The Investment Case for Lithium Battery Technology

Executive Summary

The rate at which the global automotive market is adopting electric vehicles (EVs) is accelerating at a rapid pace, creating significant opportunities for investment in battery metals, such as **lithium, cobalt, nickel, graphite, vanadium and manganese**, and the battery technologies that utilize these materials in their battery chemistry. The long-term investment case for battery metals remains compelling amid supply constraints to meet the growing demand for lithium-ion batteries globally and the prospect of a continued rise in prices of the underlying battery metals and components.

EVs are just one driver of battery metal demand. Lithium-ion batteries also power many consumer devices such as smartphones, tablets and other mobile devices. But to put this in perspective, an EV battery is equivalent to about 4,500 smartphones. Moreover, while the smartphone market is beginning to approach saturation, the current market for EVs and hybrid plug-in vehicles (PVs) stands at a nascent level, representing only 2.6% of global car sales in 2019.[1]

To meet growing demand, major battery producers plan to invest over $150 billion in expanded manufacturing capacity over the next decade in China, the United States, and Europe. This is expected to increase annual battery capacity to over 2TWh (terawatt-hour, a measure of electrical energy).[2] Furthermore, there is growing demand globally for grid-scale energy storage, which could exceed 200 gigawatt-hours by 2030, spurred by a huge rise in demand from the automotive sector.[3]

Quite simply, there is not enough supply to meet accelerating demand ignited by a global macro structural shift in mobility and energy storage. This supply-demand imbalance creates considerable investment opportunities for battery metals and battery technology. The global Lithium-ion battery market, valued at $44.2 billion in 2020, is expected to reach $94.4 billion by 2025, growing at an impressive compound annual growth rate (CAGR) of 16.4%.[4]

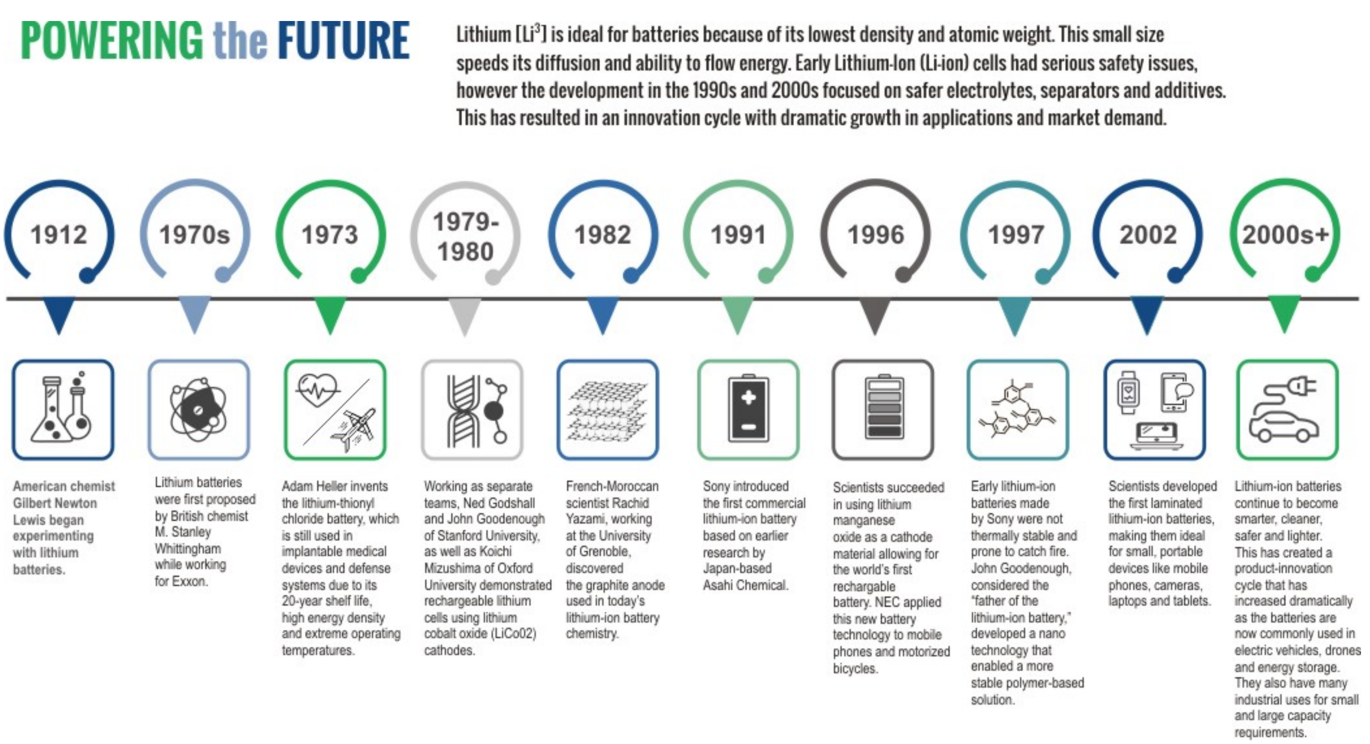
Future EV battery chemistries must balance cost and energy performance. They need to achieve price parity with internal combustion engine (ICE) vehicles, but without sacrificing power and range. The next generation of EVs are expected to run 400 miles between charges and one million miles before replacement, sparking the next phase of the global EV revolution.

[1] IEA, *Global EV Outlook 2020*, (Paris: IEA 2020), https://www.iea.org/reports/global-ev-outlook-2020
[2] Roskill, *Lithium-ion Batteries: Outlook to 2029, 4th Edition (2020, May 5)*
[3] Engel, Hauke, et al, , McKinsey Center for Future Mobility, *Second-life EV batteries: The newest value pool in energy storage* (April 2019)
[4] MarketsandMarkets *Lithium-Ion Battery Market by Type (Li-NMC, LFP, LCO, LTO), Power Capacity (0-3,000 mAh, 3,000 mAh-10,000 mAh, 10,000 mAh-60,000 mAh, above 60,000 mAh), Industry (Consumer Electronics, Automotive, Industrial), Voltage, Region – Global Forecast to 2025* (April 2020)

The Lithium-Ion Battery Revolution

Lithium-ion batteries have helped power a technology revolution. With five times the energy density of lead batteries, rechargeable lithium-ion batteries help power mobile devices such as smartphones, tablets, laptops, robots and drones. While technological advances and cost reduction have helped drive a lithium-ion battery boom for mobile devices over the last few years, the next leg of demand will come from EVs and energy storage, powering the future of green technology.

Here is a historical timeline that details some of the important milestones in the development of lithium and lithium-ion batteries:



Battery Chemistry 101

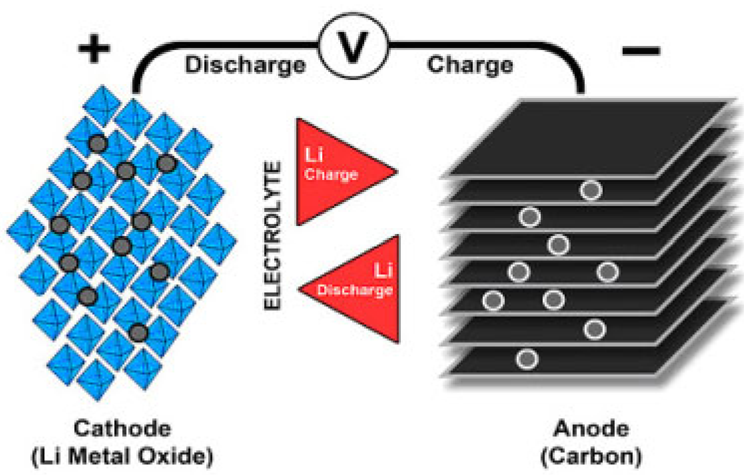
A battery is a device that stores chemical energy that is converted into electricity. Batteries are essentially small "chemical reactors," producing energetic electrons ready to flow to and power external devices. Modern technological devices require batteries that are compact, high capacity, stable and rechargeable. In 1980, the American physicist Professor John Goodenough invented the precursor to the modern lithium-ion battery, a lithium battery in which the lithium (Li) migrated through the battery from one electrode to another as a Li+ ion.

Battery Chemistry 101 ***(cont.)***

Like all batteries, a rechargeable lithium-ion battery is made up of one or more power-generating compartments called cells. Each cell has three components:

1. a cathode (positive electrode),
2. an anode (negative electrode)
3. an electrolyte, in between, which acts as a conductor.

Battery performance is a function of the ability of the cathode and the anode to accept and release lithium ions.



Ion flow in a lithium-ion battery

When the cell charges and discharges, ions shuttle between cathode (positive electrode) and anode (negative electrode). On discharge, the anode undergoes oxidation, or loss of electrons, and the cathode sees a reduction, or a gain of electrons. Charging reverses the movement.

Source: **BatteryUniversity.com**

Sony's first commercial lithium-ion battery used coke (coal product) as the anode. However, since 1997, most lithium-ion batteries have used graphite (a form of carbon) to attain a flatter discharge curve. Future battery chemistries may utilize graphene as the anode to enhance performance.

Battery Chemistry 101 *(cont.)*

Battery chemistries will continue to evolve to achieve advances such as:

- lower manufacturing costs
- higher energy density
- longer ranges
- better temperature tolerance
- faster charge rates
- lower replacement costs
- improved battery life
- safety

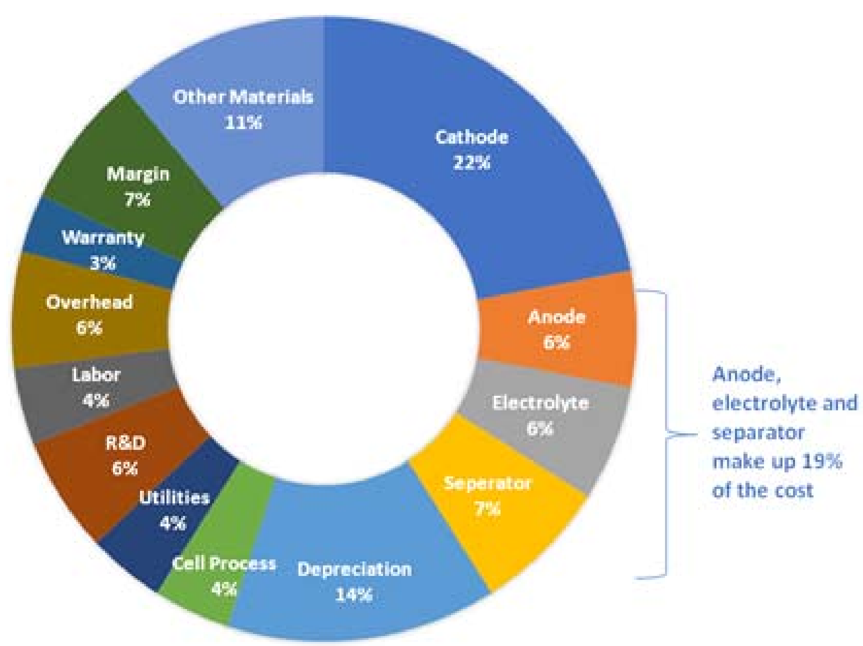
These are critical factors that need to be addressed at the electrochemical level to ensure widespread levels of adoption.

The cathode mix, as explained above, is particularly important for automotive applications as it represents 22% of the battery cost. It is a vital part of increasing vehicle range and is essentially the key limiting factor to battery performance. In order for EV adoption to increase, battery costs have to decrease and range (energy density) needs to increase without sacrificing safety (thermal stability).[5]

Battery Costs: Cathode Mix

The Cathode Represents 22% of Estimated Battery Costs

Source: US DOE, BMO Capital Markets



[5] Berman, Dziuba, Hamilton, BMO Capital Markets (February 2018). *The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See*.

Main Commercially Available Lithium Battery Chemistries

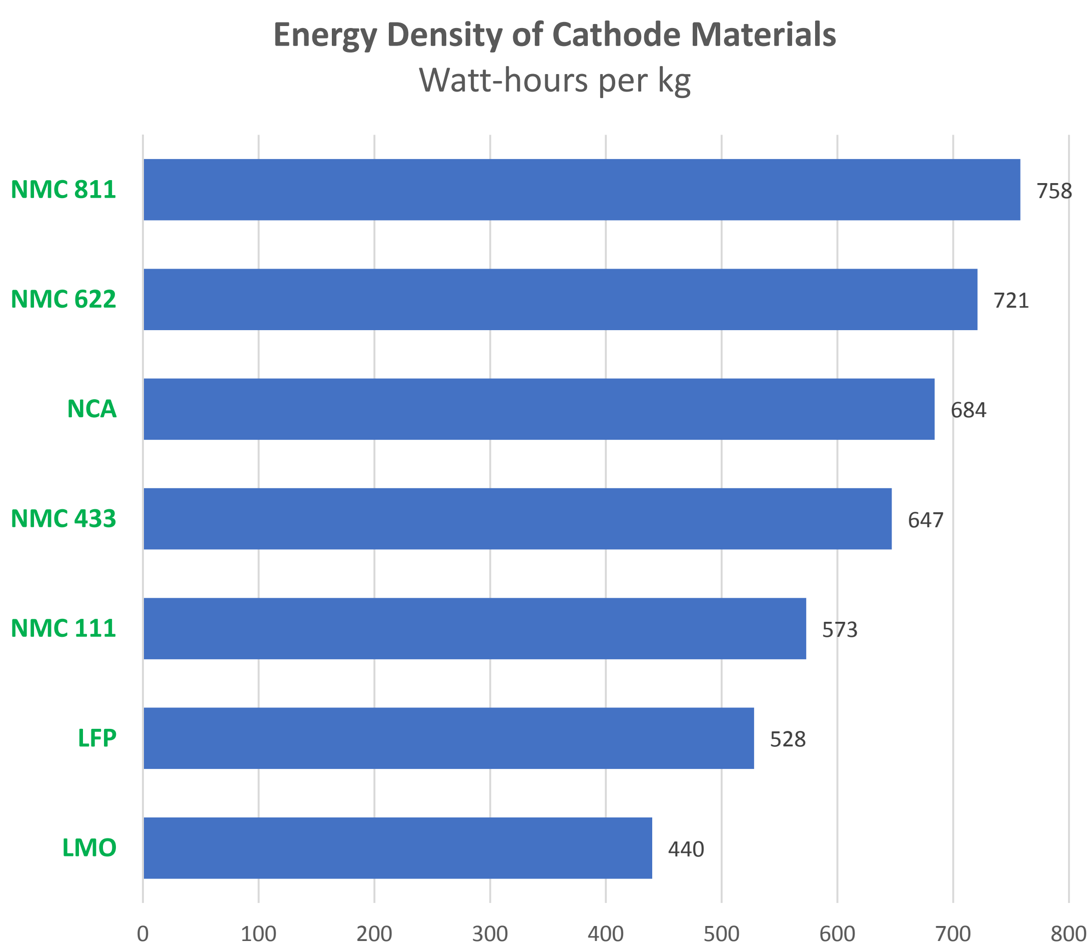
LCO - Lithium Cobalt Oxide	• Used primarily in portable electronics (cell phones, laptops, cameras, etc.) • Limiting factors such as low thermal stability (low safety) and high cost make LCO unappealing for EV applications.
LFP – Lithium Iron Phosphate	• Known for thermal stability (high safety), have low energy density (capacity) compared to other cathode chemistries. • Used in most Chinese EVs due to iron's availability in China. • Tesla's China Model 3 uses this chemistry.
LMO – Lithium Manganese Oxide	• While generally safer than other cathodes, LMO has a much shorter lifespan. To enhance long-term performance, it is usually blended with Lithium Nickel Manganese Cobalt Oxide (NMC) chemistry or aluminum. • LMO-NMC chemistries are found in the batteries of older Nissan Leaf (EV) models due to their cost advantage, but Nissan is expected to switch to a pure NMC cathode.
NMC – Lithium Nickel Manganese Cobalt Oxide	• NMC cathode is the chemistry that has been an area of focus by battery designers and researchers with the goal of reducing overall cobalt content due to its cost and limited supply. • The higher the nickel content, the better the energy density (capacity), but the greater the instability (lower safety).
NCA – Lithium Nickel Cobalt Aluminum Oxide	• Most notably used in Tesla/Panasonic batteries, NCA is potentially tied to Tesla's growth. • Similar to the NMC chemistries with increased nickel content, but is more costly and has some safety issues that make it a less-attractive option for lower-cost EVs, as more costs must be allocated to the battery management system (BMS).

Sources: BMO Capital Markets, Battery University

Lower cobalt lithium-ion battery chemistries such as NMC811 (8 parts nickel, 1 part manganese, 1 part cobalt) are becoming the industry standard for EVs. Increasing nickel content not only increases the vehicle range, but also reduces the need for the scarce, and therefore expensive, use of cobalt. However, one negative side-effect of increasing nickel content is it leads to thermal instability and lower capacity retention. These are the types of trade-offs that will have to be addressed on the path to evolving battery chemistries going forward.

Higher Density: Better Battery Storage

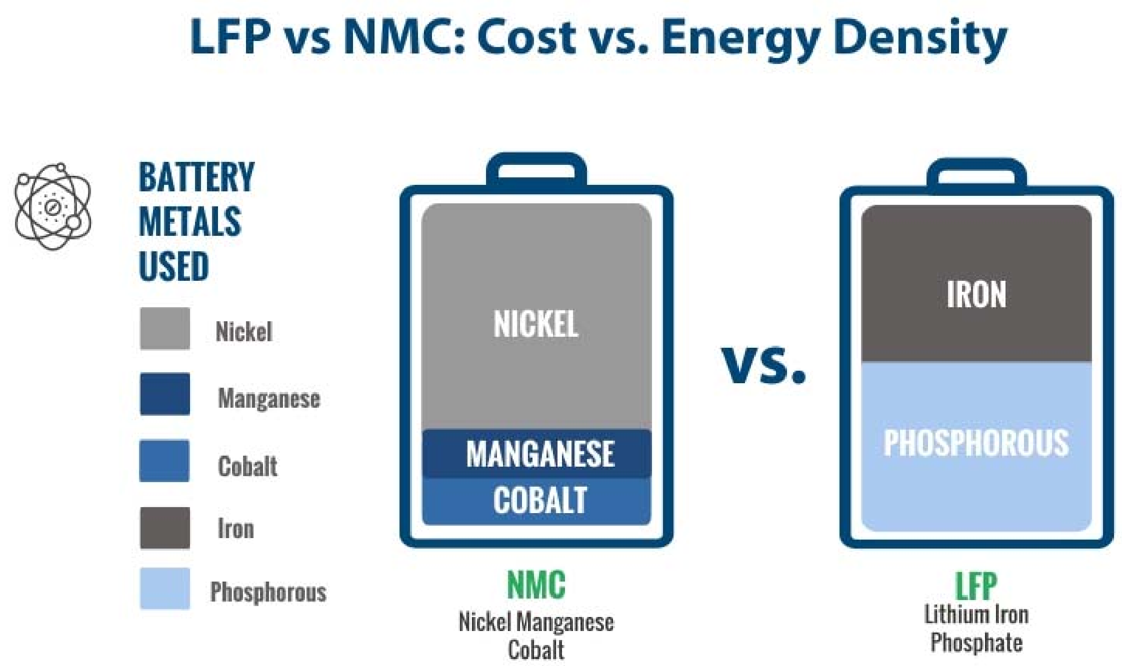
A big upside to the new NMC811 chemistries is its higher density. A battery's higher density is closely related to its total capacity, measuring the amount of electricity in Watt-hours (Wh) contained in the battery relative to its weight in kilograms (kg). Proverbially, higher density translates into more energy being "crammed" into a battery pack for a lower cost.



Source: Bloomberg New Energy Finance

Competing Battery Chemistries: Battle of Cost vs Performance

Currently there are two main battery chemistries competing for market share: low-cost LFP and high-performance (high nickel) NMC.



Source: Nickel Institute[6]

The significant downside for LFP is energy density, which is only 65% to 70% that of NMC 811 chemistries, depending on the packaging. So in order to achieve the same driving range, the physical size of the battery needs to be a third larger, which is– a big concern where space is at a premium. For example, the LFP-powered Model 3 in China, using the same battery space, has about two-thirds the NCA version's range.

But other new technologies are emerging. Chinese battery manufacturers CATL and BYD have both announced new LFP designs that are more efficient. These new designs are called cell to pack (CTP) technology. This technology is used in Tesla's Model 3 that is manufactured in China, making Tesla's vehicles there more price-competitive, with a battery cost 43% less than the company's NMC 811 models.

[6] Nickel Institute, *Battle of the batteries - Cost versus Performance (2020, June 10)*
https://www.nickelinstitute.org/blog/2020/june/battle-of-the-batteries-cost-versus-performance

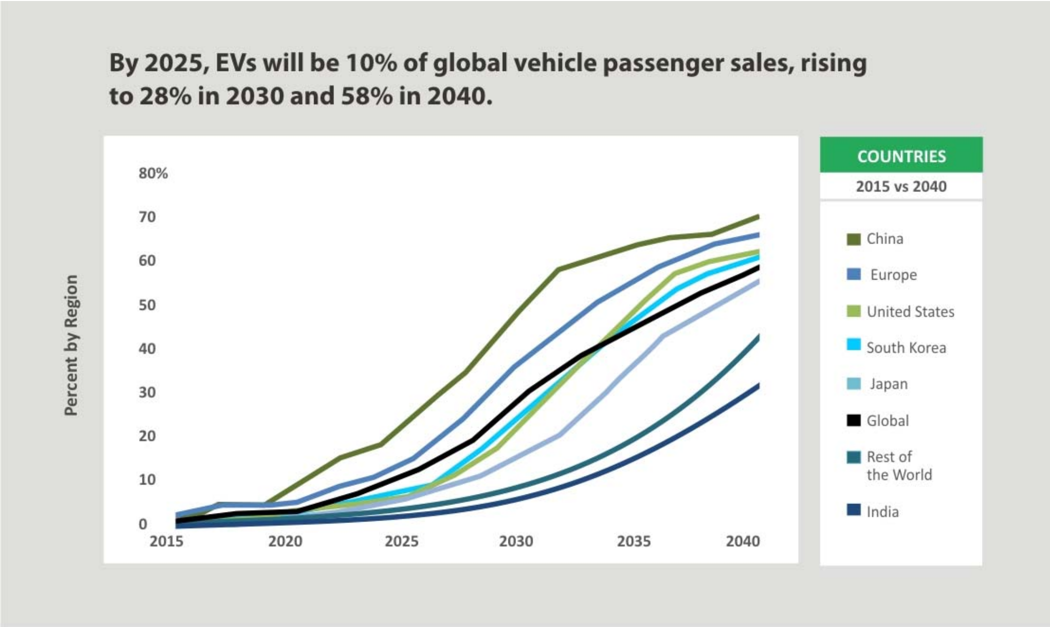
Additionally, automakers have been pursuing pack design using large prismatic cells outside of China. GM and LG Chem have partnered for the Ultium[7] battery, which are unique because the large format, pouch-style cells can be stacked vertically or horizontally inside the battery back. This allows engineers to optimize battery energy storage and layout for each vehicle design. Ultium energy options range from 50 to 200 kWh (kilowatt hour), which could enable a GM-estimated range up to 400 miles or more on a full charge with 0 to 60 mph acceleration as low as 3 seconds.

Volkswagen is also starting to use what the company calls its Modular Electric Drive Matrix (MEB)[8], which, similar to CTP and Ultium technology, has large prismatic cells, high utilization efficiency and a lower cost architecture.

Battery prices, which were above $1,100/kWh in 2010, fell 87% in real terms to $156/kWh in 2019. By 2023, BloombergNEF predicts average prices will drop to $100/kWh. These cost reductions are attributable to scale in order size, growth in battery EV sales and increased penetration of high-density cathode designs.

As cumulative demand passes 2TWh in 2024, prices will fall below the $100/kWh level, the point around which EVs start to reach price parity with internal combustion engine vehicles. Price parity will be an important catalyst to drive demand and accelerate EV penetration.

A Global Disruption in the Making



Sources: Bloomberg New Energy Finance, Electric Vehicle Outlook 2020

[7] General Motors, *GM Reveals New Ultium Batteries and a Flexible Global Platform to Rapidly Grow its EV Portfolio (2020, April 3)* https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2020/mar/0304-ev.html

[8] Volkswagen, *Modular Electric Drive Matrix (MEB)*, https://www.volkswagen-newsroom.com/en/modular-electric-drive-matrix-meb-3677

Battery Metals

While lithium-ion battery chemistries will differ, we focus on the opportunities for four key battery metal categories:

Lithium

Three-quarters of the world's lithium supply comes from four companies, namely SQM, Albemarle, Tianqi and Livent, and split between brine mines in South America's lithium triangle (Chile, Argentina and Bolivia) and open pit hard rock spodumene mines (Western Australia). Producing lithium from brines is a complicated process, but it remains the most cost-efficient method and yields a battery grade result (99.5% lithium carbonate). While spodumene mine production has a higher cost due to the need for refining, the mines themselves require lower capital expenditure than brine mines and can be constructed in a shorter period.[9]

Rechargeable batteries were the source of 45% of lithium demand in 2017. Despite new lithium mine capacity coming online, global lithium-ion demand is expected to grow by six to seven times by 2026, requiring a battery pipeline twice that of current levels. Even with major expansions planned by lithium producers such as SQM, Albemarle, Pilbara Lithium, Nemaska and Mineral Resources, mine capacity is challenged to keep pace with demand growth.[10]

Additionally, disruptions and delays to expansion and new projects have been common place and are expected to continue to derail supply growth. Battery-grade products are also more difficult to produce, which increases the risk of production delays. Finally, lithium's oligopolistic supplier base and the secretive nature of the battery industry in general, have perpetuated supply chain uncertainty and helped keep lithium prices higher.

Cobalt

Cobalt is a hard, lustrous, silver-blue metal extracted as a by-product when mining nickel and copper. Besides serving as a cathode material in lithium-ion batteries, cobalt is also used to make powerful magnets and high-strength alloys for jet engines and gas turbines. Approximately 45% of cobalt's industrial use is in batteries. Cobalt's high cost and constrained supply has caused battery manufacturers to want to reduce or eliminate cobalt content in lithium-ion batteries.

[9] Berman, Dziuba, Hamilton, BMO Capital Markets (February 2018). *The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See*.
[10] Roskill. (2018, February 7). *EV Raw Materials: Cobalt, Manganese, Lithium, Graphite, Nickel, and Rare Earths*.

Roughly 70% of cobalt is mined as a by-product of copper in the Democratic Republic of the Congo. Another 25% of cobalt is produced as a by-product of nickel in countries such as China, Canada, Australia and Russia. Small amounts of primary cobalt (5%) are produced in Morocco, and as a by-product of platinum group metals (PGM) production in South Africa.

In developing countries, cobalt is often mined under life-threatening working conditions by adults and children for low pay. It is also toxic if ingested, inhaled, or comes in contact with the skin.[11]

Demand for cobalt is likely to continue its strong growth trajectory, underpinned by steady smartphone battery usage (25% of cobalt demand) and the ramp-up of EV demand. Despite its high cost, cobalt will continue to be used in cathodes for quite some time. Considerable refined capacity expansions and investment will be required to meet the anticipated demand for cobalt. Most of this capacity is expected to come from China, representing as much as 60% of future capacity.[12]

Nickel

At present, the amount of nickel used in batteries represents a small percentage (5%) of total nickel demand, with less than 1% going into EV batteries. The primary use of nickel is in stainless steel. However, the demand prospects for nickel in batteries are growing, thanks to the rise in automobile electrification. Demand for primary nickel for batteries is expected to grow to 20% of the total market, increasing at a much more rapid pace than stainless steel. NMC (nickel-manganese-cobalt) battery chemistries are moving toward a less cobalt-heavy chemistry which is supplanted by nickel.

Other Metals: Manganese, Graphite and Recycling

Manganese is used in lithium-ion batteries and traditional batteries such as zinc-carbon batteries. Even though the manganese market is dominated by steel, it is likely that new capacity will need to be added to meet lithium-ion battery demand.

Graphite is utilized in batteries 85% of the time as an anode in lithium-ion batteries, and 15% as a minor additive in other battery applications. China currently dominates the supply of graphite, accounting for 70% of natural graphite and 46% of synthetic graphite. Lithium-ion batteries are one of the only areas where natural (flake) graphite and synthetic graphite compete with each other for market share. Brazil is the second-largest producer of natural graphite.

[11] BatteryUniversity.com, *How Does Cobalt Work in Li-ion?* http://batteryuniversity.com/learn/article/bu_310_cobalt
[12] Roskill, *EV Raw Materials: Cobalt, Manganese, Lithium, Graphite, Nickel, and Rare Earths* (2018, February 7)

As lithium-ion batteries power the globe, over 11 million tonnes of spent batteries will be discarded, creating significant opportunities for recycling. Less than 5% of lithium-ion batteries are recycled today. However, there are incentives for recycling, especially given that batteries contain recoverable cobalt which is worth $40/pound. The lithium-ion battery recycling industry is still in its infancy, but given the high price of cobalt and lithium, and a huge projected demand wave of lithium-ion batteries with 26 megafactories planned to be producing by 2021, lithium-ion recycling could emerge as a profitable trend.[13]

Battery Metal Supply Chain

The lithium-ion battery industry is positioned for massive growth. Strong demand for portable electronics, EVs and energy storage is expected to drive growth for lithium-ion batteries and their underlying metal components.

A number of factors are likely to perpetuate supply and demand imbalances in battery metals in the foreseeable future, resulting in accelerating global demand. These include limited material supply, as well as an evolving and dynamic battery chemistry.

[13] Sources: Bohlson, Matt. *A Look at the Lithium-Ion Battery Recycling Industry and Companies*; Seeking Alpha, (2018, January 23) https://seekingalpha.com/article/4139266-look-lithium-ion-battery-recycling-industry-companies

One thing is certain – despite research dedicated to other battery technologies, the lithium-ion battery is likely to remain the "gold standard" for mobility and power storage for many years to come.

Automobiles are forecast to surpass electronics as the biggest user of lithium-ion batteries…

Consider that just a 1% increase in EV penetration in the global auto industry has significant implications for the battery metal supply chain. A key issue is that materials need to be secured four to five years ahead of auto launches. Supply chains of raw materials such as lithium, nickel and cobalt could have a significant impact on EV production as battery manufacturers will also have to consider the cost and availability of key commodities in their battery chemistry and design.

Accelerating Electric Vehicle Demand

Global Drivers

The market for EVs is growing rapidly amid several key growth drivers.

➲ Government Regulatory Support in Key Markets — United States, Europe and China

Government targets for fuel efficiency and carbon dioxide emissions will require unprecedented responses from Original Equipment Manufacturers (OEMs) of automobiles to meet those standards. In the absence of greater EV adoption, fuel efficiency improvement rates would need to double to meet new government standards. The auto industry is targeting EV penetration of 14.3% in 2025.[14] However, some analysts, such as Roskill, project global auto electrification rates as high as 50% for passenger car sales by 2030.[15]

Increasingly, more countries are committing to banning, or at least limiting, the sale of internal combustion engine (ICE) vehicles over the next decades as part of efforts to reduce air pollution. Automakers were already accelerating their planned electric vehicle launch plans to comply with increasingly stringent regulations in Europe and China. While COVID-19 has delayed some of these plans, government incentives, evolving consumer preference, price parity, and a slate of new innovative models will fuel accelerating EV growth in the post pandemic world. Indeed, just recently, the United Kingdom moved its ICE car sales ban forward to 2035 from 2040.[16]

[14] Berman, Dziuba, Hamilton. BMO Capital Markets (February 2018). *The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See*.
[15] Roskill, *EV Raw Materials: Cobalt, Manganese, Lithium, Graphite, Nickel, and Rare Earths*.(2018, February 7)
[16] Lewis, Michael, Electrek, *The UK moves ICE car sales ban forward to 2035 to 2040* (2020, February 5)

Internal Combustion Engine (ICE) Sales Ban Proposals

Country	No ICE Sales	No ICE On Road
Netherlands	2030	2030
China	Actively considering and studying a ban	
Norway	2025	2025
India	2030	2030
Germany	2040	
Scotland	2040	2050
United Kingdom	2035	2050
France	2040	
Israel	2030	

Source: Refinitv, Data current as of February 2020.

In all, due to rising policy pressures, 13 countries and 31 cities and regions have announced plans to phase out internal combustion engines.

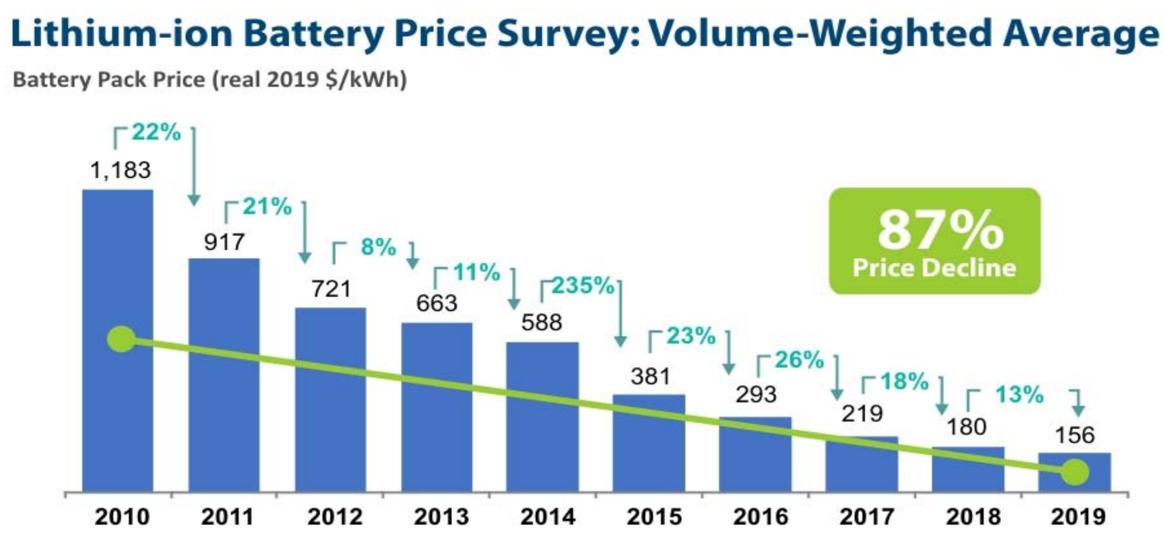
Falling Lithium-ion Battery Prices

Another factor supporting greater adoption of EVs is that battery prices, and consequently EVs themselves, continue to get cheaper. As depicted in the chart below, the average price of a lithium-ion battery pack is now below $156 per/kilowatt-hour and prices are set to fall even further to below $100/kWh by 2024.[17] To generate mass adoption, EVs and hybrid vehicles need to be priced comparably to gas-powered cars without subsidies.

https://electrek.co/2020/02/05/uk-ice-car-sales-ban-forward-2035/

[17] BNEF, *Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/kWh In 2019 (2019, December 3)*

Mass Adoption Expected to Rise as Prices Continue to Decline



Source: Bloomberg Energy Finance

➲ Increased EV Commitments from Global Auto Makers

Global passenger EV sales reached 2.1 million in 2019, or 2.7% penetration, with China accounting for over half of the total sales. While much of this growth has been driven by policy support in the United States, Europe, and China, EV commitments from automakers have also risen dramatically, despite this year's COVID-19 related model delays. Almost every global brand has committed to launching EVs over the next five years. Based on company announcements, that translates into over 500 new passenger vehicle models available globally by 2022, increasing lithium-ion battery cell manufacturing capacity from 432 GWh in 2020 to over 1,769 GWh by 2025.[18]

➲ Growing Consumer Preference

Besides a limited number of EV models, other impediments to mass-market penetration have been the effects of climate on battery performance and the challenges associated with battery charging infrastructure. EV makers have implemented a number of solutions to address temperature issues, which include changing battery design, improving battery management systems, climate grading systems and cabin preconditioning. In addition, faster charging times and greater charging capacity are coming online to help reduce "range anxiety" and further promote mass-market adoption.

[18] BloombergNEF, Electric Vehicle Outlook 2020, https://about.bnef.com/electric-vehicle-outlook/

Price parity and longer-range solutions will be important drivers of demand. But the change in consumer sentiment favoring green technology in the post COVID-19 world and exciting new models that capture the consumer imagination will be the real catalysts for acceleration in EV demand.

Battery Storage

Government incentives and private investment have fueled progress in utility-scale battery storage solutions. And with continued global growth in EVs, a new opportunity has emerged for the power sector: stationary storage used by EV batteries, which could exceed 200 gigawatt hours by 2030. During the next decade, the strong uptake of EVs will result in the availability of terawatt-hours of batteries that no longer meet required specifications for usage in an EV. Storage applications for these still-useful batteries will help bring down the cost of storage to enable further renewable power integration into our grids.

Investment Case

A number of factors will drive growth in the demand for lithium-ion batteries, including continued demand for mobile devices, the accelerating pace of global EV adoption, and the rising need for grid energy storage solutions. In particular, the growing global demand for EVs has created investment opportunities at all levels of the EV value chain, from battery metals and material producers, to battery technology and storage solution development and electric vehicle innovation. The lithium-ion battery market provides investors with a growing global opportunity with multiple drivers of demand and constrained supply conditions.

The EQM Lithium & Battery Technology Index (BATTIDX) tracks global companies associated with the development, production, and use of lithium battery technology, which includes:

- the development and production of lithium battery technologies and/or battery storage solutions;
- the exploration, production, development, processing, and/or recycling of the materials and metals used in lithium-ion batteries such as Lithium, Cobalt, Nickel, Manganese, Vanadium, and/or Graphite; and/or
- the development and production of EVs.

Conclusion

- According to Market and Markets, the lithium-ion battery market is expected to grow from an estimated $44.2 billion USD in 2020 to $94.4 billion by 2025, at a CAGR of 16.4%.
- A number of factors continue to fuel growth in lithium-ion batteries, including solid demand for mobile devices, accelerating pace of global EV adoption and the rising need for grid energy storage solutions.
- Given supply constraints to meet the growing demand for lithium-ion batteries, prices of the underlying battery metals should continue to rise and investors in the companies developing and producing battery metals are likely to be rewarded.
- By 2025, EVs will quadruple to 10% of global vehicle passenger sales, helped by government regulatory support, falling battery prices and improved battery chemistries. Other factors that will spur growth include an increased commitment from automakers to produce more than 500 new models and rising consumer demand, which will create additional investment opportunities across the entire battery technology value chain.

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Definitions

Ion – an atom or molecule with a net electric charge due to the loss or gain of one or more electrons.

Cathode – the positive electrode in a lithium-ion battery consisting of a metal oxide.

Anode- the negative electrode in a lithium-ion battery, generally made from carbon.

Electrolyte –the conductor of lithium charge and discharge in a lithium-ion battery, made from a lithium salt in an organic solvent.

Megafactories – large scale production facilities for lithium-ion batteries**.**