TRENDS
RECYCLING

Recycling Lithium-ion Batteries, the New Frontier in the Electrification of Mobility

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From mobility to the digital transition, the electrification of end-uses relies on precious minerals whose production lies in the hands of a limited number of actors. Countries can only benefit from these minerals if they have the capacity to develop and exploit them or, in the absence of virgin resources, if they can develop secondary resources from recycling and recovery. In particular, the high demand for lithium-ion batteries, which are essential for the widescale deployment of electric vehicles, increases competition to access strategic metals like cobalt, nickel and lithium. Battery recycling tends to take a backseat in industries' regionalization strategies. Yet the Canadian province of Quebec stands out for providing proactive public support to the emerging battery recycling industry.

DATA OVERVIEW

Li-ion batteries, a globalised product at the heart of national energy transitions

Enthusiasm for "emission-free" vehicles soared in 2020. The trend continued during the first half of 2021, with global sales of electric vehicles (EVs) up by 168% compared to the previous year.[1] The market is stimulated by national targets to increase the share of electric vehicles in automobile fleets, the exclusion of internal combustion engine vehicles from some cities, and incentive measures aimed at citizens and car manufacturers (**see Transport sector**). Ultimately, the juxtaposition between these public and private objectives and the growth of autonomous grid storage will boost demand for alternative technologies, including lithium-ion batteries.

Since lithium-ion batteries were first marketed in 1991, their price has dropped by 97% (**fig. 1**). On average, each time battery production doubles, the price falls by a quarter.[2] From 2010 to 2020, the average price of lithium-ion batteries dropped by 89%, from $1,100/KWh to $137/KWh.[3]

Lithium-ion batteries have several advantages: they are very dense, energy efficient, and long-lasting. Lithium has a high electrochemical potential that means it can store considerable electrical loads. On the downside, this type of battery is heat sensitive and requires circuit protection to limit the voltage and current, which makes end-of-life management more complex. Some of the battery components can represent a risk for the environment and human health. Lithium, for example, can explode when it comes into contact with combustible material or water. According to a study carried out by the consulting firm Golder, thermal runaway can also produce smoke and toxic substances, including hydrogen fluoride, which is irritating and corrosive for skin, eyes and the respiratory tract, with potentially serious symptoms depending on exposure conditions.[4] Although living organisms need minerals like copper, manganese, and cobalt to ensure numerous nervous, vascular, immunity and bone functions, excessive doses can trigger allergies, poisoning, and sometimes severe cardiac and respiratory disorders.[5]

TABLE 1

CURRENT AND PROJECTED PRODUCTION OF MINERALS CRITICAL TO BATTERY PRODUCTION

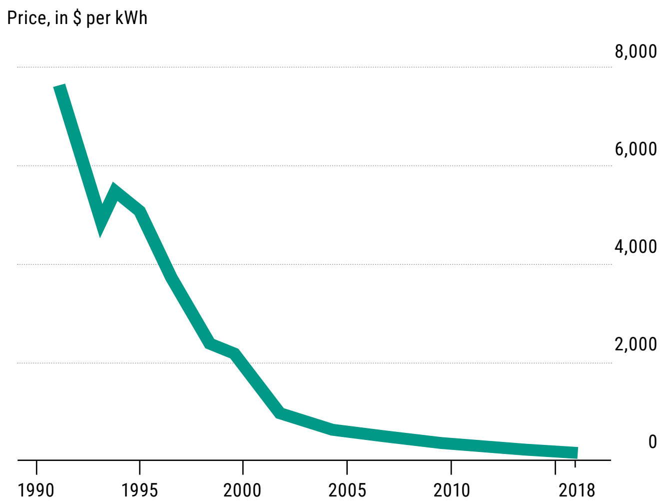
Source: World Bank, 2021

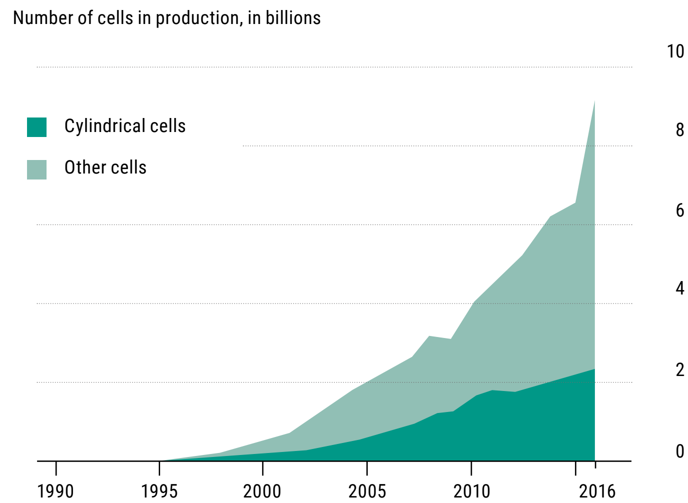
	PRODUCTION EN 2018 (MT)	PROJECTED DEMAND IN 2050	
		MT	VARIATION FROM 2018
LITHIUM	85	415	+388%
COBALT	140	644	+360%
MANGANESE	18,000	694	-96%
NICKEL	2,300	2,268	-1.4%
GRAPHITE	930	4,590	+393%

FIGURE 1

EVOLUTION OF LITHIUM-ION BATTERY PRICES ($/KWH) AND PRODUCTION OF LITHIUM-ION CELLS (BILLIONS)

Source: Ziegler, M. S., Trancik, J. E., 2021. Figure adapted from The Economist, 31/03/2021





The latest reports by the World Bank (2020)[6] and the International Energy Agency (2021)[7] make it evident: a low-carbon future will require high quantities of minerals to develop clean technologies (**see Industry sector**). In particular, the composition of lithium-ion batteries relies on five main minerals: lithium, cobalt, manganese, nickel and graphite. As shown in the table generated using data from the World Bank report, demand for three of these is set to surge over the next few years (**tab. 1**).

This rising demand is moving the pieces on the geopolitical chessboard. Actors that benefit from easy access to these materials and to industrial capacities for transforming them into finished and semi-finished products are one step ahead (**see Industry sector**).

Take lithium, for example. In its natural state it comes in two forms: either in the form of brine in salt flats, or in solid form. Several salt deposits, known as *salars* are present in South America, China and the United States. Groundwater containing lithium is first pumped to the surface, then placed in evaporation ponds for up to 18 months depending on climatic conditions (humidity, wind and solar radiation). Lithium is then precipitated in the form of carbonate. The residual components that remain after evaporation are processed in factories to separate them into, among others, sodium chloride (salt), magnesium chloride and lithium carbonate.[8]

The South American region in the Andes covering the Altiplano-Puna plateau and comprising of Bolivia, Argentina and Chile, constitutes the biggest source of lithium, mainly from the Salar de Uyuni salt flat in Bolivia with a surface area of 10,000 km^2. The lithium resources of these three South American countries represented over 53% of global reserves in 2019.[9]

The potential of the Salar de Uyuni is enormous, with an estimated 21 million tonnes of reserves, in addition to the Coipasa and Pastos Grandes salt flats.[10] Bolivia, which initially closed the door on foreign partnerships, intending to nationalize the resource, is now attempting to create a vertically integrated value chain going all the way up to battery production, or even electric vehicles, by selecting experienced international partners.[11] The joint-venture signed in December 2018 between the state company Yacimientos de Litios Bolivianos (YLB), founded in 2017, and the German firm ACI Systems was finally cancelled in November 2019 by the government of Evo Morales.[12] The agreement comprised investment in a high-tech complex in the Salar de Uyuni to produce up to 40,000 tonnes of lithium hydroxide a year over seventy years, controlled 51% by Bolivia. The country's new president, Luis Arce, elected in 2020, appears highly favourable to reinitiating his predecessor's plan to produce lithium and batteries in the country by establishing strategic alliances with international partners. In 2021, the new Bolivian government launched several calls for international projects to recommence extraction on its three sites.[13]

Like Chile and Argentina, Bolivia does not yet possess what China has established, i.e., a sizeable industrial ecosystem for manufacturing batteries. As the world's number three lithium producer (14,000 tonnes in 2020),[14] China also possesses considerable quantities of graphite and rare earths, which are critical minerals for producing batteries. The country has invested massively since the 1980s to exploit its mineral resources and produce lithium-ion batteries. In early 2019, China represented 70% of global battery production capacity.[15] To ensure a stable flow of lithium for battery suppliers and car manufacturers, strategic alliances and commercial partnerships have been established between technology firms and mining companies.

As in many industries, a concentration of production capacities leads to a concentration of recycling capacities, and batteries are no exception.

THE OBSERVATORY'S LENS

Often overlooked in the value chain, the recycling of lithium-ion batteries is getting growing attention in North America

Current global trends for lithium-ion battery recycling

When it comes to strategies to move upstream in the battery production sector, end-of-life management tends to take a backseat. According to the International Energy Agency, global recycling capacities in 2021 amounted to 180,000 t/year, half of it concentrated in China.[6] Japan, France and Germany make up most of the remaining current or announced recycling capacities (**fig. 2**). Whatever the case, global recycling capacities remain well below what is required given the quantities put on the market. In the best-case scenario, the International Energy Agency estimates that recycling will, for example, reach 12% of global demand for cobalt, and 5% for lithium in 2040.[6] In the European Union, currently only 12% of aluminium is recycled, along with 22% of cobalt, 8% of manganese, 16% of nickel, and almost no lithium.[16]

For the most part, the main recyclers are mining companies, cathode producers, and battery manufacturers. Independent recyclers are less common and have much lower capacities for recycling (**tab. 2**).

TABLE 2

EXAMPLES OF COMPANIES INVOLVED IN RECYCLING LITHIUM-ION BATTERIES

TYPES OF COMPANIES	EXAMPLES OF COMPANIES
MINING COMPANIES (LI, CO)	GLENCORE, HUAYOU COBALT, LITHIUM AUSTRALIA
CATHODE PRODUCERS	L&F CO, UMICORE, AURUBIS
BATTERY PRODUCERS	BYO, PANASONIC, LG CHEM, FOXCONN, BAK, CATL, JOHNSON CONTROLS
INDEPENDENT RECYCLERS	BRUNP RECYCLING, ACCUREC, RECYCLAGE LITHION, REDUX, AMERICAN MANGANESE, INC.

According to the projections of the TIAM-IFPEN model developed by the French think tank IFP-Énergie Nouvelles, in a climate scenario that limits the temperature rise to 2°C, the main metals that make up Li-ion batteries are subject to variable criticalities: higher for cobalt due to the concentration of its deposits in the Democratic Republic of Congo and its price, average for nickel, and relatively lower for lithium due to its geological abundance.[17] The development of lithium-ion battery recycling should nevertheless take off for other environmental, economic and social reasons:

- Environmental, because extracting minerals involves damage, and because a lack of recycling could undermine all our efforts to reduce the impact of consumption patterns. Water usage is also a major issue since production processes, in particular in *salars*, require considerable quantities of freshwater drawn from local water courses.[8] The impact of pumping groundwater and the effects on surrounding ecosystems are also unknown.
- Economic, because in the summer of 2021, the price of some minerals like lithium hit a three-year high in reaction to increasing demand for electric vehicles and a relatively low supply of the mineral (**see Industry sector**).
- Social, because in some parts of the world mineral exploitation violates numerous human rights codes, including slavery and child labour; NGOs like Amnesty International regularly denounce the working conditions in cobalt mines in the Democratic Republic of the Congo, which concentrates 90% of cobalt exploitation.[18]

According to a Bloomberg annual ranking, Canada currently ranks fifth in the world for manufacturing lithium-ion batteries over the entire value chain, partly thanks to its mining resources, while the United States comes second, due to its manufacturing capacity and domestic demand.[19]

To ensure good end-of-life battery management, several countries apply the principle of extended producer responsibility (EPR). In North America, although for the moment no regulatory framework applies to the recovery and recycling of batteries from electric vehicles, the EPR route is under study, and is currently in force for household batteries and batteries from electronic devices. Over the last three years, the Canadian organization Appel à Recycler has transported and recycled almost 170,000 smartphones a year in North America. Through the same program, Appel à Recycler has collected and recycled over 3,600 tonnes of regular and lithium-ion batteries.[20]

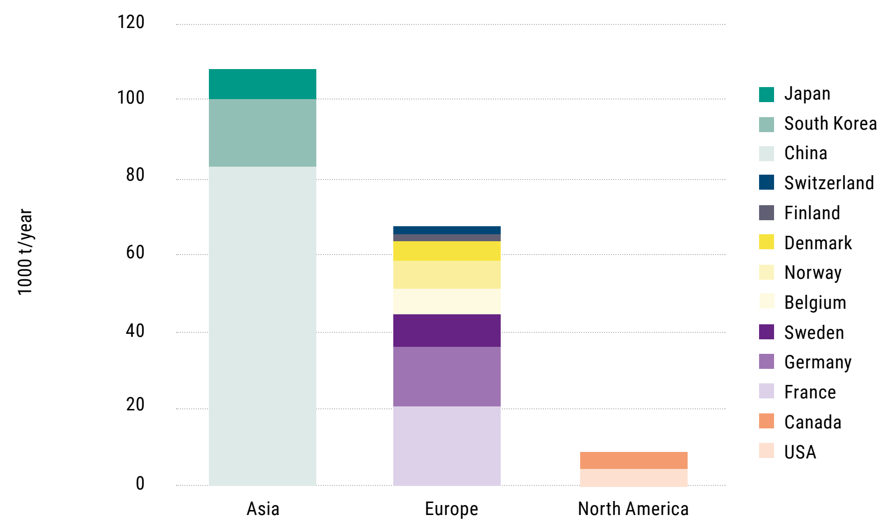
In France, manufacturers are obliged to organize and pay for the collection and processing of the waste they generate. They can establish understandings with recyclers to manage the end-of-life of car batteries, while EU regulations currently require a minimum recycling rate of 50%.[21]

The recycling performance of lithium-ion batteries is difficult to evaluate. Moreover, the growth in their use in electric vehicles is a recent phenomenon, and most have not yet reached the end of their useful life. In its report, the World Bank publishes figures from 2011 on the recycling rate of minerals, which does not exceed 70% in very rare cases. In the case of lithium, it is even below 1%.[5]

FIGURE 2

CURRENT AND ANNOUNCED CAPACITIES FOR RECYCLING LITHIUM-ION BATTERIES

Source: IEA, 2021



The review of existing literature conducted by the authors identifies three main factors holding back the growth of the lithium-ion battery recycling industry:

- The low return on investment for some types of battery: the selling price of materials recovered from some batteries does not necessarily cover the recycling costs.
- The generation of residual matter: current recycling technologies generate high quantities of waste, and the processes require significant amounts of chemicals.
- The complexity of processes: current technologies require highly refined wet chemistry processes or heating at very high temperatures, which bring a number of chemical, electric and thermal runaway risks.

Lithium-ion battery recycling operations take place in four stages.[22] First, *stabilization* aims to discharge the battery pack. Next, *pre-processing* involves opening up the battery pack to isolate the modules. Following this stage, the modules are either dismantled or crushed before separating the different materials. A "black mass" is then obtained that contains hydrophobic carbon and hydrophilic metal oxides.

Two processes can be used at this stage to recycle lithium-ion batteries: *hydrometallurgy* or *pyrometallurgy*. The latter is the most common procedure and basically consists of heating the battery to a high temperature to recuperate a metal alloy.[23] This is a standard metal recycling technique that has been adapted to electric vehicle batteries. Nevertheless, the yield of the operation is limited since it is difficult to extract high added value metals from the alloys, such as cobalt, lithium, nickel and manganese.[6]

An emerging technique for recycling batteries, hydrometallurgy, consists in dissolving the black mass in solvents (leaching) to isolate the different metals sought. Hopes are pinned on this second technique to put the strategic minerals contained in batteries back into circulation. The Quebec Plan for the Development of Critical and Strategic Minerals clearly aims at this target.

In Quebec, a regional ambition to build an integrated battery industry

Quebec intends to become a leader in the energy transition. Its Energy Transition, Innovation and Efficiency Master Plan 2018-2023, extended to 2026, sets out measures to reach the objectives established in the 2030 Energy Policy, voted in 2017. In particular, the latter includes a 40% reduction in the quantity of petroleum products consumed, and a 25% increase in the total production of renewable energy. The contribution of the 2030 Energy Policy to reducing GHG emissions is estimated at 16 $MtCO_2e$. Quebec, which emitted 83.7 $MtCO_2e$ in 2019, pursuing a rising trend,[24] has set a target to reduce emissions by 37.5% by 2030 compared to 1990.[25]

To achieve its objectives, the province can also count on an electricity mix featuring 95% hydropower.[26] Hydro-Québec, the state company responsible for electricity production, operates 61 hydropower stations with an installed capacity of 37.2 GW, along with 28 reservoirs with a combined storage capacity of over 176 TWh,[27] making the province a net electricity exporter. This position inherited from the nationalization of electricity production in the 1960s has prompted the prime minister of Quebec to express his ambition of making the province the "green battery of North America".[a]

a Tweet by François Legault, 7 November, 2020

The electricity mix in Quebec is therefore suitable for the electrification of end-uses, in particular transport, which concentrates 43% of the province's emissions.[2] The 2030 Plan for a Green Economy, which came into force in April 2021, establishes a figure of 1.5 million EVs in circulation in Quebec in 2030, or 30% of the automobile fleet.[28] Already, since January 2018, the ZEV (zero-emission vehicle) standard requires carmakers to sell a set proportion of light-duty, zero-emission vehicles with the aim of reaching 100,000 electric vehicles in circulation by 2020, featuring in the Action Plan 2015-2020 for Electrification of Transportation (PAET). On 30 June 2021, over 110,000 electric vehicles were registered in the province, which is almost half of all electric vehicles sold in Canada,[29] while Quebec only represents 25% of the total population. From only 0.7% in 2015, the market share of EVs now amounts to 7% of new vehicles sold.[30] This growth is not restricted to automobiles. For example, the company Lions Electric commercializes numerous heavy-duty electric vehicles, such as buses and delivery trucks, while electric bicycles are increasingly common in Quebec, representing 26% of total bike sales in 2020 bringing the total to 365,000 in circulation.[31] More widely, an estimated 70% of the North American vehicle fleet is expected to become electric in 2050, including light-, medium- and heavy-duty vehicles.[32]

To ensure its targets, the Quebec government recognizes the crucial role of ensuring a supply of "strategic and critical metals" (SCMs). In August 2020, the prime minister transferred to the Ministry for Energy and Natural Resources (MERN) the jurisdiction of the Quebec Energy Transition, a public company created in 2017 to stimulate the transition and ensure integrated governance with stakeholders.[33] The same ministry initiated the Quebec Plan for the Development of Critical and Strategic Minerals (QPDCSM).[34] The aims of this plan, launched in October 2020, including taking advantage of the region's mineral resources (lithium, cobalt, graphite, nickel, etc.), creating a research and development network gathering all actors in the sector, and developing recycling and re-use of critical and strategic metals.

In March 2021, the ministries and partner organizations of the QPDCSM met for a first overview of the plan's application.[35] To support the recycling of SCMs, the government has granted financial aid amounting to CA$850,000, of which CA$500,000 are earmarked for a new factory to be opened by Rio Tinto Fer et Titane (RTFT) in summer 2021 to produce scandium oxide. Among other uses, scandium is employed in aluminium alloys for the aerospace industry. The process used by RTFT extracts scandium from the residues of titanium oxide production without requiring additional extraction, according to the group.[36] The factory could meet 20% of global demand on its own, spurring Quebec's ambition to establish itself as the leader of this niche market. In March 2021, the finance minister also announced a reform of the Mining Tax Act with the aim of earmarking a portion for recovering SCMs.[37]

A study published in March 2020 by Propulsion Québec, an industrial cluster for electric transportation, estimates that somewhere between 3,000 and 7,000 tonnes of batteries will reach the end of their useful life before 2025; this quantity is estimated at 90,000 tonnes for the whole of north-eastern America.[17] For the time being, batteries from electric vehicles are not subject to EPR. Nevertheless, in January 2021, Appel à Recycler, the eco-organization responsible for recycling and recovering batteries, launched a program to recycle electric batteries from bicycles and scooters. Currently, batteries from electric cars that have reached their end-of-life are dispatched outside the province, mostly to British Columbia.

The provincial government has therefore supplemented the QPDCSM with the Quebec Strategy for Developing the Battery Industry.[38] The aim is to position Quebec among the global leaders at all stages of the industry, from the extraction of minerals from its rich subsoil right up to the manufacture of batteries, and including assembly and manufacturing of anodes and cathodes. The province's public investment company, Investissement Quebec, has announced through its CEO that it intends to invest "*from [CA$] one to two billion from public funds and four to six billion from private investments [...] over the next two to three years.*"[39]

The industry for managing the end-of-life of batteries is taking shape, both for recycling and reconditioning. In November 2020, the Quebecois company Recyclage Lithion patented a process for recycling lithium-ion batteries using hydrometallurgy. The company claims that the process will enable 95% of battery components to be recovered and processed.[40] Considered as a start-up, Lithion was founded by a consortium of public and private stakeholders with established expertise in the field. Seneca, an industrial process engineering firm, has already applied hydrometallurgy to other sectors. Lithion is also supported by the *Centre d'étude des procédés chimiques du Québec* (CEPROCQ), Hydro-Québec's Center of Excellence in Transportation Electrification and Energy Storage, and Appel à Recycler.

A first demonstration factory, at an estimated cost of CA$12 mn, started operating in 2020 in Anjou, a district of Montreal, and is capable of recycling up to 200 tonnes of batteries per year. The Quebec government is closely involved in the project. In 2018, Lithion received initial support amounting to CA$3.8 mn from Sustainable Technology Development Canada (STDC), a foundation to support technological innovation in SMEs,[41] followed by a government grant of CA$4.8 mn to support the opening of its first demonstration site.[42] Lithion plans to open its first commercial factory in 2023, with an annual processing capacity of 7,500 tonnes of batteries, which is the equivalent of 20,000 electric vehicles. To support the project, the Quebec government recently granted additional aid of CA$2 mn.[43] The Canadian branch of Hyundai, which is targeting 100% electric sales by 2040, is the first automobile manufacturer to have signed an agreement with Lithion to supply it with end-of-life batteries with a view to opening the commercial factory.[44] Earlier in the year, New Flyer Industries, an electric bus manufacturer based in Winnipeg, also signed a partnership with Li-Cycle, the biggest battery recycling company in North America, based in Ontario.[45]

Another approach involves reconditioning batteries. Cyclo-Chrome is a social enterprise based in Montreal that specializes in bicycle repairs and also trains young people, in order to combat school drop-out rates. It has a contract to maintain and repair BIXIs, the bicycles used in the city's bike share scheme, and other fleets of corporate bicycles, like those used by the Montreal city police service. With the growth in electric bikes, Cyclochrome is also seeking to develop its expertise to recondition batteries. The technique aims at removing used battery cells and replacing them with new ones to extend the lifespan of bicycles. For BIXIs alone, the biggest electric bicycle fleet in Canada, this involves managing 1,725 end-of-life batteries.[46]

The future of end-of-life battery management therefore looks bright. Not only are the minerals they contain highly sought-after, but the techniques employed to recondition and recycle them are developing fast.

KEY TAKEAWAYS

In autumn 2020, the government of Quebec launched its "Quebec Plan for the development of Critical and Strategic Minerals: a More Electric Future for an Eco-Friendly Quebec". What made a jurisdiction at a regional level of governance take on such an ambitious plan in the face of state and private giants? The answer lies in market dynamics, which clearly correspond to the evolution of economic models, particularly in electric mobility and renewable energy production. It can also be put down to proactive public authorities aware of their geological assets and the challenges involved in deploying electric vehicles. Recycling and recovery take a backseat in the regional integration strategies of battery manufacturing industries, but are receiving strong support from the Quebec government, based on a local industrial network whose ambition is to position itself as the leader of north-eastern America – a strategy that is taking shape on the field.

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RETURN TO PREVIOUS PAGE

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