STATE OF THE ELECTRIC VEHICLE

LITHIUM-ION BATTERY

MARKET

PRESCOUTER

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Advancements in battery technology and the electrification of the automobile have contributed enormously to the changing technological landscape we see all around us. Today, the race is on between different battery technologies to claim the top spot in a variety of applications. Ultimately, it is those applications and the fit between battery technology/chemistry and the requirements demanded by that application that will determine the victors of this war.

To better understand and forecast the coming changes within the battery market over the next decade — specifically, the lithium-ion battery (LIB) chemistries used in electric vehicles — we investigated relevant battery chemistries and looked at their technological evolution by analyzing academic research, patents, and an overview of the commercial landscape. We coupled this analysis with an overview of external factors that will drive battery adoption, namely the cost evolution of key raw materials, supply/demand projections, and investments in the space from key players and governments.

Our analysis forecasts that by 2030, lithium iron phosphate (LFP) batteries will have the largest share of LIBs used in electric vehicles. This evolution will be the result of a close contest between LFP and lithium nickel manganese cobalt oxide (NMC) type chemistries, which may ultimately be decided by the preferences of China, whose large investments in LFP and the LFP-manufacturing supply chain may tip the balance in favor of this chemistry.

SECTION 1

BATTERY CHEMISTRIES IN THE MARKET

To better assess the potential fit between market demands and relevant battery chemistries, we begin by presenting the most relevant lithium-ion battery chemistries for electric vehicle (EV) applications available in the market today. Research and development in these areas has led to great advances in performance, but safety concerns continue to be one drawback of these technologies, as many contain cobalt, which is toxic and dangerous to humans, and which can contribute to thermal degradation of the battery at elevated temperatures. The properties considered in choosing the relevant battery chemistries include energy and power density, safety concerns, cost, lifespan, and performance. Lithium iron phosphate (LFP), lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum (NCA), and lithium cobalt oxide (LCO) are the preferred battery chemistries for EV applications due to their distinguishing properties, namely, relatively high-energy densities and safety features.

The relevant battery chemistries are discussed in detail. For each chemistry, we provide a snapshot of the current market dynamics, the advantages and disadvantages of these batteries for EV applications, and an overview of key players and market trends. To learn more about the battery terminologies used in this report, please consult the Appendix.

Lithium Nickel Manganese Cobalt Oxide (NMC)

Market Dynamics

NMC batteries currently account for nearly 28% of global EV sales, and Fitch forecasts that market share is to grow to 63% by 2027[1]. NMC uses lithium nickel manganese cobalt oxide as the cathode and graphite as the anode. The specific energy density of NMC is 150–220 Wh/kg, with the thermal runaway being 210°C (410°F). The high cost and toxic nature of cobalt is leading battery manufacturers to move toward higher nickel content in cathodes. Compared to cobalt, nickel cells have a lower cost and longer cycle life. The main applications of NMC batteries can be seen in Figure 1.

The high cost and toxic nature of cobalt is leading battery manufacturers to move toward higher nickel content in cathodes.

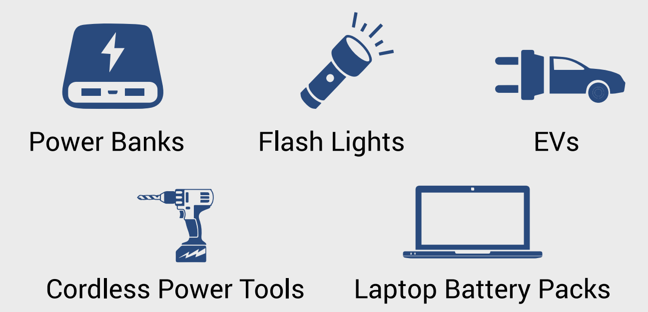

Figure 1: Applications of NMC batteries

NMC 811 cells use 8 parts nickel and 1 part cobalt and reach up to 300 Wh/kg, comparing well with the 265 Wh/kg available from lithium nickel cobalt aluminum oxide (NCA) batteries. The powerpack operates at full discharge for over 10 years of daily cycling, equivalent to a cycle life of over 3,650 cycles with over 70% capacity retention .

	NMC	DISCHARGE CAPACITY
STATE OF THE ART	**NMC 111:** $Li_{1+x}(Ni_{0.33}Co_{0.33}Mn_{0.33})_{1-x}O_2$	154 Ah/kg @ 0.1C
	NMC 523: $Li_{1+x}(Ni_{0.5}Co_{0.2}Mn_{0.3})_{1-x}O_2$	164 Ah/kg @ 0.1C
	NMC 424: $Li_{1+x}(Ni_{0.4}Co_{0.2}Mn_{0.4})_{1-x}O_2$	155 Ah/kg @ 0.1C
HI NICKEL	**NMC 622**	178 Ah/kg @ 0.1C
	NMC 811 and others	>185 Ah/kg @ 0.1C
MN RICH	**HE - NMC**	260 Ah/kg @ 0.1C
	HV - Spinel	140 Ah/kg @ 0.1C

Figure 2: The different types of NMC batteries[3]

1. http://www.mining.com/nmc-batteries-dominating-ev-sales-reach-63-global-market/
2. https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries
3. https://www.energy.gov/sites/prod/files/2014/11/f19/Fetcenko%20-%20Industry%20Partners%20Panel_0.pdf

Advantages

An NMC battery generally has a longer cycle life, more stability, and a higher energy density than lithium cobalt oxide (LCO) and lithium iron phosphate (LFP) batteries. It also has a lower cost of energy because of the ability of an NMC battery to cycle with more stability than an NCA battery. The battery has a high cycle life suitable for both off-grid and very unstable grids, with commercial products featuring a 60% state of charge (SOC) greater than 6,000 cycles at 90% depth of discharge (DOD).

Disadvantages

At a certain temperature, the cathode (cobalt in this case) releases oxygen, which makes the cell combustible because of the reaction between the electrolyte and oxygen. For an LFP cathode, the oxygen-phosphorus bond is not broken until $350^{\circ}C$, whereas this temperature range is much lower for NMC. Hence, NMC batteries are less safe because of the highly toxic nature of cobalt.

Recent Developments

Since NMC has recently gained improved energy density, it is now poised to be used more frequently in long-range EVs. Companies have switched from NMC 111 to NMC 442 to NMC 622, with NMC 811 slated for introduction in the next 2 years[4]. LG Chem and 3M have entered into a patent license agreement for using an NMC cathode. Previously, LG Chem was using Argonne National Laboratory's NMC cathode. The switch likely came due to patent coverage reasons, as Argonne's patents were valid only in the United States, whereas 3M patented NMC globally.

Key Players

LG Chem

Panasonic
HITACHI
SONY
SAMSUNG SDI
LISHEN
OptimumNano®
DLG electronics.com Measurement and Control Systems
Padre Electronics Co.,Limited
CHAM
合肥国轩高科动力能源有限公司 HEFEI GUOXUAN HIGH-TECH POWER ENERGY CO.,Ltd

4. https://cleantechnica.com/2018/03/04/exciting-developments-nmc-811-lithium-battery-technology/

Lithium Nickel Cobalt Aluminum Oxide (NCA)

Market Dynamics

NCA batteries are becoming increasingly important in electric powertrains and in grid storage because of the recent increment in energy density (>280 Wh/kg), which was previously in the 150-220 Wh/kg range[5] . They are subclassified into cylindrical and prismatic batteries.

Figure 3: The raw material content of an NCA battery cathode

Advantages

NCA batteries require a small amount of active materials yet can deliver a higher energy density. They are also more stable than NMC batteries due to the addition of aluminum.

Disadvantages

An NCA battery pose safely challenges when compared to LFP batteries, as they are more prone to thermal runways. Another setback is cost, as they are expensive to mass produce due to limited applications.

Recent Developments

For long-range vehicles, **Tesla** is currently using the NCA cell chemistry. Tesla was using NCA in the first Model S in 2012, and it had a 15% cobalt content. In 2017, **BASF** successfully tripled its NCA production capacity in Japan to meet increasing customer demands.

Key Players

Panasonic

GS Energy

TESLA

当升科技 EASPRING

BASF We create chemistry

5. https://cleantechnica.com/2018/03/04/exciting-developments-nmc-811-lithium-battery-technology/

Lithium Iron Phosphate (LFP)

Market Dynamics

LFP batteries use LiFePO4 as a cathode material and a graphite carbon electrode as the anode. The global market was valued at $4.76 billion USD in 2016[6] and is projected to grow at a CAGR of 20.7% from 2017 to 2025, reaching $25.47 billion USD by 2025. The overall market demand for LFP will double to over 200,000 tonnes/year. The Asia-Pacific region is expected to dominate the market, with the major application being automobiles.

The Asia-Pacific region is expected to dominate the LFP battery market, with the major application being automobiles.

Advantages

With operating ranges from -4.4°C to 70°C, LFP batteries handle far wider variations in temperature than other chemistries. They also have a slightly higher self-discharge rate and low cell voltage (3.3V). Thermal runaways are less common for an LFP battery, as it doesn't require cobalt.

Disadvantages

LFP batteries have a lower energy density and last for a shorter time period compared to NMC and NCA batteries.

Recent Developments

Lithium iron nanophosphate batteries can be used extensively in applications such as electric and hybrid vehicles and renewable energy generation. The Chinese battery maker Narada won a contract worth around $40 million USD to supply a lithium iron phosphate (LFP) battery system to a telecom operator in Bangladesh[7] . Nano One and Pulead Technology Industry have also recently formed a partnership to mass produce LFPs[8].

Key Players

6. https://www.marketwatch.com/press-release/lithium-iron-phosphate-material-and-battery-market-size-worth-2547-billion-by-2025-grand-view-research-inc-2017-05-17
7. https://www.bestmag.co.uk/tags/lithium-iron-phosphate-battery-system
8. https://investorintel.com/sectors/technology/technology-intel/nano-one-is-excited-by-their-lfp-battery-opportunity-with-pulead-technology/

Lithium Cobalt Oxide (LCO)

Market Dynamics

LCO batteries have a cobalt oxide cathode and a graphite carbon anode. The different types of LCOs include low-heating solid-state reaction batteries and liquid-phase synthesis batteries. The market was valued at $7.15 billion USD in 2016.

Figure 4 : Main applications of LCOs

Advantages

LCOs have a high current capability and longer calendar lifespan. They also have a high energy density and an increased safety level when compared to NMC batteries.

Disadvantages

Its relatively short life span, low thermal stability, and limited load capabilities are likely to act as restraints on demand.

Recent Developments

Nano One has built a pilot plant to demonstrate high-volume production as well as to optimize its technology across a range of materials. No other recent developments are noted in the LCO battery chemistry or its applications.

Key Players

NIPPON CHEMICAL INDUSTRIAL

湖南杉杉 Hunan Shanshan

NICHIA

Oriental

TIANJIN B&M SCIENCE AND TECHNOLOGY JOINT-STOCK CO., LTD

三德 Santoku Corp.

XTC

Jiangsu KLK Cobalt Nickel Metal Co, Ltd

CSGH

Lithium Manganese Oxide (LMO)

Market Dynamics

This battery chemistry uses manganese as the cathode and graphite as the anode. The LCO (cobalt-only) and LMO (manganese-only) batteries are precursors to NMC and NCA batteries. LMO batteries are usually used along with NMC in electric vehicles. This type of battery was first introduced in the Mitsubishi i-Mev with Toshiba's batteries. LMO-NMC blends are found in the batteries of the older Nissan Leaf models due to their cost advantages, but Nissan is also expected to switch to a pure NMC cathode in its second-generation models.

Advantages

The operating voltages of LMOs are high compared to LFP batteries. The thermal runaway for LMO is 250°C, which is relatively higher than NMC and NCA, hence they are touted as being safe.

Disadvantages

LMOs have a much shorter lifespan, ranging between 300 and 700 cycles. In addition, their high charge promotes thermal runaway and degrades quickly at elevated temperatures.

Recent Developments

In 2018, Nissan Leaf launched a blend of LMO/NMC with a 40 kWh battery size, and the batteries were manufactured by AESC/LG Chem[9].

Key Players

LG Chem

NICHIA

TOSHIBA

中信国安集团有限公司
CITIC GUOAN GROUP CO.,LTD.

9. https://insideevs.com/news/338432/nissan-leaf-40-kwh-battery-deep-dive/

Battery Comparison With Respect to EV Application

The growth of this market is being fueled by an increase in demand for plug-in vehicles, a growing need for automation and battery-operated material-handling equipment in multiple industries, and strengthening demand for smart devices and other industrial goods.

The following figure shows the characteristics of the most popular battery chemistries[10].

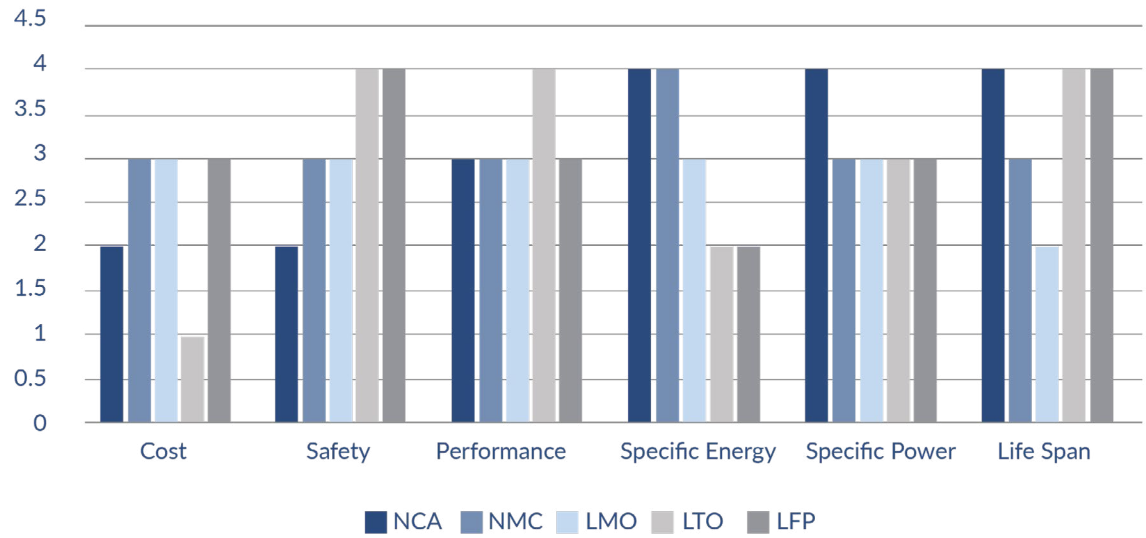

Figure 5 : A comparison of the battery characteristics of different battery types

At present, batteries with cobalt (NMC/NCA) are preferred due to their high energy density. However, safety remains an issue as NMC and NCA are prone to thermal runaways - especially as the devices get smaller. Thermal runaways may be caused by overcharging, an internal fault, physical damage to the battery, a hot environment, or a combination of the above.

LFP provides a significantly reduced chance of thermal runaway (518°F (270°C)) but provides relatively low energy and contains no cobalt. Commercial LFP batteries have a cycle life of up to 3,000 discharges, maintaining an SOC over that lifetime between 50%-60%[11]. Although lithium iron phosphate (LFP) has lower cycle life, it is used widely in China and as such the Chinese (and global markets) benefit from a well developed manufacturing infrastructure and supply chain there.

Although the cost of NMC batteries compared to LFP are high, they consume less earth materials and result in a relatively higher energy density. On the other hand, LFP batteries are the safest lithium-ion batteries in the market[12] whereas NMC/NCA are vulnerable and prone to accidents.

NMC 811 uses less cobalt compared to the previous versions and Tesla, for instance, uses less cobalt than actually present in the market[13]. The next step for LFP batteries is to increase its energy density from 250 Wh/l to close the gap with NMC batteries (580 Wh/l).

LFP batteries are the safest lithium-ion batteries in the market.

10. http://www.bcg.com/documents/file36615.pdf
11. https://www.solacity.com/how-to-keep-lifepo4-lithium-ion-batteries-happy/
12. http://dragonflyenergy.com/thermal-runaway-lithium-ion-batteries/
13. https://insideevs.com/news/338268/tesla-panasonic-quietly-outmaneuver-all-lithium-battery-manufacturers/

SECTION 2

CURRENT STATE OF THE LITHIUM-ION BATTERY MARKET

Market Overview

The global lithium-ion battery market was valued at $36.2 billion USD at the end of 2018 and is expected to grow at a CAGR of 14.9% from 2018 through 2026, to reach $109.2 billion USD by 2026. The cathode market is forecast to reach $23 billion USD by 2025[14].

14. https://www.reportsanddata.com/report-detail/lithium-ion-battery-market

Demand for Batteries

The EV battery market is currently growing rapidly (13.9%). Lithium demand from automotive applications reached over 34,000t LCE (lithium carbonate equivalent) in 2017, which is forecast to more than double by the end of the decade.

Supply-Megafactory Projection

In 2027, lithium-ion batteries in automotive applications are forecast to exceed 1 TWh in capacity, while their use in power along with motive, portable electronics and energy storage systems is expected to contribute a further ~140 MWh. The majority of this capacity will be located in China, which is projected to have 57% of the global total capacity by 2028[15]. The table shows the expected capacity in the future given the current market requirements.

The majority of LIB capacity will be located in China, which is projected to have 57% of the global total capacity by 2028.

		Capacity		
Region	Company	(Gwh, 2018)	(Gwh, 2023)	(Gwh, 2028)
China (Total)		134.5	405	631
	CATL		50	
	Nanjing (LG Chem) Plant 1		35	
	Nanjing (LG Chem) Plant 2		28	
	Samsung SDI		25	
	Funeng Technology		25	
	BYD co ltd		24	
	Lishen		20	
North America (Total)		20.98	1	148
	Tesla Gigafactory		50	
Europe (Total)		19.6	93.5	207
	LG Chem		22	
Asia Excl China		45.5	78.5	111.5

Table 1. Supplier capacity projection

15. http://futurefuelstrategies.com/wp-content/uploads/2019/03/MR_Batteries_Mar2019.pdf

The figure below, created by PreScouter with data taken from Visual Capitalist[16], illustrates the region-wide capacity projected by 2023 and 2028.

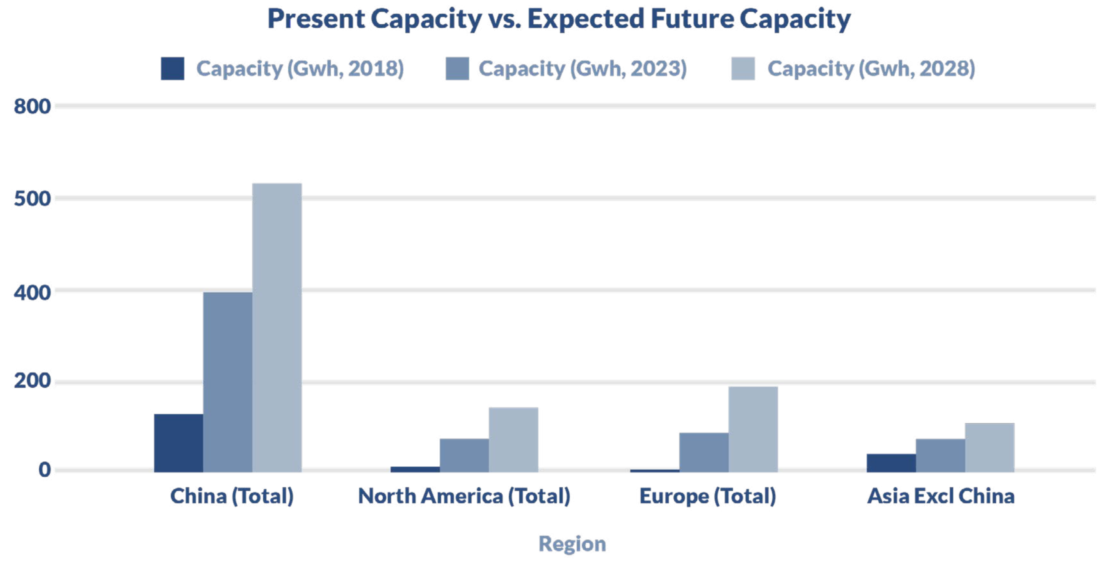

Figure 5. Region-wide capacity projection

China is expected to lead the race with a high demand for electric vehicles. The country has started a credit measure to analyze the carbon footprint of each company, in which Ford tops the list.

Evolving Chinese Automarket

Sales of EVs in China reached 770,000 units in 2017[17]. China is expected to outrun the US market because of the strict new energy vehicle (NEV) credit scores and upgrades to existing electric vehicle norms. Government regulation in China for starting, lighting, and ignition (SLI) engines states that from 2019, major manufacturers in China will be punished unless they meet quotas for zero- and low-emission cars or they buy credits from other companies that exceed the quotas. Companies that have a head start on producing NEV credits will have the highest credit scores. Those include BYD Co., BAIC BluePark New Energy Technology Co., and Geely Automobile Holdings Ltd., according to China's Ministry of Industry and Information Technology. Though their volumes are still small, upscale electric car makers such as Tesla and NIO are eventually set to obtain high scores.

The EV market is to dominate the LIB market by 2028.

Criteria for calculating the credit scores include type of EV, curb mass, vehicle range, fuel consumption, and energy consumption[18] . Considering the lower criteria, NMC seems to lead the NEV ranking because of its high energy density. However, advances in energy density due to research and development will allow LFP to also compete on credit scores.

The EV market is to dominate the LIB market by 2028, with ~7.5x times more demand for LIBs coming from electric vehicles than from both electronics and storage systems combined.

16. https://www.visualcapitalist.com/the-lithium-ion-megafactories-are-coming-chart/
17. https://www.scmp.com/business/china-business/article/2169698/made-china-2025-worlds-biggest-auto-market-wants-be-most
18. https://www.theicct.org/sites/default/files/publications/ICCT_China-NEV-mandate_policy-update_20180111.pdf

Battery Application Requirements

Every battery application has its own specific requirements. Some of the most important battery specifications include energy density, power density, cycle life, safety, toxicity, capital cost, and charging time. The following table describes the requirements EVs will demand from their energy storage solution, as well as the current state of each specification.

Needs	Full EV
Safety	
Toxicity	
Cycle Lifetime	
Power Density	
Energy Density	
Capital cost	
Reliability and charging time	
Current battery	Nimh for Hybrid, NMC or NCA, LFP for small capacity PHEV and NMC for larger capacity PHEV.
Current requirements (Reasons for advanced tech)	Stringent emission norms, Capital cost is high and low energy density, Fast charging time is required.

Table 2. Battery application requirements

A few insights can be derived from the graphic above:

- Safety, toxicity, energy density, reliability, and charging time are the categories that still need the most improvement to match market needs. Research and development of battery chemistries over the next few years will focus on reaching the requirements for EVs in each of these categories and will be market driven.
- Power density, safety, lifetime, and cost requirements have already been achieved.
- There is still room to improve LFP. Although LFP's energy density is lower (0.52 kWh/Kg) when compared to that of NMC/NCA (0.72 kWh/Kg), it poses less threat in terms of safety and toxicity, thus increasing the density will make it a fierce competitor to NMC chemistries.
- Note that for commercial vehicles, safety and charging time remains a huge barrier.

SECTION 3

THE ELECTRIC VEHICLE MARKET: EVOLUTION AND TRENDS

Following our analysis of the relevant battery chemistries, we looked at the evolution of the electric vehicle market and the drivers that would impact its growth over the next decade.

EV Battery Evolution

Following an experimental phase with a large variety of costly, low-volume concepts, the appearance of the Nissan Leaf EV in 2011 led to the dominance of the LMO-type battery. NMC batteries went mostly into the GM Volt. The next phase was the fast expansion of Tesla with their large NCA batteries, developed in partnership with Panasonic.

Starting in 2015, fast growth in China generated more LFP share in global shipments, mostly supplied by BYD. From mid-June 2018, new requirements regarding e-range (>150 km) and specific battery capacity (>105 Wh/kg) became effective for subsidy approval. This has caused most LFP batteries to become phased out from light vehicles, and NMC cathodes are expected to grow more. The evolution of battery tech is explained in the timeline below.

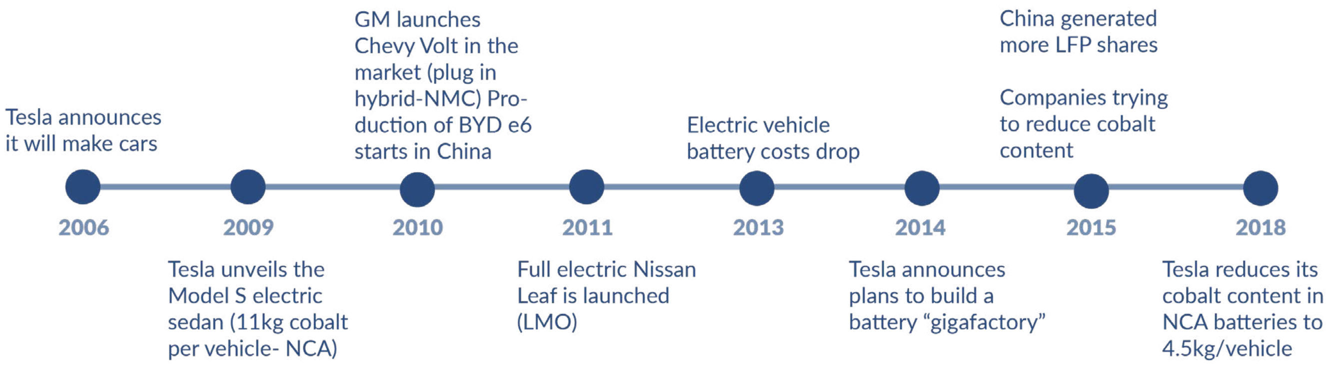

Figure 6. EV Battery Evolution

Key Trends and Market

Unlike internal combustion engine (ICE) vehicles, an electric vehicle uses fewer hardware parts. Batteries are the sole driving components of an electric vehicle. An ideal battery chemistry helps the EV in attaining higher power and higher energy density and is also safe.

Cost remains a huge factor in EV commercialization. Hence the supply and cost of raw materials impact battery prices. Technological developments are also a driving force to meet ideal battery requirements. The battery shift over the years didn't make a positive impact until NMC/NCA were put into practice. The primary market drivers are discussed below.

Raw Material Price and Availability

The price of cobalt was steady between 2012 and 2016. Due to a global supply shortage, cobalt prices rose over 120% in 2017[19]. Prices peaked in March 2018 and then fell back to near 2017 pricing in October 2018. The demand for cobalt will surpass the supply by 64,000 tonnes in 2030[20], implying that costs will likely spike before then. The figure below shows the historical raw materials price for key materials used in battery production. The large fluctuation in prices can be attributed to the spike in demand due to increased EV sales.

19. http://www.mining.com/nmc-batteries-dominating-ev-sales-reach-63-global-market/
20. https://phys.org/news/2018-11-cobalt-potential-bottleneck-transition-electric.html

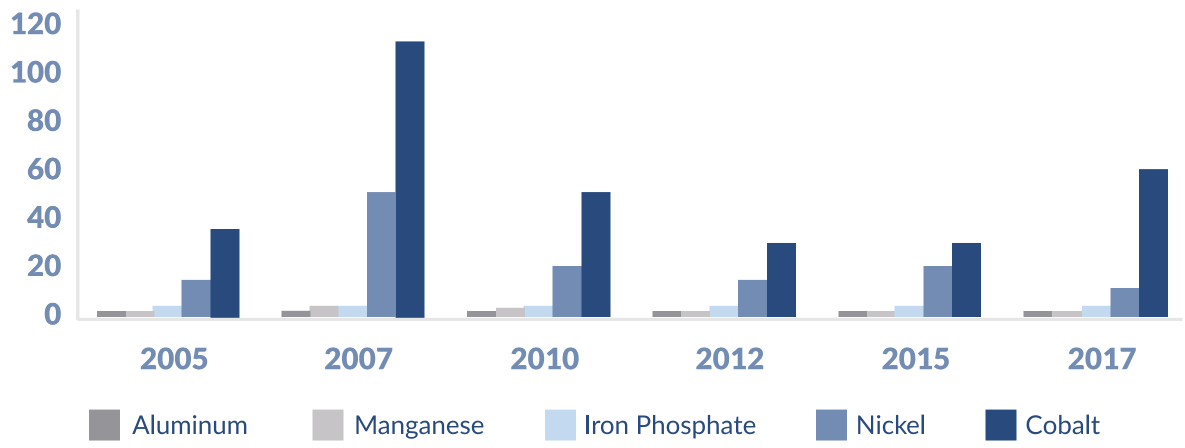

Figure 7. Raw materials price [21]

The price spike has focused attention on lithium-ion chemistries that don't require cobalt, such as lithium iron phosphate, lithium manganese oxide, and lithium titanate[22] . The large cost of cobalt compared to the other materials will be a difficult barrier to overcome, especially since the advantage in energy density provided by cobalt is reduced through development of other battery chemistries. Cobalt is a by-product of nickel production. The cost of nickel in 2010 decreased despite the demand surpassing the supply. But it is likely to increase due to an increased demand through the use of NMC for EVs.

There has been stiff competition between the miners of cobalt and nickel since the introduction of NMC 111 batteries. Nickel and cobalt both help batteries deliver high energy density. But cobalt's toxicity poses a threat to safety concerns. Developments in the industry and pressure from automakers to reduce cobalt's presence led to NMC 811, which uses 8 parts nickel and 1 part cobalt, yet the cobalt demand is likely to persist, as it provides more energy density than nickel. Cobalt consumption will go down relatively; but due to expansion and growth, the prices and demand are expected to increase because of a mismatch between supply and demand.

Increasing sales due to reducing battery prices

Over the course of the past couple of years, with an increased supply of raw materials and advancing technological developments, battery prices are decreasing every year and are expected to reach $100/kWh by 2026[23] . Along with stringent carbon emission norms, battery price will drive the commercialization of EVs in major markets sooner than expected. To boost the market, governments are also promoting the production of EVs by giving incentives and discounts to original equipment manufacturers (OEMs) and subsequently to consumers. The following figure illustrates a forecast of the increasing EV sales and the decreasing battery prices.

21. https://www.adlittle.com/sites/default/files/viewpoints/adl_future_of_batteries-min.pdf
22. https://www.greentechmedia.com/articles/read/11-lithium-ion-battery-makers-that-dont-need-cobalt#gs.3hqQbrA
23. https://www.theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

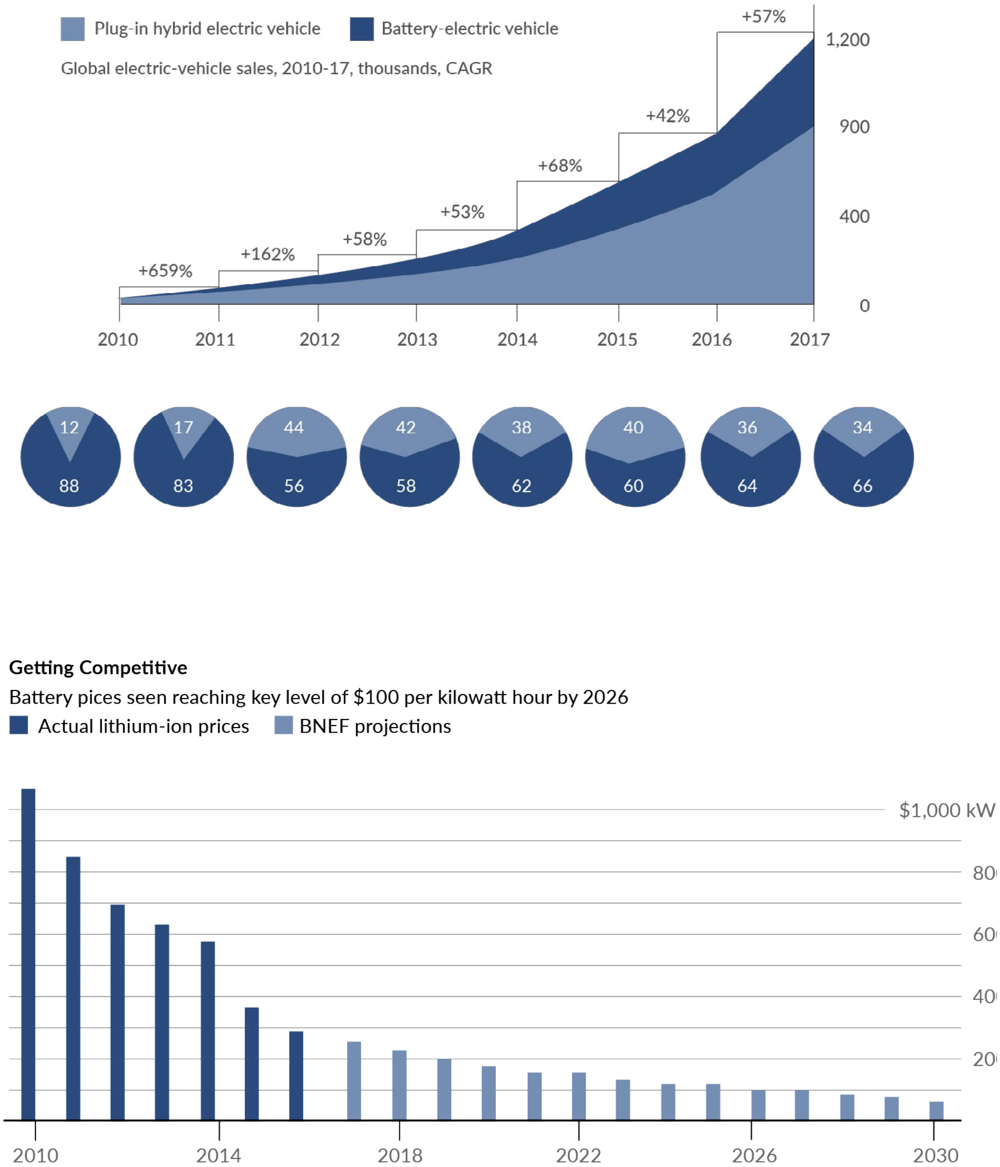

Figure 8. Increasing EV vs. Decreasing battery prices (Source: McKinsey[24] and Bloomberg[25])

NMC/NCA Adoption

NMC chemistries have become automotive OEMs' preferred technology in recent years. The target for NMC 811 includes 300 Wh/kg and $100/kWh. The current cost of NMC 811 is close to $176/kWh Companies are working toward deploying batteries containing less cobalt due to the spiking prices and toxicity concerns.

Today, LFP chemistries dominate the Chinese market with over 44% of the total battery chemistry demand. Though the rest of the world prefers NMC chemistries, China's dominance of the sector over the next decade will increase the advantages of LFP compared to NMC. China's vast resources in earth materials such as phosphate also lead to a preference of this chemistry.

24. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-global-electric-vehicle-market-is-amped-up-and-on-the-rise
25. https://www.bloomberg.com/news/articles/2017-11-28/electric-cars-need-cheaper-batteries-before-taking-over-the-road

CONCLUSIONS

Lithium-ion cells, and specifically the battery chemistries NMC and LFP, will be the dominant energy storage source for electric vehicles over the next 10 years.

Our analysis concludes that due to a combination of technological, geopolitical, and economical factors, the lithium iron phosphate battery is expected to be the market leader for EV applications by 2030. NMC will be the first to dominate this sector in the early 2020s, but it will be overtaken by LFP when a new rise in cobalt prices coincides with a boost of LFP's energy density achieved through R&D. The rise in cost of cobalt will also increase the price of NMC cells compared to LFP cells, as they contain cobalt, thus accelerating market favor for LFP.

Supporting facts

China has already begun developing a strategy targeting LFP at the center of its EV energy storage ecosystem. The country has a large resource of the raw materials required (namely, phosphate), and they are further developing the chemistry to increase energy density. China has already begun developing the infrastructure suitable for LFP. Tesla is also expected to opt for LFP in China via a partnership with CATL , making this battery the leading competitor of NMC .

Considering the toxicity of cobalt and its major presence in NMC, coupled with the negative market sentiment toward toxic materials, the market will continue to shift away from cobalt chemistries.

While LFP does suffer from lower energy density[26] than NMC at the moment, continued research and development will help bridge the gap with NMC. Soltaro has been doing R&D and developing LFP batteries in China for more than a decade. They have established research and innovation facilities around the world, including R&D centers based in China, the United States, and Europe, as well as at worldwide cooperating universities and laboratories. Soltaro dedicates more than 8% of its yearly revenue to technological innovation and new product development and is just one player doing this kind of research.

LFP is already present and used heavily for commercial vehicles and heavy-duty electric buses and trucks, due to its increased safety. This share will continue to increase with developments boosting energy density.

Market impact

The market for EVs will continue to grow rapidly, driven in part by lower energy costs, infrastructure development, and better component development. The cost of rare-earth materials will spike, with an increase in demand driven by society's move away from fossil fuels. Companies and manufacturers catering to this space will have to satisfy consumers' contradictory demands: increased energy density (and thus range) on their EVs, combined with low cost and use of safe, sustainable materials.

If LFP gains market share over NMC, the Chinese market will become the center of the electric vehicle segment, with core stakeholders and competencies in research and development, manufacturing, and commercial products.

Increased adoption of EVs and increased battery production capacity will decrease the cost of batteries, which will lead to a new market of budget EVs.

26. https://electrek.co/2019/03/11/tesla-talks-with-battery-giant-catl-china/

ABOUT THE AUTHORS

Dr. Sofiane Boukhalfa is a Senior Project Architect and Managing Director of the High Tech and Aerospace & Defense Practice at PreScouter.

Kishore Ravichandran is an Advanced Degree Researcher at PreScouter. He holds a Master's degree in Industrial Engineering & Management and a Micromasters Degree in Supply Chain Management. Previously, he worked for an automobile supply chain startup.

APPENDIX - BATTERY TERMINOLOGY

Cathode: An electrode that, in effect, oxidizes the anode or absorbs the electrons. During discharge, the positive electrode of a voltaic cell is the cathode. When charging, that reverses and the negative electrode of the cell is the cathode.

Anode: During discharge, the negative electrode of the cell is the anode. During charge, that reverses and the positive electrode of the cell is the anode. The anode gives up electrons to the load circuit and dissolves into the electrolyte.

Energy density: Ratio of cell energy to weight or volume (in watt-hours per pound, or watt-hours per cubic inch).

Power density: iA measure of power output per unit volume.

Specific energy: The ratio of the energy output of a cell or battery to its weight (Wh/kg). This term is used interchangeably with gravimetric energy density.

Battery capacity: The electric output of a cell or battery on a service test delivered before the cell reaches a specified final electrical condition, which may be expressed in ampere-hours, watt-hours, or similar units Cycle: One sequence of charge and discharge.

Cycle life: For secondary rechargeable cells or batteries, the total number of charge/discharge cycles the cell can sustain before it becomes inoperative. In practice, end of life is usually considered to be reached when the cell or battery delivers approximately 80% of rated ampere-hour capacity.

State of charge (SOC): Available capacity expressed as a percentage of some reference. In EV applications, the SOC is used to determine range.

Depth of discharge (DOD): The inverse of SOC used in conjunction with the lifetime of the battery.

Coulombic efficiency (CE): Ratio of the total charge extracted from the battery to the total charge put into the battery over a full cycle

"I don't know enough about X, and I don't have the time to research and learn it. Quickly get me up-to-speed on what I (specifically for my role and context) need to know, so I can understand my options."

Spend less time on tedious, tactical activities	Spend more time on high-impact, strategic activities
Calling external innovators for information	Collaborating with external innovators
Searching databases	Analyzing landscapes that are state of the art
Studying research journals	Road-Mapping internal programs
Mining large amounts of data	Making decisions

Have top tier advanced researchers work on your project

Our clients value the unbiased insights and innovative thinking that our network of over 2,500 researchers provides.

We take care of everything

Our proven system removes the stress of interviewing, selecting and managing talent to produce high quality results.

"PreScouter made us aware of 23 emerging technologies that we probably would not have become aware of (otherwise)"

Dr Richard Demke

SUNSTAR

PRESCOUTER IS TRUSTED BY OVER 500 CLIENTS - AND COUNTING

Micron · Coca-Cola · BASF We create chemistry · BD · CLOROX · AFTRON TRUE VALUE, TRUE QUALITY

EXPERIENCE IN MULTIPLE INDUSTRIES

Materials · Packaging · High Tech · Transportation & logistics · Consumer Goods · Natural Resources · Medical · Food and Beverage · Aerospace & Defense

PreScouter quickly gets Corporate Innovators up-to-speed on what they need to know to make informed decisions.

PreScouter, Inc. 29 E Madison St, Suite 500, Chicago, IL 60602 info@prescouter.com (872) 222-9225