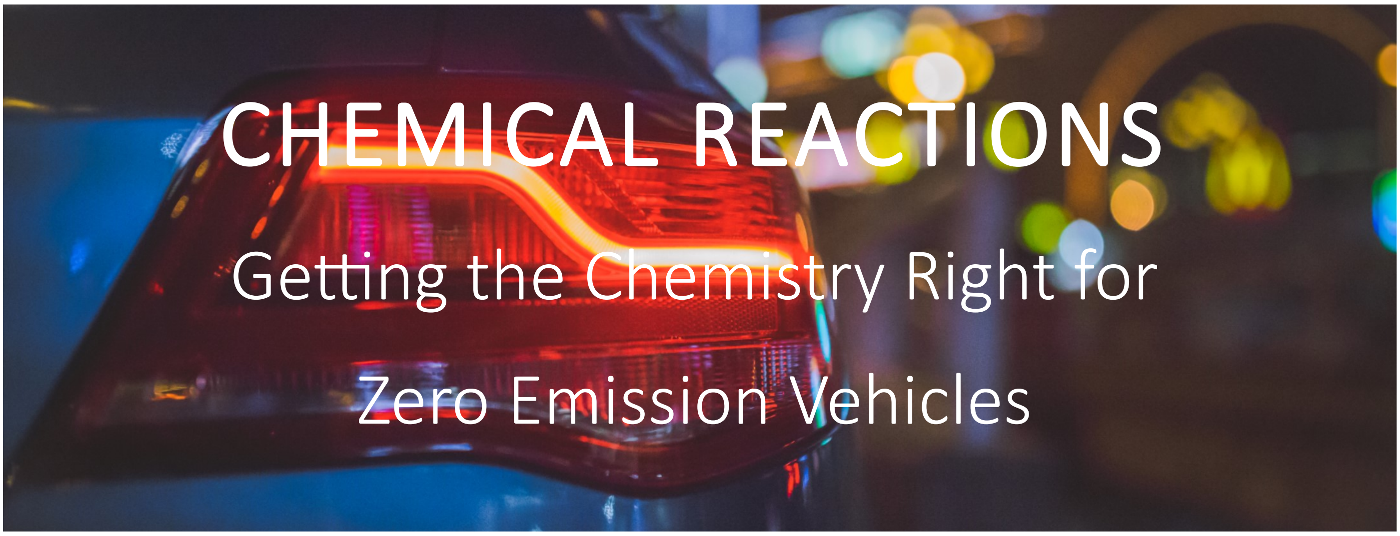



**The revelation of "Dieselgate" in September 2015 has contributed to a major shift in public opinion against diesel engines and, more broadly, the Internal Combustion Engine ("ICE"). Calls for more drastic measures to clean the air of large cities, coupled with strict $CO_2$ targets set by the Kyoto protocol, has led to a renewed impetus for a switch to Alternative Power Vehicles ("APV"). The growing availability of viable electric technology and innovative designs is having a disruptive effect on the automotive industry and its supply chain, including chemicals. The technology of choice for APVs, batteries and materials remains undecided. It will likely evolve and change over time as battery life, range and charging speeds improve, yet it is already having an impact on geo-politics, partnerships and industry consolidation. Chemical producers are enabling component manufacturers to respond to the EV challenge but the ones exposed to ICE applications will have to adapt to a gradual contraction of their end markets.**

## WHAT FUTURE FOR THE CAR INDUSTRY?

APVs, be it hybrid-electric (HEV) like **Toyota** Prius, Plug-in Hybrids (PHEV) like **Mitsubishi** Outlander, or Battery all-electric (EV) like **Nissan** Leaf, Tesla and **BMW** i3, have recently made a lasting positive impression on consumers. In particular, the **Tesla** Model S, a "newcomer" with an impressive design, quality and performance, which is competing directly in the executive car segment with premium brands like **BMW** and **Mercedes**, has propelled the image of electric cars to a previously unthinkable level.

As more affordable models and a broader range of HEVs, PHEVs and EVs become available over the next 5-10 years, we are likely to see a considerable rise in their sales. In response, most traditional auto OEMs have announced APVs to be launched sometime between 2019 and 2021.

According to the International Energy Agency ("IEA"), there were two million EVs on the road globally in 2016, making up just 0.2% of total light-duty passenger vehicles in circulation. The IEA estimates that EVs could reach 9-20 million by 2020 and between 40-70 million by 2025 (3-6% of the total).

Diesel cars are already in retreat in their European home market. In 2017 sales fell by 8%, with their market share slipping to 44% from a high of 56% in 2011. If the current trend continues, by 2022 the share of diesel in Europe could drop well below 30%, or even lower if the trend accelerates.

Are EVs about to take up diesel's lost share? For that to happen their current high cost needs to fall, the number of models on offer to increase, their effective range to improve, the current charging infrastructure to be extended and governments to retain favourable tax schemes. At present, EV production capacity is limited, so auto OEMs recognise they need to invest heavily in new production or reconfigure existing manufacturing. In parallel, they continue developing petrol ICEs and are making continuous improvements in terms of efficiency and emissions.

For these reasons we anticipate that the most popular drivetrain in the next 5-10 years is more likely to be the HEV (or PHEV), which benefits from an electric motor in cities or heavy traffic conditions and an ICE (usually petrol) for the open road and for charging the battery, which is considerably smaller and cheaper than a battery pack in an EV.

The short term advantage of HEVs is their ability to use the existing fuel station networks rather than relying on available recharging infrastructure, which is still in its infancy.

Regulatory and tax frameworks are key drivers for change in automotive technology, either against existing technologies like diesel or for enhancing sales of APVs. These encourage change but also can create distortions favouring one specific technology at the expense of another.

## ELECTRIC VEHICLES – OPPORTUNITY OR THREAT?

EVs present some monumental challenges for the traditional car manufacturers and their supply chain. The eventual replacement of the ICE, which is made up of thousands of parts, may eventually lead to the "death" of various component manufacturers. Also, car OEMs have to make vast investments to design totally new cars, make various auxiliary systems and materials compatible with electric motors, as well as use lightweight materials to counterbalance the extra weight of batteries.

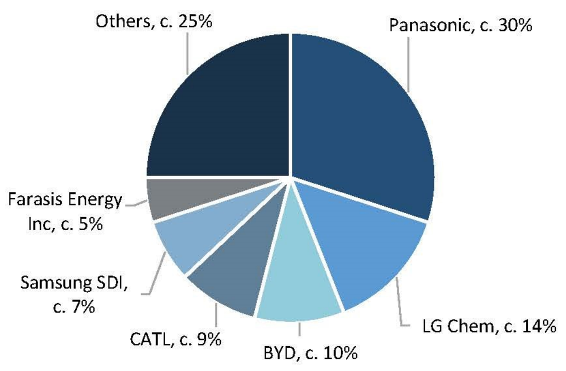
In addition, significant capital investments and build-up of know-how are required for the mass production of battery packs which are complex, as **Tesla** is finding out in its c.$5bn Gigafactory, where bottlenecks in the automated production line had to be resolved by manual override delaying the ramp up.

At present, established auto OEMs like **Volvo**, **BMW**, **JLR**, **Mercedes** and **VW**, are scrambling to launch new models and reconfigure their businesses, including design teams, supply chains and production plants. For example, JLR's Slovakian plant under construction has been expanded to include a battery assembly facility.

In addition, China is emerging as both a major market and a major producer for EVs, seeing them as an opportunity to leapfrog the established OEMs.

Main beneficiaries of the accelerating trend for EVs are the manufacturers of electrical and electronic components, such as microprocessors, electric motors and batteries.

***Figure 1.*** *Battery manufacturers market share*




Source: Bernstein (via FT). Li based batteries only

For EV batteries in particular, there are 6 main manufacturers. **Panasonic** (Japan) is No.1 by a wide margin, followed by **LG Chem** (Korea), **BYD** (China), **CATL** (China), **Samsung SDI** (Korea) and **Farasis Energy** (US).

These companies have been actively forging development agreements with auto OEMs and raising capital for growth to fund capacity ramp-up and R&D for the next generation of batteries.

In November 2017, **CATL** (Contemporary Amperex Technology Co Ltd) announced plans for a $2bn IPO on the Shenzhen stock exchange, by the end of June 2018, valuing the company at c. $20bn.

In December 2017, **Panasonic** and **Toyota** announced a development agreement with the objective to develop the prismatic battery (rectangular in shape).

In March 2018, **VW** announced a €20bn supply contract for batteries in Europe and China with **Samsung SDI**, **LG Chem** and **CATL**.

Other important players in the EV batteries industry are the main auto catalysts materials suppliers **BASF**, **Johnson Matthey** and **Umicore** all of which have entered the area of producing battery cathode materials.

**Johnson Matthey's** share price jumped by 12% last September, upon the announcement that it would invest £200m into building manufacturing capacity for its Lithium Nickel Oxide (eLNO) battery cathode material technology. It also claimed that the overall market could be worth more than $30bn in sales once battery electric vehicles have a 10% share.

Separately, in February 2018, **Umicore** who is, seen as the leader in cathode materials with Nickel Manganese Cobalt (NMC), raised c. €900m to fund investments in cathode materials and potential acquisitions to strengthen its offering in clean mobility materials and recycling.

Finally, in March 2018, **BASF** announced a JV in the US with **Toda** to produce high energy nickel cobalt manganese (NCM) and nickel cobalt aluminium oxide (NCA) cathode materials. In June last year, **BASF** announced a €400m investment into new plants for the production of cathode materials in Europe, with nickel and cobalt supplied by **Norilsk Nickel**, the Russian mining group.

## THE CONSTRAINTS OF ELECTRIC VEHICLES

Notwithstanding the relatively high price of EVs, their main constraint has not been the vehicle's on-the-road performance, but the batteries themselves, due to their relatively low range between charges and long recharging time, as well as their high cost and weight. In addition, the actual life of the EV batteries is still unknown to the broader public. **Tesla** Model S' Li-ion battery, in the 85kWh variant, weighs 540kg and gives a range of c.400km. It is covered by an 8-year, unlimited mileage warranty, but given that the first cars were sold in 2012, the field data about battery life is still being built up.

The reality is that despite the fall in battery prices, from c. $1,000 per kWh in 2010 to c. $227 per kWh in 2016, (according to McKinsey), they will and must fall further. At Tesla's Gigafactory, a replacement battery pack is still very expensive. Therefore, 6-7 years after the purchase of an EV, which has been used hard, the owners are likely to be faced with a hard choice: either spend a considerable amount of money on replacing the battery or scrap the car, making the economics of owning or leasing an EV unfavourable.

## THE FUTURE OF LITHIUM-BASED BATTERIES

Li-ion batteries, introduced in 1991, have been the most broadly used type for electronic devices and EVs. They are an attractive option for vehicles, but have their limitations in terms of energy density, recharging time, safety, ambient temperature sensitivity and life.

There have been relatively few developments in the technology used for anodes and electrolytes since their commercialisation. For example, anodes in most cases are still made of graphite, although lithium titanate anodes (LTO) have recently become commercially available. The electrolyte is typically a lithium salt dissolved in an inorganic solvent (except in lithium-ion polymer batteries).

Cathodes, on the other hand, are usually made up of lithium, metal oxides or phosphates. There are various possible formulations (see table 1). The first commercialised Li-ion batteries used Lithium Cobalt Oxide (LCO). By late 1990s the Lithium Nickel Cobalt Aluminium Oxide (NCA) cathode was introduced, which is used today by **Panasonic** in **Tesla** cars. More recently, Lithium Nickel Manganese Cobalt (NMC) has become the technology of choice for many applications. Companies continue to look for new materials. **Johnson Matthey's** Lithium Nickel Oxide (eLNO) is an example.

Some major manufacturers of chemicals and specialty materials such as, **BASF**, **Johnson Matthey** and **Umicore** are working on developing cathode materials to help optimise Li-ion battery performance and reduce their cobalt content. The optimal technology has yet to be established.

***Table 1.*** *Examples of commercialized cathode formulations, and the metals required, aside from lithium*

| **Cathode Type** | **Chemistry** | **Example Metal Portions** (excl. Li) | **Example Use** |
|---|---|---|---|
| NCA | $LiNiCoAlO_2$ | 80% Nickel<br>15% Cobalt<br>5% Aluminium | Tesla Model S |
| LCO | $LiCoO_2$ | 100% Cobalt | Apple iPhone |
| LMO | $LiMn_2O_4$ | 100% Manganese | Nissan Leaf |
| NMC | $LiNiMnCoO_2$ | 33.3% Nickel<br>33.3% Manganese<br>33.3% Cobalt | Tesla Powerwall |
| LFP | $LiFePO_4$ | 100% Iron | Starter batteries |

Source: Desjardins, J (2017, May 8). *The Cathode is the Key to Advancing Lithium-Ion Technology*

Separately, a UK-based start-up, **Oxis Energy** is developing a Lithium Sulphur (Li-S) cell, which has higher energy density, lower weight and cost compared to Li-ion, but is not yet commercialised.

In parallel, there are efforts for developing alternative type of batteries, electricity generation or storage systems. Main examples include:

### *a) Solid State Batteries*

Solid-state batteries replace the liquid electrolyte with a solid one and use lithium metal at the anode, rather than graphite. They aim to offer significantly shorter charging times and longer driving range, as well as better fire safety than the current Li-ion cells with liquid/gel electrolyte (e.g. fire incidents involving the Boeing 787 Dreamliner). Solid state battery technology is being developed by a handful of companies in collaboration with some start-ups, such as **Solid Power**, (spin out of University of Colorado Boulder), in collaboration with **BMW**, **Ilika** (spin out of University of Southampton) in collaboration with **Toyota**, **Ionic Material** in collaboration with **Renault-Nissan-Mitsubishi**, and **Dyson**, which has announced the intention to enter the EV market. They are all targeting to launch new batteries between 2022 and 2025.

### *b) Supercapacitors – Graphene Revolution Underway?*

Supercapacitors, are electricity storage systems, with limited capacity but very high charge/discharge rates and very long cycle life (up to 1 million cycles vs 3-5 thousand). Supercapacitors have been commercialised for years, but the latest development is the incorporation of Graphene. **Skeleton Technologies**, has already commercialised a supercapacitor using Graphene, termed "Graphene ultracapacitor". Other manufacturers include **CRRC** (China), **ZapGoCharger** (UK), **Angstron Materials** (US) and **Sunvault Energy** (Canada). At present, ultracapacitors are expensive and seen as a system that could be used alongside a Li-ion battery to take care of the stressful part of a battery's life, i.e. deliver sudden bursts of energy, which could double or triple a battery's life expectancy. Their other advantage is that they don't use cobalt.

### *c) Fuel-Cells*

Some auto OEMs are hedging their bets by investing considerable resources into fuel-cells, an alternative system to batteries, which uses hydrogen as fuel. **Honda** and **Toyota** stand out having both recently launched a model. In March 2018, the British Metropolitan Police announced the purchase of 11 **Toyota Mirai**, to use as patrol cars in London. This 4-door sedan has a range of 300 miles on a single hydrogen tank. A key constraining factor for the commercialization of fuel-cell cars has been the lack of hydrogen filling station networks, but some oil majors are starting to invest in that area. If the lack of availability of metals for batteries becomes a bottleneck and/or the electricity grid capacity is not sufficient to cover EV demand, fuel-cells could prove a viable alternative.

## AUTO OEMS SCRAMBLING TO SECURE RAW MATERIALS FOR LI-ION BATTERIES

As auto OEMs are accelerating their EV plans, they are quickly coming to terms with securing reliable supplies of lithium and cobalt. If no alternatives are found in the next few years, the demand for these metals is expected to soar. Over the last 10 years, the price of lithium more than doubled and as for cobalt it has more than tripled over the last 3 years. There is a limited number of lithium producers: **Albermarle** (through the $6.2bn **Rockwood** acquisition in 2014) and **FMC** of the US, **SQM** (Chile-based), in addition to **Tianqi Lithium** and **Jiangxi Ganfeng Lithium** of China. On 26th February 2018, **FMC** announced a plan to IPO its lithium business (15% stake for $500m), and subsequently spin the remaining 85%. Lithium Carbonate supply is set to double by 2025, and some investors are concerned that, despite the growth, lithium is going to become an oversupplied commodity.

China is also scrambling to secure lithium resources. Recent evidence of the Chinese appetite for lithium include the reported interest of **Tianqi Lithium**, in the 32% stake in **SQM** being sold by **PotashCorp** for c. $5bn, and a $265m acquisition of **Lithium X**, a Canadian listed lithium exploration company with no reported income, by **Nextview New Energy Lion Hong Kong**.

In addition, it has been recently reported that German OEMs, such as **BMW** and **VW**, have entered into direct negotiations with mining companies for long-term (5-10 year) supply contracts.

## OPPORTUNITIES FOR THE CHEMICAL INDUSTRY

The emergence of EVs is having a disruptive effect on the automotive industry forcing a redesign of car platforms, an R&D push in new battery technologies, and mass production of components and materials previously considered niche (e.g. carbon fibre composite body in BMW i3).

The chemical industry is already playing a central role in developing new battery technologies, as well as lightweight or eco-friendly materials. Also, EV battery recycling technology is a major opportunity given the commitments of auto OEMs for recycling end of life vehicles (e.g. EU's ELV Directive 2000/53/EC).

The eventual switch from ICE to all-electric is expected to reduce significantly demand for chemicals used for ICEs, such as lubricant additives, foundry chemicals and emission catalysts, however, even the most positive forecasts predict that by 2030 EVs are expected to take only a minority share of the new car sales. Therefore the replacement of the ICE and its repercussions, is expected to be gradual.

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