery life of 40 years (based on 20,000 km per year).

In the northeastern United States[20], a segment that Quebec could potentially capture and with a population of more than 170 million people[21], the number of electric vehicles sold could increase by more than 16% annually to reach 1.2 million in 2030. In this case recycling capacity would need to be ramped up substantially in order to process vast quantities of used batteries (between 160,000 and 220,000 metric tons per year in 2030). Current capacity is about 12,000 metric tons per year.[22]

Estimated growth in the number of end-of-life batteries – northeastern United States market[23]

2018E–2040E, end-of-life batteries, in metric tons



Sources: RBC, FleetCarma, EVadoption, IEA; KPMG analysis

Several steps remain before a lithium-ion battery recycling market can begin to take shape. Industry players will have a number of challenges to overcome, including battery supply management. Not only are lithium-ion batteries considered to be a hazardous material, but they must also be collected in sufficient quantities to make a commercial recycling operation viable. However, recycling market estimates show that the planned recycling capacity will not be enough to handle all of the end-of-life batteries that will be available.

20 Connecticut, Delaware, District of Columbia, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, Tennessee, Vermont, Virginia, Wisconsin.
21 United States Census Bureau (2018), Statistics Canada (2017).
22 Mostly at the two facilities in Canada, Retriev and Glencore.
23 Assumptions for the various scenarios:
- Short battery life = 7.5 years
- Medium battery life = 9.5 years
- Long battery life = 11.5 years

Estimates for the electric vehicle battery recycling market

MARKET	End-of-life batteries (thousands)		End-of-life battery tonnage (in thousands of metric tons)		Recycling capacity (in thousands of metric tons)	
	2025	2030	2025	2030	2019	2024
Worldwide	2 627 to 5 761	11 995 to 17 687	788 to 1 728	3 599 to 5 306	87	240
Northeastern United States	143 to 301	546 to 756	43 to 90	164 to 227	12	21
Canada	25 to 60	143 to 211	7 to 18	43 to 63	12	16
Quebec	10 to 21	58 to 88	3 to 7	17 to 26	-	10

Sources: RBC, Berenberg, AIE ; KPMG analysis

Reusing old batteries does not seem to be a viable alternative to immediate recycling, but a number of manufacturers are doing just that. Although used batteries have a long residual life, and much of their cost is associated with assembly, their reuse has many challenges, particularly in terms of safety, performance, and risk to reputation compared to new batteries available on the market. In addition, in certain cases studied, using second-life batteries (i.e., reusing batteries) is not any cheaper than using new battery cells. In the long term, technological advances may allow for batteries to be reused for stationary energy storage, but this practice will merely extend battery life and not eliminate the need to recycle those batteries when they reach the end of their life.

3- Quebec's **competitive advantages**

3.1 Who are the main players in Quebec?

Quebec is known for its resources and expertise

By building on its strengths, which include relatively low operating costs for North America, access to clean and abundant energy, readily available technological and industrial expertise, and proximity to U.S. auto manufacturers, Quebec will have opportunities to further develop its lithium-ion battery industry (Quebec's strengths are detailed in the next section).

Quebec has a variety of mineral resources (lithium, graphite, iron, phosphate, nickel, and potentially cobalt), which some players are now seeking to develop by transforming them into battery-grade materials. However, Quebec does not yet mass produce minerals with the right qualities to be used as battery components. Some companies, including Nemaska Lithium and North American Lithium/CATL for lithium, and Mason Graphite and New World Graphite for graphite, are currently working to develop a supply of battery-grade processed minerals.

Quebec's lithium-ion battery industry currently has a limited number of players representing the various links in the value chain. In particular, Quebec has expertise in mining and the development and assembly of specialized electric vehicles (buses, commercial vehicles, trucks, snowmobiles, etc.).

The province can also draw on recognized research expertise in developing lithium-ion battery technology, as it has a number of players who are excelling in this promising sector. But, their actions are not driven by a shared vision that would seamlessly integrate their efforts into the lithium-ion battery industry.

Hydro-Québec's Center of Excellence in Transportation Electrification and Energy Storage works with a number of players in the industry, in Quebec and elsewhere in the world, to develop and market lithium-ion and solid technology at all levels (battery materials, electrodes, electrochemical cells, modules, and battery packs). The Center has an extensive portfolio of patents that it markets.

The National Research Council of Canada has set up a lithium supply chain research group to develop and support the Canadian supply chain of value-added materials for lithium-ion battery applications. The group, which has research facilities in Boucherville, brings together raw material suppliers, processors, manufacturers of batteries and original equipment, and other players from all parts of the supply chain.[24]

At the university level, many researchers have created research groups and programs to study current and future issues related to lithium-ion batteries.

24 CNRC, *Groupe de R-D industrielle sur les batteries au lithium-ion (LiBTec)*, https://www.nrc-cnrc.gc.ca/fra/solutions/collaboration/libtec.html, accessed December 15, 2018.

Quebec is the home of college centers for the transfer of technology (CCTTs) of which the core work and expertease revolve around batteries and vehicles: Centre national en électrochimie et en technologies environnementales (CNETE), Centre de technologie minérale et de plasturgie (CTMP), and the Innovative Vehicle Institute (IVI). The latter has developped expertise and delivered several projects related to batteries, vehicle electrification, and now vehicle empowerment.

Intermediation organizations support the scale-up of new technologies and applications in the battery sector: the Advanced Materials Research and Innovation Hub in Quebec (Prima Québec), Consortium de recherche et d'innovation en transformation métallique au Québec (CRITM), and the InnoVÉE consortium.

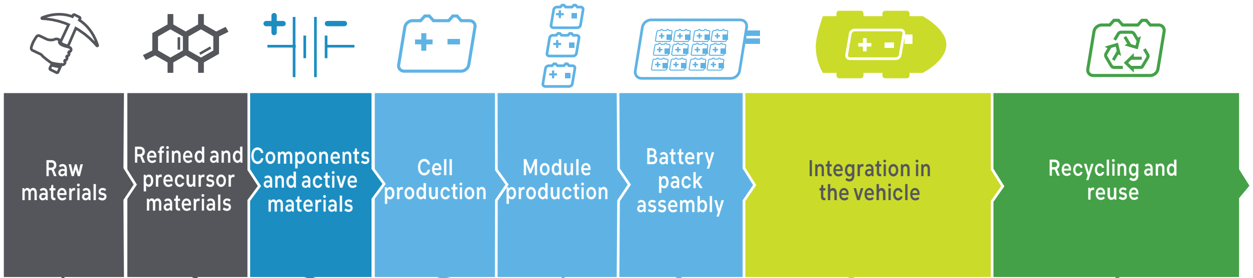
Propulsion Québec, the cluster for smart and electric transportation, was created in 2017 as a coordination agent. Its mission is to mobilize industry players and speed up the development of the smart and electric transportation industry, including the battery sector.

Lithium-ion battery recycling: An underdeveloped industry in Quebec

The battery recycling sector is still underdeveloped in Quebec. However, a number of very promising projects are being developed and slated for piloting over the next year. These projects would use hydrometallurgical processes to recover a significant proportion of the materials in batteries and purify them to a grade that would allow battery manufacturers to reuse them. Institut EDDEC highlighted the opportunity for Quebec of recycling lithium-ion batteries and why it makes sense in its March 2018 report entitled *Métaux et économie circulaire au Québec*.[25]

25 Institut EDDEC, *Métaux et économie circulaire au Québec*, 2018.

Overview of Quebec's extended lithium-ion battery value chain for electric vehicles (March 2019)



Raw materials

LITHIUM
North American Lithium/CATL (on hold)
Nemaska Lithium (commercialization imminent)
Sayona (project)
Galaxy Resources (exploration)

GRAPHITE
Imerys
Mason Graphite (pilot project)
Nouveau Monde Graphite (pilot project)

NICKEL
Canadian Royalties
Glencore
RNC Minerals (project)

VANADIUM
Métaux BlackRock (project)

Refined and precursor materials

LITHIUM
Nemaska Lithium (commercialization imminent)

GRAPHITE
Mason Graphite (pilot project)
Nouveau Monde Graphite (pilot project)

MANGANESE
Manganèse X Energy (project)

Components and active materials

Johnson Matthey (LFP cathodes)
Nemaska Lithium (project)
Raymor

Cell production / Module production

Bolloré/ Blue Solutions (LFP cells, battery modules, with integration in France)

Battery pack assembly

Batteries Mustang Technologies (battery packs)
UgoWork (battery packs for forklifts)

Integration in the vehicle

VEHICLE MANUFACTURERS*
Boivin Evolution (trucks)
BRP (snowmobiles)
Compagnie électrique Lion (buses)
Concept GEEBEE (scooters)
Ecotuned (trucks)
Groupe Volvo/ Novabus (buses)
Kargo (utility vehicles)
Letenda (buses)
LTS Marine (boats)
Motrec (utility vehicles)
Nordresa (trucks)
Phaneuf international (ice resurfacers)
SORA Electric Superbike (motorcycles)
Taiga Motors (snowmobiles)
Vélotransit (bicycles)

Recycling and reuse

RECYCLING COMPANIES
Nemaska Lithium (project)
Neometals Ltd/ Alphamet (tests)
Recyclage Lithion/ Seneca (project)
Solumet (possible)

Research

Center of Excellence in Transportation Electrification and Energy Storage (Hydro-Québec)
Centre d'étude des procédés chimiques du Québec
Centre de technologie minérale et de plasturgie
Centre de recherche industrielle du Québec
Centre national en électrochimie et en technologies environnementales
National Research Council of Canada
Metal Transformation Research and Innovation Consortium
École Polytechnique (Laboratory of New Materials for Energy and Electrochemistry)
FP Innovations
Institut de recherche d'Hydro-Québec/Dongshi
Innovative Vehicle Institute
Institut national de la recherche scientifique
Concordia University (Power Electronics and Energy Research Group)
Université de Montréal (Laboratory of Chemistry and Electrochemistry of Solids)
Université de Sherbrooke (Centre de technologies avancées)
McGill University
UQAM (NanoQAM)

Extended ecosystem

PARTS MANUFACTURERS
Kongsberg Automotive Inc.
Spectra Premium (parts expertise)
TM4 Dana (engines)

SERVICES
COREM
Hypertronic (engineering services)
OPAL-RT (system tests for vehicles)
Pantero (engineering services)
PMG Technologies
Targray (supplier of all components)
Transtech Innovations (electronic systems for vehicles)

CHARGING INFRASTRUCTURE
ABB
AddÉnergie Technologies
Bectrol inc.
Elmec inc.
Kilowattpack
MCM intégration inc.
Recharge Véhicule Électrique
Renewz

BATTERY TRANSPORT
Kuehne + Nagel

PLAYERS IN THE RECYCLING SECTOR
Appel à recycler
Recyc-Québec
Electronic Products Recycling Association

OTHER PLAYERS
Prima Québec
InnovÉÉ

CONSULTATION WITH INDUSTRY PLAYERS
Propulsion Québec
Recyc-Québec

* Some players can also assemble battery packs

3.2 Strengths, weaknesses, threats, and opportunities for Quebec

An industry worth quickly prioritizing

With the province's many competitive advantages, the outlook for developing Quebec's lithium-ion battery industry is very positive. The sector could be driven largely by the expected growth in electric vehicle sales in the northeastern United States and by recycling opportunities. Global supply chains for lithium-ion batteries are changing at an accelerated pace, and projects can take several years to complete. Quebec's window of opportunity is relatively short, so decision-makers would have to take action very soon to stake a place in this industry. Because Quebec is not the only interested party—other parts of the world also want to take advantage of these opportunities for growth and wealth creation, as evidenced by recent announcements of support for the industry by a number of governments including Germany, France, and the United States.

STRENGTHS	WEAKNESSES
• A clean and competitive energy source • Low operating costs for North America • Manufacturing capability that meets strict environmental standards (as greener processes may become a more common requirement for auto manufacturers) • Readily available industrial expertise • IREQ's preindustrial experience in cell production • Proximity to the U.S. market and U.S. car manufacturers • Logistics infrastructure to access U.S. and European markets and existing trade agreements • A government that supports the development of the electric vehicle sector to achieve its climate objectives • A stable political and regulatory environment **Component materials** • Availability of raw materials including graphite, lithium, nickel, cobalt, aluminum, iron, phosphate, manganese, and copper **Recycling** • Expertise in processing raw materials • Capability and expertise in recycling in general (collection, regulations, extended producer responsibility [EPR], etc.)	• Limited ability to take quick collective action • Limited existing capacity for lithium-ion cell production and limited industrial experience • A supply chain and logistics that are underdeveloped and not well integrated with existing international chains • Few big-name battery producers • Quebec players smaller than their Asian counterparts • Labor costs generally higher than in Asia • Red tape slows compliance with environmental regulations and access to energy

Main opportunities identified for Quebec

- The United States and the European Union have both identified the major strategic risk of their automotive industries becoming entirely dependent on Asia, mainly China, for cell supply. Both areas may want to be able to secure a significant portion (even if not the majority) of their cell supply from outside Asia or from their own region.
- The cost of capital is a significant competitiveness factor for highly capital-intense plants such as those that make cells. Through various financial tools (CDP, Investissement Québec, tax-advantaged fund, etc.), Quebec can create favorable financial conditions, particularly for initial projects (or for initial production capacity). There are also financing mechanisms in Quebec that can be used to support the development of the sector.
- According to interviews conducted, a number of international stakeholders are looking for investment opportunities in this sector.
- A green label could be created for the lithium-ion battery industry in response to demand for green products and the need for consumers to be able to assess a product's environmental performance. The label could be used to promote what Quebec is doing and highlight what sets the province apart. However, at a time when the industry's overriding concern in the short and medium term is making cells cheaper to produce, this is a promising option for the next phase. Many companies, particularly in western countries, are trying to position themselves in this market, which could eventually transition from niche to norm as electric car owners demand greener vehicles.
- As the market for electric vehicle cells is still young, stakeholders are currently using investment strategies that are not purely price-driven. There is room for strategies aimed at independence and technical differentiation.
- The lithium-ion industry is dealing with undercapacity at all levels, except cell production. This means there are opportunities to be seized, especially for the production of battery-grade materials. The number of intermediaries is large, so there is pressure for vertical integration to reduce the number of players and intermediate margins.
- Pressure on resources could sustain the price of materials and provide opportunities to develop recycling. Moreover, if the materials resulting from recycling are not the right quality or purity for batteries, they could be used in other sectors. For example, lithium is widely used in glazing and lubricants. This reduces the risk for battery recycling plant operators.

4- *Recommendations for developing* ***the industry in Quebec***

4.1 Four strategies for developing the industry

Supporting development of a lithium-ion battery industry in Quebec

Why?

- Booming global demand
- Value-added strategic activity
- Reinforces Quebec's electric transportation industry, which has many well-known active players in the battery segment

Four major underlying trends

- Demand for lithium-ion battery cells and materials are growing at accelerated pace
- There's a global race to add production capacity and desire for greater geographical diversification
- The global industry is somewhat consolidating
- There are substantial ongoing R&D efforts to i) reduce the costs of manufacturing batteries while also increasing range ii) develop robust, economically viable recycling processes to handle a large variety of batteries

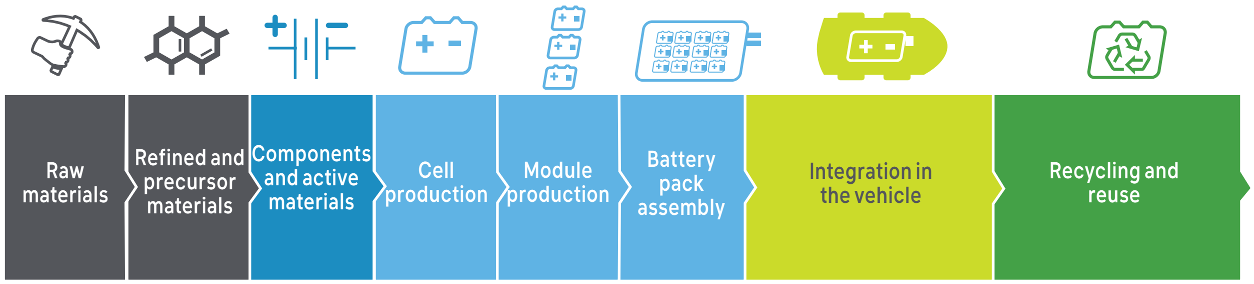
Quebec's main strengths

- Availability of raw materials (including graphite, lithium, nickel, cobalt, aluminum, iron, phosphate, manganese, and copper)
- Readily available industrial expertise
- A clean and competitive energy source
- A capacity to produce according to high environmental standards
- Relative proximity to the U.S. market and U.S. car manufacturers and to the logistics and transportation infrastructures
- Pro-development government

Main industry challenges in Quebec

- Fragmented industry, small players and few big-name battery producers
- Supply chain and logistics not integrated well with existing international chains
- Lack of battery recycling structures (neighboring regions also looking to get in on the industry)

Four strategies for developing the industry



1

Reinforcement strategy

(developing Quebec's assets/resources)

Capacity • varies according to materials/ project

Required investment • varies based on materials/project

Initial development of the industry using greater upstream integration (further promoting the transformation of raw materials into battery-grade materials); gradually, continue integration in the manufacture of components, and even in the manufacture of cells over the long term.

Conditions needed for success

- Industrial/mining players that have the technology and resources to satisfy market requirements
- Commercial partnerships with component and cell manufacturers

2

Rollout strategy

(gradual construction of a megafactory)

Capacity • 8 to 10 GWh (per phase)

Required investment* à • $1.8 to $2.9 billion (construction) and $1.1 to $1.4 billion (annual operations)

Quick development of significant cell production capacity to join global production chains.

Conditions needed for success

- Identifying a local promoter
- Alliance with a big-name manufacturer (technology transfer)
- Alliance(s) with one or more auto manufacturers (access to the market)
- Significant government support (financial and as a signal
- to the market)

3

Strategy for developing new recycling capacity

(for reuse in cell manufacturing)

Capacity • 7,000 to 10,000 metric tons over the long term

Required investment* • $40 to $120 million (construction)

Gradual rollout of local recycling capacity to recycle a share of volume from northeastern U.S., Quebec, and Ontario, with the goal of producing materials that can be reused in the cell production chain (components).

Conditions needed for success

- Regulations that promote battery collection and recycling
- A well-established collection system
- Robust and economically viable hydrometallurgical treatment processes
- Establishing partnerships with vehicle manufacturers for access to battery pools

4

Strategy for expanding current recycling capacity

(recycling for other uses)

Capacity • varies

Required investment • varies

Development of local recycling capacity to recycle a share of volume from northeastern U.S., Quebec and Ontario, using existing facilities, with the goal of producing materials for other industrial uses.

Conditions needed for success

- Regulations that promote battery collection and recycling
- A well-established collection system

* Note: for illustrative purposes only

4.2 Main factors for plant location

Based on the location criteria identified by KPMG, Quebec is in a good position to leverage its assets to develop the lithium-ion battery industry. Various location criteria for cell or component plants and recycling plants were defined. Some of the criteria—such as labor costs, energy costs, government incentives (excluding local incentives), or regulations specific to a certain country or region within a country— only allow for comparisons to be made at a national or international level, since these factors are either identical or relatively similar across the province.

But some of the criteria can be used to compare individual sites—for example, easy transport and logistics, regulations and social acceptability, proximity to customers and inputs, and local or special government support.

Weighting of criteria for the location of cell, component and recycling plants

	Component plants	Cell plants	Recycling
Strategic factors	1/4	7/8	3/4
Energy costs	1/2	3/8	1/4
Labor costs	5/8	1/4	1/4
Availability of skilled labor	3/8	1/2	1/2
Industrial ecosystem based on the recycling of materials			3/4
Transport infrastructure	1/2	3/4	1/2
Proximity to suppliers	1/4	1/4	0
Proximity to resources	1/4	1/4	7/8
Proximity to market	1/4	1/2	0
Regulations that promote recycling and collection			3/4
Regulations that promote electric vehicles			7/8

KEY: The shaded area represents the positive weighting of each factor for plant location.

Source: KPMG analysis/Globerpro

A number of sites can be considered for both a battery cell or component plant and a recycling plant. KPMG analysis focused on sites in southern Quebec because of their proximity to the U.S. market. A recycling plant would benefit from being located near or even adjacent to a cell production facility if the facility has a process for recovering metals so they can be recycled in component manufacturing. The sites identified do not represent an exhaustive list of possible locations in Quebec.

- **Beauharnois-Valleyfield**
- **Bécancour**
- **Contrecoeur-Sorel-Tracy**
- **Montréal-Est**
- **Shawinigan**

Conclusion

The global lithium-ion battery sector is growing rapidly by piggybacking on the electric vehicle industry, and announcements of increased battery cell production capacity around the world are becoming more frequent. This means there are major development opportunities to be seized for Quebec.

Although Quebec has only a small number of players in its lithium-ion battery sector compared to Asian countries (China, South Korea, Japan), the province can build on a number of strengths to position itself favorably in the global industry, including relatively low operating costs for North America, access to clean and abundant energy, readily available technological and industrial expertise, relative proximity to U.S. auto manufacturers, and expertise in the production of base and battery-grade materials.

Given the rapid transformation of the global supply chain, it is important to act quickly within a window of opportunity that could be relatively short. International players in the sector, whether mining companies, manufacturers of lithium-ion battery cells or components, or car manufacturers, are currently increasing their production capacity, forging new partnerships (particularly in new geographical areas), and investing in technological development to establish themselves within global supply chains. Governments in various countries, aware of the economic and strategic value of the industry, have announced policies to support the development of the lithium-ion battery sector as well as one-off subsidies to create production capacity in their own jurisdictions.

Among the potential development options, Quebec should:

- **Building on past success and then implementing stronger vertical integration in the sector by boosting the capacity of companies that produce resources and materials ;**
- **Building on strategic partnerships to establish a plant for the manufacture of lithium-ion battery cells or components ;**
- **Developing a lithium-ion battery recycling industry based on robust hydrometallurgical processes (yet to be developed) with a view to producing materials that can be reused in the manufacture of cell components (circular economy); and**
- **Adapting existing recycling facilities to process end-of-life lithium-ion batteries with a view to producing materials for other industrial uses.**

These strategies can be carried out separately or at the same time. The first, which hinges on the development of Quebec's natural resources, reinforces the second, which hinges on establishing partnerships with key industry players to achieve a significant level of cell production. Recycling operations based on hydrometallurgical processes in Quebec could also reinforce, and be reinforced by, these two strategies.

As the global transportation industry transitions to address climate change, Quebec has an extraordinary opportunity to leverage the mining, energy, science, technical, labour and financial resources it already has to secure a key role in the future of transportation. However, to realize its full potential, Quebec needs to create a collective vision around industry development and ensure greater coordination between the players in the sector.

Developing the lithium-ion battery industry is a logical extension of Quebec's commitment to a wide-scale transition to electric transportation and toward a sustainable future. It has the potential to drive economic development across Quebec, as long as the opportunity is seized quickly.

Bibliography

- Arthur D. Little, *Future of Batteries, 2018*, p. 18
- Autoblog, *Daimler to buy $23 billion worth of EV battery cells*, https://www.autoblog.com/2018/12/11/daimler-23-billion-ev-battery-cells/.
- Automotive News Europe, *Volkswagen to Reward Green Suppliers*, https://europe.autonews.com/suppliers/volkswagen-reward-green-suppliers.
- Avicenne Energy, *Lithium-Ion Battery Raw Material Supply and Demand*, 2017.
- Battery University, *Electric Powertrain, then and now*, https://batteryuniversity.com/learn/article/batteries_for_transportation_aerospace, accessed January 18, 2019.
- Battery University, *How do Lithium-Ion Batteries Work*, https://batteryuniversity.com/learn/article/lithium_based_batteries.
- Battery University, *Types of Lithium-ion*, https://batteryuniversity.com/learn/article/types_of_lithium_ion.
- Battery University, *What's the Best Battery?*, https://batteryuniversity.com/learn/archive/whats_the_best_battery.
- BCG, *The Future of Battery Production for Electric Vehicles*, 2018.
- BFM Business, V*oiture électrique : premier pas vers un "Airbus des batteries"*, https://bfmbusiness.bfmtv.com/france/voiture-electrique-premier-pas-vers-un-airbus-des-batteries-1632064.html.
- BIKE Europe, *BMZ Acquired TerraE To Push Plans For German Li-Ion Cell Production*, https://www.bike-eu.com/home/nieuws/2018/11/bmz-acquired-terrae-to-push-plans-for-german-li-ion-cell-production-10134875.
- Bloomberg New Energy Finance, 2018; CleanTechnica, "100 $/kWh Tesla Battery Cells This Year, $100/kWh Tesla Battery Packs In 2020," https://cleantechnica.com/2018/06/09/100-kwh-tesla-battery-cells-this-year-100-kwh-tesla-battery-packs-in-2020/.
- BMO Capital Markets, *The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See*, 2018.
- BRUNP Recycling, *Battery Recycling*, http://en.brunp.com.cn/products_list/i=48&comContentId=48.html.
- CEC, *Environmentally Sound Management of End-of-Life Batteries from Electric-Drive Vehicles in North America*, 2015.
- Chamber of Commerce of Western Australia, *WA's future in the Li-Ion Value Chain*, 2018.
- China Daily, *E-vehicle batteries to be recycled in green push*, http://www.chinadaily.com.cn/a/201809/10/WS5b95d75da31033b4f465521c.html.
- CLD Beauharnois-Salaberry, *Strategic Advantages*, http://www.cld-beauharnois-salaberry.org/en/portrait/strategic-advantages/.

- CleanTechnica, *$100/kWh Tesla Battery Cells This Year, $100/kWh Tesla Battery Packs In 2020*, https://cleantechnica.com/2018/06/09/100-kwh-tesla-battery-cells-this-year-100-kwh-tesla-battery-packs-in-2020/.

- CleanTechnica, *LG Chem Battery Production Ramps Up In Holland, Michigan*, https://cleantechnica.com/2015/10/28/lg-chem-battery-production-ramps-up-in-holland-michigan/.

- CNRC, *Lithium-ion battery industrial R&D group (LiBTec)*, https://cnrc.canada.ca/en/research-development/research-collaboration/industrial-rd-groups/libtec-industrial-rd-group.

- Contrecœur sur le fleuve, *Portrait économique*, https://www.ville.contrecoeur.qc.ca/developpement-economique/portrait-economique/.

- Credit Suisse, *Drive Train to Supply Chain 2*, 2018.

- CSIRO, *Lithium battery recycling in Australia*, 2018.

- Économie et Innovation Québec, *Fonds de diversification économique du Centre-du-Québec et de la Mauricie*, http://www.economie.gouv.qc.ca/pages-regionales/diversification-economique-du-centre-du-quebec-et-de-la-mauricie/fonds-de-diversification-economique-du-centre-du-quebec-et-de-la-mauricie/.

- Electreck, *Northvolt starts construction on first phase of its planned battery gigafactory*, https://electrek.co/2018/04/27/northvolt-construction-first-phase-planned-battery-gigafactory/.

- Electrek, *Tear down of 85 kWh Tesla battery pack shows it could actually only be a 81 kWh pack*, https://electrek.co/2016/02/03/tesla-battery-tear-down-85-kwh/.

- Electrek, *Tesla says battery fire without crash in LA was "extraordinarily unusual occurrence," still investigating the cause*, https://electrek.co/2018/09/05/tesla-battery-fire-la-without-crash/.

- Electrive, *LG to augment capacities of its U.S. battery plant*, https://www.electrive.com/2018/01/06/lg-augment-capacities-u-s-battery-plant/.

- Environment and Energy Management Agency, *The potential of electric vehicles*, 2016.

- Environnement Québec, *Le Fonds Vert*, http://www.environnement.gouv.qc.ca/ministere/fonds-vert/#utilite.

- Environnement Québec, *Le marché du carbone, un outil pour la croissance économique verte !* http://www.environnement.gouv.qc.ca/changementsclimatiques/marche-carbone.asp.

- European Commission's Joint Research Center, *Lithium ion battery value chain and related opportunities for Europe*, 2016.

- EV Adoption, *EV Market Share by State*, http://evadoption.com/ev-market-share/ev-market-share-state/.

- FleetCarma, *Electric Vehicle Sales In Canada*, 2017, https://www.fleetcarma.com/electric-vehicle-sales-canada-2017/.

- Government of Canada, *Did you know that Lithium Batteries are Dangerous Goods?*, https://www.tc.gc.ca/eng/tdg/shipping-importing-devices-containing-lithium-batteries.html .

- Government of Australia, *The Lithium-Ion Battery Value Chain—New Economy Opportunities for Australia*, 2018.

- HSBC Global Research, *European Chemicals*, 2018.
- HSBC Global Research, *Global EV Battery Materials*, 2018.
- IEA, *Global EV Outlook 2018*, 2018.
- Inside EVs, *Tesla's Secret Weapon: Intense Focus On Batteries*, https://insideevs.com/tesla-secret-weapon-intense-focus-batteries/.
- InsideEVs, *Official: $1.3 Billion In Incentives Brings Tesla Gigafactory To Nevada — Videos*, https://insideevs.com/official-1-3-billion-incentives-brings-tesla-gigafactory-nevada/.
- Institut EDDEC, *Métaux et économie circulaire au Québec*, 2018.
- International Council on Clean Transportation, *Power Play: How Governments Are Spurring The Electric Vehicle Industry*, 2018.
- International Energy Agency, *Global EV Outlook 2018*, 2018.
- J.P. Morgan Cazenove, *European Capital Goods*, 2017.
- Koffman Southern Tier Incubator, *Imperium3's Battery Factory Is Coming To Endicott Earlier Than Expected*, https://southerntierincubator.com/imperium3s-battery-factory-is-coming-to-endicott-in-2019/.
- KPMG. Competitive Alternatives, *KPMG's guide to international business locations costs*, January 2018 update.
- KPMG. *Northvolt Case Study*, 2019.
- L.E.K., *Fast-Moving EV Battery Market: How to Win Against the Competition?*, https://www.lek.com/insights/fast-moving-ev-battery-market-how-win-against-competition.
- Nomura, *Global EV batteries: Robust EV battery demand ahead*, 2017.
- Olivetti et al., *Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals*.
- Panasonic's Lithium Procurement Policy, 2018.
- Radio-Canada, *North American Lithium cesse temporairement ses opérations minières*, https://ici.radio-canada.ca/nouvelle/1154037/north-american-lithium-spodumene-prix-la-corne.
- RBC Capital Markets, *RBC Electric Vehicle Forecast Through 2050 & Primer*, 2018.
- Redburn, *Umicore Power Play*, 2018.
- Research Interfaces, *What do we know about next-generation NMC 811 cathode?*, https://researchinterfaces.com/know-next-generation-nmc-811-cathode/.
- Reuters, *Northvolt cuts cost estimate for European battery plant as seeks investors*, https://www.reuters.com/article/us-northvolt-financing/northvolt-cuts-cost-estimate-for-european-battery-plant-as-seeks-investors-idUSKBN1JA2LF.
- Reuters, Volkswagen, *Northvolt to join forces for battery research*, https://www.reuters.com/article/us-volkswagen-northvolt-batteries/volkswagen-northvolt-to-join-forces-for-battery-research-idUSKCN1R211O.

- RNC Minerals, *RNC Minerals Plans Initiatives to Allow Decision to Begin Construction of Dumont Nickel-Cobalt Project in 2019; Highlights Large Nickel and Cobalt Reserves*, https://www.newswire.ca/news-releases/rnc-minerals-plans-initiatives-to-allow-decision-to-begin-construction-of-dumont-nickel-cobalt-project-in-2019-highlights-large-nickel-and-cobalt--reserves-669346923.html.

- Roussillon RCM, *Mémoire sur le PL 85*, 2016

- Samsung SDI, *The Composition of EV Batteries: Cells? Modules? Packs? Let's Understand Properly!*, http://www.samsungsdi.com/column/technology/detail/54344.html?pageIndex=1&idx=54344&brdCode=001&listType=list&searchKeyword=.

- Smart Battery, *Lithium Ion Cylindrical Cells Vs. Prismatic Cells*, https://www.lithiumion-batteries.com/cylindrical-vs-prismatic-cells.php.

- Statista, *Number of vehicles in use worldwide 2006–2015*, https://www.statista.com/statistics/281134/number-of-vehicles-in-use-worldwide/.

- Tesla, *Mythbusters Part 3: Recycling our Non-Toxic Battery Packs*, https://www.tesla.cn/en/blog/mythbusters-part-3-recycling-our-non-toxic-battery-packs%20 .

- Transport Canada, *TDG Bulletin: Transporting Batteries*, January 2018.

- Umicore, *Life Cycle Assessments involving Umicore's Battery Recycling process*, 2011.

- U.S. Department of Energy, *Cost and Price Metrics for Automotive Lithium-Ion Batteries*, 2017.

- USGC, *Cobalt*, https://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2018-cobal.pdf.

- Vale, *Electric Vehicle Revolution — A miner's perspective*, 2018.

- Ville de Montréal, Choose Montréal, http://ville.montreal.qc.ca/portal/page?_pageid=9537,122885610&_dad=portal&_schema=PORTAL .

- Ville de Shawinigan, *Investing in Shawinigan*, https://www.investir-shawinigan.ca/en/investing-in-shawinigan/industry/infrastructures, accessed March 12, 2019.

- Wards Auto, *U.S. EV Battery Capacity Lacking, Expert Warns*, https://www.wardsauto.com/alternative-propulsion/us-ev-battery-capacity-lacking-expert-warns.

- Waste 360, *SungEel MCC Unveils Lithium-Ion Battery Recycling Plant*, https://www.waste360.com/e-waste/sungeel-mcc-unveils-lithium-ion-battery-recycling-plant.

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