



# So, You Want to Make Batteries Too?

*A Framework for Developing Lithium-Ion Battery Supply Chain Industrial Strategy*

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## Executive Summary

The 2020s will see electric vehicle deployment on a massive scale as a part of our energy transition away from fossil fuels. This will create a boom in manufacturing of lithium-ion batteries, and a rapid increase in demand for battery quality lithium chemicals. Politicians around the world are wondering how their jurisdictions can participate in the lithium-ion battery supply chain. Simultaneously, there is concern about the concentration of lithium-ion battery industrial activity in China. Further, a number of governments have announced “green deals” for post-Covid-19 capital allocation to re-activate economic growth. The confluence of these forces means that now is the perfect time for policymakers to develop industrial strategies for lithium-ion battery supply chain activity in their jurisdictions.

In this essay, we map the current, global lithium-ion battery supply chain. We analyze several case studies of both active and aspiring supply chain participation in different jurisdictions in order to understand the attributes of active supply chain participation which makes it successful, the attributes of some aspiring supply chain participation which makes them unsuccessful, and what are the preconditions for participation in a step of a lithium-ion battery supply chain. Using this analysis, we propose a framework for lithium-ion battery industrial policy development. We have seen jurisdictions with good intentions fail in execution of supply chain strategies, and we hope that this framework will help avoid similar failures in the future.

In most cases, lithium-ion battery supply chain participation and its multiple orders of benefits are realized by jurisdictions which have sizeable electric vehicle markets. In all cases, we strongly recommend policymakers to incentivize electric vehicle adoption within their borders using tax rebates or other mechanisms. Participation at the early stage of the industry’s growth will help accelerate the world’s transition to renewable energy and create value for generations.

Given the strong growth dynamics for electric vehicles (EVs) and the lithium-ion batteries (LIBs) that power them, policymakers worldwide representing jurisdictions with lithium natural resources are increasingly focused on how they can leverage their assets to participate in the battery industry. They want to capture value from the boom in demand for lithium and other chemicals widely expected to occur in the late 2020 to achieve strategic goals for their jurisdictions.

We have observed or participated in conversations across six continents that are variations of the question “We have a lithium deposit, so should we make batteries?” LIB supply chain industrial strategy is a hot topic in the wake of the Covid-19 pandemic, as we believe that economic and political dynamics are converging to realign supply chains. Governments around the world are announcing “green” stimulus programs hoping to use the energy transition to re-activate economic growth.

Simultaneously, there is geopolitical concern about the concentration of industrial activity supporting the LIB supply chain in China. However, it is not clear to many what policies should be enacted, what technologies should be used, and where capital should be allocated to counter this supply chain concentration. In this essay, we examine what lessons from the commercial successes of the current, global LIB supply chain could be used by policymakers and supply chain stakeholders. We believe that industrial strategies that seek to learn from the structure of the existing LIB supply chain are more likely to succeed.

In this essay, we map the current, global LIB supply chain by classifying a set of jurisdictions as having significant active or aspiring participation in distinct steps. Using a high-level analysis of the successes and failures of active and aspiring jurisdictions, we propose a framework for developing LIB supply chain industrial strategy to guide policy and investment decisions.

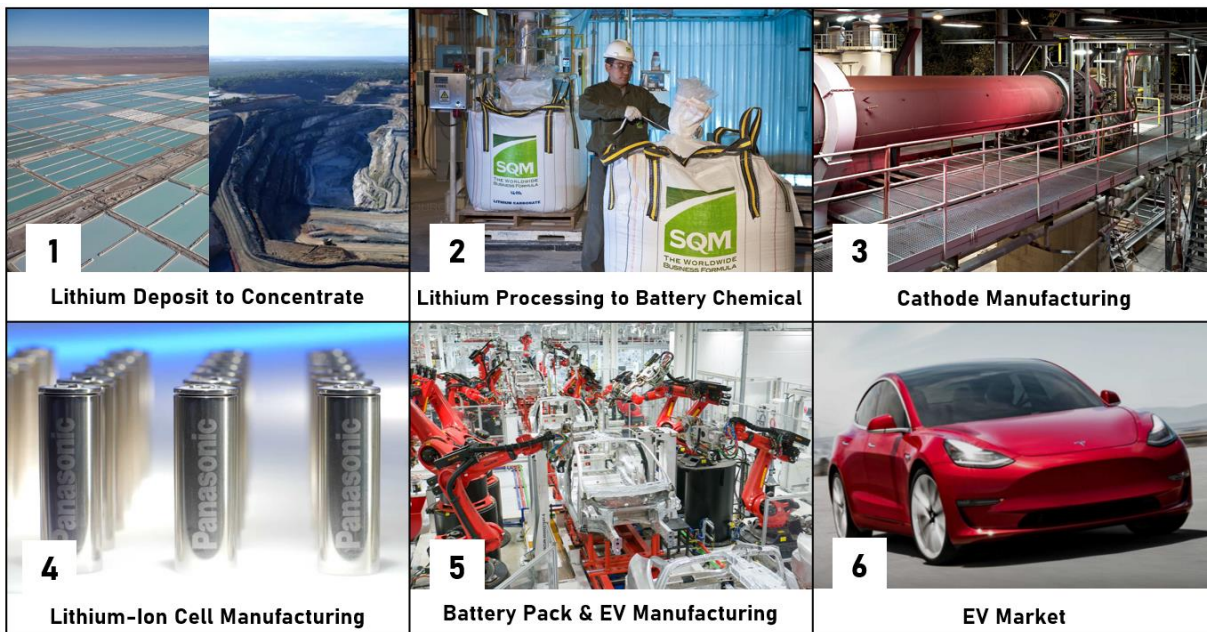
## **The Current, Global Lithium-Ion Battery Supply Chain**

Development of an economically sustainable step in a LIB supply chain requires that policymakers develop strategies with minimum and decreasing need for subsidies or direct government investment over time. Regardless of policy, new entrants to a supply chain will to some extent have to play by the same rules as the current, global LIB supply chain. For example, if a country has no natural resources, the furthest upstream they can develop is upgrading imported raw materials. And if a country has no domestic EV demand, manufacturing EVs in-country is inadvisable, as there will be no one to buy them unless a partnered jurisdiction has a large EV demand.

The individual actors within the current LIB supply chain are profitable pursuant to market swings, though many elements are initiated or supported by governments. Their activity is feasible within constraints, which we think of as rules that are implicitly followed if activity is economically sustainable. The LIB supply chain as it exists today has been shaped by a variety of underlying technical, economic, and political frameworks. Policymakers and industrial players should seek to understand these frameworks to develop LIB supply chain industrial strategies. The goal is to facilitate economically sustainable activity within a jurisdiction. These frameworks may be “obvious” or “common sense” to industry insiders, but to many new decision makers, it may not be so clear.

In order to map the current, global LIB supply chain in simple terms, we demarcate six steps. This is the story of a lithium atom's trip from natural resource to electric vehicle, though other activities and inputs are also required (e.g. other materials to make batteries).

1. **Lithium deposit to concentrate** includes natural resource extraction and concentration to a ~6% solution, ~6% lithium oxide spodumene concentrate (SC6), or other high lithium grade material that is not suitable as a battery chemical precursor. Other examples include industrial grade lithium carbonate which can be converted to battery-quality lithium chemicals.
2. **Lithium processing to battery chemical** includes conversion of a concentrate to battery-quality lithium chemicals that are used to manufacture cathode powders. In an integrated facility, steps one and two are performed by the same company and/or performed nearby.
3. **Cathode manufacturing** is the processing of chemical precursors to make a powder which can be used in the cathode of a LIB battery (e.g. NCM, NCA, LFP, etc.). Cathode powders are highly engineered materials designed specifically for different types of LIBs.
4. **Battery cell manufacturing** is the combination of cathode powders, anode powders, electrolyte, and other components to manufacture a cell (cylindrical or other formats).
5. **Battery pack and EV manufacturing** is the assembly of lithium-ion cells in an array (called a module, and multiple modules comprise a pack) and combination of the pack with the rest of the vehicle. EV manufacturing is different from internal combustion engine vehicle manufacturing, but shares some common infrastructure and skill requirements.
6. An **EV market** exists when consumers are purchasing a critical mass of new battery electric vehicles. Governments most often support the transition to EVs using tax incentives and penalty-based emission standard policies.





We map the current, global LIB supply chain as a grid. In the rows, we select a set of jurisdictions that are representative of most of the world's commercial activity in the space. In the columns, we show the six steps in a LIB supply chain.

## Simplified Map of Significant Participation in the Current, Global Lithium-Ion Battery Supply Chain – June 2020

Jurisdiction	1. Lithium Deposit to Concentrate	2. Lithium Processing to Battery Chemical	3. Cathode Manufacturing	4. Lithium-Ion Cell Manufacturing	5. Battery Pack & EV Manufacturing	6. EV Market
California	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Active
Nevada	Active	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Active	Active
North Carolina	Aspiring <sup>1</sup>	Active	Active	Active	Active	Active
Alberta	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Active
Quebec	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Aspiring <sup>1</sup>	Active	Active

Chile	Active	Active	Aspiring <sup>1</sup>	Active	Active	Aspiring <sup>1</sup>
Argentina	Active	Active	Aspiring <sup>1</sup>	Active	Active	Aspiring <sup>1</sup>
Bolivia	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>
Australia	Active	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Active	Active
China	Active	Active	Active	Active	Active	Active
Japan	Active	Aspiring <sup>1</sup>	Active	Active	Active	Active
South Korea	Active	Aspiring <sup>1</sup>	Active	Active	Active	Active
Germany	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Active	Active	Active
United Kingdom	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Active
France	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active
Spain	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active
Poland	Active	Active	Aspiring <sup>1</sup>	Active	Active	Active
Sweden	Active	Active	Aspiring <sup>1</sup>	Aspiring <sup>1</sup>	Active	Active

 Active
  Aspiring<sup>1</sup>

 Upstream
  Downstream

(1) Either commercial or political efforts exist to develop the activity within the jurisdiction (some more realistic than others)  
 Note: This map is not intended to be comprehensive

## The Preconditions for Supply Chain Participation

The majority of jurisdictions that host a lithium deposit and believe this may lend itself to downstream activity such as battery or EV manufacturing should think twice. The requirements for manufacturing downstream products go far beyond lithium natural resource availability. Each step in a LIB supply chain has basic preconditions that a jurisdiction should meet before contemplating subsidies or policy support to entice companies to build that step at home. A history in related activities that build skills necessary in a step in a LIB supply chain is the most important precondition to enable participation in the industry. Intellectual capital and experience are crucial for success.

### Preconditions for Participation in Different Steps of a Lithium-Ion Battery Supply Chain

<b>1. Lithium Deposit to Concentrate</b>	Large resource (e.g. >5Mt Li <sub>2</sub> CO <sub>3</sub> ), ability to extract economically, historic resource development, social license to operate
<b>2. Lithium Processing to Battery Chemical</b>	Chemical processing industrial history, ability to refine economically, chemical engineers
<b>3. Cathode Manufacturing</b>	Powder processing industrial history, supply of Ni, Co, Mn, Al, and/or other metals, materials engineers
<b>4. Lithium-Ion Cell Manufacturing</b>	Advanced technology industrial history, EV manufacturing or partnership with EV manufacturing jurisdiction
<b>5. Battery Pack &amp; EV Manufacturing</b>	Advanced technology industrial history, historic ICE vehicle manufacturing, an EV market
<b>6. EV Market</b>	Reliable electricity grid, charging stations, EV availability, incentives for EV ownership

While all these preconditions may vary in importance, their presence enhances the likelihood of success of a step in a supply chain in that jurisdiction. For example, it is unlikely that a small lithium resource will be developed in a small country with no mineral resource development history. It is more likely that a jurisdiction with a mature industry manufacturing another type of highly engineered powder may be successful manufacturing cathode materials, especially if other companies within the jurisdiction or in partnered jurisdictions will buy it. Similarly, jurisdictions manufacturing internal combustion engine vehicles already possess many of the attributes required for manufacturing EVs.

Active participation in a LIB supply chain provides benefits beyond primary economic activity. Expertise in lithium chemical production and sale of these products to cathode manufacturers gives producers insight into the future of cathode and battery manufacturing and builds networks. Participating in a supply chain also builds conditions to participate in other steps of a supply chain.

### Benefits of Active Participation in a Lithium-Ion Battery Supply Chain

<b>Primary</b>	Job creation, tax collection, royalty collection, vibrant domestic economy
<b>Secondary</b>	Domestic intellectual property, technical expertise, professional networks
<b>Tertiary</b>	Cultural exchange, geopolitical influence, national pride, insight into other technical fields

## Policy Questions for LIB Industrial Strategy: Past and Present

The question “We have a lithium deposit, so should we make batteries?” is only one question about industrial strategy posed by different provinces, states, and countries. Other questions include:

### **We have a lithium deposit, so should we manufacture cathode materials to capture more value upstream, thus create more jobs and collect more taxes?**

**Chile** The government solicited Asian and European cathode makers to set up manufacturing capability in Chile in order to access preferably-priced lithium chemicals provided by Atacama operators. This initiative failed, due in part because the chemical desired by the cathode manufacturers (lithium hydroxide) is not made in Chile at large enough scale. [1] It also would have necessitated cathode manufacturers to locate far from their own customers.

**Australia** Western Australia’s “Lithium Valley” initiative seeks to vertically integrate spodumene mining, lithium hydroxide manufacturing, and cathode manufacturing all within the borders of the Australian state. This concept has commercial traction for domestic lithium hydroxide manufacturing, but lacks the same for cathode manufacturing. [2]

**California** An Imperial Valley economic development agency commissioned a report to examine the attractiveness of co-locating battery manufacturing with the Salton Sea geothermal lithium resource. We are not aware of any commercial traction for the concept, though lithium chemical production from the resource is being advanced by multiple developers. [3] The region has significant experience with geothermal brine chemistry.

### **We manufacture or use cathode materials, so should we produce lithium chemicals to reduce our raw material costs?**

**Quebec** Johnson Matthey, a cathode material manufacturer in Quebec, invested in Nemaska Lithium’s spodumene mining and lithium chemical production project in Northern Quebec. They were planning on taking some of its lithium chemical product for cathode manufacturing before Nemaska went bankrupt. [4]

**South Korea** POSCO bought a lithium brine property in Argentina, where they plan to use a unique lithium extraction technology to produce a lithium phosphate concentrate for processing into lithium hydroxide. They are now also planning on building a spodumene concentrate converter in South Korea, presumably planning to purchase SC6 from Australia. [5] POSCO has vast experience in processing different metals.

**Japan** Toyota Tsusho invested in Orocobre’s Olaroz brine project in Argentina, and is now building a lithium hydroxide plant in Japan. They will use lithium carbonate from the Olaroz project as a precursor to make battery chemicals. [6] Japan has processed metals and powders for centuries before the lithium-ion battery supply chain existed.



## How do we enter a LIB supply chain?

- Alberta** Livent's investment in E3 Metals' oilfield brine technology and project has sparked the province's imagination about its role in the LIB supply chain. Alberta's present economy is dependent on its oil industry, which does not have a bright future, and it is looking for opportunities to build its future economy. There is plenty of experience in the province with moving large quantities of fluids. [8]
- Sweden** Northvolt is building facilities to manufacture cathode materials and lithium-ion cells for European EV manufacturers. They also plan to recycle batteries. [10] Sweden has a history of metals processing affiliated with downstream markets in Germany and Poland.
- Australia** Wesfarmers, an industrial conglomerate, purchased a stake in a spodumene to lithium hydroxide project in Western Australia. They have postponed their project as lithium chemical prices have recently dropped. [11]

Some of these initiatives will result in economically sustainable LIB supply chain activity, potentially allowing for growth in other steps of LIB supply chains. Some will fail. A framework for LIB supply chain development may help predict which initiatives will succeed. Below, we share four case studies of LIB supply chain development (two active, two aspiring) that inform a framework.

## Active Case #1: Tesla's Role in the American Lithium-Ion Battery Supply Chain

Tesla is an EV manufacturing company from California that was initially supported by demand for clean transportation in that state. In 2009, Tesla signed a contract with Panasonic, a Japanese company, to supply lithium-ion cells for their vehicles, [10] however Tesla still controls procurement of raw materials that go into the cathode in those cells. The lithium chemicals used to make Tesla's cathode materials are processed mainly in China and North Carolina. Those chemicals are made using Australian SC6 and lithium carbonate from Chilean and Argentine brines as feedstock. The cathode material used in those lithium-ion cells is manufactured in Japan. Tesla assembles the cells into battery packs in Nevada and California, where they are designed and optimized specially for Tesla's vehicles.

Elon Musk has said for years that he plans to vertically integrate Tesla's supply chain. In 2014, he made an offer to purchase a lithium extraction technology company so that Tesla could secure lithium chemicals from California's Salton Sea geothermal lithium brine resource, but the deal was never realized. [11] Since then, many have speculated that lithium resources in California and Nevada would be attractive acquisition targets for Tesla. Owning a resource and chemical manufacturing plant would provide an opportunity to better control their supply chain, cutting costs of raw materials. This has not yet happened. Instead, Tesla is currently scaling up its own cathode and cell manufacturing capabilities in the United States. This could result in the end of their collaboration with Panasonic (step three in their supply chain) bringing battery manufacturing fully in-house. [11] Below is a simplified schematic of the evolution of Tesla's supply chain over time. This schematic is based on public information and could vary in reality.

Simplified Schematic of Tesla's Role in the American Lithium-Ion Battery Supply Chain

■ Active    ▨ Aspiring

Year	1. Lithium Deposit to Concentrate	2. Lithium Processing to Battery Chemical	3. Cathode Manufacturing	4. Lithium-Ion Cell Manufacturing	5. Battery Pack & EV Manufacturing	6. EV Market
2010			▨	▨	■	■
2012			▨	▨	■	■
2014	▨	▨	▨	▨	■	■
2016			▨	▨	■	■
2018			▨	▨	■	■
2020			▨	▨	■	■

Tesla's supply chain was originally underpinned by the California EV market, and they may be moving upstream one or two steps at a time. It took around 15 years to develop and master the steps furthest downstream, during which time the midstream steps were developed with Panasonic, and the farthest upstream steps were developed by lithium chemical companies. While Tesla can buy lithium raw materials from multiple chemical producers, it needs to produce cathode material specifically engineered for its own batteries. So, it makes sense to manufacture their own cathode before it makes sense to make their own lithium chemicals. Cathode manufacturing is more unique to their battery than the lithium chemicals they use to make the cathode. Further, producing lithium chemicals from a natural resource is a different skillset which will take time to develop. There may not be a good strategic reason for doing this yet, especially if prices of those chemicals are low and competition among producers is strong.

## Active Case #2: Ganfeng’s Role in the Chinese Lithium-Ion Battery Supply Chain

Ganfeng Lithium is one of the largest lithium chemical producers in the world. The company has mastered lithium chemical production from SC6 and other concentrates, and is using the skills developed in lithium chemical production to create value in other steps of the LIB supply chain, including battery manufacturing and battery recycling. Ganfeng is also now a major lithium chemical exporter outside of China. Ganfeng did not start its business on either end of the supply chain, by owning a lithium natural resource or by making EVs. Ganfeng pursued strategic partnerships with spodumene producers to convert their concentrates or upgrade chemical products within China, where cathode, cell, and EV manufacturing boomed in the 2010s.

Ganfeng has been able to “start in the middle” of the Chinese supply chain – focusing on lithium refining and opting for offtake agreements from miners. The Chinese EV market underpins this supply chain similar to how the California EV market underpinned the start of Tesla’s. The Chinese government incentivized EV purchasing and the development of a LIB supply chain, allowing Ganfeng to grow into a global leader. Now that they have mastered concentrate conversion to battery chemicals, they have moved strategically to expand downstream into manufacturing materials like cathode precursors, as well as upstream via strategic investments into hard rock, sedimentary claystone, and brine resources.

Ganfeng now is a part owner in multiple natural resource projects around the world. Interestingly, they have invested in all types of natural resources including Australian/Canadian spodumene resources, Mexican sedimentary clay, and Argentine brine. Their multi-resource strategy will allow Ganfeng to learn more about lithium process chemistry than any other competitor, as they will be faced with a wider variety of challenges to overcome. Diversity of experience will be an important tool for Ganfeng as it expands downstream. Below is a simplified map of their role in the Chinese LIB supply chain based on public information. It could vary slightly in reality. Note that cathode manufacturing encompasses cathode precursor manufacturing in this simplified map.

**Simplified Schematic of Ganfeng’s Role in the Chinese Lithium-Ion Battery Supply Chain**

■ Active    ▨ Aspiring

Year	1. Lithium Deposit to Concentrate	2. Lithium Processing to Battery Chemical	3. Cathode Manufacturing	4. Lithium-Ion Cell Manufacturing	5. Battery Pack & EV Manufacturing	6. EV Market
2010		▨				■
2012		▨				■
2014		■	▨			■
2016	▨	■	▨			■
2018	▨	■	■	▨		■
2020	▨	■	■	▨		■

## Aspiring Case #1: Bolivia's LIB Supply Chain

Bolivia has one of the largest lithium resources on the planet, but almost no production of lithium chemicals. The national development company (YLB) oversees extraction of lithium from complex brines beneath the salt flats at approximately 4,000 meters altitude, converting them into fine chemicals, manufacturing cathode materials, AND manufacturing lithium-ion cells. Each of these work streams is different, making it unlikely that one company can do them all. Companies around the world are spending millions of dollars on R&D for single steps in supply chains, while YLB is not sufficiently financed or experienced to perform any of them effectively. [13]

Different skills, infrastructure, knowledge, and other supply chains (e.g. other cathode components) are required to accomplish these different tasks. YLB has been spread too thin and tasked to develop too many complex projects simultaneously and consequently has not made very much progress in the last decade. Though multiple deals with companies from around the globe have been very publicly signed to develop their brine resources, they have not succeeded. [14] If Bolivia is to contribute to a LIB supply chain in the future, it would be wise to study Tesla's and Ganfeng's supply chain development stories. Notably, these success cases undertake one to two steps at a time, rather than attempting to develop an entire supply chain from a natural resource. Since Bolivia does not yet have a large EV market, but does have a large lithium resource, the country should start upstream by developing the ability to produce a concentrate from the lithium deposit. It could then move on to producing battery chemicals in Bolivia, and exporting those to other nations where cathode materials are manufactured.

**Simplified Schematic of the Bolivian Lithium-Ion Battery Supply Chain**

■ Active    ▨ Aspiring

Year	1. Lithium Deposit to Concentrate	2. Lithium Processing to Battery Chemical	3. Cathode Manufacturing	4. Lithium-Ion Cell Manufacturing	5. Battery Pack & EV Manufacturing	6. EV Market
2010	▨	▨	▨	▨	▨	▨
2012	▨	▨	▨	▨	▨	▨
2014	▨	▨	▨	▨	▨	▨
2016	▨	▨	▨	▨	▨	▨
2018	▨	▨	▨	▨	▨	▨
2020	▨	▨	▨	▨	▨	▨

We believe that building a large, successful lithium extraction and processing operation is a very impressive feat in itself, and could have multiple orders of benefits that could support future domestic innovation in battery recycling and other industries. This would have lasting impact on Bolivia's economy for generations. Producing raw materials and high value chemicals supports decarbonization of the global energy system, even if batteries or EVs are not initially produced domestically. Argentina followed a different path from Bolivia that was much more fruitful over the last decade. In 2010, there was only one lithium extraction facility in Argentina. Now there are two major ones operating and at least four to five new ones in development. Though there are some very limited conversations about cathode and EV manufacturing in Argentina, almost all focus is on resource development and sale of lithium carbonate and lithium hydroxide products, both as intermediates and finished products. Politics aside, we wonder if Bolivia could have done the same if YLB was more focused.

## Aspiring Case #2: The European Lithium-Ion Battery Supply Chain

All of Europe is not an “aspiring” jurisdiction, but for the most part, the European LIB supply chain that will exist in 2030 does not exist in 2020. In this context, Europe serves as an aspiring jurisdiction for the purpose of making comparisons to other development pathways. Different jurisdictions in Europe participate in different steps of the current, global LIB supply chain except lithium resource development, but this participation is at a relatively small scale compared to Tesla or Chinese companies. Different arms of the European Union are now deliberately working on how to build an environmentally sustainable European LIB supply chain. The strategy involves coordination of industrial policymaking and financial support across the continent to support LIB supply chain development.

Not all “aspiring” jurisdictions are making the same progress in LIB supply chain participation. Unlike Bolivia, Poland and Sweden are on the cusp of making major contributions to the European LIB supply chain as cathode and cell manufacturing hubs. Similar to China in the 2010s, the EV market in Europe is growing at a rapid pace due to emission reduction requirements, and is developing its own ecosystem of localized participants. In both cases, a large (or potentially much larger) EV market (rather than a domestic natural resource) underpins LIB supply chain activity. These similarities suggest that Europe’s LIB supply chain may evolve similarly to China’s.

For example, activity in Europe has started mainly downstream, with vehicle manufacturing as a response to its new EV market, and domestic resources have not yet been fully developed. In China, cathode manufacturers imported lithium chemicals or concentrates for the first decade of their rapid development. But as their LIB supply chain has become more mature, Chinese production of lithium chemicals from domestic unconventional brine resources in Qinghai has also increased. In 2019, this represented around 10% of global supply. Europe is now contemplating its own domestic natural resource development strategy with a sharp focus on low CO<sub>2</sub> emissions and water impact mitigation. It should be expected that Europe will also produce domestic lithium by 2030.

Different jurisdictions bound together by the European Union and common market may play distinctive roles in the European supply chain. For example, Germany, France, Spain and the UK may remain auto-manufacturing hubs, while activity in Sweden and Poland could compliment them in the upstream supply chain. For example, Northvolt plans to produce lithium-ion cells in Sweden and a number of companies are planning to build cathode manufacturing facilities in Poland and Hungary. Each of these countries has different histories and skillsets, and together they likely have everything that Europe needs to build a complete domestic supply chain to satisfy the European EV market.

It is important to note that no single company in Europe is attempting to both produce lithium from a natural resource AND manufacture batteries the way YLB is in charge of developing all steps of a Bolivian LIB ecosystem simultaneously. We believe the European approach, where different companies with different skillsets and histories specialize in different activities, is more likely to succeed. The development of a European LIB supply chain the same size as China’s has not occurred yet, so we will not map it now.

## Bringing it Together: Resilience, Localization, and Vertical Integration

It is important to distinguish between three key terms related to supply chains. A localized supply chain is not necessarily resilient, and a resilient supply chain may not be localized. Neither have to necessarily be vertically integrated by one company or even in one jurisdiction. Resilience goes hand in hand with security of supply, and is a shared goal of both governments and companies involved in strategic material supply chains.

### Supply Chain Terminology Definitions

<b>Resilience</b>	<b>Capacity to avoid degrowth in the face of disturbances, and to recover quickly from exogenous shocks</b>
<b>Localization</b>	<b>When operations are located in the same jurisdiction or distributed across physically proximal jurisdictions</b>
<b>Vertical Integration</b>	<b>Participation in multiple steps in a supply chain to generate more profit and/or foster resilience of the supply chain</b>

Generally, resilience and localization imply higher costs or lower profit margins if more manufacturing is performed in jurisdictions where it is more expensive to operate or by operators who are less experienced. Vertical integration may foster resilience as well, if one company controls multiple steps in its own supply chain and can tolerate slack and excess inventory. However, typically the goal of vertical integration is to minimize long term costs or gain additional control.

Localization and vertical integration can both promote resilience in a supply chain, but may also help achieve other goals. The US experience with rare earths provides a well-known example that illustrates these concepts. The US extracts rare earth concentrates in California, which are processed in China and then bought back by the US in their purified forms. A dispute with China could disrupt supply of the purified forms and thus this supply chain is not resilient. We saw this play out in the early part of the last decade, and little has been done to rectify this aside from new rare earth concentrate production in Australia. If the US could buy rare earth metals mined and processed in a partnered country such as Australia, even though the supply chain may be less localized and potentially higher cost, it would be more resilient.

While localization may carry higher costs, it can bring economic benefits, political support, and the ability to resist geopolitical shocks. To be clear, we are not suggesting a model where a full supply chain exists in-country and only serves that country. We view localization as a strategy where supply chains cross borders, but these borders are partners as opposed to strategic competitors. Consumer markets in many individual countries lack the scale to attract capital for a full EV supply chain, but regional economic blocs such as the European Union, Mercosur, the Trans-Pacific Partnership (TPP), or USMCA are ideal to facilitate market size and access to capital.

## A Framework for Lithium-Ion Battery Supply Chain Industrial Policy

We believe that LIB supply chain policies and industrial strategies have the highest probability of success if they use the following framework.

### A Framework for Developing Lithium-Ion Battery Supply Chain Industrial Strategy

<b>1</b>	If your jurisdiction does not participate in a LIB supply chain, and you have a resource but no EV market or EV manufacturing, <b>incentivize upstream activity.</b>
<b>2</b>	If your jurisdiction does not participate in a LIB supply chain, and you have an EV market or historic vehicle manufacturing but no significant resources, <b>incentivize downstream activity.</b>
<b>3</b>	If your jurisdiction already produces lithium concentrates from a resource but not battery chemicals, incentivize processing to battery chemical production. Don't incentivize activity any further downstream <b>unless you have an EV market.</b>
<b>4</b>	If your jurisdiction has an EV market or EV manufacturing, move upstream one step at a time. Stop at processing to make battery chemicals if you have no significant resources, or go all the way upstream <b>if you have resources.</b>
<b>5</b>	To build a resilient LIB supply chain, build partnerships with jurisdictions who have complimentary positions in a LIB supply chain so that you can <b>vertically integrate as a team.</b>

Policymakers must understand the structure of the current, global LIB supply chain. In this paper, we map it into six steps to simplify it, but there is much more to it than that. In the context of this map, we believe that jurisdictions should implement policies that start either with lithium resource development (far upstream) or EV manufacturing (far downstream). The choice of starting point depends on how many preconditions for participation in a step of a supply chain are met in a jurisdiction, including the size and quality of its lithium resources and the size of its EV market.

In order to fully realize the benefits of active participation in a step in a supply chain, which may be preconditions for participation in another step of the supply chain, we believe that moving one step at a time every couple of years is the fastest a company or jurisdiction should try to develop its supply chain. In almost all cases, the best way to develop LIB supply chain participation for a jurisdiction is to incentivize the purchase of EVs. This is critical for realizing our global energy transition away from fossil fuels, but equally critical to each jurisdiction's participation in the future economy.

## Policy Questions for LIB Industrial Strategy: Future

If the following jurisdictions were to use the framework described above, the following industrial strategies would be developed.

- Chile** Expand lithium chemical and concentrate production from the Atacama and other salars. Policy should support producers on water impact mitigation such as new nationalized monitoring well program standards to regain social license to operate for brine producers, and adoption of new technologies for lithium extraction. Chile should double down on its current role in the global LIB supply chain.
- Australia** Support lithium concentrate and chemical producers to find cathode clients in Asia, Europe, or elsewhere. Australia should take a similar approach to Chile.
- California** Support at least one unique geothermal lithium project to be built and help find off-take for the lithium chemicals. California should focus on one investment at a time within that step of its supply chain to avoid ending up like Bolivia.
- Quebec** Support getting the Nemaska lithium project built, ideally using its innovative low CO<sub>2</sub> and low waste processing flowsheet. Policymakers could help expand cathode manufacturing there if lithium-ion cell manufacturing in North America continues to grow. Quebec should realize its natural resource potential, and its companies should integrate with jurisdictions with complementary steps in LIB supply chains.
- South Korea & Japan** Stop funding research on lithium extraction from seawater and help develop more domestic concentrate conversion from brines or spodumene. It is highly unlikely that the ocean will be an economic source of lithium chemicals, and Korean and Japanese cathode manufacturers need those chemicals now. South Korea and Japan should take a complementary approach to Australia and Chile.
- Alberta** Support getting at least one unique oilfield lithium project built and help find off-takers for the lithium chemicals. The province's history of natural resource development will facilitate a positive transition from oil to lithium. Alberta should emulate Chile or Australia's supply chain participation. Cathode & EV manufacturing in Ontario could be a good match, since the US may integrate less with the rest of North America.
- Sweden** Support Northvolt's plans as part of an integrated European approach to cathode, cell, and EV manufacturing. Northvolt should vertically integrate its supply chain in a similar step-wise approach to Ganfeng, but from a different starting place. Similarly, Europe should develop its own natural resources and/or build concentrate conversion capacity. Sweden should continue developing its capability in the middle of the European LIB supply chain and expand upstream over time.



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