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International Journal of Mining, Reclamation and Environment

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/nsme20

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INTERNATIONAL JOURNAL OF MINING, RECLAMATION AND ENVIRONMENT
2022, VOL. 36, NO. 1, 68–80
https://doi.org/10.1080/17480930.2021.1965316

The potential of lithium in Quebec for the electric vehicle market: state of the art, opportunities and challenges

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ABSTRACT

The demand for lithium-ion batteries for electric vehicles (EV) has triggered an unprecedented interest in this metal. Although there is asignificant history in the scientific literature regarding lithium mining in Quebec between 1950–1980, very few studies document the current state of the art and address the possibility of the province integrating alocal production chain oriented towards the EV battery market. This paper presents Quebec's position and analyses its needs and potential market through aliterature review focusing on the main opportunities to produce domestic spodumene concentrates, as well as the major challenges the province will have to face to make the most of its competitive advantages. Furthermore, it provides an updated list of lithium mineral resources and reserves in Quebec, in compliance with NI 43–101. The results show that Quebec holds 94.1% and 85.8% of all Canadian mineral reserves and resources, respectively. The paper also provides an overview of the lithium industry in the province and compares its status with other Canadian jurisdictions. Quebec lithium mines would benefit if their production could be directly integrated with other local or nearby partners, generating ajoint benefit throughout the manufacturing chain of lithium-ion batteries for the EV market.

ARTICLE HISTORY
Received 22 October 2020
Accepted 3 August 2021

KEYWORDS
Lithium; Quebec; opportunities; challenges; spodumene; electric vehicles

1. Introduction

Lithium properties in multiple applications are highly valued in the industrial sector, especially to produce lithium-ion batteries. These batteries are nowadays largely used in telecommunications following the rapid development of light, powerful, rechargeable devices. However, the recent emergence of the electric vehicle (EV) on the market has created a new and globally significant market [1]. As EVs become more and more popular and accessible, different applications such as public transit, personal transportation and even underground mining equipment are considering the electric battery as a viable alternative [2]. Consequently, it is predicted that the amount of lithium produced in 2015 should more than double by 2025 to keep up with demand [3]. In this sense, it is not https://www.icorrectproof.com/tandf/Home/iViews#surprising that there is a trend in the literature showing an increasing interest by both developed and developing countries in previously considered uneconomic mineralisations of lithium [4].

Although significant identified reserves in Canada have yet to be categorised [5], the history of lithium exploitation in the country is not new. The American Chemical Society reported lithium

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deposits in Canada almost a century ago [6] and, in the case of the province of Quebec, the first technical reports about lithium-pegmatites were written in the following decades [7–10]. In fact, Quebec was one of the world's suppliers of lithium in the past, before the development of batteries for the EV market. It was an important producer of spodumene (a lithium mineral derived from pegmatites) concentrates from 1955 to 1959 and of lithium carbonate and hydroxide from 1960 to 1965, both from the Quebec Lithium Corporation property located in La Corne Township. That lithium production ceased in 1965, but numerous lithium bearing pegmatites have been identified, several of them being still undeveloped [8]. As a matter of fact, according to the Ministry of Energy and Natural Resources of Quebec, there were 11 lithium projects in the province in 2011 [11]. Most of these projects are located in the Abitibi region, in the north of Chibougamau, and in the Eastmain-Nemiscau sector of James Bay, and are associated with spodumene indicators discovered mainly between the 1940s and the 1960s. However, even if recent studies still report that Quebec exhibits some of the world's largest spodumene deposits [12], the province is struggling to position itself as a major player in this prized market. Furthermore, there are currently no studies in the literature that quantify lithium mineral reserves and resources in Canada.

The objective of this work is therefore to collect the required data and information to understand the reason impeding the materialisation of these mining projects in the context of a growing demand for lithium-ion batteries dedicated to the EV market. The main contribution of this manuscript consists of establishing a baseline on Quebec's prospects to produce batteries for EVs from lithium mining on its territory as a societal choice. It should thus serve as a basis for further research on specific economic and environmental aspects. In this regard, most recent research has focused on analysing the potential of individual projects, whereas this study seeks to provide a macroscopic view by going beyond the profitability of projects, by rather focusing on prospects of adding value to lithium mining in Quebec through direct integration into a local battery production chain in the context of EVs.

The paper is organised as follows. Section 2 briefly explains the research methodology followed to collect the data. Section 3 presents the global perspective about lithium, providing background information as well as considerations about the market, mining/processing, and its use for manufacturing batteries for EVs. It also provides an outlook of Quebec EV fleet status and growth. Section 4 analyses the province's opportunities and challenges in light of the collected data. Lastly, the final section of this paper summarises the conclusions and proposes orientations for future work.

2. Methodology

In a first step, data collection focused on understanding the current lithium market context, types of lithium deposits, and mineral processing routes. The literature review also provided background information on EVs and lithium-ion batteries. It highlighted the specifics of the EV market in Quebec and the global demand for lithium-ion battery.

The second step identified active lithium projects in Quebec in compliance with the national standard of reporting mineral resources and reserves in Canada (NI 43–101) or equivalent, considering all public feasibility studies from the last ten years. This review of technical reports aimed at elaborating an update of the directory of mineral resources and reserves in Canada, by province, in order to determine Quebec's position. It is worth emphasising that other less advanced studies, such as preliminary economic assessments, were excluded because they only analyse the potential viability of a given project mineral resources, while feasibility studies are intended to evaluate if a mineral reserve can be mined effectively and if it can be profitable. The consideration of only the last 10 years follows the same purpose, i.e. to refer to projects showing a potential of materialising in a foreseeable future.

The last step consisted in extracting specific information about the resulting lithium mining projects in order to identify what are Quebec's actual opportunities.

3. Literature review

3.1. Lithium: background information, economics and demand

Lithium is part of the alkali metal group and occurs naturally as a monovalent cation. It is a soft, silvery metal when pure but rapidly oxidises in moist air to a dull grey. It has the lightest density of all metals [3]. Lithium exhibits excellent electrical conductivity and stands as the most electronegative metal, which is one of the properties that makes it ideal for use in batteries [13]. Lithium forms a large range of mineralogical compounds, and different nomenclatures in the literature describe the quantities involved: lithium content (Li), lithium oxide content (Li_2O) or lithium carbonate content (Li_2CO_3). However, production quantities are often expressed as lithium carbonate equivalent (LCE).

LCE represents the largest lithium product market based on volumes sold, accounting for around 50% of global lithium sales in 2015 [1]. Uses of lithium are very diverse. These include applications in medicine, air treatment, polymers, metallurgy, greases, glass and ceramics, and rechargeable batteries [3]. Lithium metal in batteries was first considered in 1912, however it took until the 1970's before significant research efforts were invested into developing actual working units, and the first lithium-ion cell was only built in 1985 [1]. Lithium in rechargeable batteries is the most important use (around 65%) [14]. The electrification of transports, driven by environmental campaigns and regulations to reduce the use of fossil fuels, added to the technological development of electronic devices and energy storage systems, have pushed the demand for lithium. The increasing demand for lithium is also due to significant cost reductions associated with production from brines [13]. This growing interest in lithium has resulted in an unprecedented surge in exploration and exploitation of lithium deposits during the last few years as depicted in (Figure 1). The mine production tripled between 2015 and 2018, and then started decreasing in 2019. Reported mining resources steadily increased from 25 Mt in 2010 to 40 Mt 2013, then plateaued until 2015 before starting to rise again to reach 80 Mt in 2020. Similarly, (Figure 2) shows the lithium carbonate ton price over the last decade, displaying a soaring trend between 2016 and 2018, followed by a return to the 2016 level in 2020.

At the beginning of 2020, seven hard rock operations, six in Australia and one in China, and three brine facilities, one in Argentina, one in Chile, and one in China, accounted for the majority of

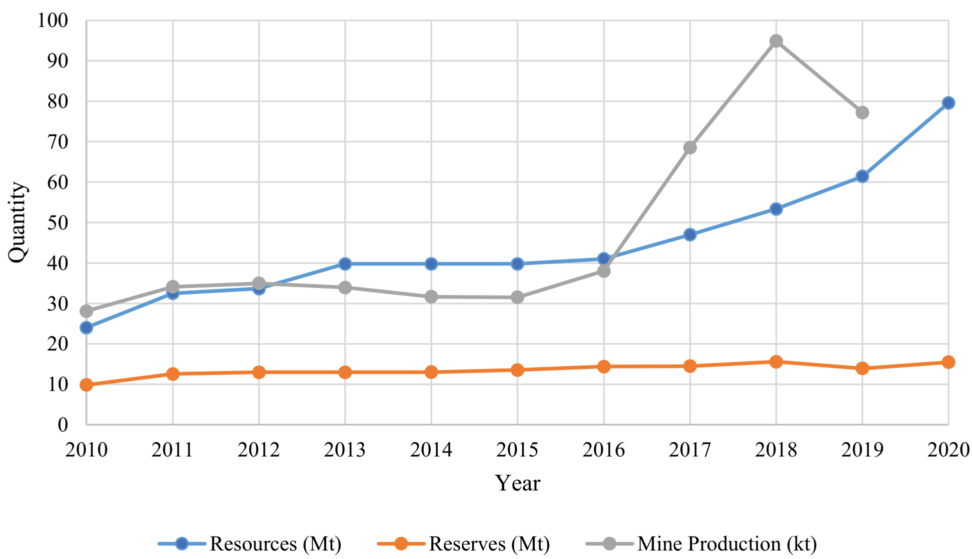

Figure 1. Lithium mineral resources, mineral reserves and mine production. Source: Elaborated from data available from the [14]

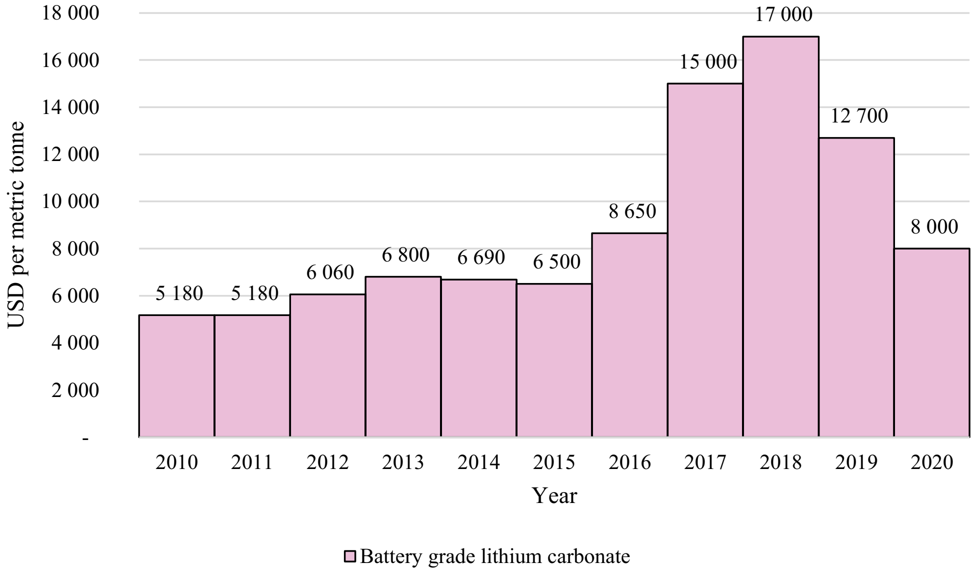

Figure 2. Average annual price of battery grade lithium carbonate. Source: Elaborated from data available from [46]

world lithium production. Owing to overproduction and decreasing prices during the period 2016–2020, several established lithium operations postponed capacity expansion plans. Junior mining operations in Australia, Canada, and Namibia ceased production altogether [15]. According to the [16], the world's largest exporters of primary cells and primary batteries of lithium are USA (14%), Singapore (13.8%), China (10.8%), Hong-Kong (10.7%), Indonesia (7.43%) and Japan (6.48%). The same report indicates that the world's largest importers of this commodity are USA (12.2%), Hong-Kong (11.1%), China (7.4%), Singapore (7.01%) and Germany [5.86%).

In the literature, some authors claim that despite the growing demand for lithium products, expansion in production capacities from existing operations and new mines are likely to create a surplus of lithium on the market in the coming years, while others predict the opposite. In fact, [17],report that the availability of lithium is not expected to be a bottleneck for the rapid and widespread adoption of electric vehicles, since the distribution of deposits around the world should be sufficient to meet future demand (4]. Other sources indicate that there is enough lithium to accommodate a significant number of electric vehicles [18], and that the overall annual supply increase needed to satisfy the anticipated demands in low-carbon scenarios is not excessive [19]. However, more recent studies report that supply bottlenecks are to be expected especially for lithium, nickel, and cobalt, specially for developed countries such as Germany, owed to the excess of allocated resource stocks and the high concentration of the production in only a few countries [20].

3.2. Lithium deposits and exploitation

The main lithium resources and reserves in the world are hosted in three types of deposits [21]:

(1) Pegmatite deposits, including the lithium–caesium–tantalum (LCT) family of granitic pegmatites and associated metasomatic rocks, plus the highly peralkaline varieties, and the metasomatic deposits associated with pegmatites, which are rich in tantalum, caesium, fluorine, and tin;
(2) Volcanic clay deposits, where Li occurs hosted in hectorite or other clay minerals;
(3) Brine deposits (and hydromorphic deposits).

There are more than 145 different lithium-containing minerals, but only a handful, namely spodumene, lepidolite, petalite, amblygonite and eucryptite, currently exhibit a commercial interest. Among these, spodumene (a lithium-rich granitic pegmatite) represents the most abundant lithium ore [22]. Although pegmatites are not particularly unusual, lithium-bearing ones are relatively rare. In spite of this, they have been the predominant source of lithium for many decades, and it is only following the development of continental brine operations in recent years that the share of lithium supply originating from pegmatites was reduced [23]. On the other hand, the most abundant source of lithium-rich brine is mainly found in an area known as the 'Lithium Triangle' in three South American countries: Argentina, Bolivia and Chile. Half of global lithium reserves are found in this brine deposits [24] and they are also the largest source (59%) of world production [25].

Spodumene-rich pegmatites processing starts in a similar fashion to many minerals: the ore is first ground and upgraded using flotation to produce a concentrate. The material is then roasted or calcined at approximately 1,040 to 1,100°C to convert α-spodumene structure into β-spodumene, a polymorph less resistant to chemical attack which can be leached into solution under moderate chemical extraction conditions [26]. Based on the individual deposits, some ores need to be further processed to concentrate lithium oxides from other minerals, like micaceous minerals, which can be trapped with lithium in the crystal structure. For example, the typical process for obtaining lithium carbonate equivalent (LCE) considers 12 steps after mining extraction as presented in (Figure 3).

On the other hand, in brine deposits, the naturally occurring solution is pumped to open man-made ponds, where solar evaporation is used to concentrate the lithium by reducing the volume of contained water, exploiting the inverse relationship between atmospheric pressure and altitude [4]. The brine is transferred through a series of these ponds, becoming progressively more concentrated, until the lithium can eventually be extracted by chemical means, as lithium chloride or, more commonly, as lithium carbonate [4]. The typical process for obtaining LCE from brine in salars, as for the Cauchari JV Project in Argentina, considers different steps after pumping brine from wells as indicated in (Figure 3).

The suitability of lithium production from pegmatite deposits depends on their lithium content (grade) and total lithium value, the degree to which the mineral content is zoned, and the amenability of the deposits or deposit groups to mining [27]. The same authors indicate that relatively few pegmatite bodies have been mined by modern underground methods. Nevertheless, open pit mining will probably be necessary on most deposits simply to generate sufficiently high production volumes. Where the pegmatites are exposed, they can be mined by open pit methods if they are sufficiently thick to avoid dilution.

In this regard, [28],points out that the development of a hard-rock producer will have a notable advantage: the speed with which lithium carbonate can be produced. Only five days are needed between the time the ore is mined and the final product is ready for shipment. In countries such as Australia and Chile, brine evaporation can take between 18 and 24 months. This time can be considerably longer if there is an unexpectedly high rainfall events onto the ponds [3].

In addition, brine processing presents its own set of inherent challenges. Different technologies are used around the world, and from this variety results a heterogeneity of operating costs. Other major challenges that brine extracting companies face are the high Mg/Li ratio, the weather, and the lack of infrastructure, among others [1]. Also, the suitability of brine deposits for production of lithium depends on the composition of the brine, including its lithium concentration, as well as the volume, accessibility, and its amenability to local processing [27]. The preparation of the ponds also represents an important capital cost [3].

3.3. Electric vehicles (EVs) and lithium battery technologies

Unlike other types of low emission automobiles, such as hybrid electric (HEVs) and plug-in hybrid electric vehicles (PHEVs), EVs rely exclusively on batteries and an electric powertrain and they are recharged by plugging them into a terminal connected to the electrical grid. There are several

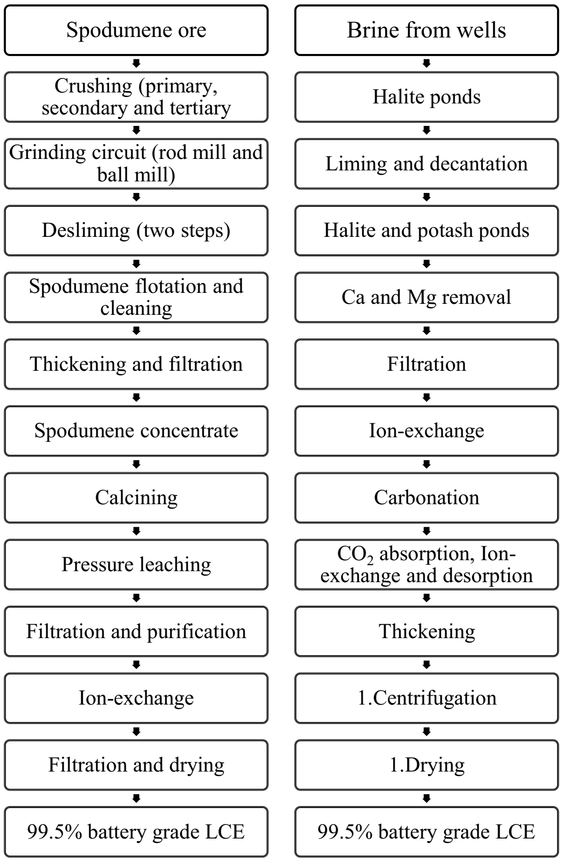

Figure 3. Flowsheet to obtain battery grade LCE from hard-rock minerals (left] and from brines [right). Source: Elaborated from data from [47,48]

lithium-ion battery cells with ample range of specific energy and specific power. This variety can be used to provide tailored solutions for specific applications, and EVs typically require batteries with high energy density in order to achieve the longest possible range between charging stations.

Rechargeable battery cells use a negative electrode material (anode) and a positive electrode material (cathode) to convert chemical energy into electrical energy and vice-versa. The lithium-ion cell uses a lithium-based metal oxide as the cathode. Graphite is generally the anode material of choice because of accessibility, price and charge capacity [1]. The most common lithium metal oxides used in cathodes for EV batteries are

- lithium nickel cobalt aluminium oxides, $LiNiCoAlO_2$ (NCA),
- lithium nickel manganese cobalt oxides, $LiNiCoMnO_2$ (NMC) and
- lithium iron phosphate, LiFePO4/C (LFP).

Most electric cars currently use NMC cells and few manufacturers, including Tesla, use NCA [29]. LFP find some applications in electric buses [30]. A report from the Bank of Montreal Capital Markets estimates that the market share of NMC would increase from 50% in 2015 to nearly 70% in 2025, in particular due to their energy density, which allows greater autonomy [31]. Additionally, improvements in the chemistry of NMC batteries should allow decreasing the use of cobalt, whose exploitation has sometimes been associated with illegal activities and the violation of human rights [32].

Although lithium batteries have improved so far, today's technology is still limited [33]. Moreover, improvements in spent battery collection, recycling schemes and energy content are mandatory, and these can only be obtained by renewing the lithium battery concept [34]. In this regard, it should be noticed that the next generation of lithium-ion battery technology, set to enter the market in the coming five to ten years, is likely to have low nickel content and use either NCA, with less than 10% nickel, or NMC 811 cathodes, which would go from having an equal proportion of the three elements to 80% nickel, 10% manganese and 10% cobalt [35]. Furthermore, the same report states that for the next decade, the lithium-ion battery is likely to dominate the EV market. For the period after 2030, several potential technologies might be able to push the boundaries beyond the performance limits imposed by lithium-ion battery technology. These include the lithium-metal solid state battery, lithium-sulphur, sodium-ion or even lithium-air [35].

Regarding the use of EVs in Quebec, [36],reports:

- a total of 69,332 low emission vehicles on Quebec roads as of 31 March 2020, 37,664 of which are EVs [54%);
- an annualised growth rate of EVs in the province is at almost 57%.

In this regard, [37],argues that the main factors influencing the rate of adoption of EVs are the:

- reduction of the cost of battery manufacturing, which affects the final selling price of EVs;
- improvement of lithium-ion battery technology, which will improve the autonomy or the speed of recharging;
- adoption of public policies, such as financial incentives for buyers, support for the development of the sector, regulations, taxation linked to carbon emissions, etc.
- development of alternative technologies;
- rate of adoption of autonomous vehicles, which has an impact on the total number of vehicles on the road;
- evolution of the oil price;
- speed of deployment of recharging infrastructure.

[37],also reports that the production of lithium-ion batteries is roughly equivalent to the production and sales number of EVs in China. Conversely, the European Union and United States account together for about 40% of EV production, but display only about 10% of global cell manufacturing capacity. In other words, the domestic lithium-ion cell supply cannot keep up with the demand of their car industry. Moreover, assuming that globally 70% of the announced plants will be built and completed on time and reach the design throughput, the planned generation capacity of 1,085 GWh in 2028 would meet the lower end of the range of global lithium-ion battery demand estimated for the EV market only [37]. According to the same source, a similar situation prevails in the North American market, where the announced generation capacity of 103 GWh in 2028 would also meet the lower end of the demand range. The North American market, excluding Mexico, for all EVs would grow from about 250,000 vehicles in 2018 to about 2 million in 2030.

4. Results and discussion

(Table 1) reports the mineral reserves and mineral resources of lithium mining projects by province in Canada, in compliance with NI 43–101 standard and whose technical reports date from the last ten years. Considering the 11 lithium projects listed, Canada has a total of 98.4 Mt of documented mineral reserves [proven and probable), of which 94.1% are in Quebec. Among the 248.14 Mt of documented mineral resources in Canada, Quebec holds 85.8% of them. Moreover, it should be

Table 1. Canadian lithium mineral resources and mineral reserves in compliance with NI 43–101.

			Reserves(proven + probable)			Resources(measured + indicated + inferred)			
Province	Deposit name	Type	Mt	Grade	Unit	Mt	Grade	Unit	Source
Alberta	Buckton Zone	Black shales	–	–	–	0.30	374.04	ppm	[50]
Manitoba	Zoro Lithium	Pegmatite	–	–	–	1.07	0.91	Li_2O (%)	[51]
Ontario	Georgia Lake	Pegmatite	–	–	–	13.29	1.09	Li_2O (%)	[52]
Ontario	Pakeagama Lake	Pegmatite	5.8	2.00	Li_2O (%)	10.42	1.82	Li_2O (%)	[53]
Ontario	Separation Rapids	Pegmatite	–	–	–	10.20	1.40	Li_2O (%)	[54]
Quebec	Authier	Pegmatite	12.1	1.00	Li_2O (%)	20.94	1.00	Li_2O (%)	[55]
Quebec	James Bay	Pegmatite	–	–	–	40.30	1.40	Li_2O (%]	[56]
Quebec	Lithium Quebec	Pegmatite	17.1	0.94	Li_2O (%)	47.00	1.20	Li_2O (%)	[47]
Quebec	Moblan	Pegmatite	–	–	–	14.25	1.41	Li_2O (%)	[57]
Quebec	Rose Li-Ta	Pegmatite	26.8	0.85	Li_2O (%)	34.70	0.92	Li_2O (%)	[58]
Quebec	Whabouchi	Pegmatite	36.6	1.30	Li_2O (%)	55.70	1.40	Li_2O (%)	[59]

noted that the province presents a world-class deposit of lithium-rich pegmatites: the Whabouchi project. This project alone represents 37.2% and 22.4% of the country's mineral reserves and mineral resources, respectively. Across Canada, there are currently 11 lithium projects, at different stages of development, which are reporting mineral resources and/or reserves in compliance with NI 43–101.

As shown in (Figure 4), the Canadian market has followed the global trends by significantly increasing its imports of primary lithium and lithium-ion batteries over the last decade. The province of Quebec, with the highest potential in the country in terms of lithium production, thus displays a market opportunity. These results align with the findings of [37], which also considers that Quebec is in a good position for the development of this key sector of activity due to the:

- access to a diversity of strategic minerals;
- proximity to American and Ontario automobile industry representing an interesting leverage;

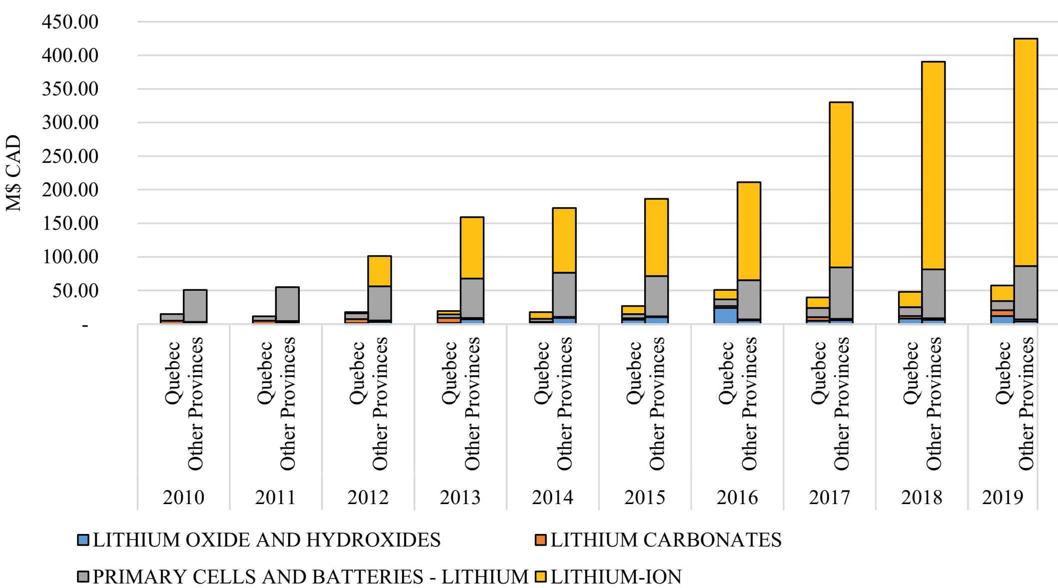

Figure 4. Canadian lithium related imports trend. Source: Elaborated from data available from Institut de la statistique du Québec, [49]

- presence of a core group of companies spread across the different stages in the lithium-ion battery value chain;
- know-how in the development and manufacturing of specialised EVs; and
- research expertise.

Clean and renewable hydro power, considered one of the cheapest in the world, represents over 99% of the Quebec's supply, and gives the province a unique advantage to fully electrify its transport system and further reduce its GHG emissions [38]. In fact, the potential environmental impact of an EV used in Québec is primarily associated with component manufacturing (particularly the electric motor) and the battery [39].

As introduced above, the province could benefit from the development and the establishment of a local production line of lithium-ion batteries for the EV market. Quebec can rely on an industrial base consisting of some 30 companies. These include the following companies [40]:

- AddÉnergie: designs, manufactures and operates recharging solutions for EVs for all market segments (institutional, commercial, industrial, residential, multi-residential, etc.). It is also the supplier of the two largest networks of charging stations in Canada;
- B3CG Interconnect: is a manufacturing company specialised in the assembly of cables, harnesses and complex electromechanical assemblies; it also offers specialised battery assembly services tailored to the needs of vehicle manufacturers;
- Elmec: is a company specialised in the design and manufacture of electromechanical and electronic systems and web applications; it manufactures charging stations for residential, commercial and industrial use.
- Johnson Matthey Matériaux de batteries (formerly Clariant Canada Inc. and Phostech Lithium Inc.): manufactures lithium iron phosphate used to produce lithium-ion batteries for use in various types of EVs and stationary energy storage applications; the company's expertise enables it to manufacture materials, sold worldwide, that meet the high purity requirements of battery manufacturers;
- LTS Marine: designs and manufactures electric powertrains for the recreational boating industry; the company offers a range of integrated solutions designed for multiple types of boats, from water sports boats to pontoons, and sells its products throughout North America;
- Solutions Bleues Canada (formerly Bathium): is a manufacturing company specialising in the research development and manufacturing of lithium metal polymer batteries for light vehicles and stationary energy storage applications;
- TM4: a subsidiary of Hydro-Québec that designs and manufactures electric drive systems marketed worldwide;
- Varitron: offers a full range of electronic assembly services in the field of EVs and also in the medical, military and automotive sectors as well as in the energy, telecommunications and aerospace industries.

It is important to note that this existing chain could be further enhanced. Indeed, Nemaska Lithium could potentially supply these manufacturers by promoting local integration. Johnson Matthey Matériaux de batteries has already approved the lithium hydroxide delivered by Nemaska Lithium [41].

In addition, recent research work shows that advanced process control is a very interesting avenue to increase the economic performance and reduce the energy consumption of mineral processing operations. In this regard, [42],introduced an economic model for a grinding-flotation circuit using a virtual sensor to measure liberation and convert it to expected profits. [43],developed a similar model to propose a real-time optimisation system maximising the processing plant profit. This kind of development could potentially be used to offset the cost of producing lithium carbonate from Quebec's mines, and compete with brine-based facilities.

On the other hand, there are several barriers to the widespread adoption of the EV technology in Quebec. One of them is the lack of charging stations and related infrastructure, which limits the range of these vehicles. This limitation is gradually being overcome by Hydro-Quebec. The network expansion provides a new incentive for the purchase of EVs, and even developing batteries that lower the cost of electric vehicles [44].

[45],announced construction of a pilot plant to recycle 200 tons of lithium-ion batteries per year (the equivalent of 300 to 650 electric car batteries). The components of EV batteries (mainly nickel from Ni-MH batteries and cobalt from lithium-ion batteries) currently provide an economic incentive for recycling. As volumes of spent EV batteries increase, the development of an effective recycling industry will be key to the sustainability of lithium-ion batteries. By recovering critical materials, a robust recycling system would reduce demand for raw materials, greenhouse gas emissions and negative local impacts from mining and refining [35]. On the other hand, battery designs are evolving, resulting in fewer valuable materials being used, and in turn lower interest for future recycling activities [44].

According to [35], battery collection and recycling policies have usually focused on other industries and battery technologies than the lithium-ion batteries used in EVs, such as consumer electronics or lead-acid batteries. Several countries, including members of the European Union and the United States, are beginning to work on setting standards for EV battery recycling. The adoption of such standards in Canada could affect the potential demand for lithium from Quebec mines.

5. Conclusions

The province of Quebec exhibits important lithium resources necessary to produce lithium-ion batteries. Some of these deposits have already proven to have mineral reserves and could soon be in production. In this sense, the mining tradition of the province means that it has the expertise and skilled labour to develop mining projects. This article highlighted the growing demand in the rest of Canada for imported lithium-ion batteries that Quebec could take advantage of. In fact, this research indicates that Quebec has the infrastructures and necessary knowledge in the field for manufacturing advanced lithium products, which would add value to the production chain.

Moreover, the proximity to the US market, which does not have the capacity to produce all the lithium batteries its automotive industry needs, is another interesting option to explore, especially for long term agreements. Moreover, as most of the electrical energy in Quebec comes from clean renewable sources, gradually renewing the automobile fleet with EVs would mean a considerable reduction in GHG emissions. This measure would be in line with government policies. Additionally, some research suggests that mineral processing could become more efficient, achieving a cost reduction that would eventually make Quebec spodumene concentrates even more competitive compared with brine-based production or other pegmatite operations.

However, the province still faces some major challenges to overcome. The cost of existing skilled labour is high, and the remoteness of some deposits could put them out of reach of the Hydro-Quebec power grid. In addition, the variability in the price of lithium, which could experience a drop as a result of the increase in world supply and/or the increase in production of major brine deposits, may render some Quebec projects unprofitable in the long run. In this regard, attracting the capital needed to bring the mines into operation remains an issue that has caused them to lose part of the market and best prices. It should be also noted that manufacturing lithium batteries requires other scarce minerals, such as cobalt, graphite or rare earths. Although Quebec presents the geological potential for future exploitation of these minerals, the time needed to develop a mining project is usually quite long. The province would therefore continue relying on external supplies at least in the medium term should an integrated manufacturing industry for lithium-ion batteries emerge within its border.

Future work should further investigate two main aspects: i) whether the potential GHG emissions reduction would not be overshadowed by GHG emissions from the construction of the necessary infrastructure for developing and operating the mines and the processing plants, and ii) how other economic factors, including operating and capital costs, can make lithium projects in Quebec competitive. This will allow the province to seek the appropriate strategies for maximising the return on public investments and minimising the risks. Lastly, since time seems to be another crucial factor, effort will be necessary to establish a long-term market for lithium produced in Quebec.

Acknowledgments

This work was supported by the Fonds de recherche du Québec – Nature et technologies (FRQNT) and Fonds vert. The authors are thankful to the Ministère de l'énergie et des ressources naturelles du Québec (MERN), especially Dr. Andrea Amortegui and Mr. Laurent Roy, for their support.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Fonds de recherche du Québec - Nature et technologie (FRQNT) [2019-GS-260904].

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