VettaFi | EQM INDEXES

BATT: Investing in Lithium Battery Technology

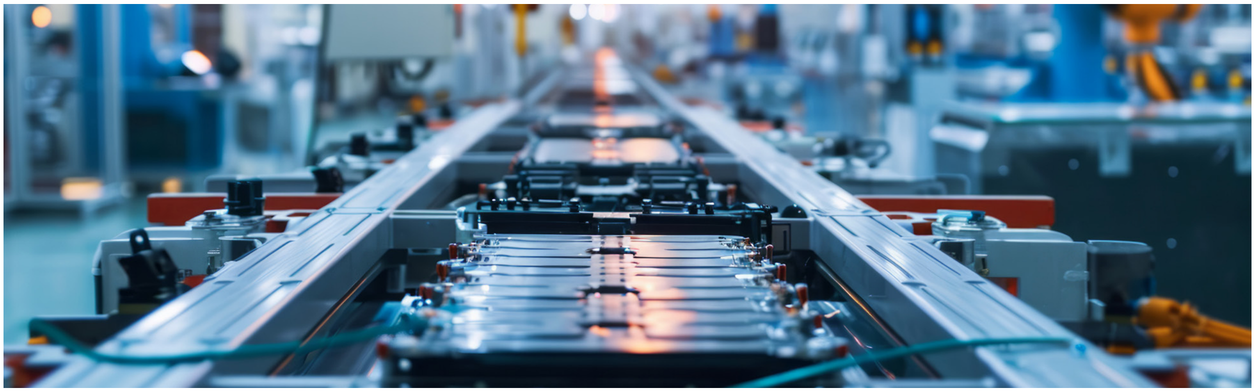
The investment case for battery metals

Post-pandemic supply and demand imbalances have subsided, allowing costs to come down and the rate at which the global automotive market is adopting electric vehicles (EVs) to accelerate at a rapid pace. This has created significant opportunities for investment in battery metals over the long term, such as lithium, cobalt, nickel, graphite, vanadium, and manganese, and the battery technologies that utilize these materials in their battery chemistry and for energy storage. There is a supply constrained capacity to meet the growing demand for lithium-ion battery technology. As a result, the prices of the underlying battery metals and components should continue to rise in the years to come, making them a good long-term investment.

Electric vehicles 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. And while the smartphone market is beginning to approach saturation, the current market for electric and hybrid plug-in vehicles (PVs) stands at a nascent level, representing only 16% of global car sales in 2023.[1]

---

[1] King, Neil, *EVs Forecast to Account for Two Thirds of Global Light-Vehicle Sales in 2035,* EV-Volumes.com, https://www.ev-volumes.com/#:~:text=EVs%20are%20therefore%20expected%20to,%2C%20down%20from%2035%25%20previously.



Global automakers and battery makers are planning to invest more than $860 billion by 2030, with nearly $210 billion expected to be invested in the U.S., more than any other country.[2] Furthermore, there is growing demand globally for grid-scale energy storage, which is expected to increase over six-fold from 18GWh to 119 GWh by 2030.[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. According to MarketsandMarkets, the global Lithium-ion battery market, which accounted for $56.8 billion in 2023, is expected to reach $187.1 billion by 2032, growing at an impressive compound annual growth rate (CAGR) of 14.2%.[4]

Future EV battery chemistries must balance cost and energy performance. On the one hand 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 go as long as 500 miles, and maybe even a 1 million miles between charges, sparking the next phase of the global EV revolution.

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 electric vehicles and energy storage, powering the future of green technology.

Illustrated on the next page is a historical timeline that details some of the important milestones in the development of the lithium and lithium-ion batteries.

---

[2] Gabriel, Noah, *$210 Billion of Announced Investments in Electric Vehicle Manufacturing Headed for the U.S.* EV Hub, January 12, 2023.

[3] Solar Energy Industries Association, *New Report Charts the Path to an American-Made Energy Storage Future,* SEIA.org, November 16, 2023.

[4] MarketsandMarkets, *Lithium-ion Battery Market Global Forecast to 2032,* August 2023, https://www.marketsandmarkets.com/Market-Reports/lithium-ion-battery-market-49714593.html

Powering the future

Lithium (Li^3) is ideal for batteries because of its lowest density and atomic weight. This small size speeds its diffusion and ability to flow energy. Early Lithium-Ion (Li-ion) cells had serious safety issues, however the development in the 1990s and 2000s focused on safer electrolytes, separators and additives. This has results in an innovation cycle with dramatic growth in applications and market demand.

1912-1980

1912
American chemist Gilbert Newton Lewis began experimenting with lithium batteries.

1970s
Lithium batteries were first proposed by British chemist M. Stanley Whittingham while working for Exxon.

1973
Adam Heller invents the lithium-thionyl chloride battery, which is still used in implantable medical devices and defense systems due to its 20-year shelf life, high energy density and extreme operating temperatures.

1979-80
Working as separate teams, Ned Godshall and John Goodenough of Stanford University as well as Koichi Mizushima of Oxford University demonstrated rechargeable lithium cells using lithium cobalt oxide (LiCo02) cathodes.

1982-1990s

1982
French-Moroccan scientist Rachid Yazami, working at the University of Grenoble, discovered the graphite anode used in today's lithium-ion battery chemistry.

1991
Sony introduced the first commercial lithium-ion battery based on earlier research by Japan-based Asahi Chemical.

1996
Scientists succeeded in using lithium manganese oxide as a cathode material allowing for the world's first rechargeable battery. NEC applied this new battery technology to mobile phones and motorized bikes

1997
Early lithium-ion batteries made by Sony were not thermally stable and prone to catch fire. John Goodenough—considered the "father of the lithium-ion battery" developed a nano technology that enabled a more stable polymer-based solution.

2000s

2002
Scientists developed the first laminated lithium-ion batteries, making them ideal for small, portable devices like mobile phones, cameras, laptops and tablets.

2000+
Lithium-ion batteries continue to become smarter, cleaner, safer and lighter. This has created a product-innovation cycle that has increased dramatically as the batteries are now commonly used in electric vehicles, drones and energy storage. They also have many industrial uses for small and large capacity requirements.

Battery chemistry 101

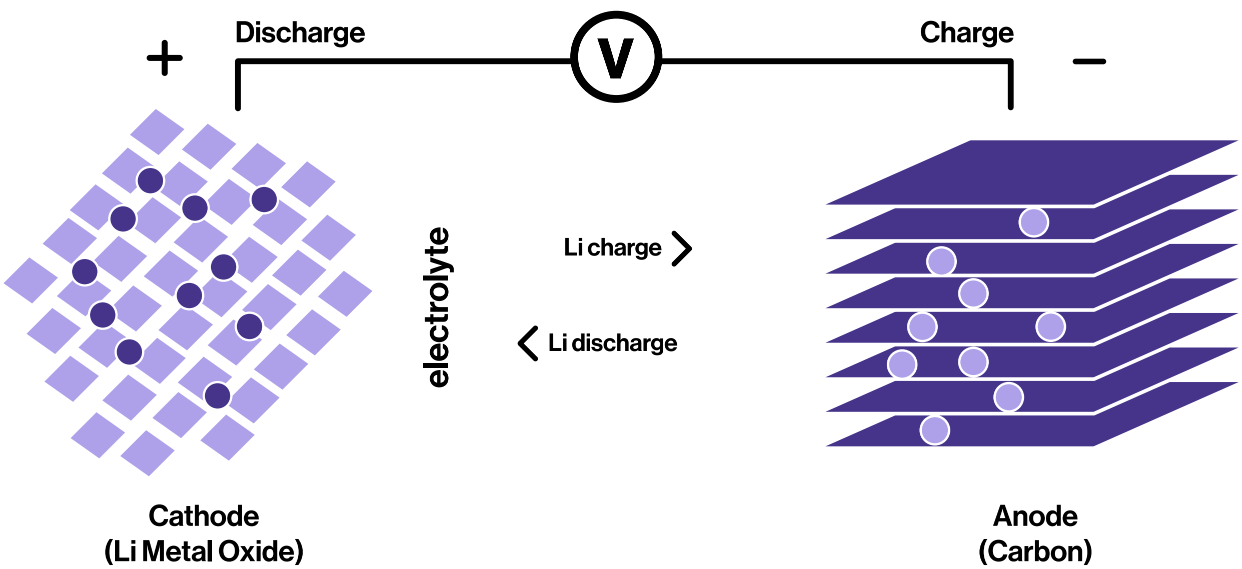
A battery is a device that stores chemical energy which is converted into electricity. Batteries are essentially small "chemical reactors" which produce energetic electrons ready to flow to and power external devices. Modern technological devices require batteries that are compact, high capacity, stable 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.

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:

- a cathode (positive electrode),
- an anode (negative electrode)
- 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 chemistries will continue to evolve to achieve advances such as:

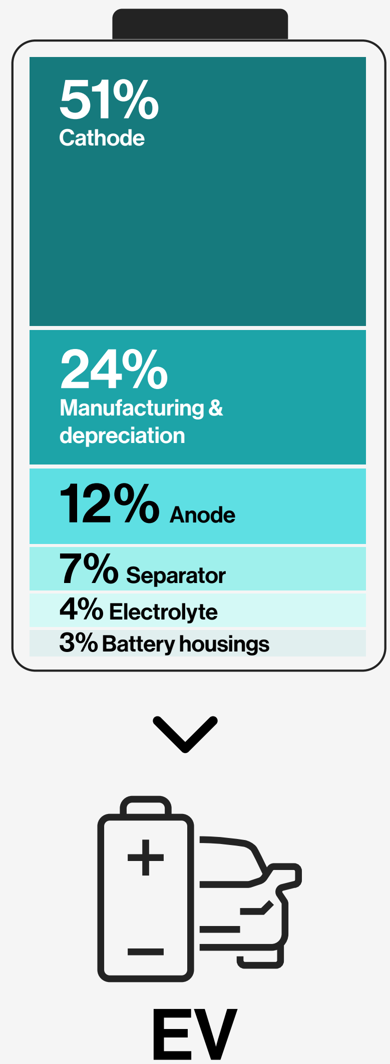
- lower manufacturing costs
- higher energy density
- longer ranges
- better temperature tolerance
- faster charge rates
- lower replacement costs
- improved battery life
- safety

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

The cathode mix, is particularly important for automotive applications as it now represents 51% 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 electric vehicle adoption to increase, battery costs have to decrease and range (energy density) needs to increase without sacrificing safety (thermal stability).[5]

Main commercially available lithium battery chemistries

The cost of an EV battery



Source: LeithCars.com, https://www.leithcars.com/blogs/1421/lifestyle/what-goes-into-the-cost-of-an-ev-battery/

[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.*

Battery compounds	Uses
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).
Future Battery Chemistries	• **Solid State.** Solid electrolytes are more compact, meaning batteries can be smaller and store more energy. Less flammable and do not require same cooling infrastructure. • **Lithium-Sulfur (Li-S).** High specific energy but poor cycle life and poor loading. • **Lithium-Air.** High specific energy but poor loading, needs clean air to breath and has short life.

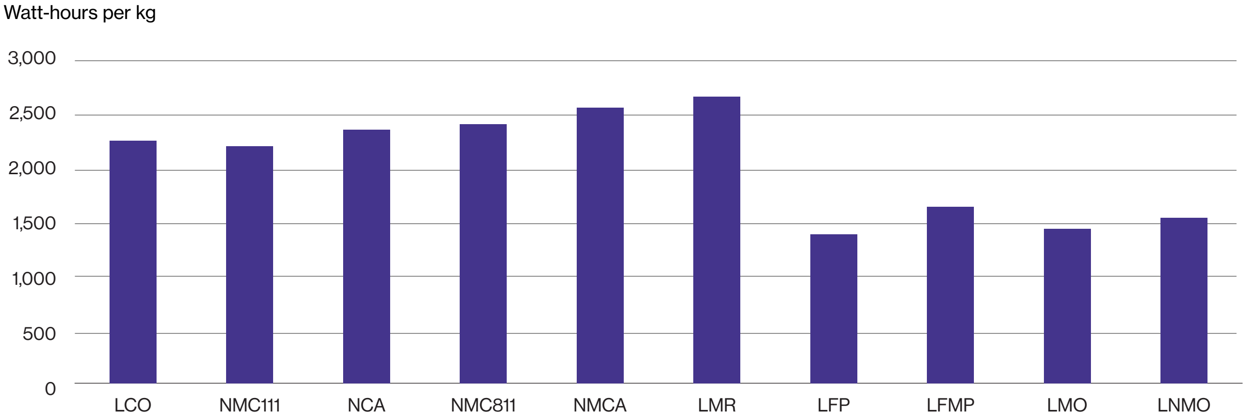
Sources: BMO Capital Markets, Battery University

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 newer battery chemistries is their 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.

Energy density of cathode materials



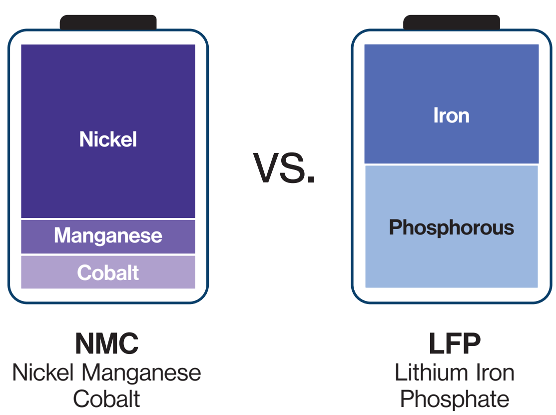
Source: Nickel Institute https://nickelinstitute.org/en/blog/2020/february/competitive-technologies-to-high-nickel-lithium-ion-batteries-the-pros-and-cons/

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.

The significant downside for LFP is energy density, which only 65-70% 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 – a big concern where space is at a premium. As an example, the LFP-powered Model 3 in China, using the same battery space, has about two-thirds the NCA version's range.

LFP vs. NMC: Cost vs. energy density



Source: Nickel Institute[6]

But other new technologies are emerging. Chinese battery manufacturers CATL and BYD have both announced new LFP designs which are more efficient. This new design has been termed cell to pack (CTP) technology. This technology is being used in Tesla's Model 3 being manufactured in China, making their vehicles there more price competitive, with a battery cost 43% less expensive than their NMC 811 models.

Pack design using large prismatic cells is also being pursued 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

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

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

back. This allows engineers to optimize battery energy storage and layout for each vehicle design. Ultium energy options range from 50 to 200 kWh, which could enable a GM-estimated range up to 400 miles or more on a full charge with 0 to 60 mph acceleration in as little as 3 seconds.

Volkswagen uses what it calls its Modular Electric Drive Matrix (MEB), which similar to CTP and Ultium technology has large prismatic cells, high utilization efficiency, and a lower cost architecture. Volkswagen and Ford recently formed a strategic alliance that allows Ford and other car manufacturers to use the MEB platform to electrify their portfolios.[8] Lithium battery pack prices, which were at $780 in 2013, have fallen to $139 today. In the near future, BloombergNEF predicts average prices will drop to $100/kWh.[9] These cost reductions are attributable to scale in order size, growth in battery electric vehicle sales, and increased penetration of high-density cathode designs.

When prices 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 electric vehicle penetration.

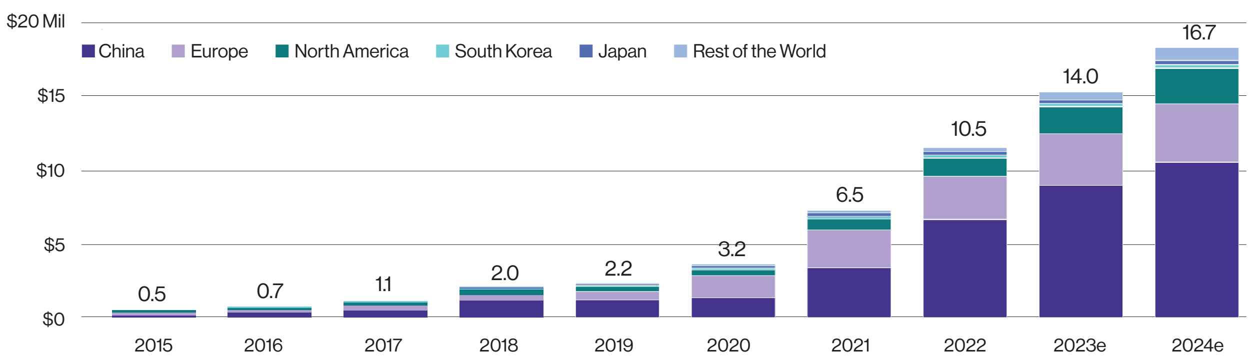
Rise of solid-state battery technology

One of the most promising innovations in battery technology are solid-state batteries. According to MarketandMarkets, the global solid-state battery market is projected to reach $963 million USD by 2030, growing at a CAGR of 41.5% from 2023 to 2030.[10]

A global disruption in the making

Global passenger EV sales will top 16.7 Mil. in 2024

Number of new passenger electric vehicles sold annually



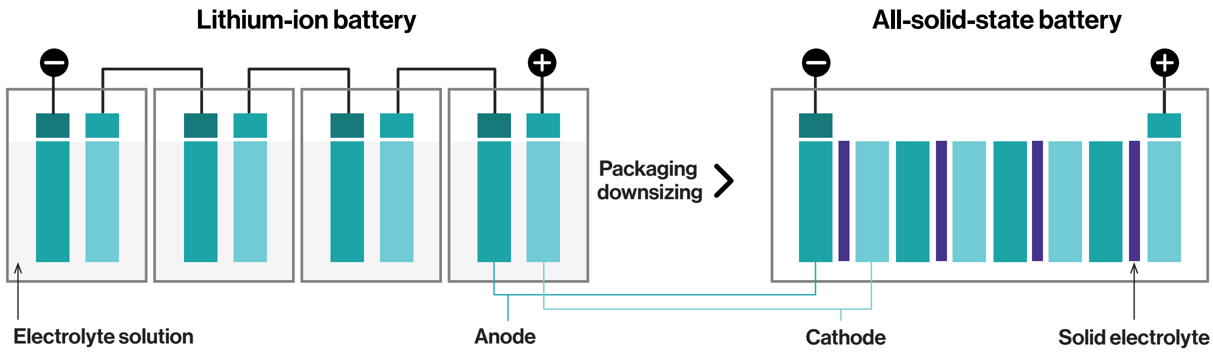
Source: BloombergNEF.

Note: Total includes battery-electric vehicles (BEV) and plug-in hybrid vehicles (PHEV). 2023e 2024e is estimated in 2023 and in 2024.

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

[9] Shahan, Zachary. Record Low EV Battery Prices in 2023, CleanTechnica, , https://cleantechnica.com/2023/12/01/record-low-ev-battery-prices/

[10] MarketandMarkets, Solid State Battery Market October 2023 https://www.marketsandmarkets.com/Market-Reports/solid-state-battery-market-164577856.html



Source: Solid State Battery Infographic Source – AndroidAuthority

Solid electrolytes are more compact, meaning batteries can be smaller and store more energy. The inventor of the lithium-ion battery, and winner of the Nobel Prize in Chemistry in 2019, John B. Goodenough, together with fellow researcher Maria Helena Braga, published a paper in 2017 on the development of a low-cost battery based upon a glass electrolyte that is non-combustible and has a long cycle life (battery life) with a high volumetric energy density and fast rates of charge and discharge: now known as the solid-state battery.[11]

Solid-state batteries have 3X the energy density of lithium-ion batteries by using an alkali-metal anode (lithium, sodium, or potassium) that increases the energy density of the cathode and delivers a longer life cycle. Another advantage of solid-state electrolytes is that they are less combustible and safer than lithium-ion battery chemistries. Solid-glass electrolytes also can operate at sub-zero temperatures down to -20C, addressing another major shortcoming of standard EV batteries. Finally, solid-state batteries also charge faster.

Many major car companies are partnering with solid-state battery companies or researching the technology in-house. Volkswagen has invested $300 million in solid-state battery company Quantumscape. Ford and BMW led a $130 million investment round in Colorado solid-state battery start-up Solid Power Toyota has confirmed its plans to launch solid state batteries which charge in 10 minutes and provide up to a 750 mile range. Toyota's batteries are expected to hit the market as soon as 2027.[12]

Battery metals

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

Lithium

With over 350 million EVs expected to be sold globally by 2030 according to IEA projections, how will we meet the lithium demand of the future?[13]

---

[11] Braga, Maria & Grundish, Nicholas & Murchison, Andrew & Goodenough, John. (2017). Alternative Strategy for a Safe Rechargeable Battery. Energy Environ. Sci.. 10. 10.1039/C6EE02888H.

[12] Johnson, Peter. *Toyota confirms 750 mi range solid-state EV battery plans to catch up to Tesla, but when?* Electrek, January 11, 2024, https://electrek.co/2024/01/11/toyota-solid-state-ev-battery-plans-750-mi-range/

[13] Kennedy, Alan. *The Lithium Rush: Can We Meet Tomorrow's Lithium Demand?* Visual Capitalist, October 25, 2023. https://www.visualcapitalist.com/sp/tomorrows-lithium-demands/

Australia and Chile: Dominating Global Lithium Supply

Australia and Chile stand out as the top producers of lithium, accounting for almost 77% of the global production in 2022.

Rank	Country	Mine production 2022E (tonnes)	Share (%)
1	🇦🇺 Australia	61,000	46.9%
2	🇨🇱 Chile	39,000	30.0%
3	🇨🇳 China	19,000	14.6%
4	🇦🇷 Argentina	6,200	4.8%
5	🇧🇷 Brazil	2,200	1.7%
6	🇿🇼 Zimbabwe	800	0.6%
7	🇵🇹 Portugal	600	0.5%
8	🇨🇦 Canada	500	0.4%
	🌎 Other countries*	700	0.5%
	🌐 **World Total**	**130,000**	**100.0%**

**U.S. production data was withheld to avoid disclosing proprietary company data*

Source: Visual Capitalist.

In 2022, – Australia and Chile – accounted for almost 77% of the world's lithium production. Australia's lithium mining predominantly relies on hard-rock mines that produce spodumene concentrate, which is then converted into lithium. The majority of Chile's production comes from salar brines with high concentrations of lithium. China, the world's third-largest lithium producer, has secured more than $5 billion worth of lithium mining projects in various countries over the last few years. China is also where most of the world's lithium processing plants are located, turning lithium spodumene (the mined ore) into a version that can be used in electric car batteries, consumer devices, and energy storage.

In the 1990's, the U.S was the world's largest lithium producer, producing over one-third of the world's global production in 1995.[14] Today the U.S. currently accounts for very little of the world's lithium production, but new capacity in Nevada, North Carolina, Arkansas, and the Salton Sea, should drive that number higher. As the need for lithium increases, exploration will play a key role in unlocking new sources of production, especially in countries like the United States, which are currently lagging in the lithium race.

Disruptions and delays to expansion and new projects have been commonplace and are expected

[14] Venditti, Bruno. Visualizing the World's Largest Lithium Producers, Visual Capitalist, June 12, 2023, https://www.visualcapitalist.com/visualizing-the-worlds-largest-lithium-producers/

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, along with the global pandemic, perpetuated supply chain issues and helped keep lithium prices higher. But in 2023, lithium prices plummeted 80% to $13,600 a ton.[15]

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 50% of cobalt's industrial use is in batteries.[16] Cobalt's high cost and constrained supply has caused battery manufacturers to want to reduce or eliminate cobalt content in lithium-ion batteries.

Roughly 70% of cobalt is mined as a by-product of copper in the Democratic Republic of the Congo (DRC). 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.

Cobalt in developing countries is often mined under life-threatening working conditions by adults and even children for low pay. It is also toxic if ingested, inhaled, or comes in contact with the skin.[17]

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.

China is the world's leading producer of refined cobalt, most of which it produced from partially refined cobalt imported from DRC. China is also the world's leading consumer of cobalt, with more than 80% of its consumption being used by the rechargeable battery industry.[18]

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.

---

[15] Cohen, Ariel. Lithium: *Price Collapse Secures Green Transition, Causes Headaches, Forbes,* December 17, 2023, https://www.forbes.com/sites/arielcohen/2023/12/27/lithium-price-collapse-secures-green-transition-causes-headaches/?sh=159bcdc84a61

[16] Pistilli, Investing News. *Cobalt Use: Batteries and More.* https://investingnews.com/daily/resource-investing/battery-metals-investing/cobalt-investing/cobalt-applications/

[17] *How Does Cobalt Work in Li-ion?* BatteryUniversity.com. http://batteryuniversity.com/learn/article/bu_310_cobalt

[18] Basov, Vladimir, *The world's largest cobalt producing countries in 2021 – report,* Kitco News, February 2, 2022.

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 places where natural (flake) graphite and synthetic graphite compete for market share. Brazil is the second-largest producer of natural graphite.

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 global market for lithium battery recycling was estimated at $6.5 billion in 2022 and is projected to reach $35.7 billion by 2031.[19]

Battery metal supply chain

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

> “
>
> Automobiles are forecast to surpass electronics as the biggest user of lithium-ion batteries ...

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

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.

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.

---

[19] Sources: MarketsandMarkets, April 2023.. https://www.marketsandmarkets.com/Market-Reports/lithium-ion-battery-recycling-market-153488928.html

The underlying metals for Lithium-ion batteries

Lithium [Li]	Cobalt [Co]	Nickel [Ni]	Manganese [Mn]	Graphite [C]
A soft, silvery-white alkali metal. Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest specific energy per weight.	Hard, lustrous silver-gray metal extracted as a by-product when mining nickel and copper. Used as a cathode material in Li-ion batteries, but is very expensive.	A silvery-white lustrous metal with a slight gold tingle that can be traced back to 3500 B.C. Found in large nickel-iron meteorites on earth and found in combination with iron.	Produced by mining iron and other minerals, it is relatively abundant. Steel manufacturing uses roughly 90% of manganese production. Also used as a cathode material.	Graphite is an allotrope and stable form of carbon. Used as an anode, it is heat-resistant, electrically and thermally conductive, chemically passive and lighter than aluminum.
BATTERY USE				
LCO • LMO • LFP • NMC • NCA	LCO • NMC• NCA	NMC • NCA	LCO • NMC	LCO • LMO • LFP • NMC • NCA

Battery type: **LCO** – Lithium Cobalt Oxide; **LMO** – Lithium Cobalt Oxide; **LFP** – Lithium Iron Phosphate; **NMC** – Lithium Nickle Manganese Cobalt Oxide; **NCA** – Lithium Nickel Cobalt Aluminum Oxide.

Global drivers accelerating electric vehicle demand

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

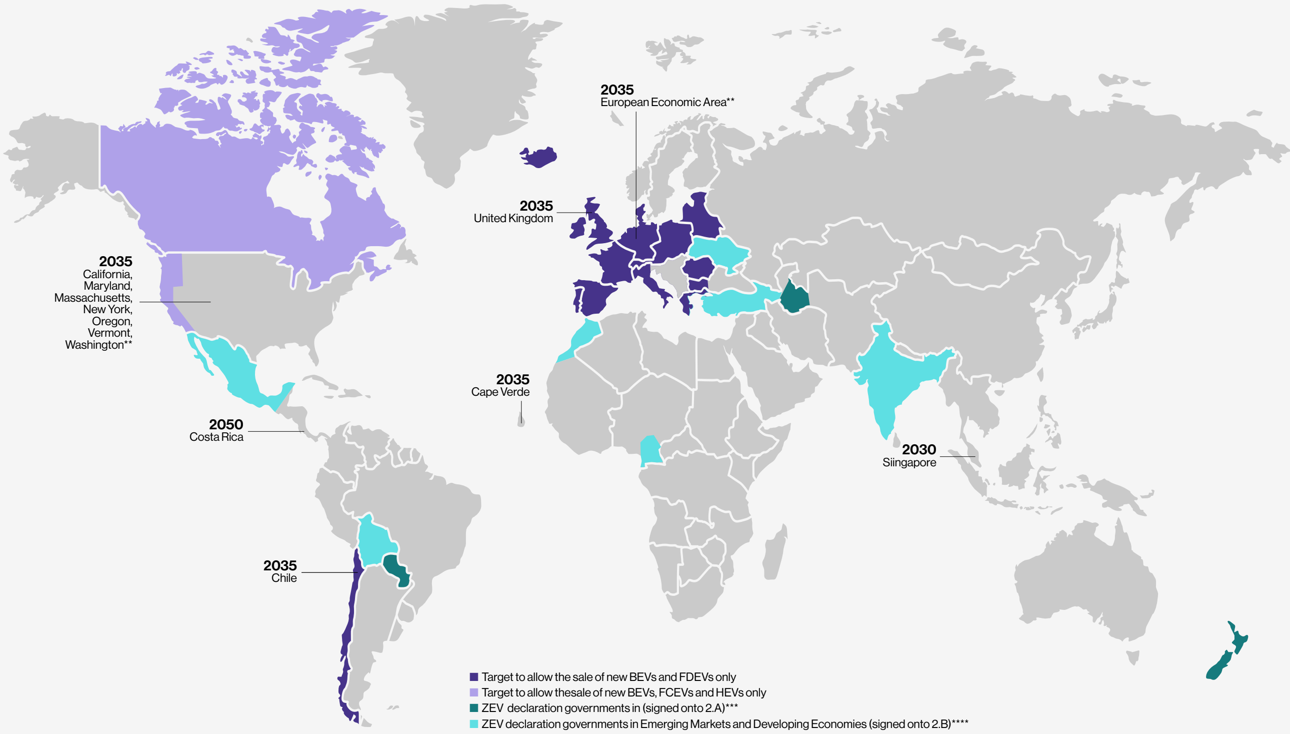
Government targets for fuel efficiency and carbon dioxide emissions will require unprecedented responses from Original Equipment Manufacturers (OEMs) of automobiles to meet those standards. In the absence of greater EV adoption, fuel efficiency improvement rates would need to double to meet new government standards. The auto industry is targeting EV penetration of 14.3% in 2025.[20]

However, some analysts project global auto electrification rates as high as 50% for passenger car sales by 2030.[21]

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. By 2035, all new vehicles sold in China must be powered by "new energy." Half must be electric, fuel cell or plug-in hybrid – the remaining half, hybrid vehicles. The UK has plans in place to ban sales of fossil-fueled vehicles by 2035. In Norway, where electric vehicles accounted for 83.7% of new registered vehicles in January 2022, 2025, is the point set at which all new cars must be new-energy vehicles.[22] Europe, Belgium, Ireland, and the Netherlands set 2030 as their deadline, while

[20] Berman, Dziuba, Hamilton. BMO Capital Markets (February 2018). The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See.
[21] Roskill. (2018, February 7). EV Raw Materials: Cobalt, Manganese, Lithium, Graphite, Nickel, and Rare Earths.
[22] Hill, Joshua, Norway's stunning new EV numbers: 84% of new car sales in January all electric, The Driven, February 3, 2022.

Governments with official targets to 100% phase out sales or registrations of new internal combustion engine cars by a certain date*



Includes countries, states, and provinces that have set targets to only allow the sale or registration of new battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and plug-in hybrid electric vehicles (PHEVs). Countries such as Japan with pledges that include hybrid electric vehicles (HEVs) and mild hybrid electric vehicles (MHEVs) are excluded as these vehicles are non-plug-in hybrids.

** The Canadian providence of British Columbia has a regulation to enforce its 2040 target, as do California, Maryland, Massachusetts, New York, Oregon, Vermont, and Washington for their 2035 targets. The European Union (EU) also has a regulation enforcing its 2035 target; it is applicable to the member states of the European Economic Area (EEA), that is the 27 EU member states and, pending adoption by the EEA Joint Committee, to some or all EEA European Free Trade Association (EFTA) states, which include Iceland, Liechtenstein, and Norway. Norway has set a 2025 phase-in target and Austria, Denmark, Greece, Iceland, the Netherlands, and Slovenia have set 2030 phase-in targets, but those are not binding.

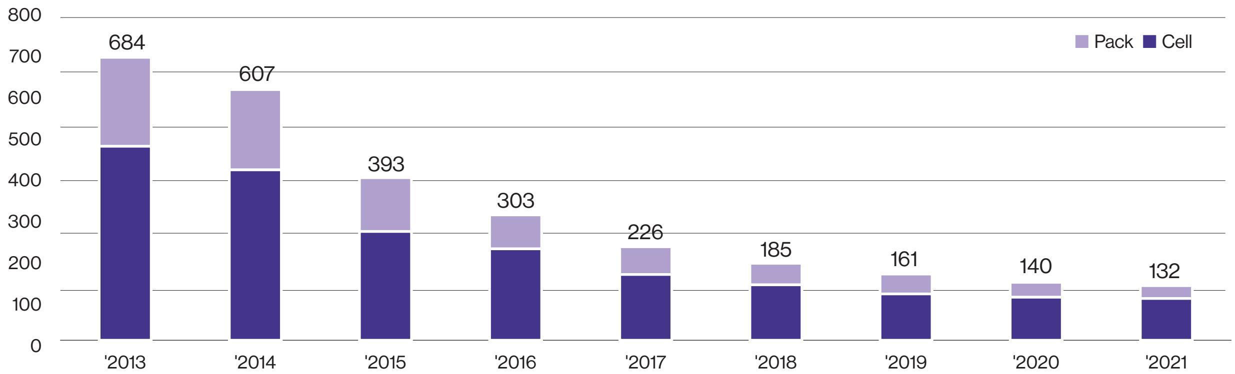
*** Zero-Emission Vehicle (ZEV) Declaration signatories to 2.A committed to phase-in targets by 2035 for lending markets and by 2040 globally. Countries with existing official targets (binding and non-binding) are not separately highlighted, including Austria, Belgium, Canada, Cape Verde, Chile, Croatia, Cyprus, Denmark, Finland, Greece, Iceland, Ireland, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Slovenia, Spain, Sweden, and the United Kingdom.

**** Zero-Emission Vehicle (ZEV) Declaration signatories to 2.B committed to work intensely toward accelerated proliferation and adoption of zero-emission vehicles.

Source: International Council on Clean Transportation, October 2023

Mass adoption expected to rise as prices continue to decline

Volume-weighted average lithium-ion battery pack and cell price split, 2013-2023



Source: Bloomberg NEF, Historical prices have been updated to reflect real 2023 dollars. Weighted average survey value includes 303 data points from passenger cars, buses, commercial vehicles, and stationary storage.

France and Germany lag behind with an end of 2040 deadline. In the U.S., only California has announced any kind of ban, limiting the sale of gasoline-powered cars by 2035.[23]

Falling Lithium-ion battery prices

Another factor supporting greater adoption of EVs is that battery prices, and consequently electric vehicles themselves, continue to get cheaper. As depicted in the chart below, the average price of a lithium-ion battery pack is now below $132 per/kWh, a 6% drop from $140/kWh in 2020.[24] To generate mass adoption, EVs and hybrid vehicles need to be priced comparably to gas-powered cars without subsidies.

Increased EV commitments from global auto makers

Global passenger EV sales experienced exponential growth in 2023, with 14.1 million units sold, a 34% increase over 2022.[25] While much of this growth has been driven by policy support in the U.S., Europe, and China, EV commitments from automakers have also risen dramatically, despite COVID-19 related model delays. Almost every global brand has committed to launching electric vehicles over the next five years. Progress on electric commercial vans and trucks is also picking up.

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

23 Source: World Economic Forum, China joins list of nations banning the sale of old-style fossil-fuelled vehicles, November 11, 2020. https://www.weforum.org/agenda/2020/11/china-bans-fossil-fuel-vehicles-electric/

24 BNEF, (November 30,2020), BloombergNEF's annual battery price survey finds prices fell 6% from 2020 to 2021. https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/#:~:text=Innovation%20Forum-,Battery%20Pack%20Prices%20Fall%20to%20an%20Average%20of%20%24132%2FkWh,Commodity%20Prices%20Start%20to%20Bite&text=Hong%20Kong%20and%20London%2C%20November,from%20%24140%2FkWh%20in%202020.

25 King, Neil, EVs Forecast to Account for Two Thirds of Global Light-Vehicle Sales in 2035, EV-Volumes.com, https://www.ev-volumes.com/#:~:text=EVs%20are%20therefore%20expected%20to,%2C%20down%20from%2035%25%20previously

and the challenges associated with the 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.

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 that acceleration EV demand.

Battery storage

Government incentives and private investment are fueling progress in utility-scale battery storage solutions. And with continued global growth in electric vehicles, a new opportunity is emerging 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 tWh 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 electric vehicle adoption, and the rising need for grid energy storage solutions. In particular, the growing global demand for electric vehicles has created investment opportunities at all levels of the EV value chain from: battery metals and material producers, 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 including: 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 electric vehicles.

Conclusion

- According to MarketsandMarkets, the global Lithium-ion battery market, which accounted for $56.8 billion in 2023, is expected to reach $187.1 billion by 2032, growing at an impressive compound annual growth rate (CAGR) of 14.2%
- A number of factors continue to fuel growth in lithium-ion batteries including solid demand for mobile devices, the accelerating pace of global electric vehicle adoption, and the rising need for grid energy storage solutions.
- Given the supply constrained capacity 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, improved battery chemistries and increased commitment from automakers with more than 500 new models. Rising consumer demand will create additional investment opportunities across the entire battery technology value chain.

To learn more about VettaFi Indexing click here

About VettaFi

VettaFi is a provider of indexing, data & analytics, industry leading conferences, and digital distribution services to ETF issuers and fund managers. It operates the ETFdb, Advisor Perspectives, and ETF Trends websites and the LOGICLY portfolio analytics platform – engaging millions of investors annually – empowering and educating the modern financial advisor and institutional investor. VettaFi owns and administers the EQM Indexes Series. For more information, please visit: www.vettafi.com.

VettaFi LLC, is a wholly-owned subsidiary of TMX Group Limited (TMX Group). For more information about TMX Group, please visit: www.tmx.com.

vettafi.com | 1330 Avenue of the Americas, New York, NY 10019

VettaFi Disclaimer

This Document Is Impersonal and Not a Solicitation. EQM Indexes, LLC is a wholly owned subsidiary of VettaFi LLC. VettaFi LLC, collectively with its affiliates and subsidiaries, is referred to herein as ("VettaFi"). This document does not constitute an offering of any security, product, or service. All information provided by VettaFi in this document is impersonal and not customized to the specific needs of any entity, person, or group of persons.

About the Index. The EQM Lithium & Battery Technology Index ("BATTIDX" or the "Index") tracks global companies associated with the development, production, and use of lithium battery technology including: 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 electric vehicles. The Index and its trademarked name are the exclusive property of VettaFi.

No Advisory Relationship. VettaFi is not a fiduciary or an investment advisor, and VettaFi makes no representation regarding the advisability of investing in any investment fund or other vehicle. This document should not be construed to provide advice of any kind, including, but not limited to, investment, tax or legal.

You Must Make Your Own Investment Decision. It is not possible to invest directly in an index. Exposure to an asset class represented by an index is available through investable instruments based on that index. You should not make a decision to invest in any investment fund or other vehicle based on the statements set forth in this document. You should only make an investment in an investment fund or other vehicle after carefully evaluating the risks associated with such an investment in the investment fund, as detailed in the offering memorandum or similar document prepared by or on behalf of the issuer. This document does not contain, and does not purport to contain, the level of detail necessary to give sufficient basis to an investment decision. VettaFi does not sponsor, endorse, sell, promote, or manage any investment fund or other investment vehicle that is offered by third parties and that seeks to provide an investment return based on the performance of any index.

No Warranties; Limitation of Liability. While VettaFi believes that the information contained in this document (collectively, the "Content") is reliable, VettaFi does not guarantee the accuracy, completeness, timeliness, or availability of the Content in whole or in part. VettaFi is not responsible for any errors or omissions, regardless of the cause, in the Content which may change without notice. VettaFi makes no warranties, express or implied, as to results to be obtained from use of the Content, and VettaFi expressly disclaims all warranties of suitability with respect thereto. VettaFi shall not be liable for any claims or losses of any nature in connection with the use of the Content, including but not limited to, lost profits or punitive or consequential damages, even if VettaFi has been advised of the possibility of same.

Research May Not Be Current. This document has been prepared solely for informational purposes based on information generally available to the public from sources believed to be reliable. VettaFi does not assume any obligation to update the Content following publication in any form or format.