When compared to an ICE, an electric powertrain is superior in three ways

1 /

It is more Powerful

An ICE produces enough torque only in a certain RPM range. On the other hand, an electric motor can produce full torque from zero RPM. At lower speeds, electric motors deliver more torque than ICE. Torque is essentially what gets the car going. With more torque at lower speeds, an electric car gives more acceleration than a comparable ICE car.

ICE do perform better at very high speeds. However, for the speed range that matters the most, an electric powertrain is more powerful.

2 /

It is Simpler

With less torque at low speed, ICE needs help from a transmission to step down engine RPM to wheel RPM. A transmission system adds further complexity to an ICE powertrain.

Electric powertrains do not need any transmission. At most, they have a couple of operating modes that have different motor efficiency profiles which have no impact on acceleration.

The simplicity of a powertrain makes electric cars vastly easier to service as well.

3 /

It is Smarter

ICE control systems have come a long way in accuracy and performance. An electric powertrain provides even better opportunities to monitor vehicle performance and adjust it.

Electric powertrains are best suited for future automobile trends like autonomous driving, connected vehicles, etc. With the endless possibilities that electric vehicles bring, they are less like traditional automobiles and more like laptops or smartphones on wheels. Similar to laptops and smartphones, software updates will become an increasingly regular part of EV ownership.

Key components of an EV

Battery and motor are the two key components that are replacing the engine in an ICE vehicle. The technology to store a large amount of energy in a small battery in an economical and safe manner has been the primary hurdle in EV adoption. Battery costs constitute up to 35% of the vehicle cost – making battery the most critical component of an electric vehicle.

The motor is the second most critical component in an EV. The motors also need sophisticated controllers in order to derive best performance and energy parameters. These three components have been covered in detail in the following section, along with an overview of other key components.

EXHIBIT 5

Key components of an electric vehicle and their respective cost contribution

Electric Car

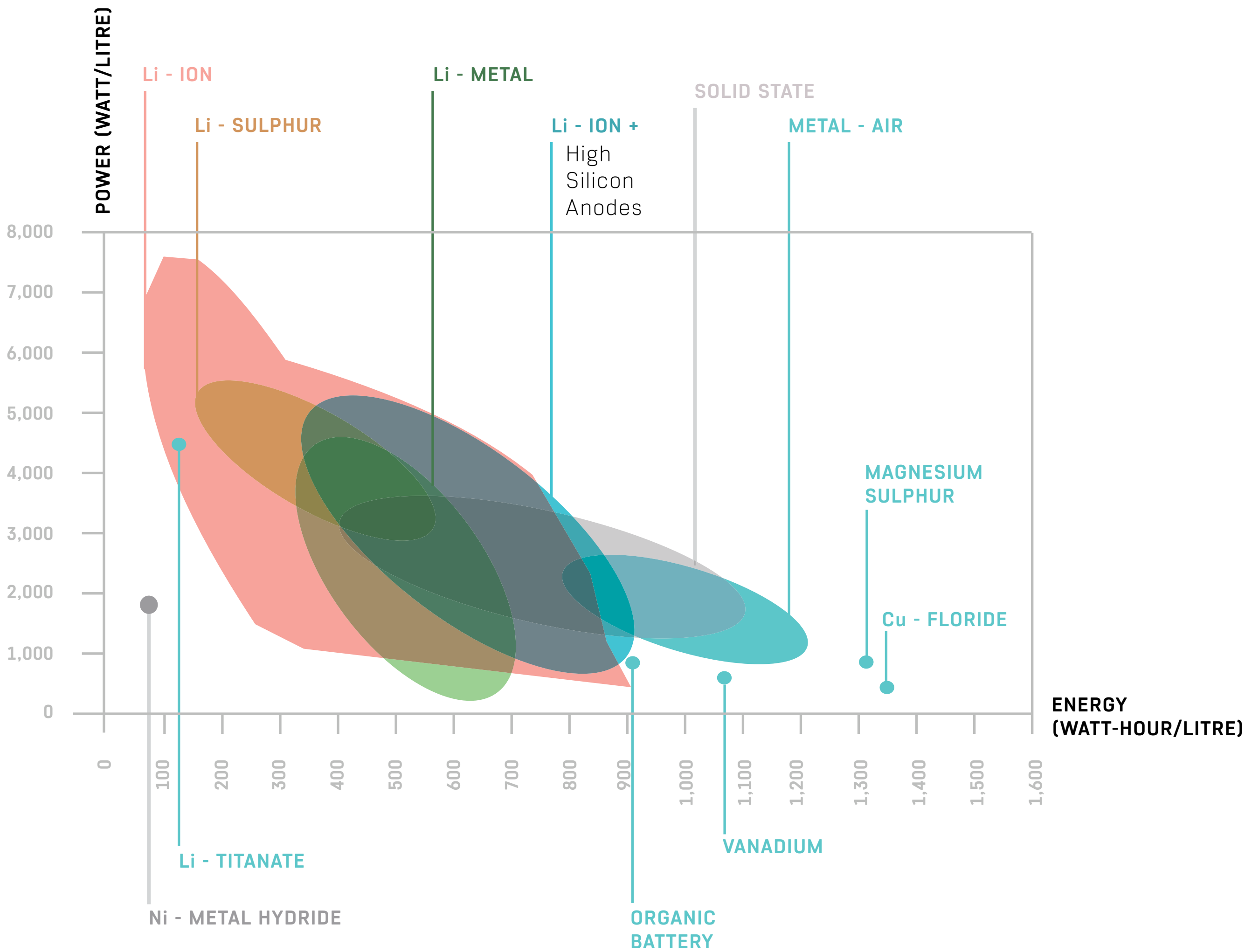
Battery 35%	32%	CATHODE	Panasonic, LG Chem, SAMSUNG SDI, CATL
	18%	CURRENT COLLECTORS	
	18%	SEPARATOR	
	15%	ELECTROLYTES	
	11%	ANODE	
	6%	OTHER	
Drivetrain 25%	40%	ELECTRIC MOTOR	MAGNA, Nidec, BOSCH, Continental
	30%	CONTROLLER	
	30%	OTHER	
Chassis and Body Parts 20%		Systems, Equipments, Other Components 20%	APTIV, LEAR CORPORATION, AISIN, faurecia, ZF

EV Battery — 101 Li-ion is the future of EVs

Li-ion is the most mature battery technology currently and there is nothing that can potentially replace it, at least in the next 5 years. Li-ion presents a wide range of power–energy performance that is significantly better than previous battery technologies like Lead Acid, Nickel Metal Hydride, or Nickel Cadmium. There are a number of chemistries which theoretically can be safer and more efficient than Li-ion but none of them are close to commercial deployment.

EXHIBIT 6 ↘

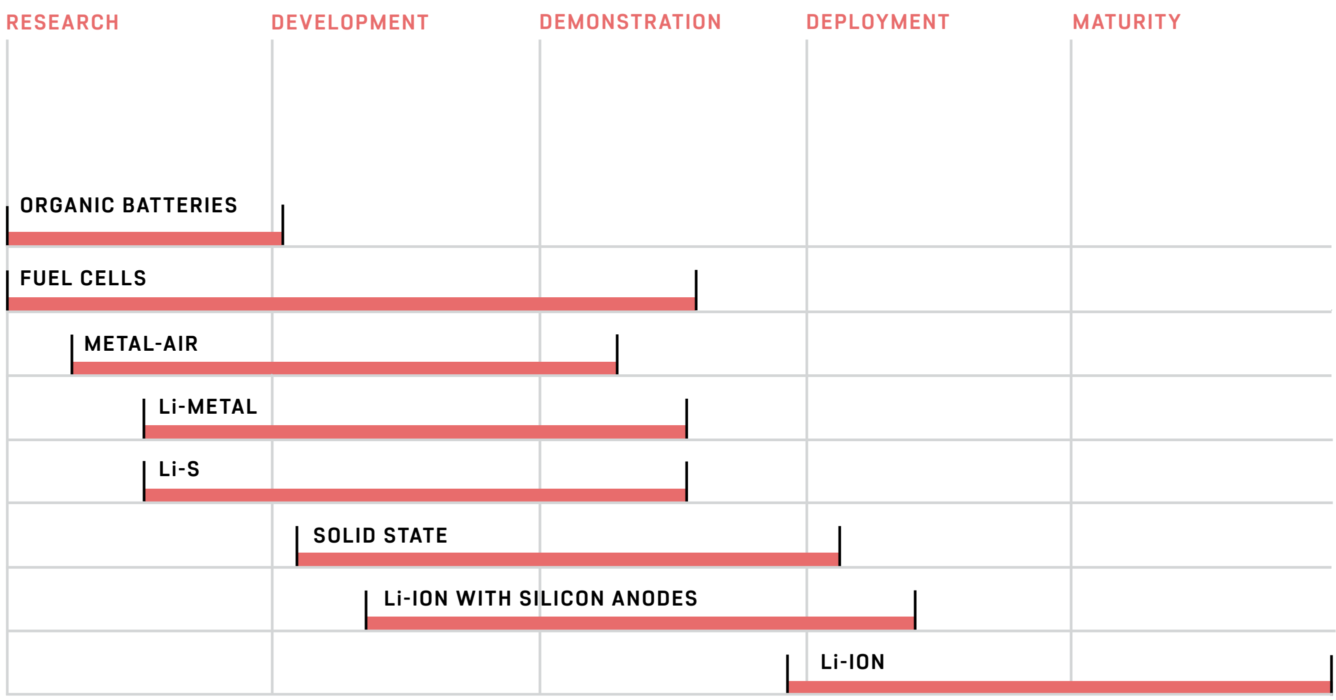
Power/Energy density map for different battery chemistries



The chart below shows stages at which various battery chemistries currently are. While the chart doesn't relate to a timeline, an understanding of the evolution of Li-ion technology shall add perspective to the development timelines. Li-ion technology was invented in the 1970s, the first commercial applications were developed in 1991, the first electric vehicle batteries were commercialized in the late 2010s, and today in 2020, a large-scale commercial application is taking shape. While the rate of technology metamorphosis has accelerated significantly over the last few years, it is safe to say that the development, successful piloting/demonstration, scale up and finally, the deployment of alternate chemistries keeps Li-ion insulated for at least 5 years.

EXHIBIT 7

Advanced technologies in different stages of the development cycle



The industry has already backed Li-ion

While the debate around technological superiority or maturity can be endless and identifying a clear winner could be difficult, the industry at large has accepted Li-ion as the future of EV batteries in the medium term.

~300 GWh

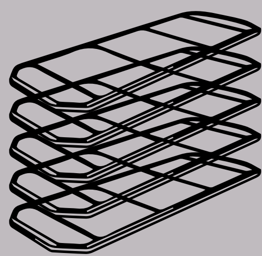
LI-ION CAPACITY ACROSS THE GLOBE

Only <50% is currently utilised

100 GWh

TOTAL CAPACITY

Top 5 Gigafactories



$ 30Billion

WORLDWIDE, SINCE 2010

Total investments in manufacturing Li-ion batteries

$ 60 - 100Million

LI-ION BATTERY MANUFACTURING PLANT

Capital Expenditure/GWh

115

Gigafactory projects in the pipeline

EXHIBIT 8 ↘
Li-ion — the race within

Li-ion is not one chemistry. It is a broad set of competing chemistries, each having its unique advantages and disadvantages.

NCA

Supports low discharge currents, great capacity/cycle life and physically resistant

SPECIFIC ENERGY	SPECIFIC POWER	CYCLE LIFE	SAFETY
180 - 200 Wh/Kg	500 - 1000 W/Kg	800 - 2000 CYCLES	LOW

Li Ni Co Al Oxide

Used in **Tesla**

NCM

Low resistance of Manganese and high energy of Nickel

SPECIFIC ENERGY	SPECIFIC POWER	CYCLE LIFE	SAFETY
160 - 220 Wh/Kg	480 - 800 W/Kg	800 - 2000 CYCLES	MEDIUM

Li Ni Co Mg Oxide

Used in **Volkswagen, BMW, MG**

LFP

Excellent safety and long life span but moderate specific energy and elevated self-discharge

SPECIFIC ENERGY	SPECIFIC POWER	CYCLE LIFE	SAFETY
130 - 140 Wh/Kg	>1000 W/Kg	2000 - 5000 CYCLES	HIGH

Li Fe Phosphate

Used in **Mild hybrids & heavy duty vehicles**

LTO

Rapidly chargeable batteries that are extremely safe

SPECIFIC ENERGY	SPECIFIC POWER	CYCLE LIFE	SAFETY
50 - 100 Wh/Kg	>1500 W/Kg	1000 - 3000 CYCLES	HIGH

Li Ti Oxide

Used in **Mitsubishi and Honda in select models; Buses**

LMO

Used in flash lights, no built in protective circuit and high current discharge at low temperature

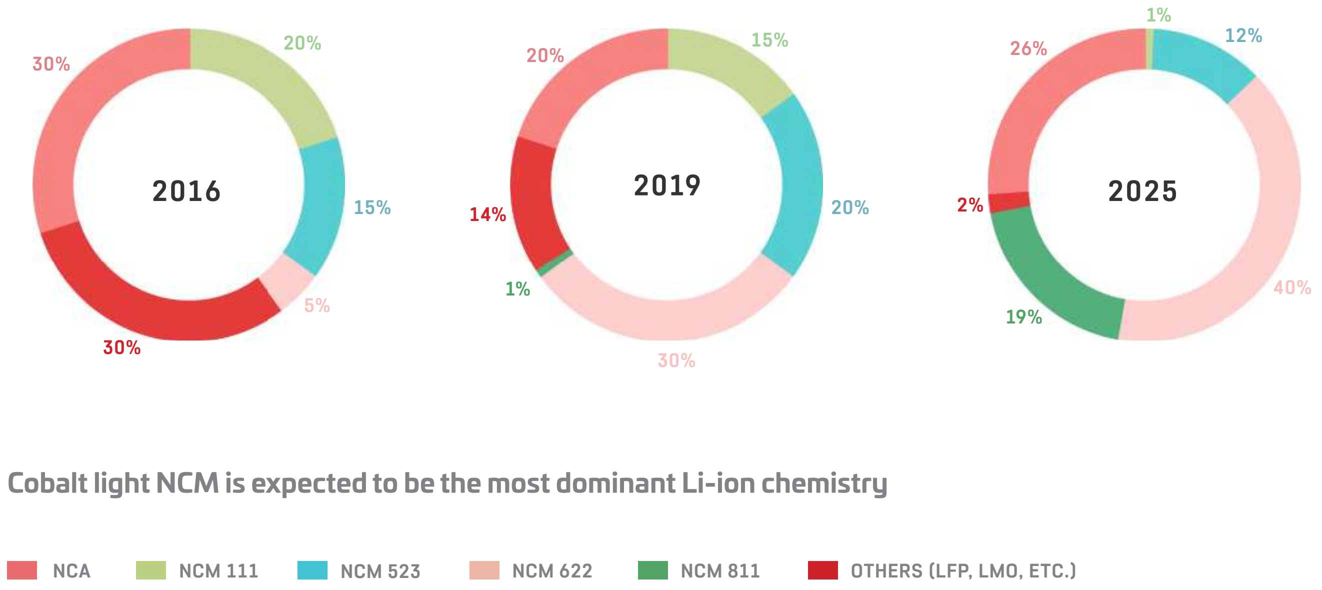
SPECIFIC ENERGY	SPECIFIC POWER	CYCLE LIFE	SAFETY
100 - 200 Wh/Kg	160 - 720 W/Kg	500 - 2000 CYCLES	MEDIUM

Li Mg Oxide

Used in **Early EVs & Flashlights**

EXHIBIT 9

Change in cathode chemistry mix



NCM and NCA would account for majority of the Li-ion battery market going forward. At present, a large portion of the Chinese EV market is powered by LFP, but even that is expected to decline. Within NCM, the cell composition will move from 1:1:1 (1 part of Nickel for every 1 part of Manganese and 1 part of Cobalt) to NCM 8:1:1.

Reduction of Cobalt content in batteries is a core focus area for battery developers. Cobalt reserves are limited and not enough to support 100% electrification. 50% of the reserves and 70% of production of Cobalt is concentrated in the Democratic Republic of Congo (DRC). Thus, there are significant geopolitical risks associated with Cobalt supply. Tesla, in collaboration with Panasonic, managed to reduce 60% of its Cobalt dependency and aims to completely eliminate Cobalt from its batteries.

However, Nickel rich cathodes come with their own problems. Nickel rich batteries tend to heat up rapidly, thus, safety concerns are higher. With lower Cobalt, the life cycle of a battery gets negatively impacted. Lower Cobalt formulations require special dry environments, thus, increasing operating costs and becoming a bottleneck in scaling up. However, with superior BMS developments and battery pack architecture with advanced cooling systems, there is a shift to minimize Cobalt usage. A number of global OEMs have already shifted to intermediate NCM formulations like 6:2:2 and 5:2:3. With more technological developments, NCM 8:1:1 would also witness large scale adoption.

Battery — Cell to Pack

A cell is the most basic unit of a battery pack. Each cell has an anode and a cathode separated by a separator. A number of cells put together form a module and a number of such modules put together build a battery pack.

ANODE	The negative terminal in a Li-ion cell generally consists of Graphite. When the cell is charged, Li-ions get stored in Graphite layers.
CATHODE	The positive terminal consists of Lithium along with other metals like Nickel, Cobalt, Manganese in the case of NCM chemistry; Ferrous, Phosphorus in the case of LFP, etc. Lithium ions migrate from the anode to the cathode during discharge to create an electric current. During the charging process, this process reverses.
ELECTROLYTE	It enables the flow of ions between the cell terminals. Typically, it is a non metallic, liquid conductor. Currently, the most commonly used electrolyte is Lithium Hexafluorophosphate.
SEPARATOR	Separator is made out of permeable material that isolates the two terminals of a cell. It prevents the flow of electrons through it but allows the passage of Li-ions.
CURRENT COLLECTORS	Each terminal of a cell has a current collector. The movement of Lithium ions from the anode to the cathode creates a charge at the positive current collector. The electric current then flows to the vehicle. During the charging process, the electric current flows to the negative current collector where the charge is stored.

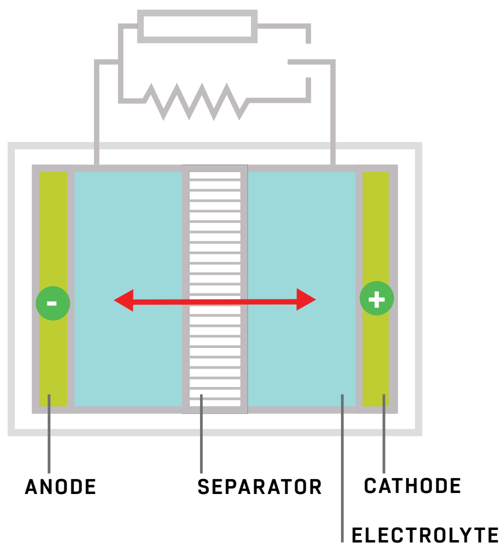
EXHIBIT 10

Li-ion Cell — Correlation between components and characteristics

	CATHODE (+)	ANODE (-)	ELECTROLYTE
CAPACITY	✓	✓	✓
SAFETY			✓
FAST CHARGE		✓	
POWER			✓
SUSTAINABILITY	✓	✓	✓

FIGURE 1

Battery cell illustration — The diagram below depicts a Li-ion cell and its different components. Each component has a specific role to play in the overall battery characteristics.



Cell form factors

The three most common form factors for cells are — Cylindrical, Prismatic and Pouch

A /
CYLINDRICAL

This format has battery material (electrodes and separator) rolls that are continuously wound into a round Aluminum housing. It is relatively smaller compared to other form factors, increasing the number of cells needed for a battery pack which leads to a requirement of a more sophisticated battery management system. Panasonic manufactures NCA cells for Tesla in this form.

B /
PRISMATIC

In this format, multiple sets of battery materials (electrodes and separator) are wound and inserted into a rigid Aluminum can. The insertion of the materials into the can and the welding of the can adds to the complexity and cost of this format but provides significantly higher safety. Samsung manufactures prismatic cells for BMW's model i3.

C /
POUCH

In this format, battery material rolls are stacked and wrapped around with a thin Aluminum polymer foil. The thin cell housing reduces the cell weight and results in higher specific energy. It also allows for more flexibility in designing battery packs. However, the Aluminum pouch format provides less safety features due to lesser rigid cell housing. LG Chem manufactures pouch cells.

FIGURE 2
Different cell form factors

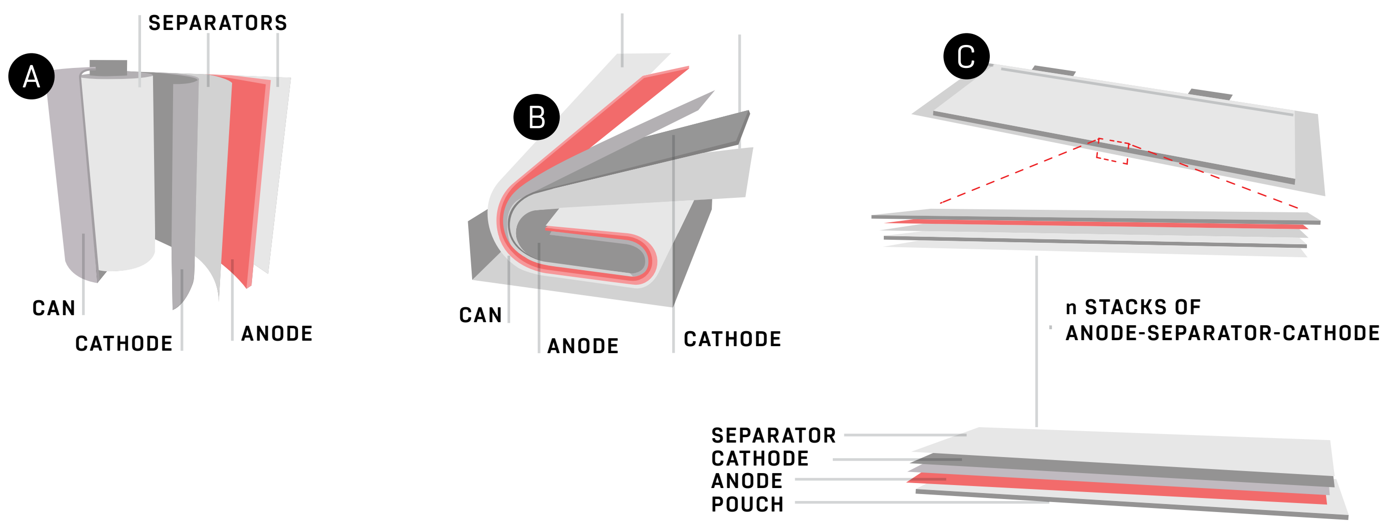


EXHIBIT 11

Comparison of cell form factors

	CYLINDRICAL	PRISMATIC	POUCH
Arrangement	Wound	Wound	Stacked
Mechanical Strength	High	Medium	Low
Thermal Management	Most Efficient	Less Efficient	Less Efficient
Battery Pack Design Flexibility	Low	High	High
Safety	High	High	Low
Energy Density	Low	High	Medium
Cell Cost	Least Expensive	Less Expensive	Most Expensive

Battery Packs

Cells are put together into modules, which are put together to form a battery pack. While the cell chemistry largely dominates the pack characteristics, battery pack design itself has significant scope to create efficiency.

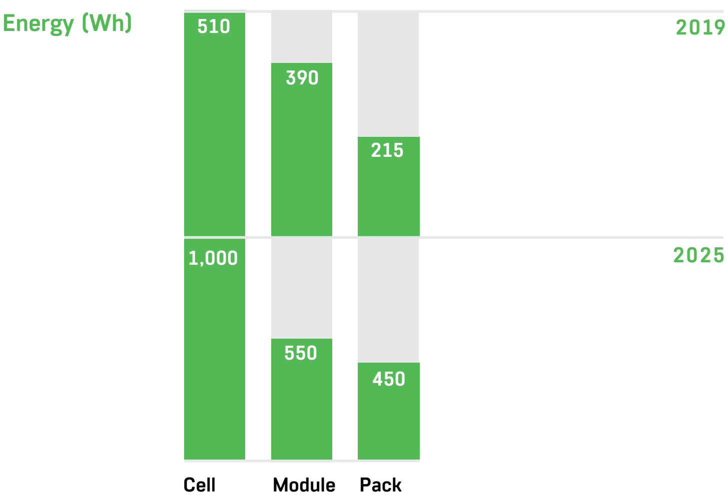


EXHIBIT 12

Cell to pack efficiency potential with developments in cell chemistry and cell-module-pack design

Led by improvements in —

Cell Chemistry

Cell Design

Module Package

Battery Package

Battery Management System

The brains behind the battery

Battery Management System (BMS) is the brain of a battery pack. BMS measures critical parameters and controls them to keep the battery safe and operate efficiently. Batteries, without a good BMS, are suboptimal in performance, life and safety. The single most important function of a BMS is cell protection. Li-ion cells can get damaged if overcharged or if discharged below a threshold level. Overcharging results in overheating which not only causes structural damage but also creates a huge risk of explosion and fire. Each time a battery is drained out below a critical level, its capacity gets reduced to an extent permanently. BMS ensures that the battery's charge doesn't go above or below certain threshold limits.

The second important function performed by a BMS is energy management. The BMS measures how much energy is left – State of Charge (SOC). It monitors the rate at which energy is getting used and how long will it last. Accurate assessment of SOC is critical for effective battery management.

BMS plays a critical role while charging a battery, ensuring that the battery is charged in a safe manner without impacting its life. During hot summers in North India, e-rick drivers experience longer charging times – that's essentially a result of the BMS slowing down charging to ensure that cell temperatures are within a safe limit. BMS also does cell balancing. This ensures that all cells are charged or discharged together, thus, preventing a few cells from getting stressed which could result in premature charge termination and a reduction in the overall cycle life of the battery. Typically, in a fast charge, 80% of the battery gets charged in one-third of the charging time. The remaining 20% takes longer because the BMS is conducting cell balancing.

The robustness of a BMS plays an important role in the performance of the battery. Two batteries with the same hardware can deliver significantly different performance, depending on how sophisticated their BMS is. Tesla, for example, has a BMS capable of monitoring each and every cell in its battery pack. On the other end of the spectrum, simple BMSs comprise a basic protection circuit. Majority of BMSs that are used in EVs today monitor a set of modules rather than each and every cell or module resulting in limited control over battery pack.

Key BMS Blocks

Thermal Management Block

Reads temperature and starts cooling or heating operation to maintain the temperature in the optimal range.

Also, it sends signals to ECU if the temperature goes beyond allowable limits. These systems can include both passive and active cooling systems.

Battery Algorithm Block

Estimates state of health and state of charge. Based on the measured values, it calculates current stage with respect to full charge, which is essential for ensuring that the battery is not overcharged.

Measurement Block

Measures cell temperature, current voltage at different places and the ambient temperature.

Capability Estimation Block

Sends information of the safe levels of charge or discharge to ECU and charger unit.

Cell Equalization Block

Compares the highest and lowest cell voltages to apply cell balancing techniques.

Battery Thermal Management

Charging, discharging and ambient temperature are the three factors that impact battery temperature. EV batteries at a lower temperature (<0ºC) are inefficient because of slower reactions which results in lesser power. At higher temperatures (>40ºC), Lithium plating can occur causing irreversible damage to the batteries. The ideal temperature to maintain is between 20ºC and 30ºC. The cooling system does this job with the help of signals from the BMS. The choice of cooling system varies with the heat generation characteristics of the battery.

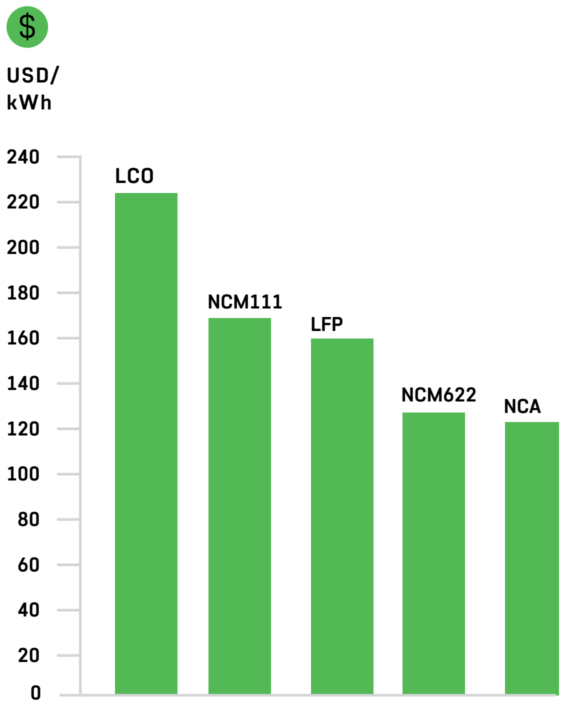
Air cooled systems are lighter and inexpensive but also have lower effectiveness in terms of cooling. They use ambient air and force the air to flow through the battery.

Liquid cooled systems are heavy and expensive compared to air cooled systems. These systems are more effective in cooling the batteries. However, as the number of cells increase, it's difficult to design these systems efficiently. Thermal design is a critical aspect of battery design. While air cooled batteries are cheaper, they have limitations when it comes to large and compact batteries. Bus batteries, despite being large in size, have the benefit of being less compact and can be designed with air cooling.

However, a battery designed for fast charge, like a 3C LFP bus battery would require liquid cooling. Car batteries above 30 kWh usually come with liquid cooling given their compact design. (C or charge speed is a ratio of charging power to battery capacity; e.g. if a 30 kWh battery is charged at a 60 kW power, it is being charged at C=2). The extent of liquid cooling also varies. Depending on the requirement, it could be limited only to the battery pack exterior or could be designed at a cell/module level.

Battery Economics

A battery has three cost components —
Cells, BMS and Balance of Pack. Cells constitute 60-70% of the cost, the BMS constitutes 10-15% and the Balance of Pack which includes thermal management and mechanical components like housing, etc. constitutes the remaining 15-20%. The cost split between these systems depends upon the size of the battery pack. Larger battery packs tend to have higher costs skewed towards cells as the Balance of Pack cost does not increase linearly with the battery size.



Basis estimated prices in 2018

EXHIBIT 13

Comparative battery cost — impact of cobalt

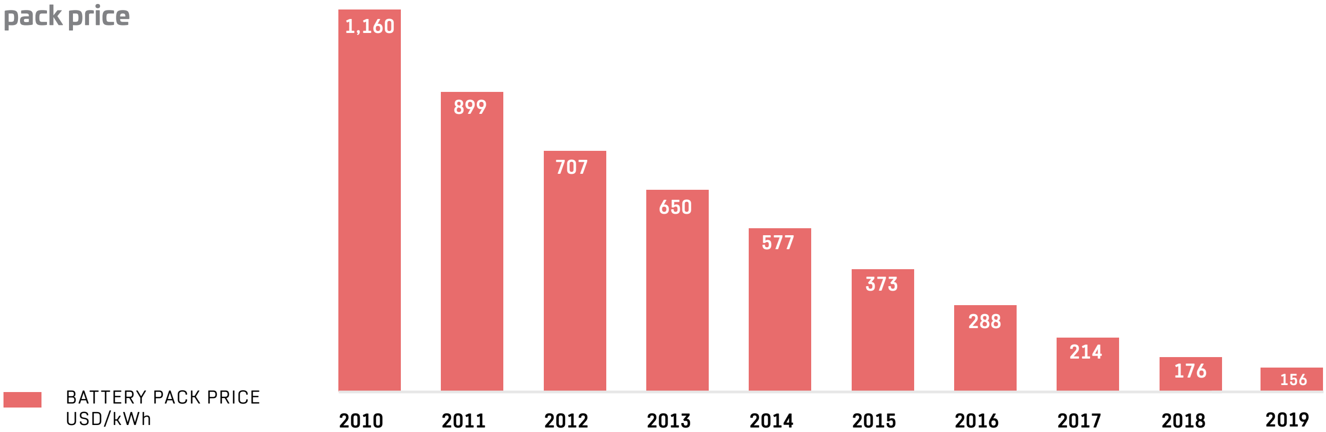
Assumes the following raw material prices

COBALT METAL USD **50,000** / tonne	**LITHIUM HYDROXIDE** USD **15,000** / tonne
NICKEL USD **15,000** / tonne	**COPPER** USD **7,000** / tonne

Battery pack prices have rapidly declined over the past 10 years. According to the widely cited study by Bloomberg, the battery pack prices have dropped from USD 1,160 / kWh to USD 156 / kWh between 2010 and 2019. But more than the precise price points, the data highlights the important facts about the rapid decline in battery prices. As far as the price of batteries in the market is concerned, it actually varies widely depending upon chemistry, scale of demand and design. Especially in India, battery prices are considerably different when compared to the global average numbers. There are two main reasons for that: a) The global average battery prices are heavily influenced by top manufacturers like Tesla – Panasonic who have completely different cost structures on account of material partnerships and massive scale of operation and b) The data represents the large size battery industry (>10kWh) and is not very indicative of the small size battery industry (<10 kWh) which is more prevalent in India.

EXHIBIT 14

Global Li-Ion battery pack price



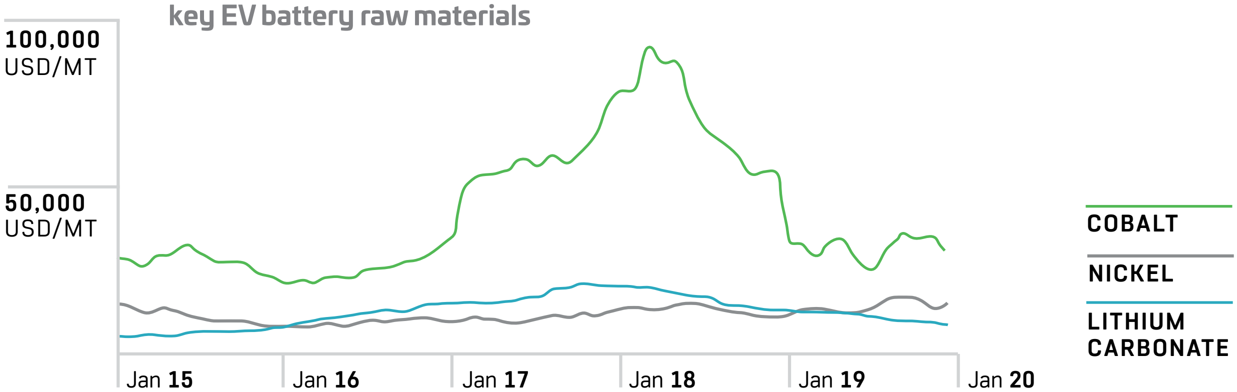
In the Indian market today, the battery pack price is largely in the range of USD 180/ kWh to USD 250/kWh. The prices vary depending on chemistries, cell quality, BMS design and thermal design. 2W batteries with a basic BMS and air-cooling cost between USD 190-220 /kWh. A smart BMS can add up to USD 50 to the battery cost. Car battery packs cost between USD 180-210/ kWh. Fast charging batteries are expensive due to the chemistry as well as sophisticated thermal management systems. At the lower end of the price spectrum are batteries made from low grade cells or second life batteries from China that are as cheap as USD 150-160/kWh.

Raw materials are key to battery economics. Lithium and Cobalt are two important raw materials for cell manufacturing. These materials are rare and exhibit reasonably volatile pricing trends.

There are only 8 countries that produce Lithium and of them three – Chile, Australia and China account for 85% of the total production. Four companies – Talison, SQM, Albemarle and FMC control a majority of the Lithium production.

EXHIBIT 15

Historical price movement for key EV battery raw materials



Analysis by Benchmark Mineral Intelligence suggests that taking into account operational supply and projected supply, there could be supply vs demand gap for Lithium from 2027.

70% of global Cobalt production is currently concentrated in the DRC. Russia, Cuba, Australia and Canada are the next largest suppliers that cumulatively account for 13% of the global production. While the mines are concentrated in limited regions, unlike Lithium, Cobalt production is quite fragmented amongst the producers with the top 3 companies producing less than 40%.

There are several key issues with Cobalt supply.

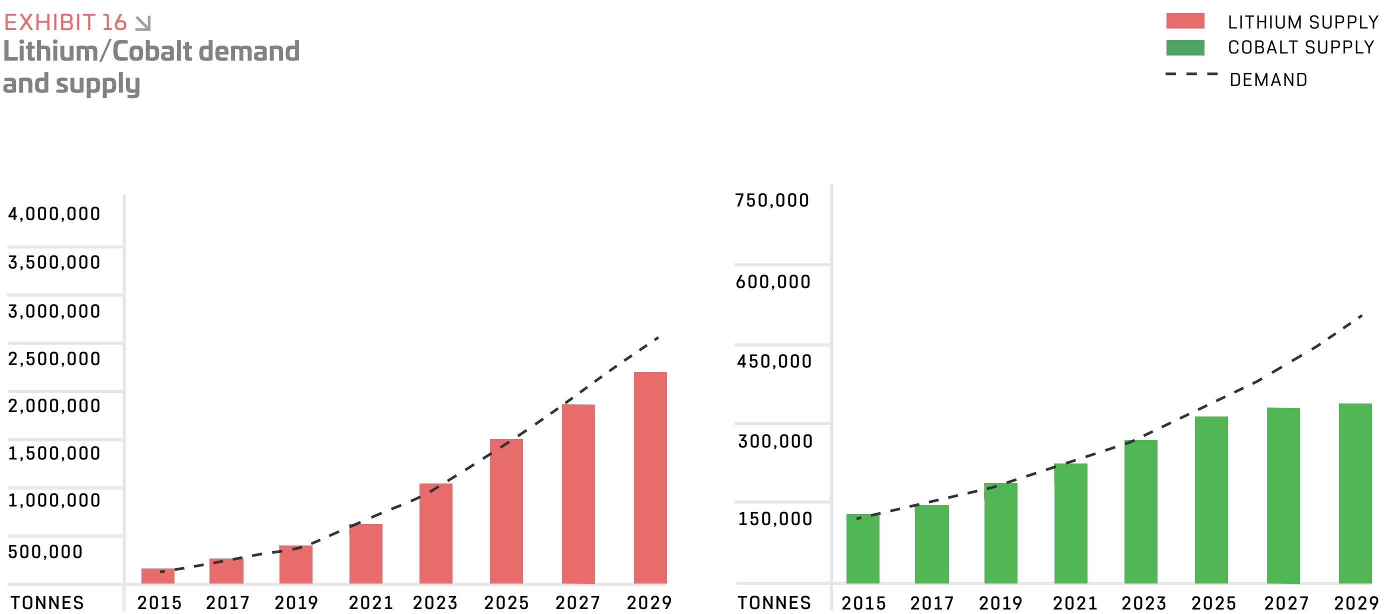
The DRC is a politically unstable region and has witnessed large scale supply disruptions. In addition, the DRC is mired with controversies surrounding artisanal mining and child labour. Multiple key industry stakeholders have clearly highlighted plans to minimize Cobalt usage in order to avoid sourcing from the DRC.

Unlike Lithium, Cobalt is extracted as a by-product during the production of Copper or Nickel. 90% of the Cobalt produced in the world today is generated as a by-product. This means that all Cobalt expansion projects are dependent on Copper and Nickel demand dynamics.

Apart from the source concentration (in the DRC), 50-60% of Cobalt refining capacity is concentrated in China today.

EXHIBIT 16 ↘

Lithium/Cobalt demand and supply



Battery chemistries of the future

1 /

LI - ION WITH SILICON ANODES

Silicon has much higher specific capacity of (amount of charge delivered per unit weight of electrode) 3,600 mAh/g as compared to 370 mAh/g of Graphite, since a Silicon lattice structure can hold a much larger number of Li-ions as compared to Graphite. Thus, Li-ion batteries with Silicon anodes can have 20-40% higher energy density with the same cathode chemistry.

However, the problem with this technology is Silicon swelling. Accumulation of Li-ions during charging causes anode to expand. In case of Graphite, the change in volume is only 10%. Silicon, on the other hand, undergoes a volume change in excess of 300%. This large volume expansion creates stress on anode material, causing it to fracture or crumble and detach from the current collector. The expansion affects the rest of the cell structure as well, especially the solid electrolyte interphase.

Leading companies working on Silicon anode technologies are Sila Nanotechnologies (USA), Nexeon (UK) and Wacker Chemie (Germany).

2 /

METAL AIR

Metal-Air batteries use metal as anode and air as cathode. These batteries have exceptionally high energy densities. Li-Air has the highest theoretical energy density of ~11,500 Wh/kg.

Other metals suitable for such batteries are Iron, Zinc, Magnesium, Aluminum, Sodium and Potassium. Metal-Air batteries can either use a solid electrolyte or a liquid electrolyte. The manufacturing process involving solid electrolytes faces similar challenges as those discussed in Solid State batteries.

Currently, focus is on Metal-Air batteries with liquid electrolytes. Lithium, Sodium and Potassium are highly reactive in liquid electrolyte and thus, need a solid electrolyte. Hence, more researched Metal-Air chemistries include Aluminum, Zinc and Manganese.

Aluminum-Air chemistry has been keenly explored given the abundant availability of Aluminum and its safety of usage. Phinergy (invested by Alcoa and Indian Oil) is a leading Israel based company in the Aluminum-Air space. In India, Log9 Materials (invested by Sequoia) is also engaged in the same space.

The key challenges for Metal-Air batteries are —

A/ Unwanted solid electrolyte interphase layer formation – leading to loss in battery performance

B/ Dendrite growth on the anode leading to short circuits

C/ Finding an electrolyte that meets all the desired properties and stability of the cathode materials

3 /

SUPERCAPACITORS

Capacitors have two electrodes separated by a dielectric material. Energy is stored electrostatically in a capacitor as against through chemical reactions in batteries. Capacitors have a very high power density, therefore, they can be charged rapidly and also, can provide very high power.

However, traditional capacitors have very low energy density of <5 Wh/kg, making them unsuitable for energy storage applications. Supercapacitors have electrodes made with special materials like Graphene – which enable them to hold a much larger amount of energy without losing on high power density. Currently, supercapacitors with energy densities as high as 60-200 Wh/kg have been developed and they make a strong case for adoption in electric vehicles provided that the technology can be scaled up.

High quality materials that can hold such high energy (which is often associated with higher cell voltage) and can also withstand the high voltages is the key bottleneck in development of supercapacitors. Technological developments in Graphene chemistry is an encouraging sign for supercapacitors, yet the technology is a distant possibility.

While supercapacitors might take a long time to be able to replace batteries, they are already being used as a power assist in vehicles. The applications leverage the high power density of supercapacitors to assist the battery while accelerating rapidly and then recharges the capacitors during regular operation.

4 /

Li - METAL

Lithium metal batteries use Lithium anodes rather than Graphite as in the case of Li-ion batteries. Lithium is much lighter than Graphite and has twice the energy density vis-à-vis Li-ion batteries. However, the main issue with the Li-Metal battery is its low life cycle. This is largely attributed to metal deposit formation that depletes active Lithium and creates unwanted Solid Electrolyte Interface (SEI). Li-Metal batteries are most likely to get commercialized along with the development of solid-state batteries, as they are difficult to design using a liquid electrolyte due to the high reactivity of Lithium in an aqueous medium. In that sense, Li-Metal batteries would not only be a subset of solid-state batteries but probably the largest subset as well.

5 /

ORGANIC BATTERIES

Organic batteries use organic radical polymers as an electrode, eliminating metals from batteries. They are eco-friendly as the materials are biodegradable. Theoretically, organic batteries can offer the same or even better performance as compared to Li-ion batteries. They are also suitable for more efficient form factor designs as the organic electrode materials are flexible.

Organic batteries could be the ultimate destination for the evolution of battery technologies but these batteries are still decades away from commercial applications.

6 /

SOLID STATE BATTERIES

The current Li-ion batteries use liquid or polymer gel electrolytes. These electrolytes are flammable and are the main reason behind the safety concerns related to Li-ion batteries. In solid state batteries, this liquid/ polymer gel electrolyte is replaced by a solid electrolyte which is non-flammable, takes up lesser space and is a faster conductor of ions, thereby making solid state batteries lighter, smaller, safer and more powerful. A battery with a Li-anode and a LiI/Al_2O_3 electrolyte can offer 2.5x the energy density of traditional Li-ion batteries.

The technology is not yet ready for large-scale commercial production. One of the key problems with this technology is the formation of metal deposits when Lithium anodes are used, often causing such deposits to penetrate the electrolytes. Identifying uniform material for electrolytes and producing it commercially at low cost is a key hurdle for solid state batteries. Also, solid state batteries cannot function at low temperatures as the solid electrolyte's conductivity decreases with temperature.

Major OEMs like Ford, Hyundai, Nissan, Toyota, and Volkswagen have invested in this technology. Leading companies in this space are Sakti3 (USA) – Funded by Dyson, QuantumScape (USA) – Funded by Volkswagen.

7 /

LITHIUM SULPHUR

Lithium Sulphur (Li-S) batteries use Sulphur as a cathode material and Lithium as an anode. The biggest advantage of Li-S battery is its high energy density of 600 Wh/kg. In addition to the high energy density, Sulphur is abundantly available in nature and is also safe for use, unlike the current cathode materials which are not only scarce but are also unsafe. Li-S batteries can be used with very high depth of discharge and do not require any top up charging, which means they can be stored or left uncharged for a long time without having any effect on battery health.

The biggest challenge with this technology is that the underlying chemical reaction is complex and its mechanism is not fully established. This makes it difficult to model the cell performance and hence, the batteries require extremely complex algorithms.

There are several other issues with Li-S technologies like volume expansion of the cathode, unwanted reactions with electrolytes and polysulfide shuttling that results in degradation of the battery.

Oxis Energy is the leading company in this space. Other notable players working on this technology are Sion Power and Sony.

EXHIBIT 17 ↘

Snapshot of new battery technologies

Limitations

- \+ CATHODE
- − ANODE
- ▯ ELECTROLYTE
- ⚡ SPECIFIC ENERGY

Li-ion NCM

CURRENT TECHNOLOGY

Safety and energy density limitations

- − Graphite
- \+ Li+NCM
- ▯ Non-metallic Liquid/Polymer Gel
- ⚡ 200-300 Wh/Kg

Metal Air

Formation of unwanted layer at electrode

Dendrite growth on anode

- − Li/Al/Zn
- \+ Ambient Air
- ▯ Non-metallic Liquid/Polymer Gel
- ⚡ 1000-1200 Wh/Kg

Li-Sulphur

Complex reaction

Volume expansion at cathode

- − Li
- \+ Sulphur
- ▯ Non-metallic Liquid/Polymer Gel
- ⚡ 600-700 Wh/Kg

Li-ion with Si anodes

Silicon swelling causing cell damage

- − Silicon
- \+ Li+NCM
- ▯ Non-metallic Liquid/Polymer Gel
- ⚡ 250-400 Wh/Kg

Li-Metal

Metal deposits lead to low cycle life

- − Li
- \+ Metal Compounds
- ▯ Solid
- ⚡ 600-700 Wh/Kg

Super Capacitors

Provides high power but low energy density

Can be used in combination with batteries

- − NA
- \+ NA
- ▯ NA
- ⚡ 60-200 Wh/Kg

Solid State

Metal deposits at anode

Low performance at low temperatures

- − Graphite
- \+ Li+NCM
- ▯ Solid
- ⚡ 500-600 Wh/Kg

Organic Batteries

Poor electrical conductivity

High solubility of interactive species

- − Organic Polymers
- \+ Organic Polymers
- ▯ Organic
- ⚡ NA

Fuel Cell

Too nascent to be a threat for batteries

A /

FUNCTIONING

A fuel cell is fundamentally different as compared to a battery. While a battery only stores electricity and needs recharging, a fuel cell produces energy by consuming fuel (Hydrogen). In these cells, Hydrogen reacts with Oxygen to form water and the reaction creates a flow of electrons in an external circuit, resulting in an electric current which is used to drive the motor.

Current fuel cell cars come with a battery as well, since the fuel cell design is not robust enough to cater to the sudden power demand on rapid acceleration. Even if the fuel technology was to become flexible enough to cater to large variations in power demand, batteries would be needed for storing electricity generated through regenerative braking, an auxiliary system (for heating up, etc.) during start-up of the fuel cell and to power other low voltage systems within the car.

B /

CHALLENGES

Prima facie, the fuel cell technology looks clearly superior to battery technology and one might think that batteries do not have a long-term future. However, there are several challenges associated with Hydrogen economy.

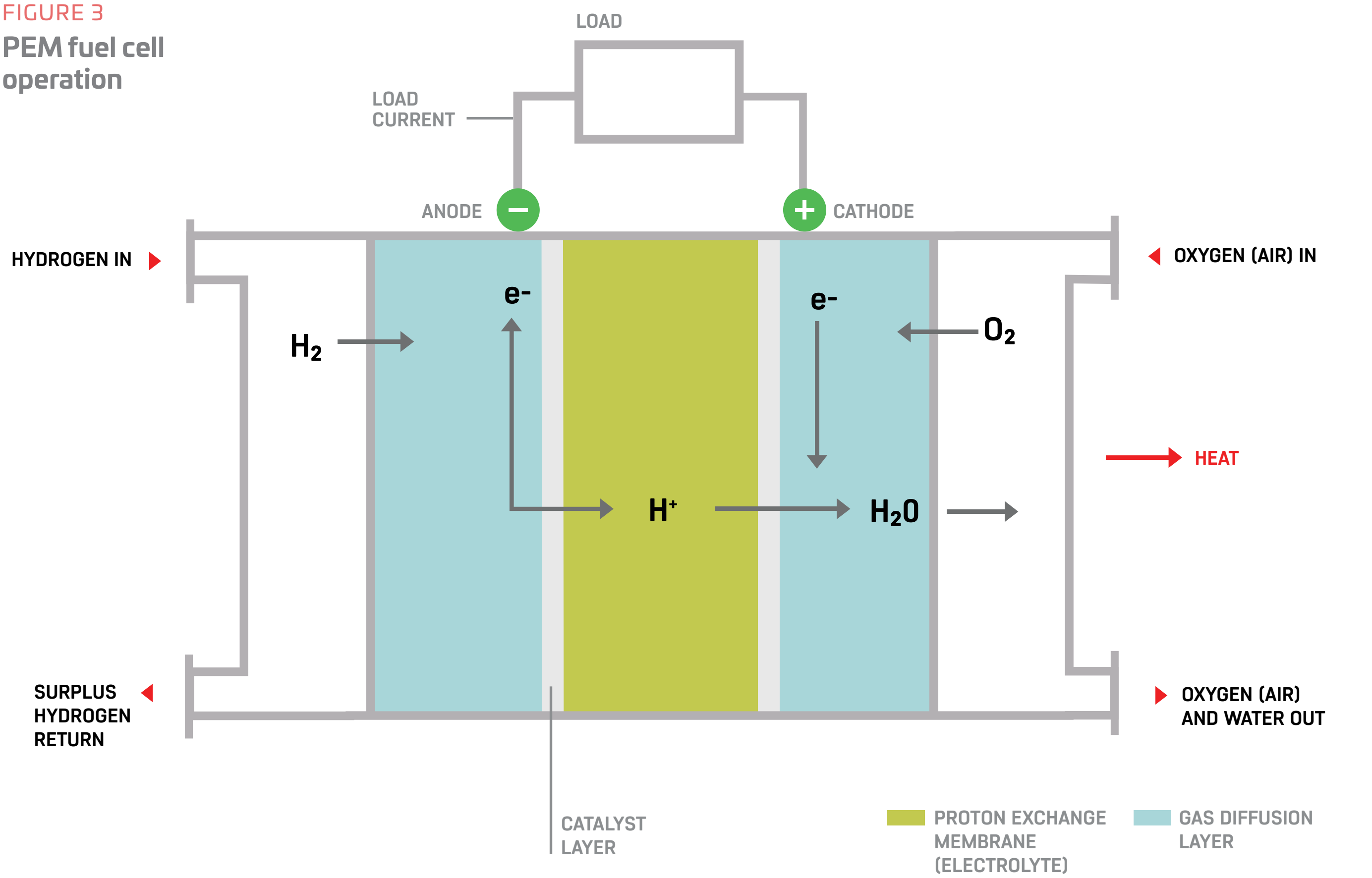
The majority of Hydrogen that is used today comes from fossil fuels by a process called reforming. To use fossil fuel to produce Hydrogen only for use in EVs would not make sense as it would only be shifting the source of pollution away from the tail pipe to Hydrogen production plants. Also, the overall system would be less efficient than ICE vehicles on a well to wheel efficiency.

The sustainable option to cater to Hydrogen demand is through water. Water can be converted into Hydrogen and Oxygen through electrolysis. The electricity for electrolysis can come from the grid. Again, for truly addressing the pollution problem the electricity has to come from renewable sources.

Advantages of a fuel cell

Hydrogen has a specific energy of ~40,000 Wh/kg as compared to Li-ion which is in a range of 160-280 Wh/kg. Hence, fuel cells are extremely suitable to offer higher driving range. The weight compounding problem (weight of vehicle increasing with range of vehicle) is not an issue with fuel cell technology. Also, refuelling of Hydrogen can be done very quickly, unlike the long charging time needed for batteries.

FIGURE 3
PEM fuel cell operation



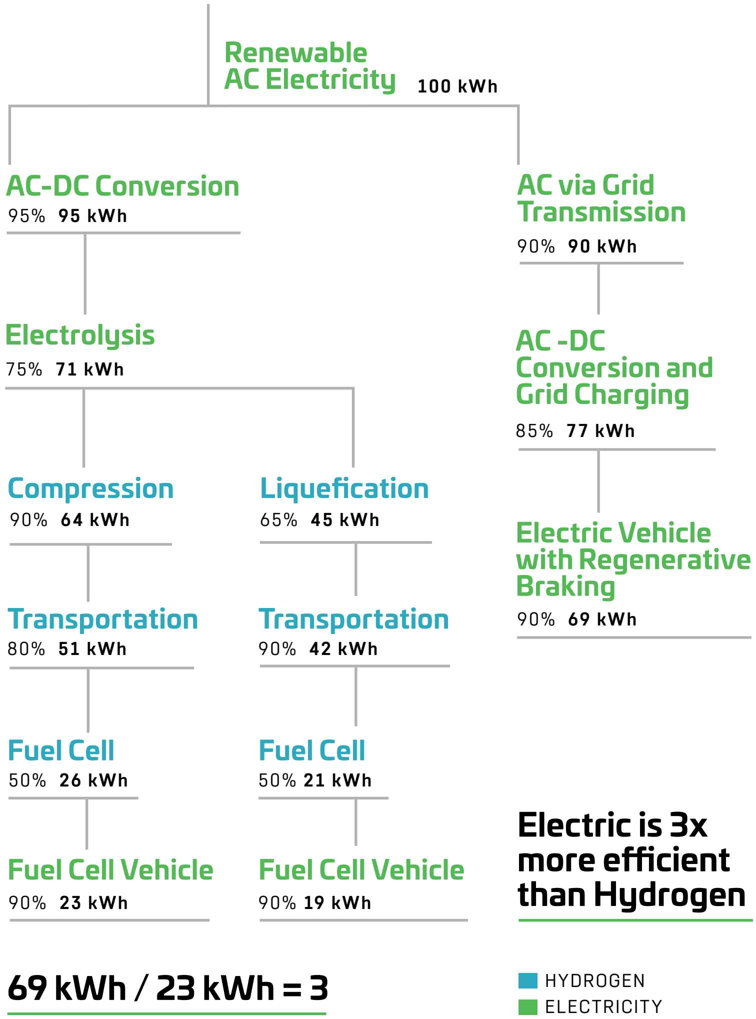
Is fuel cell a superior technology?

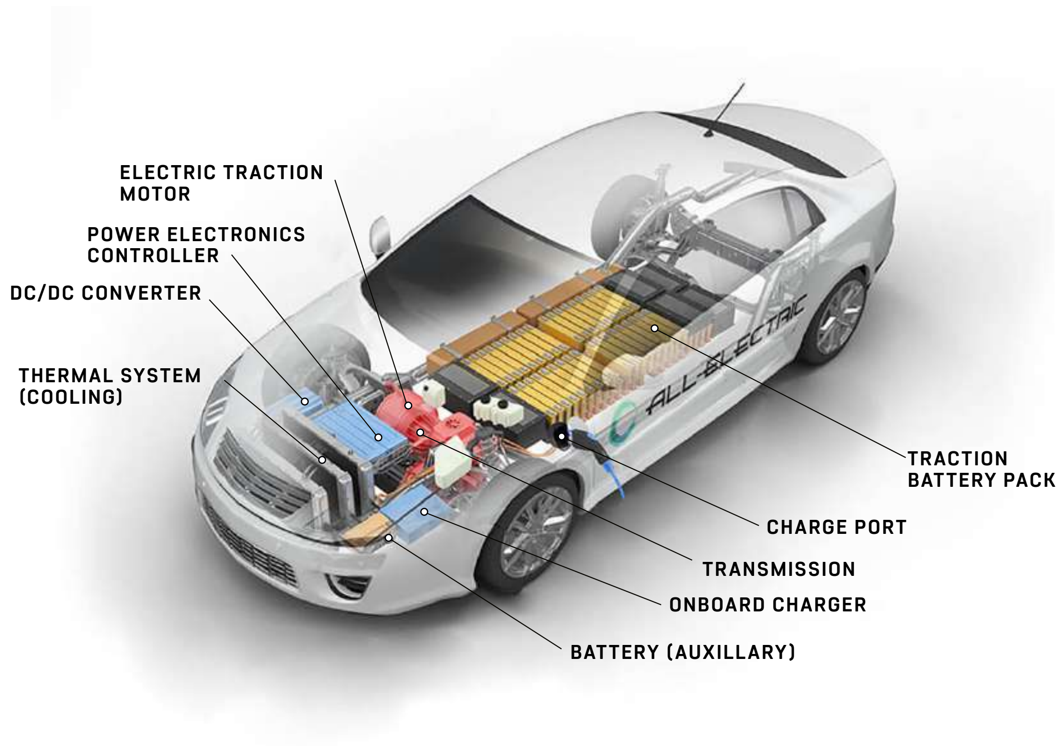
The answer is probably yes. But on a well to wheel ecosystem comparison, the advantages of fuel cells against batteries are negated both in terms of efficiency and feasibility of creating an ecosystem.

A number of countries and companies have increased their fuel cell focus. Japan has taken a lead in pushing for a Hydrogen economy. Countries like the USA, France and China are also doing work to develop fuel cell technologies. However, the space is very nascent and the ecosystem is non-existent. Thus, fuel cells are unlikely to be a threat for battery based electric vehicles in this decade at least. In the long term, one will have to wait and see how the fuel cell landscape evolves.

EXHIBIT 18

In terms of well to wheel efficiency, the BEVs have an edge over the fuel cells as shown in the figure below





Introduction to other key components and systems

1 /

MOTORS

An electric motor performs the same function as an engine does in an ICE vehicle – it propels the vehicle. It is the second most critical component after the battery, and along with the battery, replaces the engine in an ICE vehicle. Different types of motors have different characteristics and it is important to choose the right type of motor for an electric vehicle.

The most commonly used motors in EVs are Brush-Less Direct Current (BLDC) Motor, Permanent Magnet Synchronous Motor (PMSM) and Induction Motor (IM).

Apart from these, Switched Reluctance Motors are becoming increasingly popular for application in electric vehicles. They have higher power density, higher efficiency and longer power range. Tesla, which traditionally has been using Induction Motors, introduced a new motor technology in Model 3 - Permanent Magnet Synchronous Reluctance Motor. A similar technology is used by BMW for their model - BMW i3.

BLDC **Brush-Less Direct Current Motor**

A BLDC Motor has a rotor made of permanent magnets and a stator that is electronically commutated

BLDC motors can be configured in two ways – in-runner (rotor inside stator) or out-runner (rotor outside stator)

- ✓ More efficiency than an Induction Motor
- ✓ More compact and lighter
- ✓ Higher torque density

- ✕ Higher cost because of permanent magnets
- ✕ Shorter constant power range
- ✕ Decreased torque with increased speed

APPLICATIONS

Light electric vehicles like 2W/3W

EXAMPLES

Out-runner: Hero Electric Optima
In-runner: Ather 450x

PMSM **Permanent Magnet Synchronous Motor**

A PMSM is similar to BLDC with the key difference in type of input current. It works on AC current

- ✓ No torque ripple
- ✓ More energy efficient than BLDC Motors
- ✓ Suitable for in-wheel application
- ✓ Operable in a wide speed range

- ✕ Costlier than BLDC Motors
- ✕ Iron loss at high speeds during in-wheel operation resulting in heat

APPLICATIONS

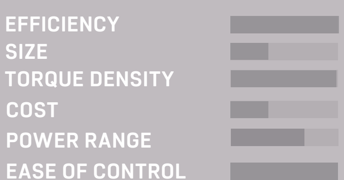
High performance applications like cars and buses

EXAMPLES

Nissan Leaf, Hyundai Kona, Toyota Prius

IM **Induction Motor**

In an IM, AC current in the stator induces current in the rotor which creates a magnetic field that chases the stator's magnetic field. These motors do not use permanent magnets



- ✓ Cheaper, easier to design and more robust
- ✓ No dependency on rare earth magnets

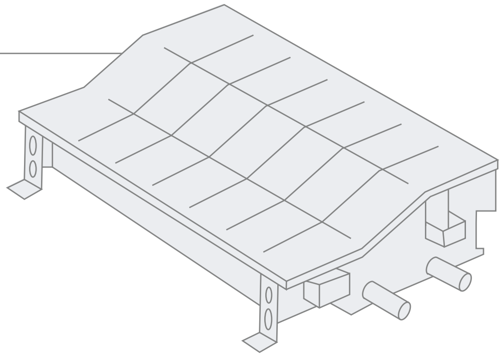
- ✕ Low starting torque under traditional v/f operation method; for high starting torque need complex controllers that work on FOC
- ✕ Requires complex inverter circuit

APPLICATIONS

Performance oriented applications from 2W to buses

EXAMPLES

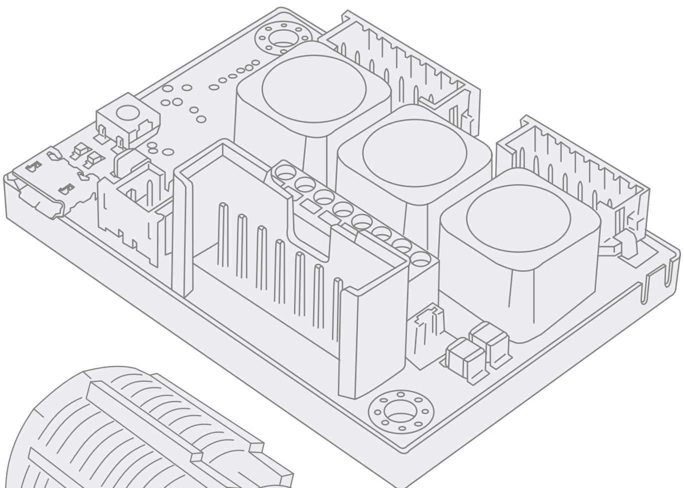
Tesla Model S, X

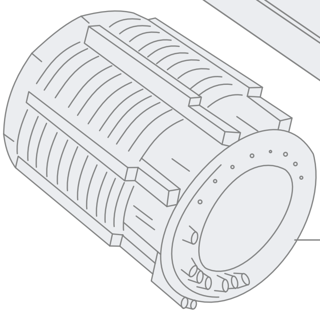


2 /
CONTROLLERS

The controller is somewhat of an intermediary between a battery and a motor. It is essentially the brain of an EV powertrain as it estimates how much energy needs to be supplied to the motor for the EV to function smoothly on a road. The controller receives an indication of how much power is demanded by the driver basis the movement of the accelerator pedal. The controller then assesses the demand, considers the current operating parameters, and calculates how much energy should flow from the battery to the motor.

The controller takes care of a variety of other functions within the EV powertrain as well. Reverse rotation, when required, and regenerative braking are examples of some of the other functions. A good controller is essential for the efficient use of energy stored in a battery, a smooth drive and vehicle safety.

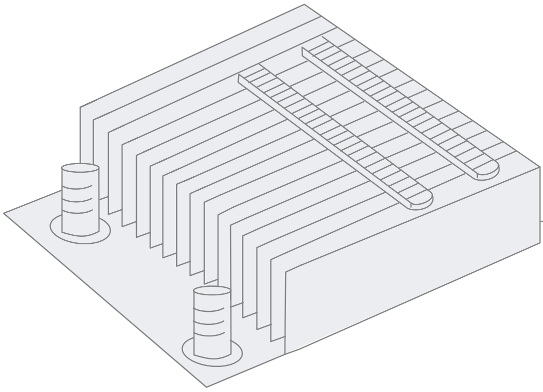




3 /
E- AXLES

E-axles combine motor, power electronics and transmission into a single casing. This allows for neat packaging, simple integration of various components and improved efficiency. It acts as the powertrain of an electric vehicle. The design of E-axles vary based on the type of vehicle configuration and the components used for integration. Designing an E-axle with optimal thermal management will be a key consideration for OEMs, as the performance of the motor will be impacted by this. This component provides an opportunity for traditional axle companies to continue their business but with additional investments for developing advanced design capabilities.

In addition to the components discussed here, electric vehicles also require extensive design changes to the components that are common with ICE vehicles. For example, the chassis design of an EV is completely different to an ICE vehicle. Wiring harness specifications are very different as the voltage levels in EVs are very high. The impact an EV has on traditional ICE components has been elaborated in a later section.

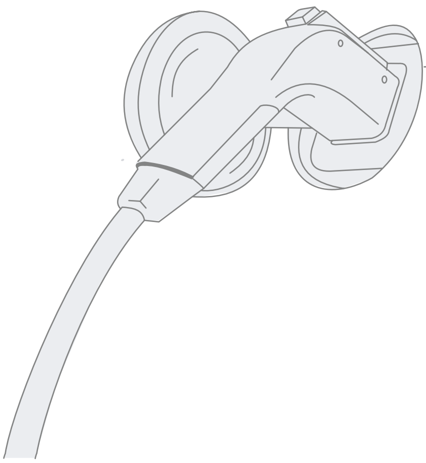


4 /
INVERTERS

An inverter converts DC current from a battery into AC current for a motor (for AC motors only). The inverter can change the speed at which the motor rotates by adjusting the frequency of the alternating current. It can also increase or decrease the power or torque of the motor by adjusting the amplitude of the signal.

5 /
DC-DC CONVERTERS

DC-DC converters are used to either step up or step down the voltage as per the requirement of various components within the EV architecture. The electric vehicle battery stores electricity at a very high voltage. Step down DC-DC converters are used to supply energy to smaller systems like infotainment devices. In case a DC motor is being used to drive the electric vehicle, it often requires a higher voltage than the battery voltage and a step up DC-DC converter can be used.



6 /
ONBOARD CHARGERS

On-board chargers enable users to charge vehicles by plugging them into an AC source, either at home or at public charging stations. These are essentially rectifiers that convert AC to DC that have several safety and control logics built in. Onboard chargers have basic configuration and take time to charge a vehicle. When a vehicle is charged using a Fast DC charger, the onboard charger is bypassed and the battery is charged directly.

EV Charging

Charger Schematic — Charging Basics

Unlike an ICE vehicle, which can be refuelled within minutes at a gas station, EVs need to be charged, and this charging process is significantly slower than refuelling. EV charging is an important aspect of an EV ecosystem, considering the customer's anxiety towards driving range and charging time.

EV chargers, also known as EVSEs (Electric Vehicle Supply Equipment), are used to charge a vehicle. The speed at which an electric vehicle can be charged is dependent on the power of a charger.

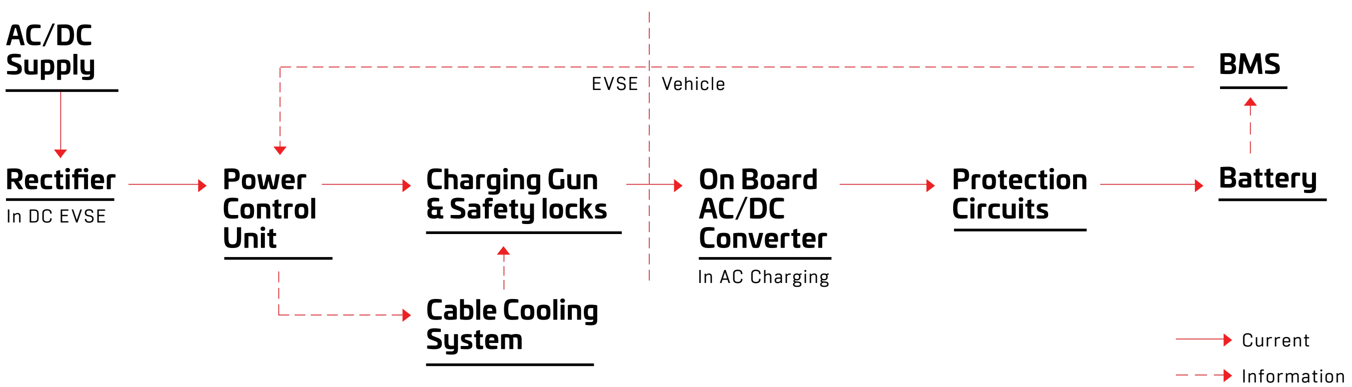
The charging speed is often limited by the battery design. Charging a battery faster than the maximum specified rate can damage the battery.

The major components of an EV charger are rectifier, power control unit and charging gun. A rectifier is only present in DC chargers and is used to convert AC power into DC power. After the power is converted to DC, the power control unit takes signal from the BMS of the vehicle and supplies the requisite power to charge the battery. There are safety locks that ensure that the current does not flow from the device, till it is connected to the vehicle.

DC Chargers with high power output (~100 kW+) may require liquid cooled cables and high stress materials.

EXHIBIT 19

EV charging operation using EV Chargers



EV chargers are characterized mainly on the following four parameters —

Power and Voltage levels

Based on the power and the range of voltages that are supported by EV chargers, they are classified into three levels. A) <3.3 kW are Level 1 chargers, B) between 3.3 and 22 kW are Level 2 chargers, and C) >22 kW are Level 3 chargers.

AC or DC

If AC power is used, then the vehicle needs to have a device that can convert the power to DC. Generally, all vehicles have an onboard AC-DC converter to enable charging using AC or DC. AC chargers don't require a rectifier and are cheaper.

However, in case of AC chargers, there are limitations on the peak power with which vehicles can be charged, which limits the rate of charging and increases the time required to charge.

Mode

The mode of an EV charger is defined to decide its charging application and level of communication between the charger and the vehicle. Globally, there are four modes

MODE 1

Connection with the vehicle is through a standard socket without any other communication

MODE 2

Connection with the vehicle is through a standard socket, along with other communication and safety features

MODE 3

Connection between the AC charger and the vehicle is through a wall mounted AC charger, with communication and safety features between them

MODE 4

Connection between the DC charger and the vehicle is through a wall mounted DC charger, with a high level of communication and safety features between them

Charger Types

A charger type typically refers to the output socket and the connector used by a charger. It also includes the high-level communication protocols between the charger and the vehicle which are required for Mode 4 charging. Globally, there is a wide variation between the different types of sockets used, due to discretion of manufacturers and OEMs and also due to presence of several international bodies governing the relevant standards. International Electrotechnical Commission (IEC) is the leading international standardization organization for EV chargers. These standards are generally adopted by different trading zones and national organizations.

Efforts to consolidate charging standards are underway in Japan and China. They plan to develop a new standard which is backward compatible with both, GB/T and CHAdeMO standards.

EXHIBIT 20

Popular global charging standards

AC CHARGERS

1 /

Type 1 AC Charger

USED IN
Japan & USA

MAXIMUM POWER
7.4 kW

2 /

Type 2 AC Charger

USED IN
The EU (except France and Italy)

MAXIMUM POWER
4.4 kW

3 /

Type 3 AC Charger

USED IN
France & Italy

MAXIMUM POWER
22 kW

DC CHARGERS

4 /

CHAdeMO

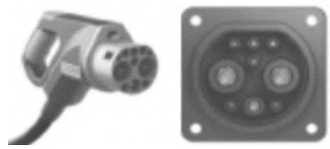
COMMUNICATION PROTOCOL
Control Area Network (CAN) for Communication

USED IN
Japan, Parts of USA & Europe

MAXIMUM POWER
400 kW DC Charging

5 /

GB/T



COMMUNICATION PROTOCOL
Control Area Network (CAN) for Communication

USED IN
China

MAXIMUM POWER
237.5 kW DC Charging

6 /

Tesla Super Charger

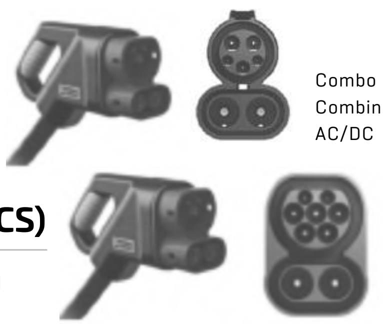
COMMUNICATION PROTOCOL
Control Area Network (CAN) for Communication

USED IN
USA, Europe for Tesla users

MAXIMUM POWER
135 kW DC Charging

7 /

Combined Charging System (CCS)



Combo 1 — Combined AC/DC

Combo 2 — Combined AC/DC

COMMUNICATION PROTOCOL
Power Line Communication (PLC) for communication which is more complex and compatible with Vehicle to Grid (V2G) Charging

MAXIMUM POWER
43 kW AC & 400 kW DC

USED IN
Europe & USA