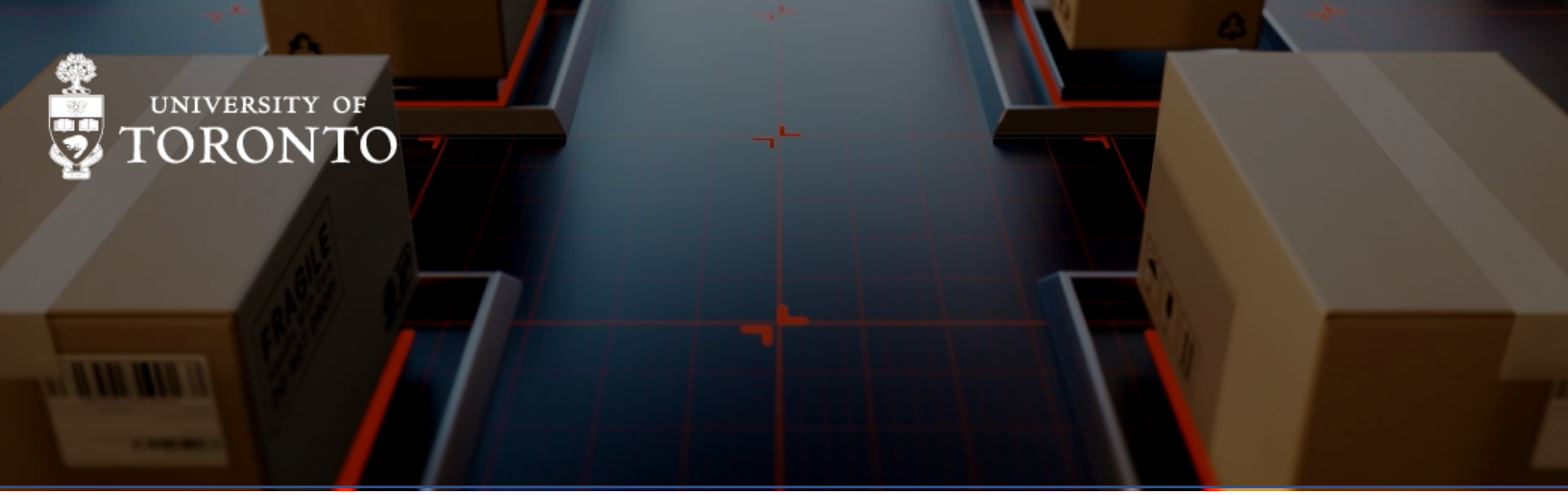

Supply Chain and Operations for EV Battery Production:

North America Perspective

APS 1028 – Project Report

Team 2

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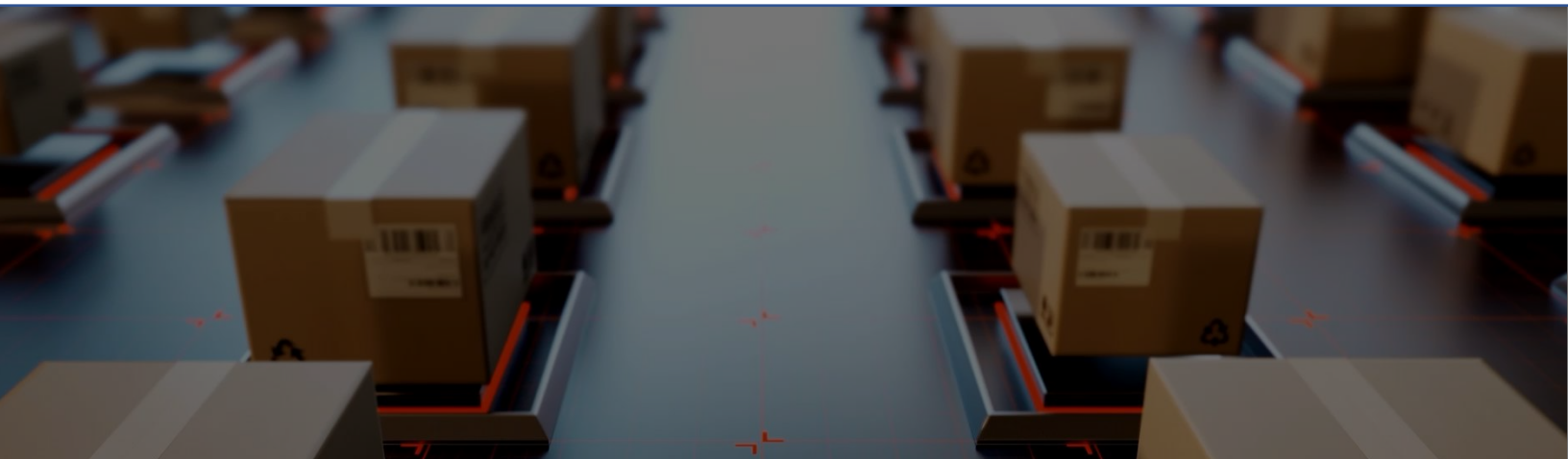

Executive Summary

The North American EV industry is rapidly expanding, and EV battery production is a critical component of the supply chain. This project investigated the structure of the EV battery supply chain and evaluated the operations of major North American EV battery manufacturers. The goal was to develop an operations strategy that would optimize the supply chain and meet the industry's future demands.

After analyzing the value chain and conducting industry-specific case studies, a comprehensive strategy for optimizing the North American EV battery industry was developed. Investing in R&D, infrastructure, diversifying raw materials, developing a sustainable business model, improving the supply chain, and increasing the skilled labor force are all part of the strategy. The overall goal is to optimize operations throughout the EV value chain by securing raw material access, supporting domestic industry growth, stimulating manufacturing sectors, and facilitating end-of-life reuse and critical material recycling. Circular growth is a promising strategy for the EV battery industry, with the potential to increase domestic raw and processed material supply, reduce waste, and benefit the environment. The next steps will be to conduct additional research, develop federal policies to encourage sustainable practices, and establish a multinational spending pool.

We also suggested the next steps for the EV industry in North America. Three key next steps are recommended for EV battery manufacturers. To begin, case studies on critical materials such as nickel, cobalt, and graphite are being researched to ensure their sustainable sourcing, production, and recycling to support circular growth in the industry. Second, by encouraging the use of recycled materials, sustainable mining practices, and the development of new recycling technologies, the federal government can incentivize all sectors of the value chain to promote sustainability.

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1. Project Charter

1.1 Description

The overall objective of this project is to provide a comprehensive analysis of the EV battery supply chain operations and offer strategic recommendations to North American manufacturers aiming to enhance their market share. Our recommendations will be based on extensive research and analysis of industry trends and future demands to help manufacturers develop effective operations strategies to meet the evolving needs of the market.

1.2 Scope

Within Scope:

- Supply Chain Operations of EV Battery in North America
- EV Battery Production Process **Extraction – Processing – Assembly**
- Environmental consequences and policies related to EV Battery
- Sustainable development opportunities for EV Battery **Recycling**
- Newer battery technologies for EV battery in Recycling

Out of Scope

- Different battery chemistries
- Cell and Pack design
- Mining process plan and Raw Material extraction methods
- Scientific technicalities of raw material ore processing
- Processing plant design

1.3 Objectives

Research and analyzes the EV battery supply chain operations to identify opportunities to meet future demands of the industry and recommend operations strategy for North American manufacturers.

- Examine and describe the structure of the EV battery supply chain.
- Investigate and evaluate the operations of the major EV battery manufacturers in North America.
- Determine the opportunities to optimize the supply chain to meet future demands for EV batteries.
- Develop Operations Strategy based on identified Key Performance Indicators (KPIs).
- Conduct SWOT and analyze pros and cons of the proposed operation strategy.
- Evaluate the next steps for EV battery manufacturers in North America.

1.4 Team Members and Roles

Member	Role	Main Responsibility
Mandeep Malhotra	Team Coordinator, Communications Liaison	Responsible for the final presentation and report development, monitoring, and compilation of project activities. Create an operations strategy in accordance with the manufacture of EV batteries.
Arshia Ghasemi	Research Analyst	Research, operations, and production activities of EV batteries in North America
Sahand Fazli	Strategy Analyst	Lead the project reports, finer elements of the presentation, and EV battery operations research.
Srikanth Ranganathan	Research Analyst	Performing deep research on case studies defined within the scope of operations and production management
Jitesh Jodhani	Research Analyst	Responsible for compiling the team portfolio, maintaining internal team communications, and researching relevant case studies.

2. Industry Background

The EV industry in North America is rapidly growing, driven by the increasing demand for electric vehicles. Major players in the industry include Tesla, General Motors, and Ford. The North American EV battery market size was valued at USD 7.2 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 21.4% from 2022 to 2030 [1]. Trends show growth in investment and innovation of the supply chain and EV Cell production in the North American market. The future growth of the industry is expected to be fueled by advancements in battery technology, government incentives, and the shift towards clean energy.

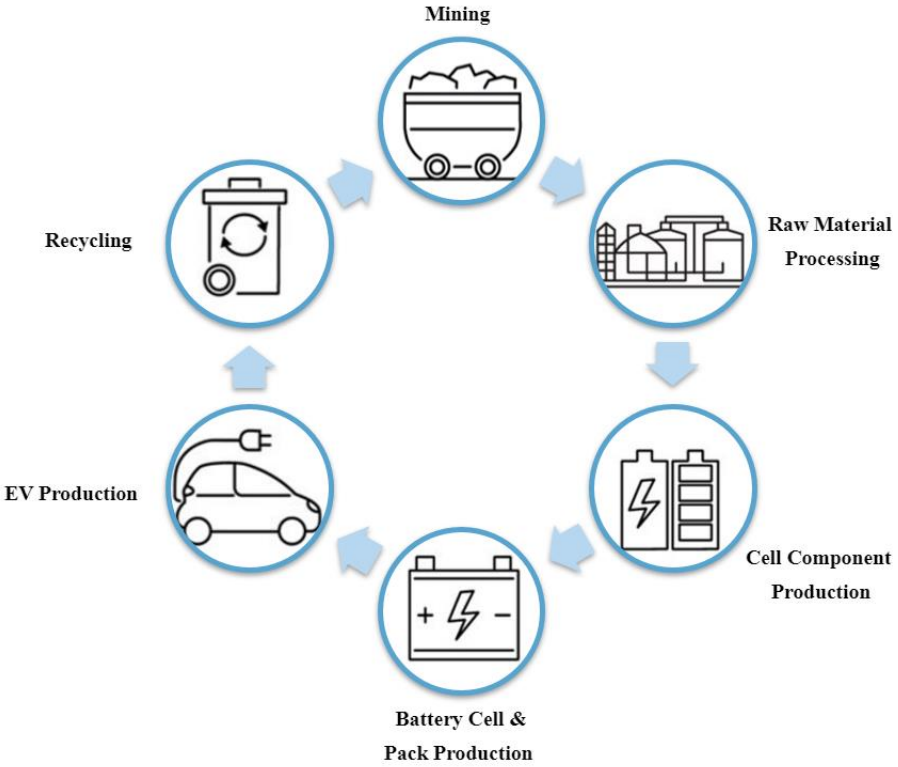


Figure 1: EV Battery Life Cycle

3. Research

3.1 Lithium Supply Chain: Mining and Processing

3.1.1 Raw Material Mining and Processing

Lithium mining and processing are essential to produce lithium-ion batteries, which are used in many electronic devices, including electric vehicles. Lithium is primarily extracted from brines and hard rock ores, and the processing involves several steps to produce high-purity lithium carbonate or hydroxide. The mining and processing of lithium can have significant environmental impacts, such as water scarcity, soil contamination, and greenhouse gas emissions, which need to be mitigated through sustainable practices. Therefore, developing a secure and sustainable supply chain for lithium is crucial for the future of clean energy and the transition to a low-carbon economy.

The most common combination for a lithium-ion battery is Lithium Cobalt Oxide as the cathode and Graphite as the anode, with various other materials making up the remainder. Three critical materials for EV batteries are Lithium, Cobalt, and Nickel, but our project will only focus on Lithium. Specifically, we aim to develop a strategy for securely sourcing the critical raw material of Lithium by refining our scope to the mining and processing of this element.

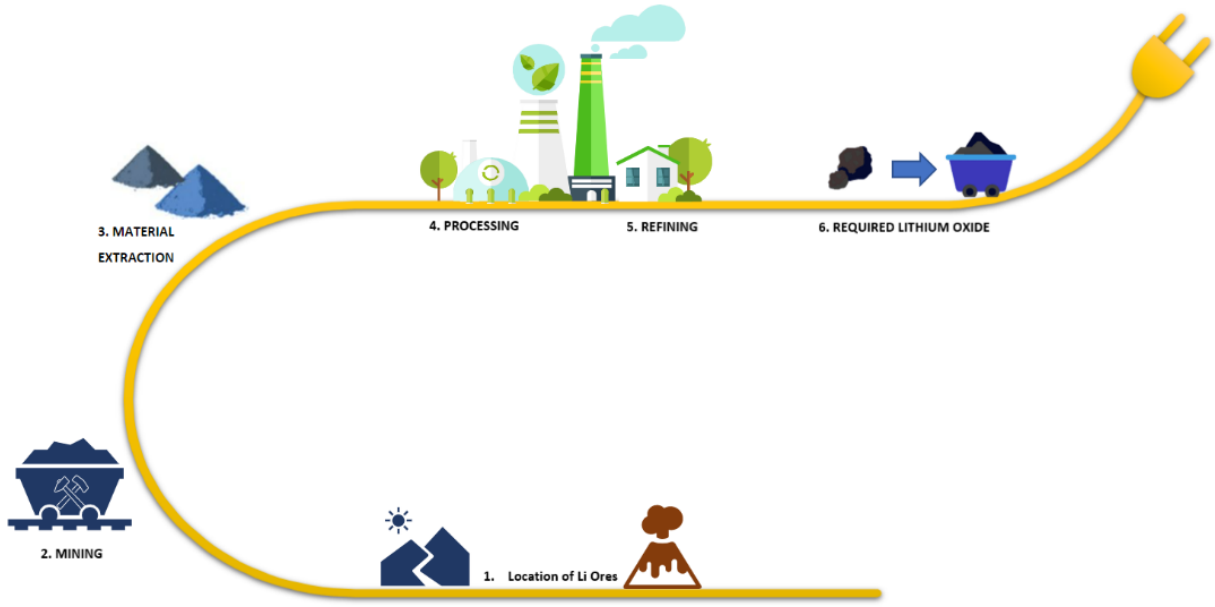


Fig 2. Raw Materials Pipeline for EV Batteries.

3.1.2 World and North American Perspective

- **North America Perspective**

The North American perspective on lithium mining and processing is complex, with various stakeholders expressing different viewpoints. On the one hand, there is significant interest in developing domestic sources of lithium to reduce dependence on imports and to support the growing demand for lithium-ion batteries used in electric vehicles and renewable energy storage

systems. However, there are also concerns about the environmental impact of lithium mining and processing, particularly in terms of water usage and contamination, as well as the social impact on communities living near mining operations.

Proponents of lithium mining and processing argue that environmental impacts can be minimized using advanced technologies and sustainable practices. For example, some companies are exploring the use of direct lithium extraction (DLE) methods that can significantly reduce water usage compared to traditional mining methods. Additionally, companies are working to establish partnerships with local communities to address concerns about employment opportunities, environmental impacts, and cultural heritage preservation.

Opponents of lithium mining and processing argue that the environmental and social impacts are too great to justify its development, particularly given the availability of alternatives such as recycling and the use of other battery chemistries. They argue that mining can have long-lasting and irreversible impacts on ecosystems, water resources, and the health of local communities and that these impacts disproportionately affect marginalized and Indigenous communities. They also point to the high energy and carbon footprint associated with lithium production, particularly in regions with coal-powered electricity grids.

- **World Perspective**

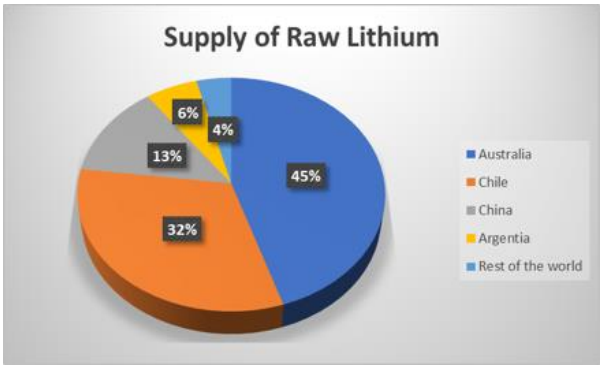


Fig 3. Lithium Supply in the World

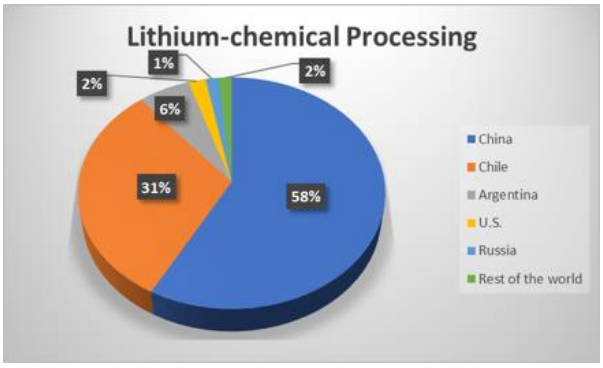


Fig. 4 Lithium Ore Processing in the World

Lithium is a crucial element in the production of batteries that power electric vehicles and portable devices. Australia and Chile hold over three-quarters of the world's extractable Lithium reserves, with China and Argentina also having significant reserves. The processing of Lithium into usable forms has been monopolized by China and Chinese companies, with about 58% of the world's Lithium being processed by them. Chile processes about 31% of the world's Lithium [5].

China's dominance in Lithium processing is due to its ability to produce Lithium-ion batteries at a lower cost than other countries, making it a leader in the EV industry. Other countries like the US, Canada, and Australia have started investing in Lithium mining and processing projects to reduce their dependence on China.

In conclusion, the demand for Lithium is expected to grow as the production of EVs and portable devices increases. While Australia and Chile have the majority of extractable Lithium reserves, China and Chinese companies dominate the Lithium processing industry. However, with more investments in the Lithium industry, the balance of power may shift in the future.

3.1.3 Case Study 1: Mining and Extraction

The Lithium chemical mining market in North America lags behind the rest of the world, with very low operational output. However, there are ongoing case studies aimed at improving the situation. In this slide, we will take a closer look at these case studies and their potential impact on the Lithium market in North America.

- **Business Issue:**

According to recent studies, North America has approximately 1,280,000 metric tons (MT) of Lithium deposits, which amounts to roughly 6.2% of the world's deposits [4][5][6]. However, the current operational output of Lithium mining in North America is low, with only around 5,000 MT of Lithium being mined annually from the Silver Peak Mine [7].

Furthermore, although there are two known Lithium deposits in North America, namely the Thacker Pass, and Tin-Spodumene, they are not yet operational and are still under development.

Another major issue facing the Lithium market in North America is the lack of secure access to Lithium chemicals for North American companies. This lack of secure access to Lithium chemicals can hinder the growth of Lithium mining and processing industries in North America, which may impact the region's ability to meet the increasing demand for Lithium in the global market.

- **Business Opportunity:**

The demand for Lithium in North America is expected to increase significantly due to the growing production of electric vehicles (EVs). In the US alone, it is projected that around 360,000 metric tons (MT) of Lithium will be required by 2050 to meet the demands for EVs [8].

Moreover, there is a business need for secure access to raw materials in the domestic supply chain for Lithium-ion EV batteries in North America. This would enable the region to reduce its dependence on foreign sources for Lithium chemicals, which can improve the stability and security of the supply chain.

To achieve this, efforts are being made to enable domestic mining operations in North America. Albemarle, which currently operates the Silver Peak Lithium mine, plans to increase its output to 10,000 MT [7][3]. Lithium Americas also has plans to mine 35,000 MT of Lithium at the Thacker Pass Lithium Mine [9]. These developments may help to increase the operational output of Lithium mining in North America and improve the region's ability to meet the growing demand for Lithium in the global market.

- **Value Creation:**

The mining of Lithium is a critical aspect of the electric vehicle (EV) battery value chain, as it is a key component of Lithium-ion batteries. The operation of the Thacker Pass in Nevada, along with the Silver Peak Lithium Mine, is expected to produce approximately 100,000 metric tons per annum (TPA) of Lithium Carbonate Equivalent (LCE) [9][10].

In-house mining operations can help reduce the cost of production of Lithium chemicals, which can benefit the domestic manufacturing sector. This can also improve the market share of North America in the EV battery value chain.

Domestic mining of Lithium can also enable secure access to the critical raw material, which can reduce the region's dependence on foreign sources for Lithium chemicals. This can help to improve the stability and security of the supply chain, while also supporting the growth of Lithium mining and processing industries in North America. These developments may ultimately help the region meet the growing demand for Lithium in the global market.

3.1.4 Case Study 2: Lithium Processing

The lack of processing of Lithium chemicals in North America has resulted in a limited supply of raw materials for electric vehicle (EV) battery manufacturing, which can pose significant challenges to the region's EV industry. To address this issue, several organizations are working on implementing processing plants in North America. In this slide, we will examine some case studies that are aimed at improving the region's ability to process Lithium chemicals and support the growth of the EV battery sector.

- **Business Issue:**

North America faces a significant challenge in that only 1% of Lithium is processed and produced domestically, amounting to approximately 1000 MT per year. In contrast, about 79% of the world's Lithium is processed in China [4]. The lack of infrastructure, resources, and support for domestic processing in North America means that companies in the region are heavily dependent on importing Lithium. However, strict regulations due to environmental hazards associated with Lithium processing have limited domestic processing.

As a result, the USA alone imports over 2500 MT of Lithium Carbonate Equivalents (LCEs) each year, incurring an expenditure of over $80 Million. The high import costs and dependence on foreign supplies of Lithium pose a significant challenge for the region's EV battery sector, necessitating the establishment of local processing facilities to ensure a reliable and secure supply of Lithium for Battery Manufacturing [4][8].

- **Business Opportunity:**

Piedmont Lithium's initiative to enable the domestic processing of lithium in North America is expected to have a significant impact on the lithium market. Piedmont has invested $58 million in a project to process 30,000 MT of lithium annually at the Tin-Spodumene belt in North Carolina. This move is expected to reduce North America's dependence on imported lithium and provide secure access to raw materials for lithium-ion battery manufacturing [11].

Piedmont has also partnered with Atlantic Lithium to provide spodumene concentrate for the domestic processing of lithium hydroxide at Tennessee Lithium. The location of Tennessee Lithium offers several benefits, including proximity to customers, reduced transportation distances, and excellent infrastructure, including rail, road, and river transportation. The project is expected to boost the domestic lithium processing industry in North America, create job opportunities, and provide a sustainable source of lithium for the lithium-ion battery sector [11].

- **Value Creation:**

The establishment of domestic processing plants for Lithium oxide in North America will reduce the region's dependence on imports from China, the dominant market. Government initiatives aimed at accelerating the domestic processing of raw materials for EV batteries include tax credits and incentives. Vertical integration of critical material processing enables control over costs and supply chain disruptions to ensure quality control.

With such initiatives, there will be more control over costs and the supply chain, reducing the likelihood of disruptions. The initiatives will help to maintain quality control and produce better products. This move will enable North America to play a more significant role in the global EV battery value chain.

3.2 Lithium Supply Chain: Cell Production

3.2.1 Cell Production Process

The cell production process includes cell manufacturing, pack assembly. The cells are made of several components like the anode (graphite or silicon-based materials), the cathode (Lithium cobalt oxide, Lithium iron phosphate, Nickel Manganese Cobalt (NMC) oxide), the electrolyte (lithium salt (such as LiPF6), ethylene carbonate or dimethyl carbonate), the separator, the current collectors, and the housing or casing. The cell manufacturing process involves assembling individual battery cells into larger modules assembled into battery packs. The battery packs are then installed in the EVs (Electric vehicles) during the final assembly process.

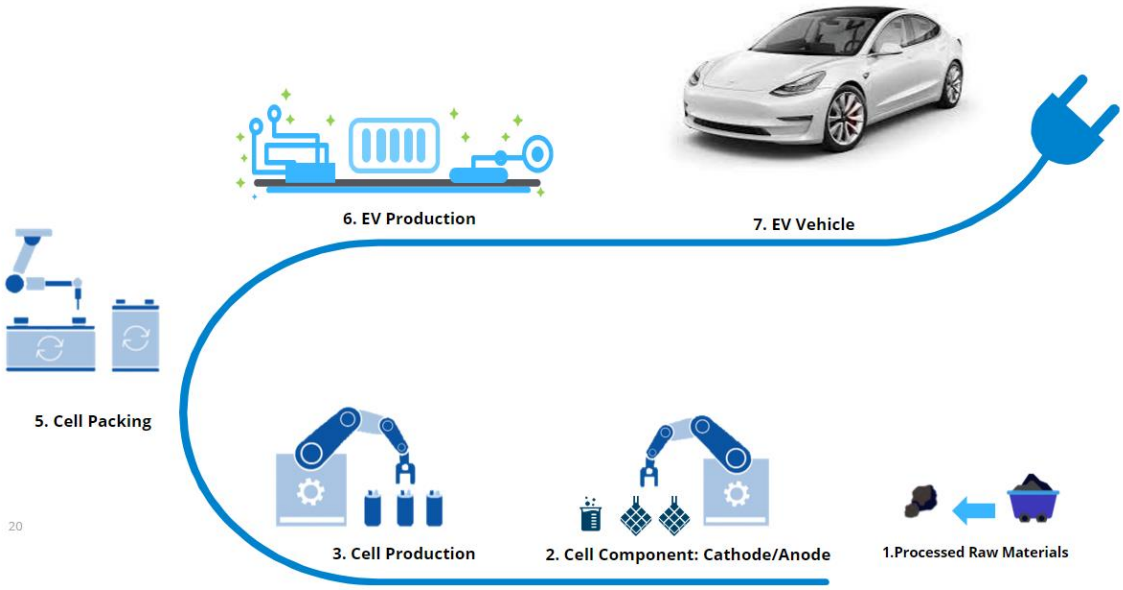


Figure 5: Cell Production Process

3.2.2 North American and World Perspective

- **North America Perspective**

The production of battery cell components in North America is limited compared to other regions, such as Asia and Europe. However, several companies produce battery components in North America, including Tesla, General Motors, and Panasonic. These companies primarily produce batteries for electric vehicles and energy storage systems. The United States is North America's largest market for electric vehicles, with an estimated 1,369,611 electric vehicles sold in 2021 [12].

The production of electric vehicle (EV) batteries and their components in North America is relatively limited compared to other regions, particularly China. However, there are some companies and facilities in North America that are involved in the production of these components. Here are some estimates for producing key EV battery components in North America:

- Cathodes: Currently, there are a limited number of cathode production facilities in North America. However, some companies are making significant investments in this area, including Tesla and GM, are planning to develop new cathode production facilities in the United States [24]. Providing an exact percentage of cathode production in North America is difficult, as the market is still developing.
- Anodes: Several companies in North America are involved in anode production for EV batteries, including Tesla and Livent. However, the majority of anode production capacity is still located in Asia. North America is estimated to account for less than 1% of global anode production [13].

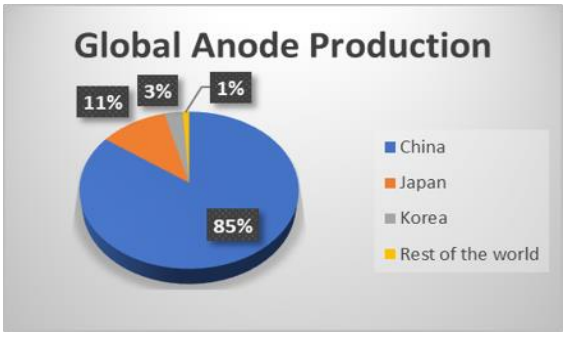
- Electrolytes and Separators: A few companies in North America are involved in producing electrolytes and separators for EV batteries, including 3M and Celgard. However, again, most of the production capacity for these components is still located in Asia.
- EV Battery Production: North America currently accounts for a relatively small percentage of global EV battery production, estimated to be less than 7% [13]. However, several companies, including Tesla and General Motors, are investing in new EV battery production facilities in the region, which could increase the percentage of production in the coming years [14].

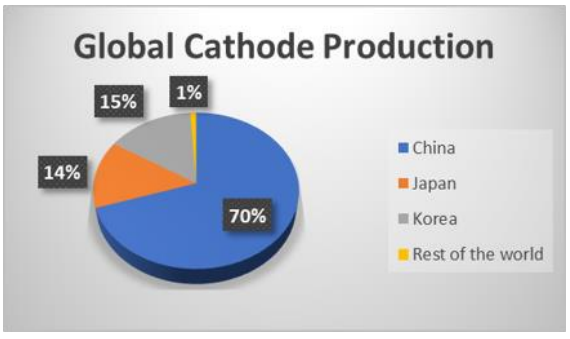
The Supply chain of EV batteries, the mining and processing are geography-based, even though US (United States). And Canada has some reserves to get started. These reserves are far from big enough to sustain the EV battery demand. So, North America will have to rely on strategic partnerships with countries like Australia, Democratic Republic of Congo, etc. But the downstream supply chain is somewhere the US can grow easily and is where it is focussed. Currently, the highlight in North America is the influx of funding and promotional government policies.

- **World Perspective**

The production of battery cell components is dominated by several countries in Asia, including China, Japan, and South Korea. These countries account for the majority of the world's lithium-ion battery production. Other countries, such as Germany and France, also have significant battery production capabilities comparable to that of The United States' capabilities.

The production of electric vehicle (EV) batteries involves several key components, including cathodes, anodes, electrolytes, separators, and other materials. Below are the graphs that represent the share of each of the key stakeholder countries that are responsible for the global cathode production, anode production, and EV battery production [13]:





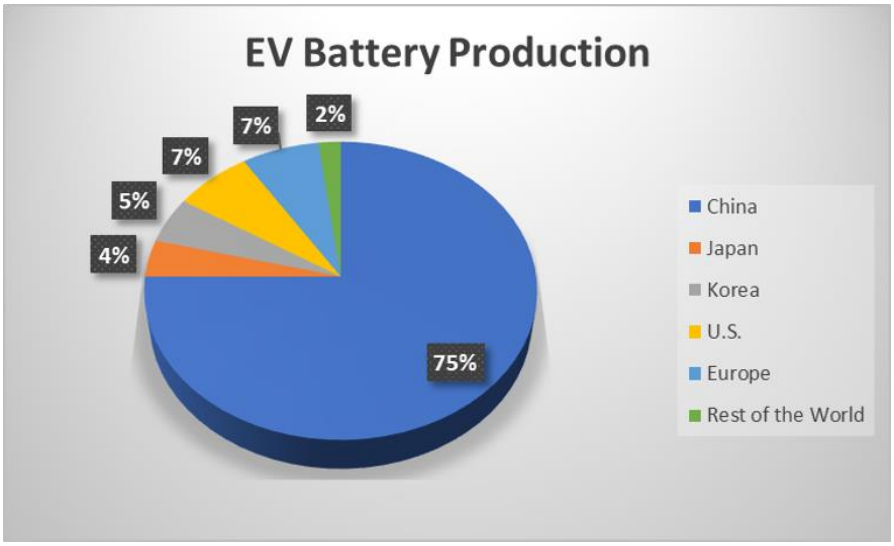


Figure 6: Global Cathode, Anode, and EV battery Production

3.2.3 Case Study 3: Tesla

Tesla is dominating the U.S. EV market, with a production of over 3,429,532 electric vehicles since 2018, of which 1,369,611 electric vehicles were made in 2022 [12]. Analysing Tesla's operations and business strategies will provide solutions for any company trying to grow their share of EV production and grow the North American Industry. Tesla has taken several actions to increase the production of electric vehicle (EV) batteries in North America.

Tesla directly gets processed materials and then handles the rest of the production process in-house, including cell manufacturing, pack assembly, and EV production. This means that Tesla has full control over the production process and can optimize it for efficiency and quality. By controlling the entire production process, Tesla can ensure that their batteries meet their high standards for performance and reliability.

Business Issues:

- Lack of Investment:

Tesla is not following in the footsteps of North America's Automobile Industry Giants and their lack of investment in the EV cell production. They are taking steps and investing globally in many different areas like Tesla's $3.6 Billion investment into its Nevada Plant, which will dedicated to producing EV Batteries for its semi-trucks [14].

- Supply Chain and Raw Material Dependence:

Starting in 2022 for a 3-year period Gangfeng Lithium will provide Tesla with processed raw Material [15]. But as tesla aims to shift to North American suppliers by making new partnerships like in January of 2023, Tesla struck a deal with Piedmont Lithium, a North American lithium producer, to provide it with 125,000 MT of spodumene concentrate by end of 2025 [15].

- Competition:

The EV market is becoming increasingly crowded, with established automakers such as General Motors, Ford, and Volkswagen investing heavily in EV production. This Competition puts pressure on Tesla to innovate and differentiate itself from competitors.

- Regulatory Issues:

As a new and disruptive technology, EVs are subject to a complex web of regulations and incentives that vary by region and country. Compliance with these regulations and securing the necessary permits and approvals can be challenging for EV manufacturers like Tesla.

Opportunities:

Tesla plans to increase its battery production by expanding its manufacturing capabilities and investing in innovative technologies. Here are some ways Tesla is planning to increase its production:

- Building new Gigafactories:

Tesla plans to build additional Gigafactories worldwide, including in Texas and Germany [25]. These factories will be dedicated to producing batteries and electric vehicles, significantly increasing Tesla's production capacity.

- Increasing automation:

Tesla is investing in automation technologies to streamline its production process and increase efficiency. This includes using advanced robotics and artificial intelligence to optimize manufacturing and reduce production time. Like its large investments and rollout of its 4680 Battery Automation Line [16]

- Improving battery technology:

Tesla is constantly improving its battery technology, which allows for greater energy density and longer range for its electric vehicles. By developing new battery chemistries and manufacturing processes, Tesla can increase the production capacity of its batteries and reduce costs. A great example is their investments in research labs like that of the Tesla Advanced Battery Research Lab located in Halifax, Canada that is working on batteries that can 100 years [17].

Overall, Tesla is leveraging its battery technology and manufacturing expertise to increase its production capacity and meet the growing demand for electric vehicles. By investing in new technologies and expanding its manufacturing capabilities, Tesla is well-positioned to continue leading the way in the EV market.

Value Creation:

The value creation of Tesla's in-house production and actions to increase battery production is multifaceted. Here are some of the key benefits:

- Reduced costs:

By vertically integrating its production process, Tesla can reduce costs by avoiding supply chain disruptions and ensuring quality control. In addition, by developing new battery chemistries and manufacturing processes, Tesla can increase the production capacity of its batteries and reduce costs.

- Increased production capacity:

Through building new Gigafactories and increasing automation, Tesla can significantly increase its production capacity, which is critical for meeting the growing demand for electric vehicles.

- Enhanced supply chain:

By expanding its supply chain and sourcing materials from North America, Tesla can reduce its dependence on foreign suppliers and ensure a steady supply of raw materials and components. like the deal with Piedmont Lithium, a North American lithium producer, that will provide Tesla with 125,000 MT of spodumene concentrate by end of 2025 [15].

Tesla's in-house production and actions to increase battery production can lead to increased efficiency, reduced costs, improved technology, and a more sustainable future. These benefits can help Tesla maintain its position as a leader in the electric vehicle market and attract more consumers to its products.

3.3 Lithium Supply Chain: Recycling

According to the International Energy Agency (IEA) [18], approximately 13 million electric cars have been sold worldwide in the last decade. EVs are popular due to their environmental benefits and lower costs. However, disposing of EV batteries generates electronic waste. EV battery recycling is a solution that recovers valuable materials and reduces costs. Recycling involves disassembling the battery pack and reusing metals like lithium, cobalt, and nickel. The demand for EV battery recycling is expected to increase significantly as the number of EVs on the road grows, with approximately 145 million expected by 2030.

3.3.1 EV Battery Recycling Process

Only 5% of the world's lithium-ion batteries are thought to be recycled today [26], with severe environmental and financial consequences for the projected 8 million tons of waste. While the challenges of recycling will range from financial to policy, the scientific challenges and emerging research landscape surrounding this enormous opportunity for North America.

Recycling EV batteries entails disassembling the battery pack and separating its components, which include metals such as lithium, cobalt, and nickel. Battery sorting, crushing, chemical treatment, separation, purification, and recycling are all part of the recycling process. Battery sorting classifies batteries based on their type, size, and chemistry. According to the IEA, over 3 million EVs were on the road in 2017, with a total of 125 million expected by 2030. [18].

The second step in the recycling process is battery crushing, which involves crushing the battery pack into small pieces that can be easily separated into their various components. This

contributes to the materials being recovered efficiently and effectively. According to Bloomberg NEF, 13 million electric cars were sold globally in the last decade, with the average life of an EV battery in a vehicle being 10 years [23].

Chemical treatment is used in the third step of EV battery recycling to extract metals from battery components. This can be accomplished through hydrometallurgical processes in which metals are dissolved in acid or base solutions, or pyrometallurgical processes in which metals are melted at high temperatures. According to a US Department of Energy report, recycling one million EV batteries can result in 100,000 tons of lithium-ion batteries containing valuable metals such as cobalt, nickel, and lithium.[27].

The fourth step in the recycling process is separation and purification, which involves separating and purifying the metals using various techniques such as filtration, precipitation, and electrolysis. According to the International Energy Agency, the demand for lithium and cobalt is expected to rise significantly in the coming years, and recycling these materials can help meet this demand while reducing waste and cost [18]. The final step in the process is recycling, which involves selling the purified metals to manufacturers who will use them to make new batteries or other products.

3.3.2 Case Study 4: Li-Cycle

Li-Cycle Holding Corp, a Canadian Startup, has created a 95% efficient sustainable recycling solution for EV batteries. Their closed-loop process recovers between 80 and 100 percent of all materials, including lithium, cobalt, nickel, copper, and aluminium. Li-Cycle is dedicated to reducing its environmental impact and has formed alliances with EV manufacturers. As the demand for EVs grows, so will the need for sustainable and efficient battery recycling solutions. The solution developed by Li-Cycle is a game changer in the industry.

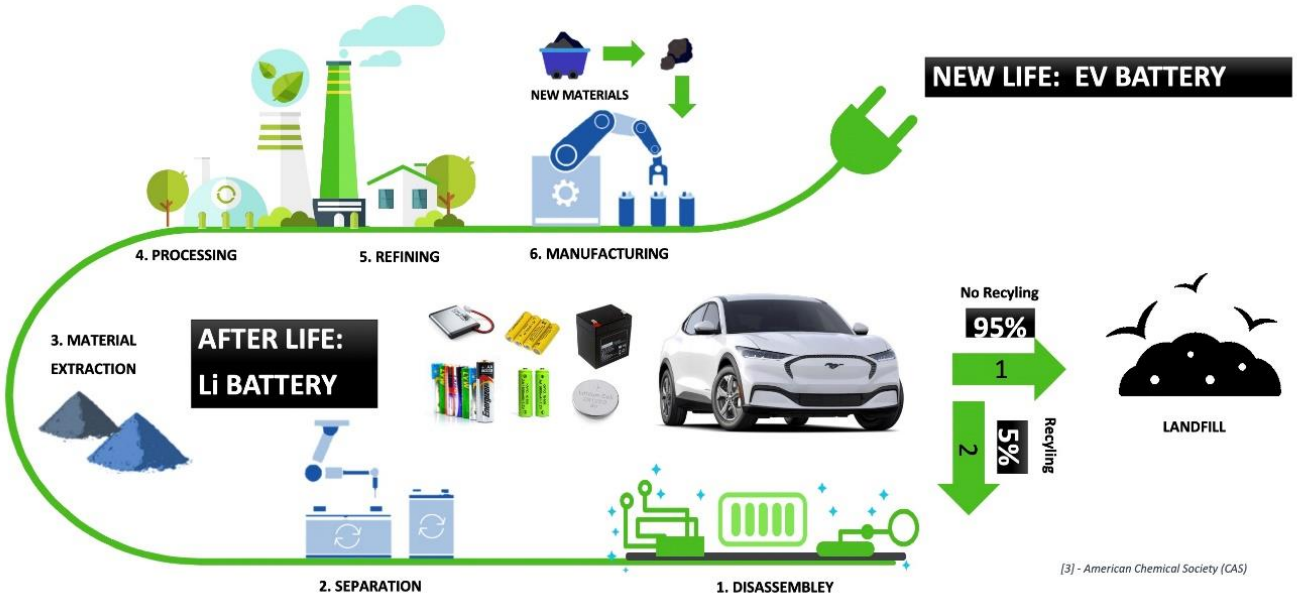


Figure 7: EV Battery Recycling Proces

- **Business Issue**

North America's electric vehicle (EV) market is rapidly expanding, with the region expected to account for 60% of the global market by 2035 [19]. In 2021, there will be over 303,000 EVs on the road in Canada, indicating a significant increase in demand for electric vehicles [20]. Due to foreign competition from dominant battery market countries such as China, Japan, and Korea, raw material procurement becomes a challenge for North American companies as EV demand grows. Long-term solutions are required in North America due to environmental risks and limited supply. EV battery recycling can help reduce reliance on imports and promote sustainable practices. Companies such as Li-Cycle Holding Corp are leading the way in sustainable solutions, recovering up to 95% of all battery materials through a closed-loop process.

- **Business Opportunity**

Li-Cycle Holding Corp and other battery recycling companies have a significant business opportunity in North America due to the low recycling rate of Li-ion batteries. Currently, only 5% of Li-ion batteries are recycled in North America, with the remainder ending up in landfills or incinerators. However, Li-ion batteries are 100% recyclable, presenting a huge potential for the recovery of valuable materials. Companies offering high-efficiency recycling solutions can capitalize on this opportunity by providing a cost-effective and sustainable method for recycling Li-ion batteries.

Process Innovation of Li-cycle- Typically, the traditional EV battery recycling process recovers only 50 to 60% of the raw materials. Li-Cycle's innovative process, on the other hand, can recover up to 95% of the materials from EV batteries [21]. This is accomplished through a patented combination of mechanical and hydrometallurgical technologies that allows for greater material recovery.

- **Value Creation**

Li-Cycle's innovative recycling solution not only reduces the environmental impact of EV battery waste, but it also adds value in a variety of ways. To begin, the company has established in-house production with four operational spokes and hub plants in North America, giving them a processing capacity of 30,000 tonnes per year, or roughly 60,000 EVs.

Second, Li-Cycle's recycling solution aligns with the growing business demand for environmentally friendly practices in the automotive industry. According to Grand View Research, the North American EV battery recycling market is expected to reach $265.08 million by 2028, with a 19.1% CAGR. [19]

Third, by reducing the use of new materials and emissions, Li-Cycle's recycling solution helps to reduce the environmental impact of battery waste. Their closed-loop process reduces energy use by 82%, water use by 77%, and harmful emissions by 91%.

Finally, Li-Cycle's recycling solution contributes to a 40% reduction in production costs [22]. The company can reduce the need for expensive new materials and lower overall production costs by recovering and reusing valuable materials from EV batteries.

4. SWOT Analysis

SWOT analysis is a strategic planning tool that is used to identify and analyze the Strengths, Weaknesses, Opportunities, and Threats of an organization, project, or individual.

The acronym SWOT stands for:

• Strengths: Internal factors that give an organization an advantage over others.

• Weaknesses: Internal factors that put an organization at a disadvantage compared to others.

• Opportunities: External factors that can be exploited by an organization to its advantage.

• Threats: External factors that can negatively impact an organization.

SWOT analysis is used by businesses to evaluate their current position and to develop a strategy for the future. It is also used by individuals to assess their strengths and weaknesses and to identify opportunities for personal growth and development.

4.1 Strengths

I. Natural Resource Access:
   - North America's biggest strength is the availability of Lithium Deposits of about 1,280,000 MT.
   - Increase in production plants from the growth in demand

II. Strong Trade Partnerships:
   - North American EV Battery producers are increasing partnerships with North American Lithium Miners and Processors.
   - As the global demand for EV batteries grows, North American producers can expand their operations and partner with international companies to tap into new markets.

III. Investments in Research & Development:
   - Strong innovations in the operations in the manufacturing and extraction processes.
   - Investing in finding innovative technologies for automation and battery technology.

IV. Market Leading EV Manufacturers:
   - Established companies with pedigree shifting to EV's.

V. Growth in Demand:
   - Growing Demand for EV's from the consumer and goal for governments to shift to meet carbon emission goals
   - Building new Gigafactories to meet the growing demand across North America

VI. Skilled Labour:
   - Increase the skilled labor force of North America
   - Collaborating with universities to create programs and courses to teach future generations with the necessary skills required for the growth in this industry

4.2 Weaknesses

I. Limited Supply Chain:

- Most of the lithium used is imported from countries like China, Korea, Japan.

II. Higher Labour Cost:
   - North America has a higher minimum wage than competing countries which will result in higher costs.

III. Lack of Infrastructure:
   - Lack of technical expertise for handling the raw materials as the North American industry is behind compared to Asian counterparts.
   - The infrastructure for EV battery recycling in North America is still developing and needs significant investment to keep up with the increasing demand for EV's.

IV. Less Investment:
   - North American companies are investing less compared to their counterparts.

V. Environmental Policies:
   - North Americas has strict environmental policies on dealing with the hazardous materials that make up EV batteries.
   - Companies need to invest more in finding cleaner production methods compared to their counterparts.
   - Strong backlash from local communities near mines and plants make it more difficult to manufacture in North America.

4.3 Opportunities

I. Creating new jobs:
   - Shifting skilled labor from other industries that are increasing in automation to the EV (Electric Vehicle) battery industry to help manufacturers meet the growing demand.

II. Growing EV Demand:
   - Growth in EV production means an increase in demand for raw materials for the batteries that North American suppliers can meet
   - By 2050 the USA alone requires 360,000 MT of LCE (Lithium Carbonate Equivalents) to meet its EV demands.

III. Increase Investments in R&D, and Infrastructure:
   - Investing in research and development can lead to the development of advanced battery technology, which can improve their competitive edge.
   - Investments in charging infrastructure, battery recycling, and renewable energy sources can further drive the growth of the EV market and increase demand for EV batteries.

IV. Government Support:
   - New Bills and Acts from the governments allows growth in this industry.
   - Collaboration between private and public sector allows a boost in the auto industry.

V. Major Player in Global Recycling Market:
   - North America is becoming a global leader and hub for producing EV batteries with recycled materials.

4.4 Threats

I. Foreign Competition:
   - Lower prices compared to what North American companies can offer, resulting in slower growth.
   - Foreign competition is larger and more well established and can better withstand volatility in the market.

II. Political Tensions:
   - With the rise in tensions between North America countries and other global powers like China, any escalation can lead to supply chain disruptions.

III. Foreign Control of North American Deposits:
   - Starting to see foreign companies from China investing in North American mines like seen in Australia and Chile.
   - A foreign power that is in a constant state of argument and tension with has control of vital resources important to the EV battery industry.

IV. Reliance on Government Incentives
   - North American manufacturers are excessively reliant on the incentives provided by the government.
   - If the incentives disappear the industry can crash, or cost of production will increase so much that it will not become viable for continuance.

5. Identified KPI's:

KPI stands for Key Performance Indicator. It is a metric, or a set of metrics used to measure the performance of an organization, a team, or an individual against specific goals or objectives. KPIs are used to evaluate how effectively an organization is achieving its strategic objectives.

KPIs can be quantitative or qualitative and they can be used to measure various aspects of performance such as productivity, profitability, customer satisfaction, employee satisfaction, quality, safety, and more. Examples of KPIs include revenue growth rate, customer retention rate, employee turnover rate, average order value, conversion rate, and net promoter score.

KPIs are typically set by management or stakeholders and are used to monitor progress towards achieving specific goals. They are an important tool for measuring performance, identifying areas for improvement, and making data-driven decisions.

I. Securing Independent Access to Raw Materials:
   - It can ensure sustainable and uninterrupted supply of materials for recycling. cost stability, reduced environmental risks, and increased competitiveness.

II. Cost Control:
   - Controlling the cost of producing raw materials, processed materials, EV cell components, and packing. By reducing and controlling the cost per unit, North American companies can increase profitability and competitiveness in the market.

- Reducing production costs or increasing the sale price of the EV will have positive effects on the industries yearly revenue.

III. Optimized Supply Chain:
   - Logistics and transportation costs are reduced as materials and components are not shipped from overseas and instead supplied by domestic producers.
   - How many strong key partnerships companies can create with North American or democratic countries that politically align with the North American region.

IV. Research & Development:
   - Increase in investments in R&D will have positive effect on North Americas competitiveness and allow companies to develop new products that meet customer needs.
   - Promote R&D to find new technologies and materials that can be used to create cheaper, more efficient, and more environmentally friendly EV batteries.

V. Plant Location:
   - Plan for future production plants to be closer to North American deposits to save on time and costs to get raw materials from ground to the production line.
   - Recycling plants in the major hubs for EV use and for its production to streamline future recycling.

VI. Government Support:
   - Boost the industry with support of incentivized programs.
   - Supporting the industry by improving supply chain infrastructure.

VII. Yearly Metric Tons Turnover:
   - Focusing on the production capacity of the raw material processing and EV cell production.

VIII. Enable Recycling:
   - Develop an industry wide federal policy for the use of recycled materials in EV battery production.
   - Promote use of recycled EV batteries in the future and people to upgrade less efficient older EV's for newer more efficient EV's.
   - Create plans for upgrading battery packs on older vehicles that are less efficient to new EV packs and recycling the old packs to create new packs.

6. Business and Operations Strategy

It is recommended that the North American EV battery industry invest more in R&D and infrastructure, collaborate with the public and private sectors, diversify raw material sources, and develop a sustainable business model. Improving the supply chain and increasing the skilled labour force are also critical for meeting the growing demand for EV batteries.

6.1 Strategy Development

Our overall strategy is to optimize operations across the EV value chain to ensure a reliable and sustainable supply for the battery manufacturer in North America. This will involve securing raw material access, supporting domestic industry growth, stimulating manufacturing sectors, and enabling end-of-life reuse and critical material recycling.

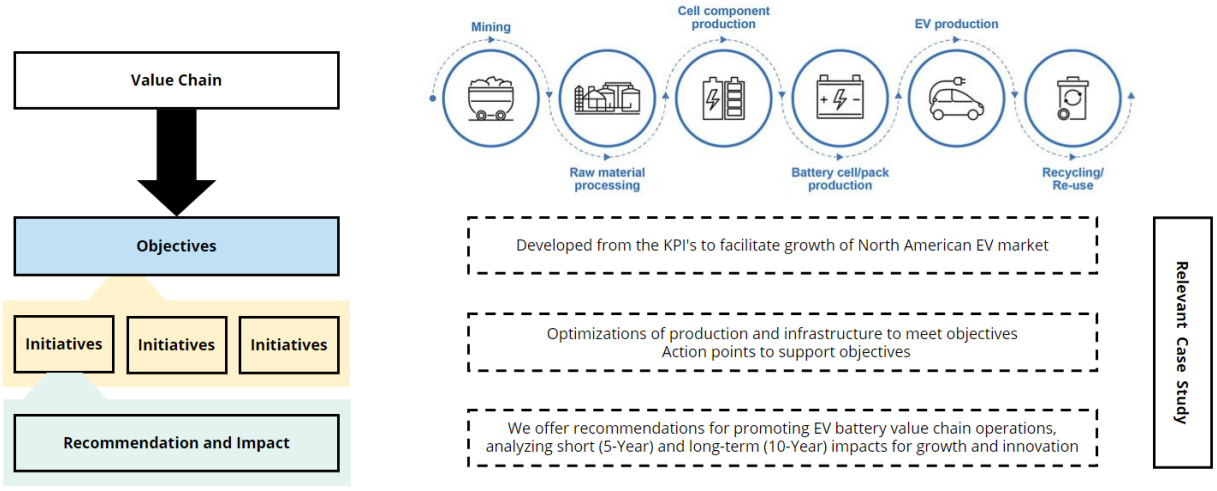
Develop a comprehensive strategy for EV battery value chain optimization, including mining, raw material extraction, cell and battery pack production, and recycling, for a reliable and sustainable supply for EV battery manufacturer in North America.

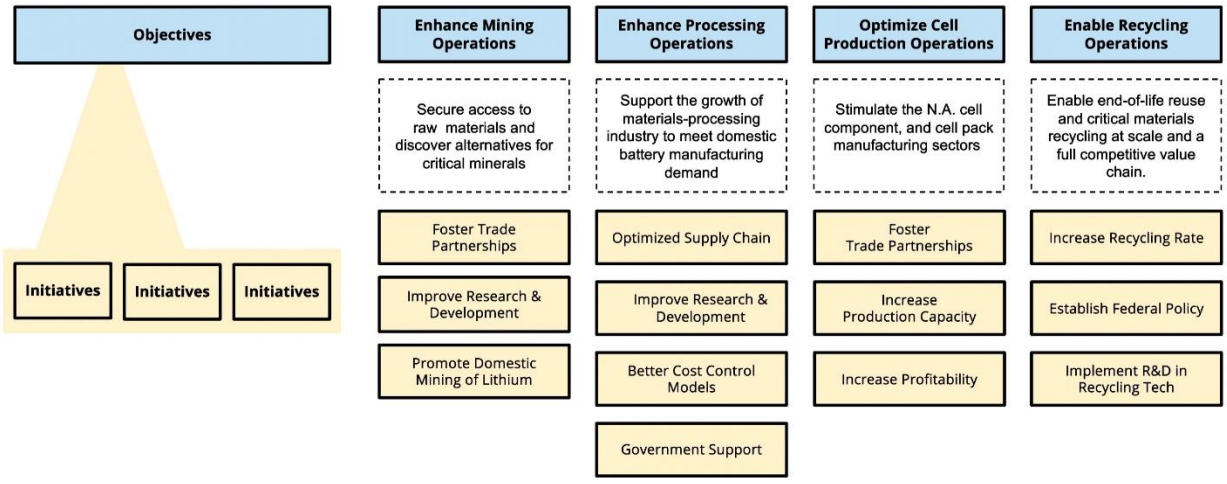
- **Strategy Development Concept**

For mining our strategy is centered around the improvement of the North American raw materials supply chain by improving and increasing the domestic mining operations and foster trade relationships with other nations and industries in the sector resulting in the amelioration of the material supply chain.

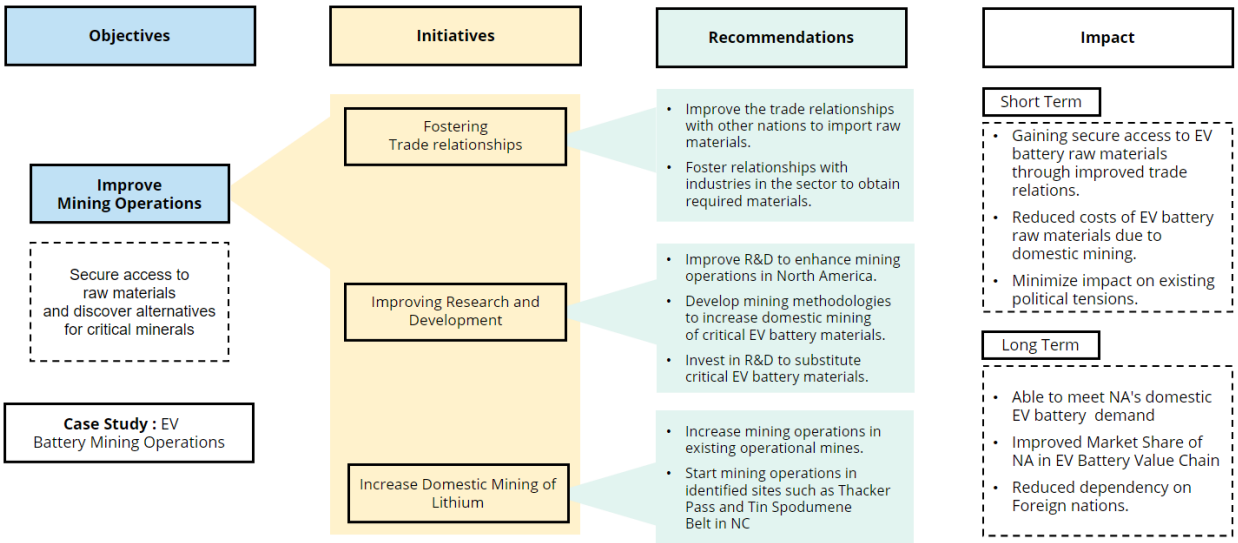
- **Strategic Objectives**

Optimize operations across the EV value chain to ensure a reliable and sustainable supply for the battery manufacturer in North America. This will involve securing raw material access, supporting domestic industry growth, stimulating manufacturing sectors, and enabling end-of-life reuse and critical material recycling.

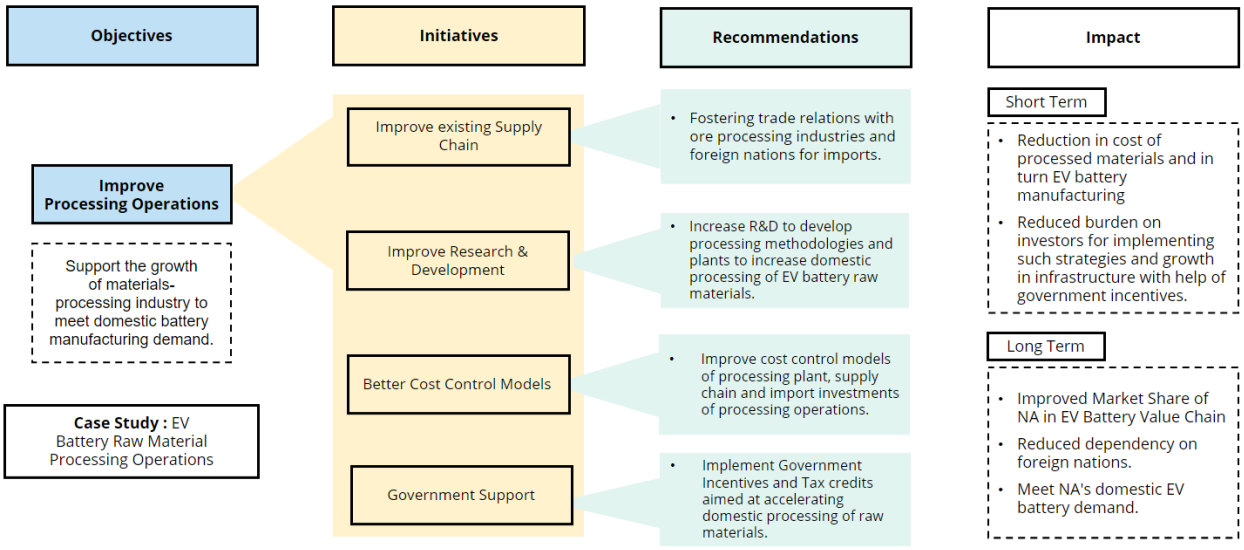




- **Enhance Mining Operations** - Secure access to raw materials and discover alternatives for critical minerals. Improve the North American raw materials supply chain by improving and increasing the domestic mining operations and foster trade relationships with other nations and industries in the sector resulting in the amelioration of the material supply chain.

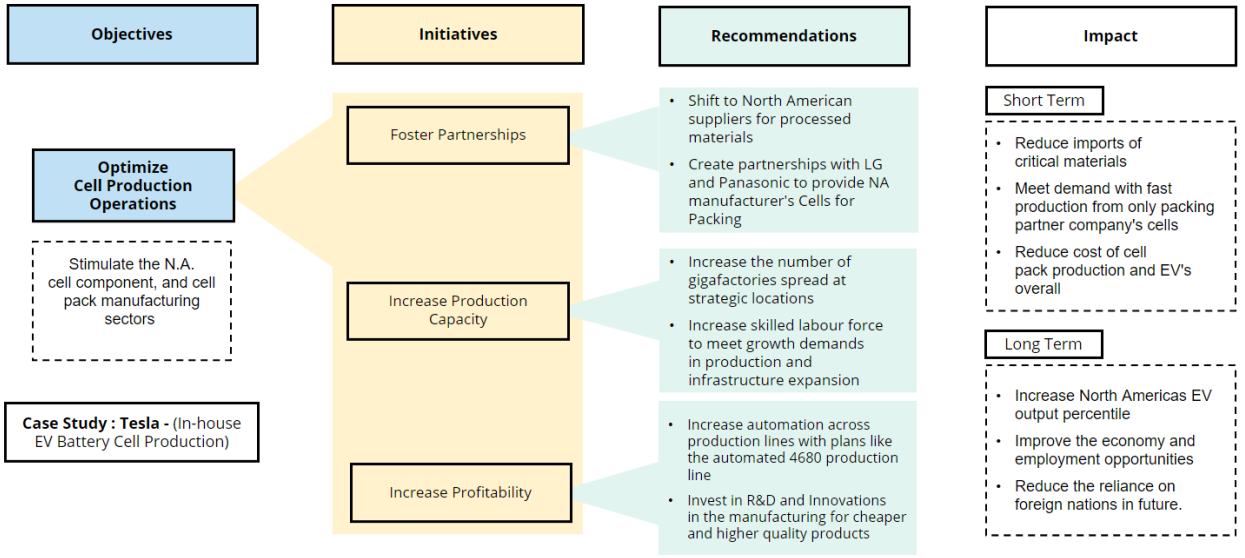


- **Enhance Processing Operations -** Support the growth of materials-processing industry to meet domestic battery manufacturing demand. For processing our strategy is centered around the enhancement of the EV battery raw material supply chain in North America through domestic processing enterprises, trading links with processing centers, and improved government backing.

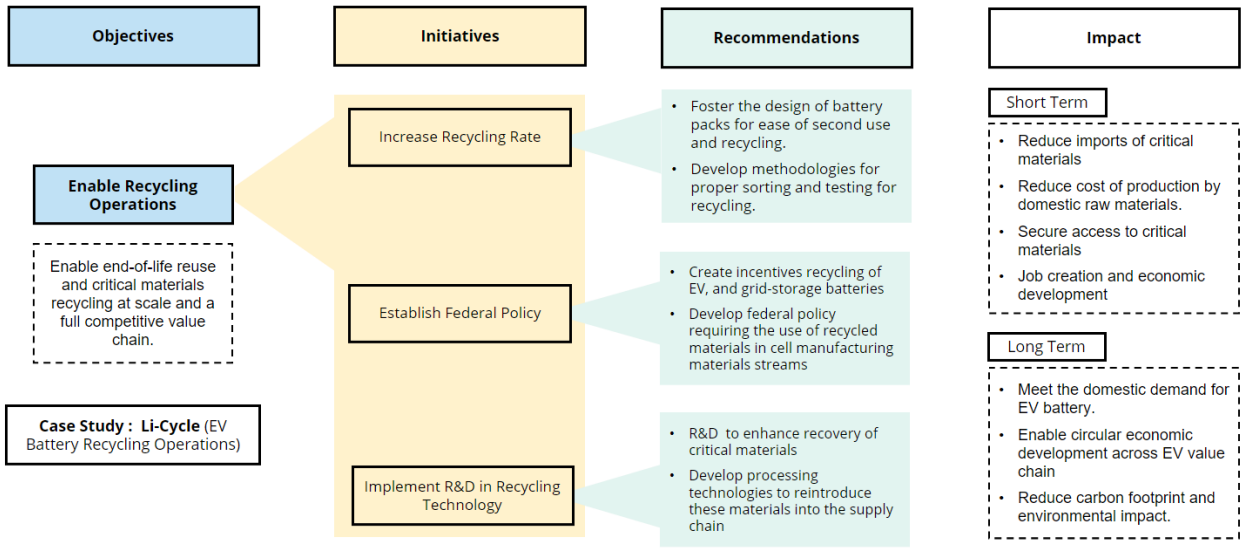


- **Optimize Cell Production Operations** - Expand the cell component and cell packing sector in North America by growing partnerships, improving the sectors production capacity and increase

the profit margins to incentivize manufacturers. For cell production our strategy is centered around the expansion of the cell component and cell packing sector in North America by growing partnerships, improving the sectors production capacity and increase the profit margins to incentivize manufacturers.



- **Enable Recycling Operations:** For recycling our strategy is centered around the enablement of the competitive and scaled end-of-life reuse and critical material recycling of lithium-ion cells in the North America by reducing transportation costs, developing better methods for second-use applications, and increasing recycling penetration into the commercial market for a domestic circular battery economy.



7. Conclusion:

Circular Growth Effect on Operations and Production of EV Battery

Circular growth is a production and operations approach that aims to create a closed-loop system with minimal waste and efficient resource use. This approach has significant potential for the electric vehicle (EV) battery industry, where raw materials and energy are in high demand. The increase in domestic raw material supply is one of the primary advantages of circular growth in the EV battery industry. Significant amounts of raw materials, such as lithium, cobalt, nickel, and manganese, are required to produce EV batteries. These materials have traditionally been sourced from abroad, resulting in a heavy reliance on imports. However, using the circular growth strategy, new deposits of these raw materials can be discovered and developed in the United States, providing a reliable and sustainable source.

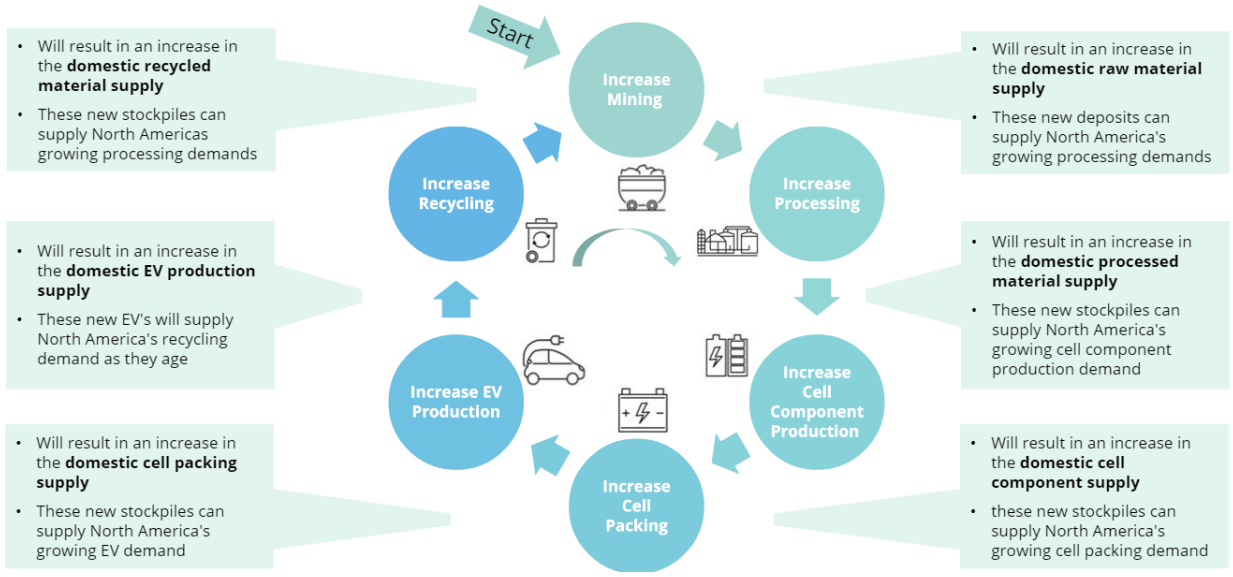


Figure 8: Steps to Increase EV Production

Circular growth can lead to an increase in domestic processed material supply in addition to an increase in raw material supply. The transformation of raw materials into usable components for EV batteries is an important step in the manufacturing process. As the number of EVs on the road grows, so will the demand for EV battery recycling. Circular growth can also contribute significantly to meeting this demand. As EVs reach the end of their useful life,

Furthermore, circular growth in the EV battery industry can benefit the environment. The method can help to reduce waste, energy consumption, and harmful emissions. Recycling can aid in the recovery of valuable materials, reducing the need for new mining operations and lowering the carbon footprint of EV battery production. The circular growth strategy for the EV battery industry is not without difficulties. Discovering and developing new domestic raw material deposits necessitates substantial investment and expertise. The transformation of raw materials

into usable components necessitates specialized knowledge and equipment. However, the potential benefits of circular growth, such as a reliable and sustainable source of materials, lower production costs, and a lower environmental impact, make it a worthwhile approach to pursue.

7.1 The Engineer General

The policies and strategies required to enable such a circular growth can greatly benefit from the help of an Engineer General. The Engineer General can advocate for and help bridge the gap between the industry and the policy makers and ensure that any new incentives or policies created aim to aid this industry. Not all government officials will have the required knowledge for making decisions regarding the operations and engineering of the EV battery industry. Thus, they can be aided by the person in this roll (The EG) and be guided to make decisions that can enable proper growth by providing appropriate funding at the right stage of the value chain.

8. Next Steps:

These are some of the recommendations for areas of research for anyone looking to expand their understanding on this topic:

1.) Research Case Studies about other critical materials such as Nickel, Cobalt and Graphite

In terms of the next steps in EV battery research, it is critical to look beyond lithium and consider other critical materials such as nickel, cobalt, and graphite. These materials are also important components in EV batteries, and their sustainable sourcing, production, and recycling are critical for the industry's overall circular growth.

2.) Create a federal policy framework to incentivize all the sectors of across value chain to promote circular growth.

To address this, a federal policy framework should be developed to incentivize all value chain sectors to promote circular growth. This includes policies that promote the use of recycled materials in battery production, encourage sustainable mining practices, and support the development of new recycling technologies. The industry can be incentivized to adopt more sustainable practices that benefit both parties by creating a regulatory environment that prioritizes sustainability.

3.) Create multinational spend plan for funding and research to develop new materials and manufacturing processes to meet EV battery demand.

Additionally, a multinational spend plan for funding and research should be developed to meet the increasing demand for EV batteries. This plan should prioritize the development of new materials and manufacturing processes that are more sustainable and efficient, reducing the need for raw materials and energy consumption. This can be achieved through collaboration between governments, private industry, and academia to fund research and development that promotes circular growth.

9. Timeline and Key Deliverables

A visual list of our project's tasks or activities organized in chronological order within the scope and schedule to accomplish the necessary deliverables.

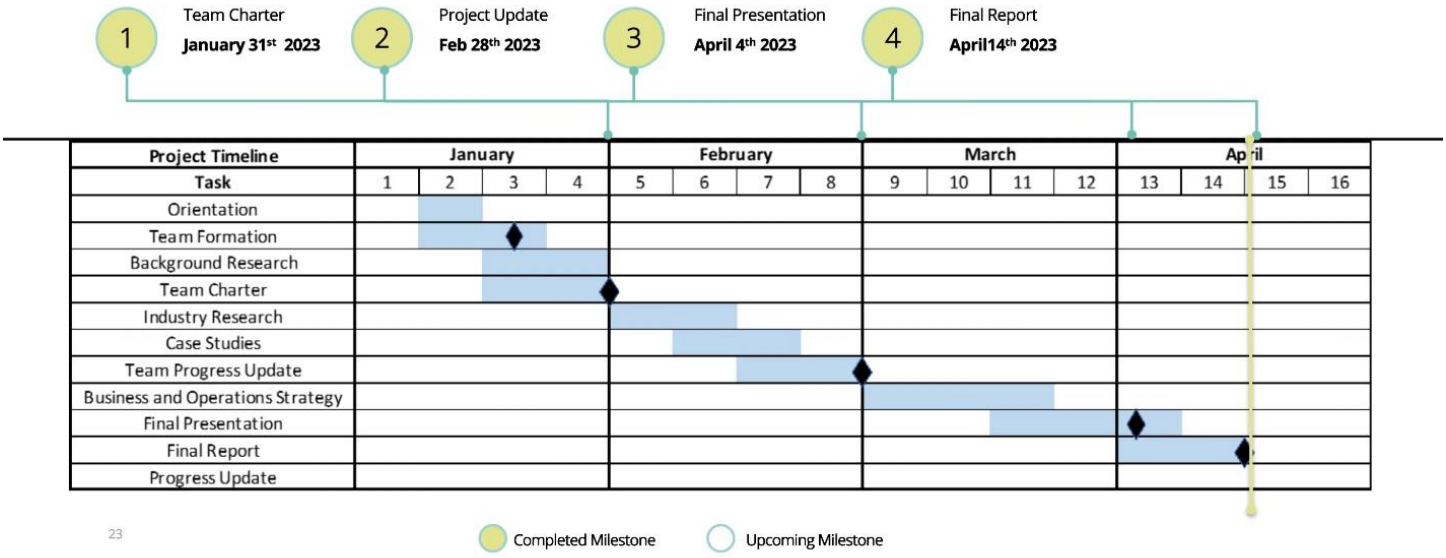


Figure 9: Gantt Chart

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