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An Introduction to the Electric Vehicle Batteries Industry

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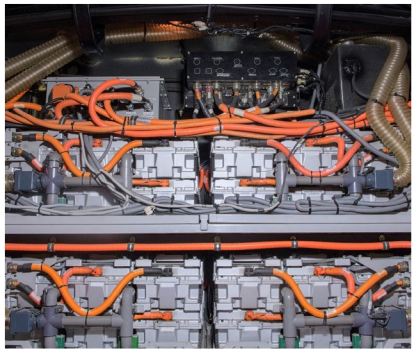
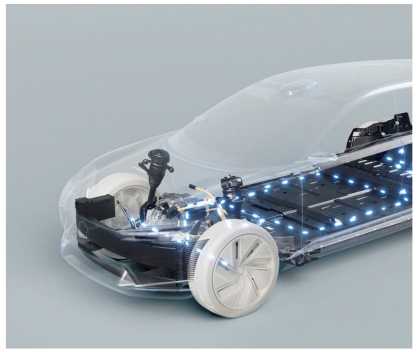


Electric Vehicles Battery 101

Next-generation Battery Technologies

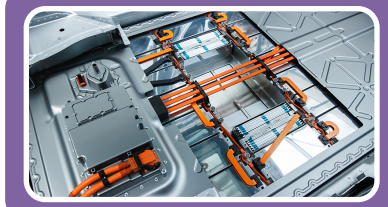


Market Trends

Major Players

Electric Vehicles Battery 101

Types of Batteries for Hybrid and Plug-In Electric Vehicles



Lithium-Ion Batteries

- Most of today's PHEVs and EVs use lithium-ion batteries.
- High energy per unit mass, high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge.
- Most components of lithium-ion batteries can be recycled, but the cost of material recovery remains a challenge for the industry.

Nickel-Metal Hydride Batteries

- Widely used in HEVs, offer reasonable specific energy and specific power capabilities.
- Longer life cycle than lead-acid batteries and are safe and abuse tolerant.
- The main challenges with nickel-metal hydride batteries are their high cost, high self-discharge and heat generation at high temperatures, and the need to control hydrogen loss.

Lead-Acid Batteries

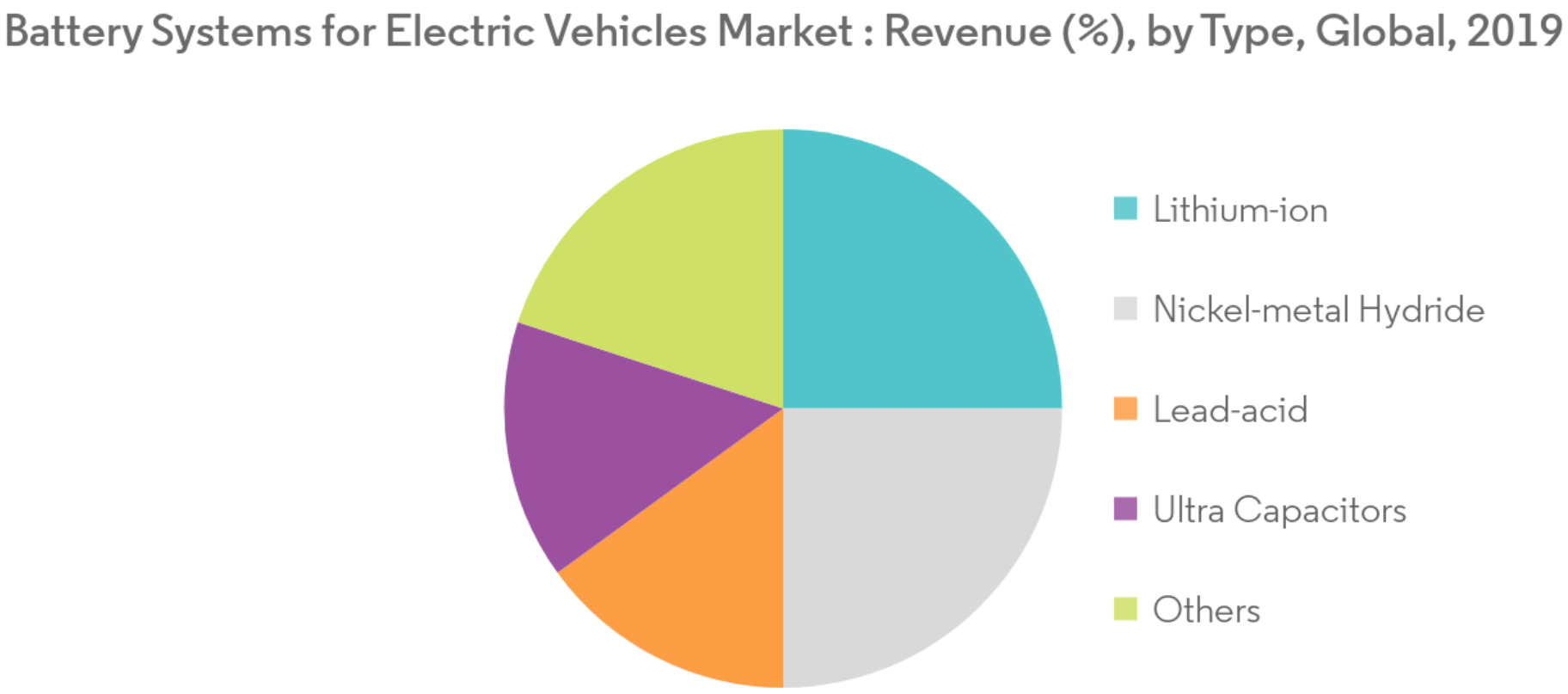
- Lead-acid batteries can be designed to be high power and are inexpensive, safe, and reliable.
- However, low specific energy, poor cold-temperature performance, and short calendar and cycle life impede their use.

Ultracapacitors

- Ultracapacitors store energy in a polarized liquid between an electrode and an electrolyte.
- Ultracapacitors can provide vehicles additional power during acceleration and hill climbing and help recover braking energy and can be useful as secondary energy-storage devices in electric-drive vehicles

Source: Alternative Fuels Data Center (AFDC)

Battery Systems for Electric Vehicles Market by Type



Source : Mordor Intelligence

Key Battery Technology Performance Characteristics

Energy Density

- Energy density is also known as volumetric energy density (Wh/L) or gravimetric energy density, which is defined as specific/gravimetric energy (Wh/kg) in technical terms. These two values are associated directly to the amount of energy that can be stored per unit volume or mass.

Power Density

- Battery power density is the amount of energy released by a battery when it is discharged within a given capacity. Specific power, like specific energy, refers to the amount of energy produced per unit of mass.
- Charging rate is a term used to describe the amount of power required to charge a device (C-rate). The discharge power of a battery measures how much energy it can produce at any given moment, while the C-rate embodies how fast a battery can be fully charged.

Life Span

- A battery's capacity decays with the amount of charge and discharge cycles, showing how long it will last. A battery should be reused (second life applications) or recycled once it has degraded to a point when it is no longer suitable for its intended application.

Cost

- The cost of battery is usually defined on a per kWh basis and is the key focus in achieving EV cost parity with internal combustion engine (ICE) vehicles as a battery pack system is the most expensive single component of an electric vehicle (EV).

Safety

- Because of the flammable liquid electrolyte and the release of thermal energy when the cathode material 'fatigues' after a certain number of cycles, battery safety is a concern. The rising concerns over battery safety could inhibit the wide adoption of EVs and batteries for energy storage applications.

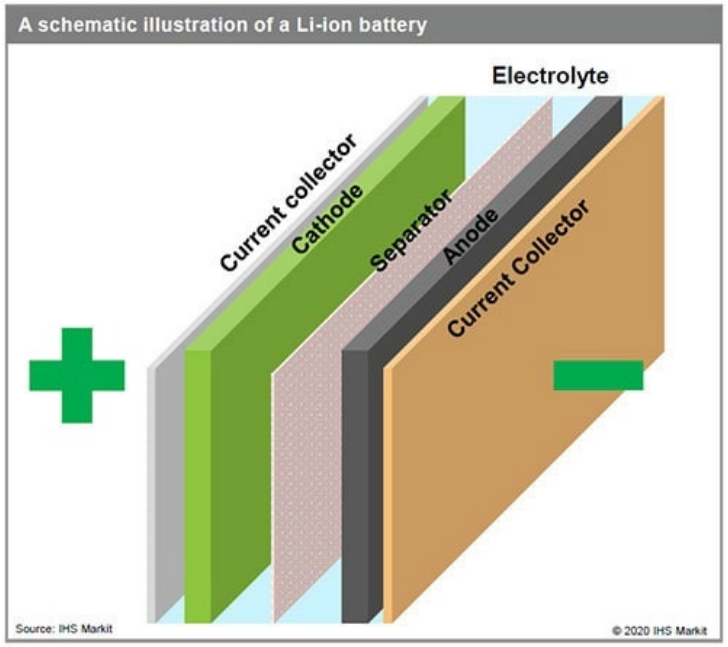
Source: HIS Markit

Battery Parameters Comparison

	Li-ion Battery	NiMH Battery	Lead-acid Battery
Mass Energy Density	100-180 Wh/kg	40-120 Wh/kg	30-40 Wh/kg
Volume Energy Density	200-300 Wh/L	140-400 Wh/L	60-75 Wh/L
Power Density	1000-5000 W/kg	300-1000 W/kg	180 W/kg
Charge/Discharge Efficiency	95-99%	65-80%	70-92%
Self-Discharge Rate	1-5%/ month	~30%/month	3-20%/month
Cycle Durability	500-15000 cycles	500-1000 cycles	500-800 cycles
Typical Cost	$0.50-$2.50/Wh	$0.30-$0.60/Wh	$0.15-$0.30/Wh

Source: https://www.omazaki.co.id/en/electric-car-batteries-and-their-characteristics/

Anatomy of Li-ion Batteries



Battery Components	Typical Composition	Function
Cathode	Lithium, Nickel, Cobalt, Manganese, Aluminum, Iron, and Phosphate	Contributing Li-ions through the channel of electrolyte and electrons to be stored at anode side
Anode	Graphite, Silicon (Si)	Keeping Li-ions stored when battery is charged and releasing Li-ions and electrons back to cathode when discharged
Separator	Polyethylene (PE)	Keeping cathode and anode materials separated while allowing Li-ions capable of travelling between them
Current collector (Cathode)	Aluminum (Al)	Collecting electrons generated from the electrochemical reaction at the cathode side while preventing it from being oxidized by cathode materials
Current collector (Anode)	Copper (Cu)	Collecting electrons generated from the reaction at the anode side while preventing it from being oxidized by anode materials
Electrolyte	Solvents (EC, DMC, DEC, EMC, PC, and etc.); Salts (LiPF6, LiClO4, LiBF4, and etc.)	Providing Li-ions with a good conductivity while maintaining a good thermal stability and a wide operable voltage window

Source: HIS Markit

LiFeMnPO4 Lithium Batteries vs Ternary Lithium Batteries

Ternary Lithium batteries and LiFeMnPO4 batteries are the two main types of Lithium Batteries that are used in electric vehicles.

- Lithium iron phosphate battery (LiFeMnPO4) refers to a lithium ion battery that uses lithium iron phosphate as a positive electrode material.
  Advantages： High temperature resistance, strong safety and stability, low price and better cycle performance.

- Ternary material lithium battery refers to a lithium battery that uses lithium nickel cobalt manganate as the positive electrode material and graphite as the negative electrode material.
  Advantages： High power and energy density, high-rate charging and low-temperature resistance.

	Power Density	Energy Density	Life Cycles	Safety	Cost
LiFeMnPO4	HIGH	MEDIUM-	HIGH	HIGH	LOW
Ternary	MEDIUM	HIGH	LOW	POOR	MEDIUM

Source: https://ferkart.com/lifepo4-vs-ternary/

Lead Acid Battery Types

Flooded (Wet Cell) Lead Acid Batteries

Flooded Lead Acid batteries are the most commonly found lead acid battery type and are widely used in the automotive industry. They provide the most cost effective solution, as the least cost per amp hour, of any lead acid battery type.

The modern wet cell comes in two styles; **serviceable** and **maintenance free**. Normal flooded batteries require extra care and regular maintenance in the form of watering, equalizing charges and keeping the terminals clean. Flooded cells need to be mounted the right way up and can be susceptible to spillage.

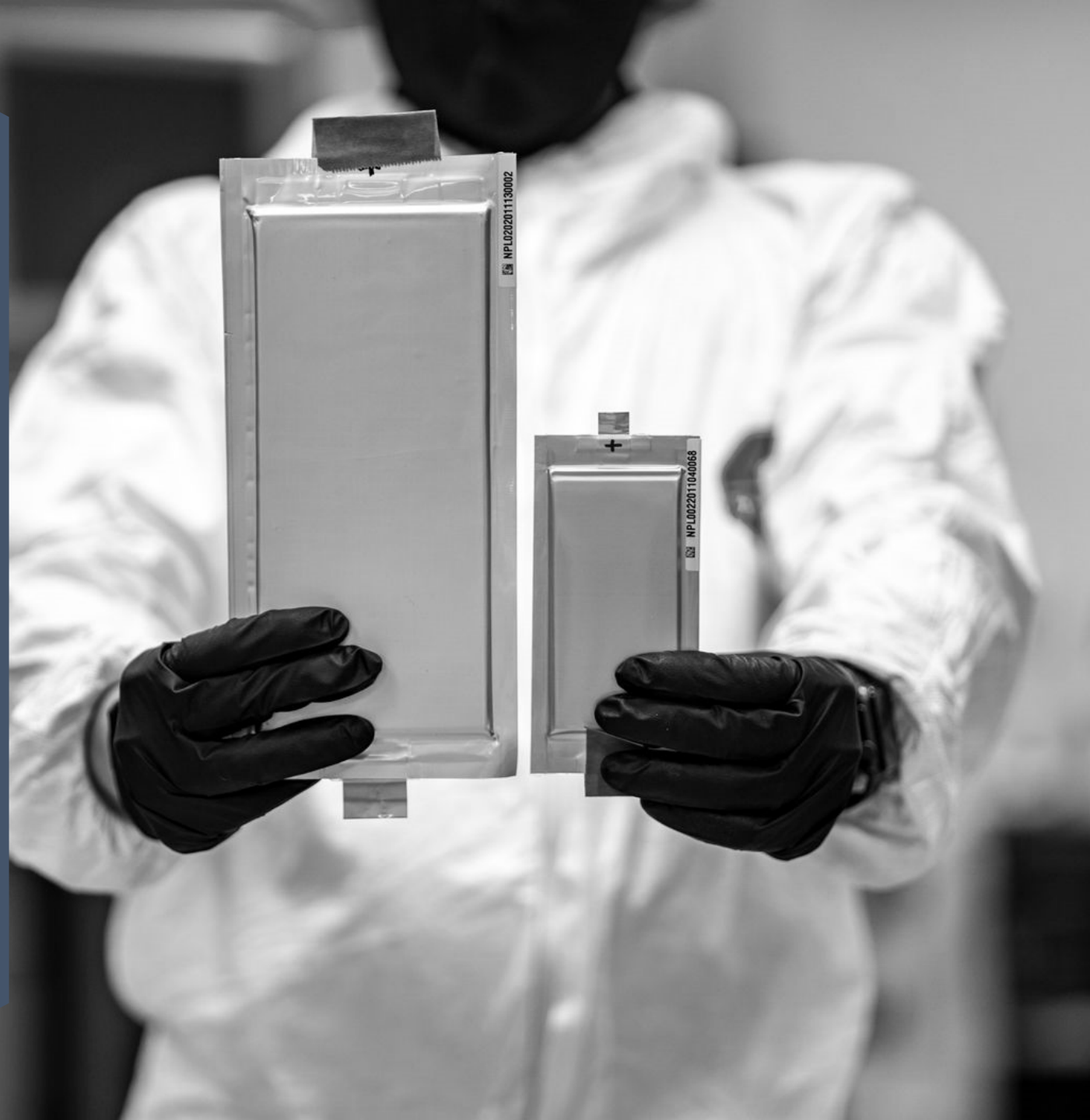
Valve Regulated Lead Acid (VRLA) Acid Batteries (a sealed lead acid (SLA) battery)

- **AGM (Absorbed Glass Matt) Sealed Lead Acid Battery**
  fast recharge; low cost; high energy density; standard shipping

- **Gel Cell (gelified electrolyte) Sealed Lead Acid Battery**
  completely maintenance free; standard shipping; low discharge rate

Source: https://www.mrpositive.co.nz/buying/knowledge-base/lead-acid-battery-types/

Next-generation Battery Technologies



Next Generation Li-ion Battery Technology

Solid State Battery (SSB)

Key technology to eliminate battery fire concerns and deliver moderate performance improvements.

- Cathode material: NMC 811, NCA 90, LNMO (high-voltage)
- Anode material: graphite with large amount of pure Si or Li-metal
- Electrolyte: ceramic, polymer or sulphur-based solid electrolyte
- Separator: as part of solid-state electrolyte
- Current collector: Cu and Al foils

Gr-Si Anode / Hi-Ni Cathode

Most likely to be adopted on light vehicle EVs that require longer ranges and fast charging.

- Cathode material: NMC 811 or NCA 90
- Anode material: natural/artificial graphite with SiOx or pure Si
- Electrolyte: carbonate-based liquid organic solvents
- Separator: Polymer thin films
- Current collector: Cu and Al foils

Lithium Sulphur / Air

Revolutionary technologies that diverge from all previous chemistry systems.

- Cathode material: Li-metal
- Anode material: Sulphur or Oxygen/Air
- Electrolyte: solid-state
- Separator: as part of solid-state electrolyte
- Current collector: Porous carbonaceous material, noble metal catalysts, and Cu foil

Source: HIS Markit

Next Generation Li-ion Battery- Challenges and Technology Trends

Technical Challenges for Next Generation Li-ion Batteries

- Battery cells are much **more inclined to catch fire** as lithium-ion battery energy density continues to be improved.
- As the EV penetration rate rises, the efficiency of the charging network requires faster charging infrastructure. However, **fast-charging a high energy-density battery is more likely to cause safety issues**.
- Anode materials must match up the cathode with the same amount of Lithium-ion capacity. **Graphite is becoming the limiting factor** to the rising capacity of cathode materials.

Technology Trends to Improve Parameter

- Cathode technology is transitioning from a typical Ni percentage of 50%, towards 80% and 90%, respectively, for NMC and NCA batteries.
- In order to match up the capacity provided by hi-Ni percentage cathodes, adding a minor amount of Silicon oxides or pure Silicon into graphite anodes is growing in favor by cell manufacturers.
- Battery cells are increasing in size so that more energy can be stored in one cell with less casing materials used, which leads to reduced weight. (this also applies to the transition towards larger battery module sets)

Source: HIS Markit

Recent Developments in Solid-State Battery Race

Ford Motor Co (F.N) and BMW AG (BMWG.DE) have invested in startup **Solid Power**, which expected to deliver test batteries to BMW, Ford in 2022. Solid Power is going public in $1.24 Billion SPAC deal expected to be completed in the fourth quarter of 2021.

Germany's Volkswagen (VOWG_p.DE) has invested in Bill Gates-backed U.S. battery firm **QuantumScape Corp** (QS.N), which aims to introduce its battery in 2024 for VW's EVs and eventually for other carmakers.

South Korea‘s Hyundai Motor (005380.KS), which has invested in startup **SolidEnergy Systems (SES)**, plans to mass produce solid-state batteries in 2030.

Renault-Nissan-Mitsubishi alliance and Hyundai have invested in Solid-State Battery Company **Ionic Materials,** which expected to become production-ready by 2025.

Japan's **Toyota Motor Corp** (7203.T) is one of the front runners to mass produce solid-state batteries. It recently announced a $13.6 billion investment in battery technology (including, but not limited to, solid-state batteries), spread out between research and development and production equipment.

Sodium-ion Batteries- A Hedge Against Lithium

Sodium-ion Battery Advantages

- **Low-cost materials**—Sodium battery manufacturers benefit from sodium being one of the most abundant elements on Earth and therefore priced accordingly, this means system costs are lower at the equivalent level of development compared with Li-ion.
- **Depth of discharge**—All sodium technologies mentioned can completely discharge without degradation to the cell.

Sodium-ion Battery Disadvantages

- **Capacity**—Sodium-ions are larger atoms compared with Li-ion; therefore, the level of capacity cells can store is lower. However, these challenges are being minimized in the latest cell designs/technologies.

Source: HIS Markit

Sodium-ion Batteries- a Hedge Against Lithium

Sodium-ion Battery Commercial Accelerators

Safety concerns—With growing concerns around fires and thermal runaway in lithium batteries, sodium battery solutions can position themselves as a safe alternative.

Low-cost resource—Sodium is an abundant resource and costs one-tenth of the price of lithium for the equivalent hydroxides (NaOH and LiOH).

Sodium-ion Battery Commercial Challenges

Production capacity—As many companies are moving from the start-up phase to establishing production, volumes are still limited.

Production line—Manufacturers pursuing battery solutions can utilize existing production lines currently used for Li-ion battery cell manufacturing; however, it is likely that these will remain Li-ion as demand for these cells continues to increase.

Source: HIS Markit

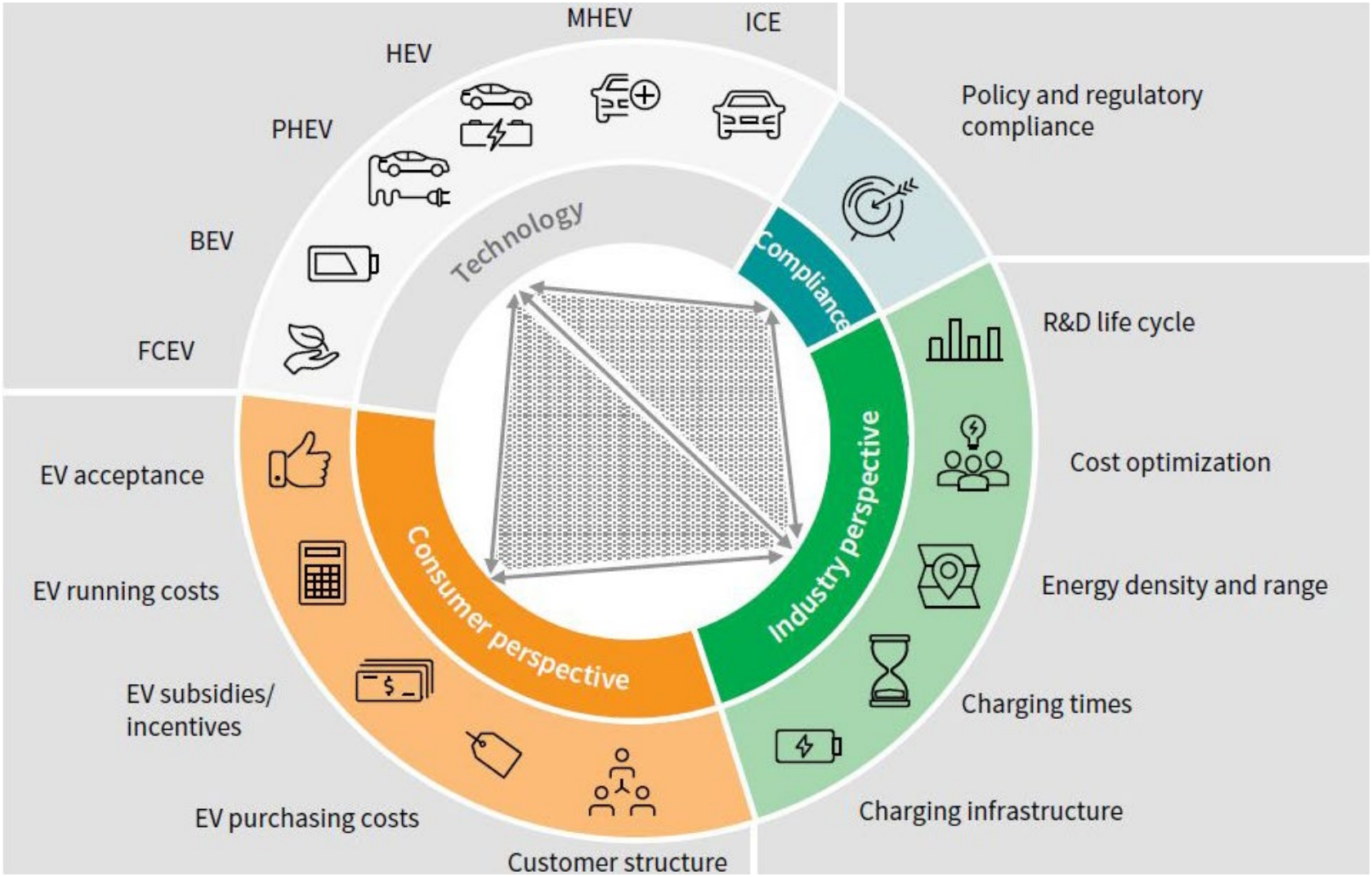
Recent Developments in Sodium-ion Battery Race

Contemporary Amperex Technology (CATL) unveiled its newly-developed sodium-ion battery at a launch event in July 2021. CATL (300750.SZ) plans to build a supply chain by 2023 to produce sodium-ion batteries, which have lower energy density than lithium-ion models, but are fast charging and more resilient in cold temperatures.

Faradion Ltd., the world leader in sodium-ion battery technology, has announced a new partnership with Infraprime Logistics Technologies (IPLTech) for its high energy sodium-ion batteries for use in commercial vehicles in the Indian market.

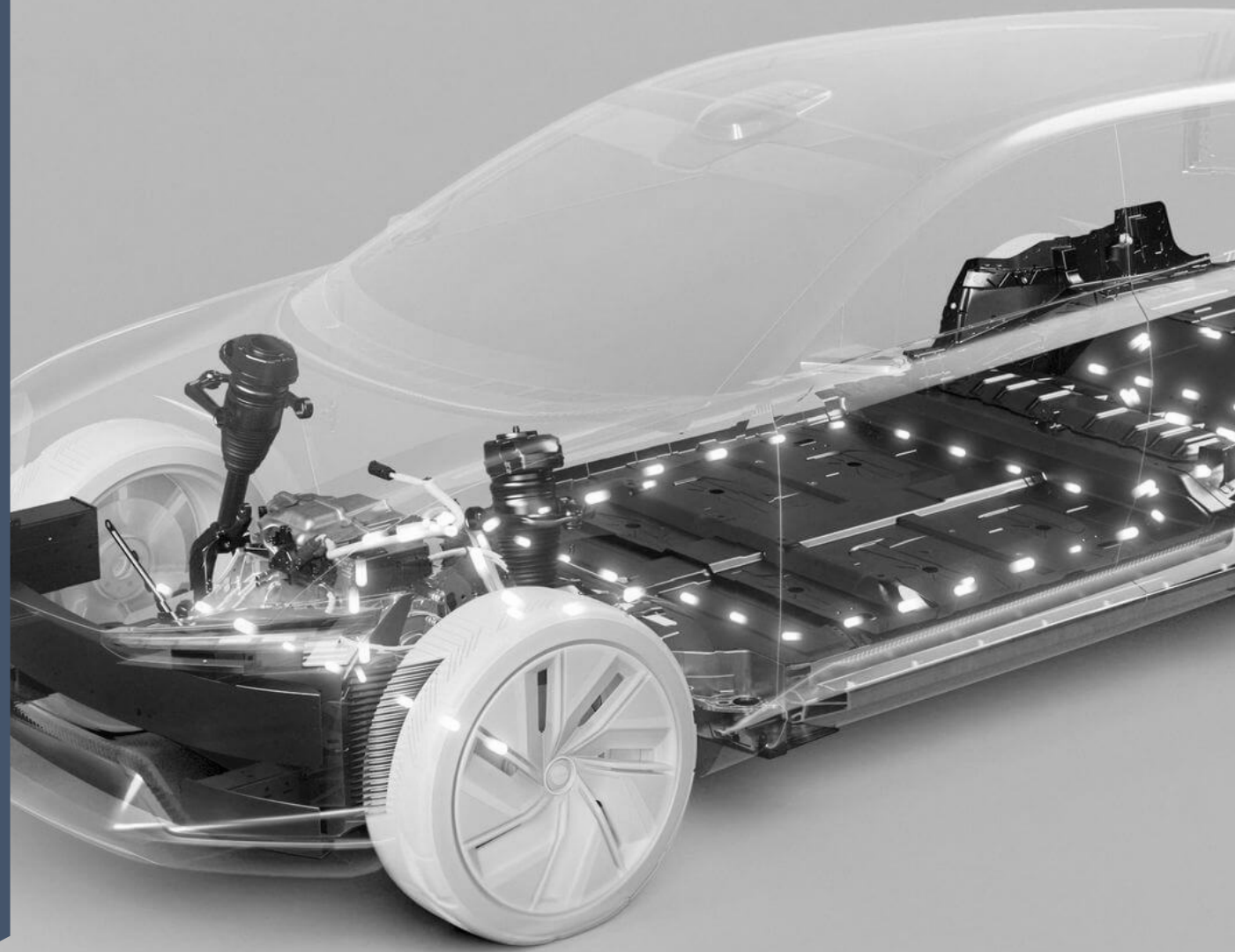
Phillips 66 (NYSE: PSX) and Faradion, one of the U.K.-based companies behind the first demonstration of a sodium-ion powered vehicle, have launched a technical collaboration to develop lower-cost and higher-performing anode materials for sodium-ion batteries.

Drivers for Auto Industry Technology Development



Source: HIS Markit; Image source: Microsoft

Market Trends



Asia-Pacific Market Growing at a Faster Pace

- As a result of the changes in the climatic conditions worldwide and the impact of globalization, most of the countries have been notified to control their emissions. **The adoption of electric vehicles is increasing at a significant growth rate.**

- The United States and China are already leading in global EV sales, along with other developing economies, like India, which has already begun transforming its public transportation infrastructure for EVs.

- **By the end of 2023, Asia-Pacific will account for the majority of the market share**, driven by the Environmental Protection Agency (EPA) regulations governing emission and fuel standards in the region, followed by North America.

Policy Support is a Critical Driver for the Adoption of Electric Vehicles

- In the current market scenario, policy support plays a crucial role in driving the adoption of electric vehicles. Policy support enables market growth by making vehicles appealing to consumers, reducing risks for investors, and encouraging manufacturers to develop electric vehicles on a large scale.

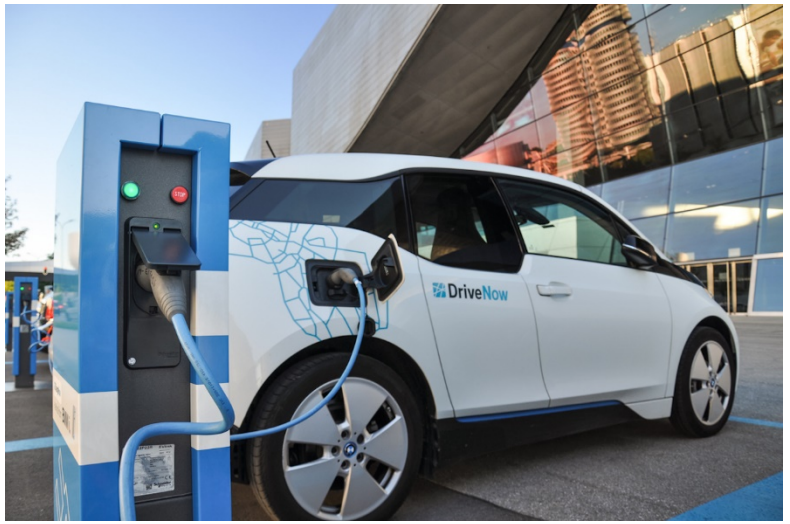
- **Governments in many countries have extended benefits in the form of financial incentives to the buyers of battery electric vehicles.** The amount of these incentives usually depends on the size of the battery. For instance, the Sustainable Energy Authority of Ireland (SEAI) provides buyers of battery electric vehicles with grants of up to USD 5,400 and exempts them from vehicle registration tax.

Battery Cost and Performance Still Facing Challenges

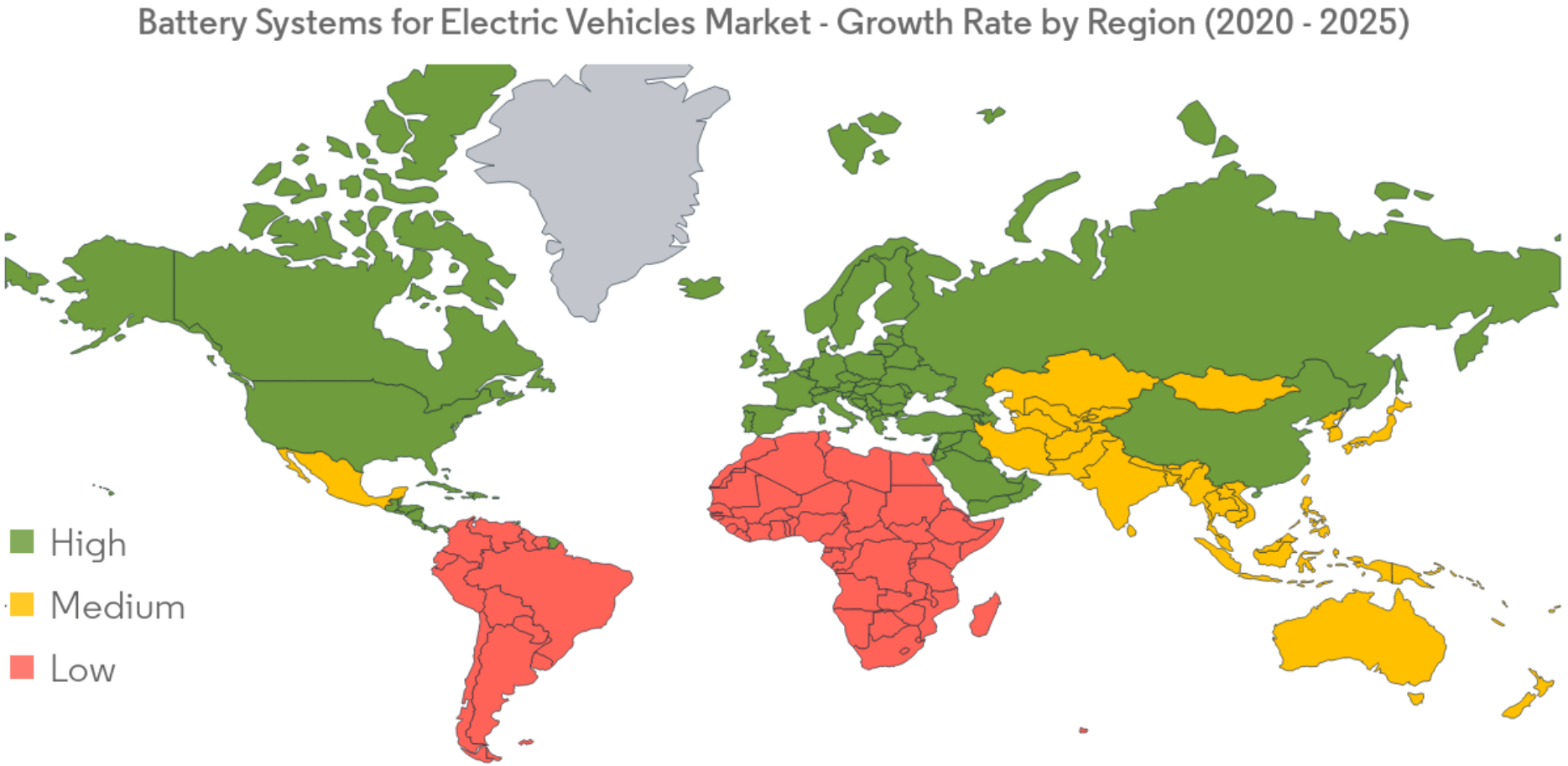
- **The range and performance of the battery in the electric vehicles are the significant restraints for the market.** The batteries are typically less powerful and have limited range (60-100 miles per charge) and are considered suitable only for short distance travel. The limited travel range of batteries of electric vehicles raises concerns among the consumers that their vehicles may run out of charge/power before reaching the destination.

- Longer charging duration is another major challenge for the market. **Lack of availability of supercharging stations adds to the woes associated with the use of batteries in an electric vehicle.**

- The high cost of the battery in the electric vehicle also poses a threat to the growth of the battery market in particular and battery electric vehicles in general. Over the time, falling battery prices and improving technology are expected to bring price-competitive electric vehicles to the market, creating demand for battery technologies.

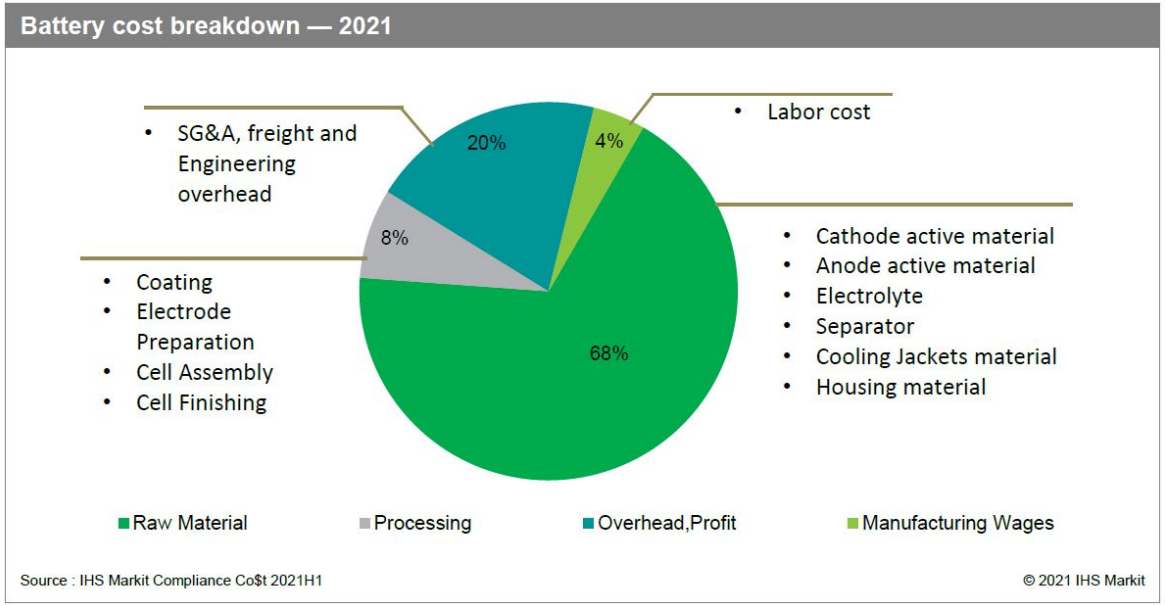


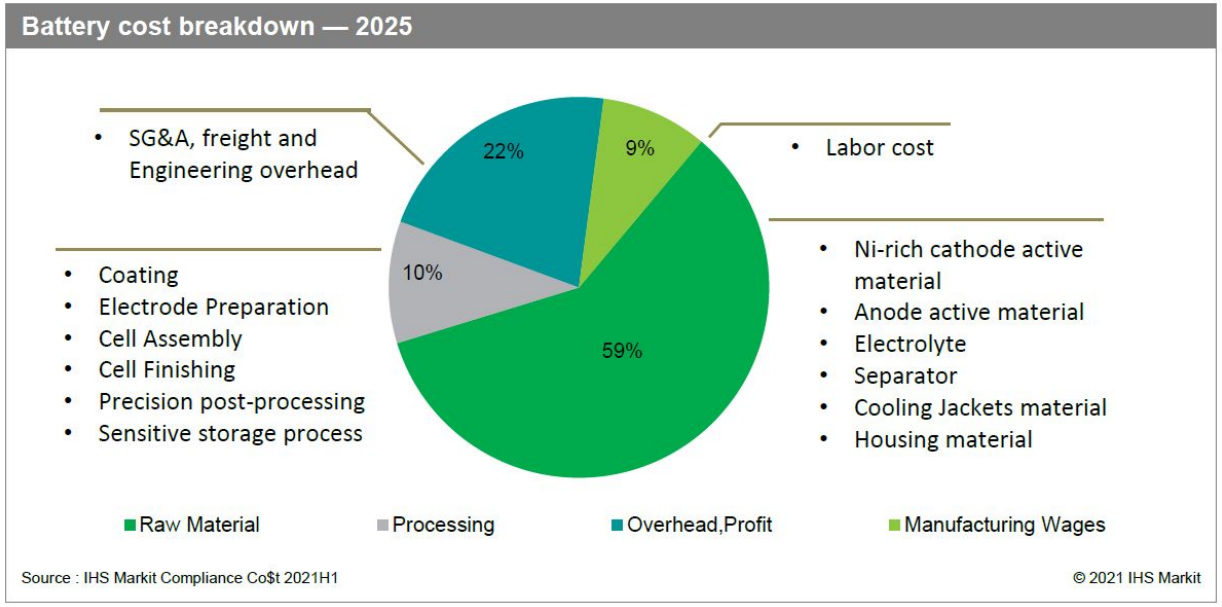
Market Growth Rate by Region



Source : Mordor Intelligence

Battery Cost Breakdown Trend





Major Players

Major Players

Asia-Pacific

CATL

FARASIS

LG Chem

BYD

BAK

SAMSUNG SDI

Gotion

EVE
ENERGY VERY ENDURE

SK innovation

LISHEN

EXIDE

Panasonic

Envision AESC

SES
Beyond Li-ion™

TOYOTA

GS YUASA

North America

TESLA

CLARIOS

QuantumScape

Solid Power

IONIC materials

Europe

faradion

saft

northvolt

Major Players

Company	Geographic Region	Focus Segment	Stock Information	Leading Technology	Website
Contemporary Amperex Technology Co., Limited (CATL)	China	lithium-ion batteries for electric vehicles and energy storage systems;	SHE: 300750	CTP Module-free; High-nickel Technology; Ternary transition metal oxide systems; Sodium-ion battery	https://www.catl.com/en/
BYD Co. Ltd.	China	NiMH batteries, Lithium-ion batteries and NCM batteries	HK: 01211 SHE: 002594 OTC: BYDDY	Blade battery; Lithium Iron Phosphate;	http://www.byd.com/en/index.html
Gotion High-tech Co., Ltd.	China	lithium-ion power battery products	SHE:002074	Lithium Iron Phosphate;	https://www.gotion.com/
TianJin Lishen Battery Joint-Stock CO.,LTD.	China	lithium-ion power battery products	-	Continuous pulping; High-speed coating;	http://en.lishen.com.cn/index.aspx
Envision AESC Group	China	AIoT Defined Battery Solutions	-	AIoT technology to precisely predict each individual cell's reliability and status	https://www.envision-aesc.com/en/

Chart: Dragon Gate Investment Partners

Major Players

Company	Geographic Region	Focus Segment	Stock Information	Leading Technology	Website
Farasis Energy (GanZhou) Co.,Ltd.	China	lithium-ion power battery products	SHA: 688567	lithium-silicon technology	https://en.farasis.com/
Shenzhen BAK Technology Co., Ltd.	China	lithium-ion power battery products	-	cylindrical battery	http://www.bakpower.com/about_en.php
EVE Energy Co., Ltd.	China	lithium-ion power battery products	SHE: 300014	Lithium-Thionyl Chloride Batteries	https://en.evebattery.com/
Exide Industries Limited.	India	lead-acid batteries	NSE: EXIDEIND	patented power grid technology	https://www.exideindustries.com/
SES	Singapore	hybrid Li-Metal rechargeable batteries	NYSE: IVAN (SPAC deal to be closed)	battery materials, cell and module design, AI powered algorithms	https://ses.ai/
LG Chem	South Korea	lithium-ion power battery products	KS: 051910	Aluminum-added NCMA Cathode and Silicon Anode Material Technology	https://www.lgensol.com/en/index

Chart: Dragon Gate Investment Partners

Major Players

Company	Geographic Region	Focus Segment	Stock Information	Leading Technology	Website
Samsung SDI Co. Ltd	South Korea	lithium-ion power battery products	KS: 006400	Cell technology; 'High-Ni' Technology	https://www.royole.com/en
SK Innovation Co Ltd.	South Korea	lithium-ion power battery products	KR: 096770	high energy density ternary lithium-ion battery; high-nickel technology	http://eng.skinnovation.com/business/battery.asp
Panasonic Corporation	Japan	advanced lithium-ion batteries; Ni-MH battery cells	TYO: 6752 OTC: PCRFY	High energy density technology; cobalt free technology	https://na.panasonic.com/us/automotive-solutions/ev-hev-energy-0
Toyota	Japan	nickel-metal hydride batteries; lithium-ion batteries	TYO: 7203	solid-state battery;	https://global.toyota/en/
GS Yuasa Corporation	Japan	lead acid and lithium-ion batteries	TYO: 6674	pressure compensated lithium ion cells; storage battery technology	https://www.gs-yuasa.com/en/products/automotive_motorcycle_batteries/

Chart: Dragon Gate Investment Partners

Major Players

Company	Geographic Region	Focus Segment	Stock Information	Leading Technology	Website
Tesla, Inc.	United States	nickel-metal hydride batteries; lithium-ion batteries	NASDAQ: TSLA	NCA technology; tabless cells; cobalt-free technology	https://www.tesla.com/
Clarios	United States	low-voltage vehicle batteries; lead-acid batteries	-	AGM technology; flooded batteries technology;	https://www.clarios.com/
QuantumScape	United States	solid state lithium metal batteries	NYSE:QS	separator material;	https://www.quantumscape.com/
Solid Power	United States	All-Solid-State Batteries	NASDAQ: DCRC (SPAC deal to be closed)	proprietary sulfide solid electrolyte	https://solidpowerbattery.com/
Ionic Materials	United States	polymer electrolyte material for batteries	-	polymer electrolytes for solid-state batteries	https://ionicmaterials.com/

Chart: Dragon Gate Investment Partners

Major Players

Company	Geographic Region	Focus Segment	Stock Information	Leading Technology	Website
Faradion	United Kingdom	sodium-ion batteries	-	non-aqueous sodium-ion cell technology	https://www.faradion.co.uk/
Saft Groupe SA	France	Lithium-ion batteries; Nickel technology batteries	-	solid-state technology	https://www.saftbatteries.com/
Northvolt AB	Sweden	Lithium-ion cells	-	Cell Traceability & Prediction; Revolt	https://northvolt.com/

Chart: Dragon Gate Investment Partners

Thanks!

Thanks for reading Xuan's ***Manufacturing in Our Lives*** series, if you have any questions regarding the report, please contact xuan.luo@dgipl.com.

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