ILZSG Insight

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THE POTENTIAL IMPACT OF HYBRID AND ELECTRIC VEHICLES ON LEAD DEMAND – UPDATE 4

1. Introduction

Sales of hybrid and electric vehicles are surpassing even the most optimistic predictions, particularly in China and Europe. Their combined share of the new light duty vehicle global market rose from only 3% of in 2015 to 26% last year and is expected to increase further over the next few years. According to Macquarie Research's recent projections, hybrid and electric vehicles will capture a substantial 62% of the new vehicle market by 2030, which is in line with forecasts published by other well regarded consultants, including Avicenne Energy and IHS Markit.

Government legislation has been key to the commercial success of hybrid and electric vehicles in recent years. Either by offering incentives to purchase these vehicles or imposing increasingly low fleet-wide carbon dioxide (CO2) emission limits on automakers, governments in a number of countries have been successful in their aims to promote the electrification of private transport. The fact that some of these incentives have started to be phased out in China and some European countries, without any major negative impact on the sales of the vehicles of which they were targeted, reveals that this market is moving to a mature state in those regions.

However, it should also be noted that environmental legislation has never been so stringent, particularly that aimed at limiting automotive CO2 emissions. The formal adoption by the European Parliament of a proposal that requires a reduction in the emissions of light duty vehicles by 100% by 2035, which in practice bans the sale of new cars with an internal combustion engine (ICE), is a further strong signal of the regulatory support for the electrification of vehicles within the EU.

Lithium based battery technology has become the standard choice for torque assistance and traction purposes in hybrid and electric vehicles, due to its high power and energy density compared with both nickel-metal hydride and lead-acid batteries. Lithium batteries also benefit from a high dynamic charge acceptance and a long service lifetime if operating within their specified temperature range. In recent years automakers have tended to favour NMC lithium batteries, which combine nickel, manganese and cobalt oxide in the cathode and use a graphite anode. Alternative chemistries include the cost-effective lithium iron phosphate (LFP) batteries, which are currently gaining market share in particular for low to medium cost vehicle models.

The principal weakness of lithium-based batteries is their high cost, which is typically around 2 to 3 times more than lead-acid, reduced power at low temperatures and propensity to overheating, limiting their safety in extreme conditions. The fact that supply chains for some the materials used in these batteries, most notably cobalt and lithium, still face unsolved challenges may also be considered a disadvantage. Additionally, their product-life circularity and environmental sustainability have been a cause for concern as recycling used lithium-ion batteries is a complex and difficult task.

These are the main reasons for the current low penetration of lithium technology in the 12V battery market. This situation is likely to persist over the next decade or so, with lead acid batteries continuing to be the standard choice for batteries used for starting, lightning and ignition (SLI) duties in vehicles using an ICE as well as for auxiliary safety and comfort applications in pure electric vehicles and some hybrids. The main reasons for this are the fact that 12V lead based battery technology is proven, low cost, does not require the use of scarce or expensive materials, performs well in cold cranking conditions and remains stable and safe over a wide temperature range. Furthermore, lead acid batteries are easily recyclable with well established collection and recycling networks operating in most countries.

Since they are not required to start an internal combustion engine, 12V batteries used for auxiliary duties contain a smaller amount of lead than the typical battery used for SLI purposes. This fact, combined with the rising penetration of hybrid and electric vehicles, has been perceived by some analysts as a threat to the future of the lead industry, since the 12V battery market is a key consumer of lead metal.

However, an empirical predictive analysis based on forecast sales of light duty vehicles (LDV) that has been included in section 6 of this paper demonstrates that the large replacement market of batteries used in ICE LDVs, combined with the increasing demand for auxiliary 12V batteries could balance losses due to lower sales of vehicles with an ICE and the resulting fall in demand for new SLI batteries over the period 2023-2030. In addition, other important lead consuming industries, including E-bikes, telecom backup systems and energy storage systems used in the renewable energy sector and for charging stations for electric vehicles are also expected to continue to support demand for lead.

This Insight, an update of the papers of the same name published in March 2010, June 2011, July 2013 and May 2015 will assess the current situation in the hybrid/electric vehicle market and the likely consequences for future lead metal usage.

Comments or Questions

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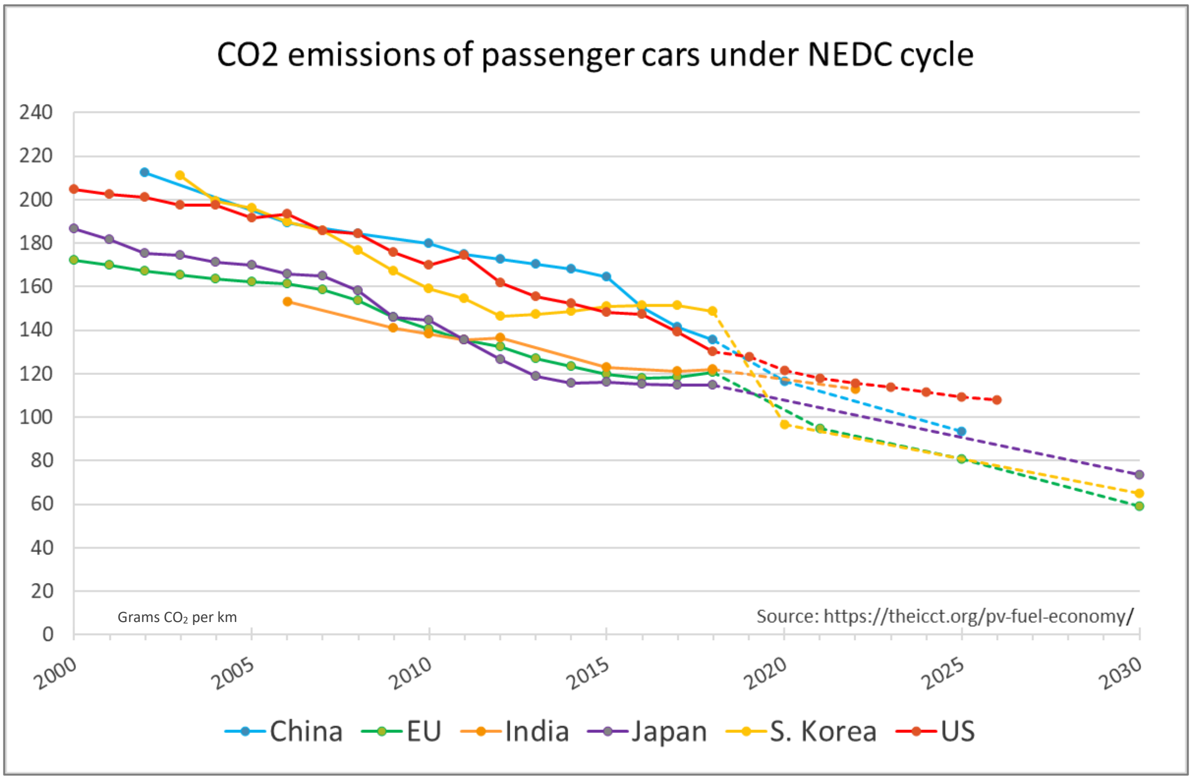
2. Regional Environmental Regulation Framework and Governmental Incentives Towards Vehicle Electrification

Sustained policy support has been crucial for recent years' commercial success of hybrid and electric vehicles. Either by offering incentives to purchase these vehicles or imposing increasingly low fleet-wide carbon dioxide (CO2) emission limits to automakers, governments in a number of countries have been successful in their venture to promote the electrification of private transport. These include, amongst others, the European Union (EU), China, India, Japan, the Republic of Korea and the United States (US), where automotive CO2 emission limits (see chart 1) are being enforced for more than two decades. In the EU, this regulatory framework has been particularly stringent and its latest Regulation on vehicle CO2 emission limits, put forward in 2019, imposed a maximum of 95 grams per km by 2021 and reductions by 15% from 2021 levels by 2025 and 37.5% from 2021 levels, corresponding to around 60 grams per km, by 2030. Many of these countries are members of the Electric Vehicles Initiative, a multi-governmental policy forum coordinated by the International Energy Agency (IEA) that was established in 2010 to promote the adoption of electric vehicles (EVs) worldwide and has put forward ambitious vehicle electrification targets for the coming decades.

Chart 1

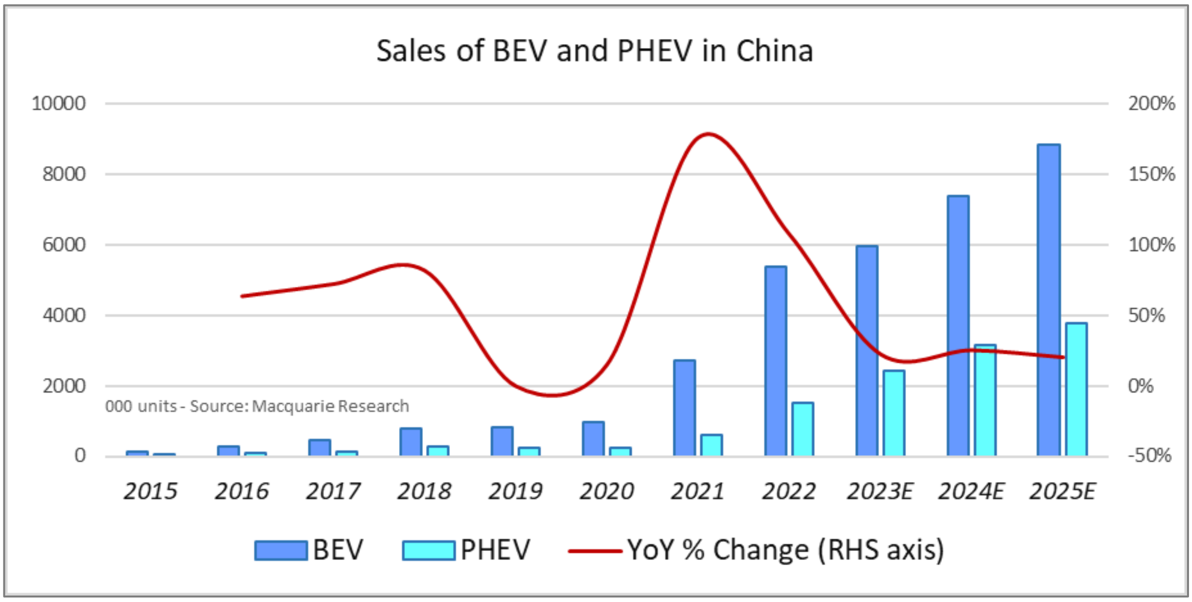


In addition to imposing CO2 emission limits to car manufacturers, governments from all over the world have also been offering a wide range of incentives to purchase hybrid and electric vehicles, with public spending on such subsidies being estimated at USD 30 billion globally in 2021. However, in some countries these incentives have recently started to be perceived as redundant due to the consistently high sales and market penetration of the vehicles they were targeted at. Its consequent phasing out confirms that the envisaged goals of supporting the hybrid and electric vehicles market into reaching a mature state have been accomplished. Such changes in governmental strategy towards vehicle electrification have recently been implemented in Sweden and will be in Germany and the United Kingdom (UK) in 2023. Other European countries are likely to follow this trend in the near future since the price of hybrid and electric vehicles continues to fall compared to ICE.

China

China has become the world leader in the EV market in recent years. In 2021, sales of NEV's - a term generally used in China that refers to plug-in hybrid (PEHV), pure electric or battery electric (BEV) and fuel cell vehicles - increased by 176% compared to the previous year. More NEVs were sold in China in 2021 than in the entire world in 2020, allowing its fleet to rise to 7.8 million units in circulation. In 2022, a further 6.9 million NEVs were sold, accounting for a year-on-year increase of 107% and roughly 26% market share of new vehicle sales. The Chinese 14th Five-Year Plan (2021-2025) includes the objective of NEVs accounting for at least 20% of total car sales in 2025, which has already been met, and states that there should be a sufficient number of charging stations to meet the needs of 20 million NEVs by 2025.

Chart 2



In 2010, Chinese authorities introduced a number of incentives aimed at boosting sales of NEVs. Being adjusted on an annual basis, these were progressively widened in subsequent years, comprising tax discounts in the purchase, a reduction in VAT for research and development of batteries and subsidies for the expansion of the EV charging infrastructure. Additionally, EV's have been exempt from both purchase and driving restrictions in a number of cities throughout the country and benefited from numerous local subsidies or tax breaks. These policies have proved very effective since NEV sales in China have increased more rapidly than in other country in the world. As a consequence they started to be progressively phased out in 2020, after the introduction of China's new governmental policy for the EV market, the "dual-credit scheme" in 2019. At that time the Chinese EV market was dominated by low-priced and relatively low-performing models with small batteries and limited range, even though the average range of BEVs had increased by 50%

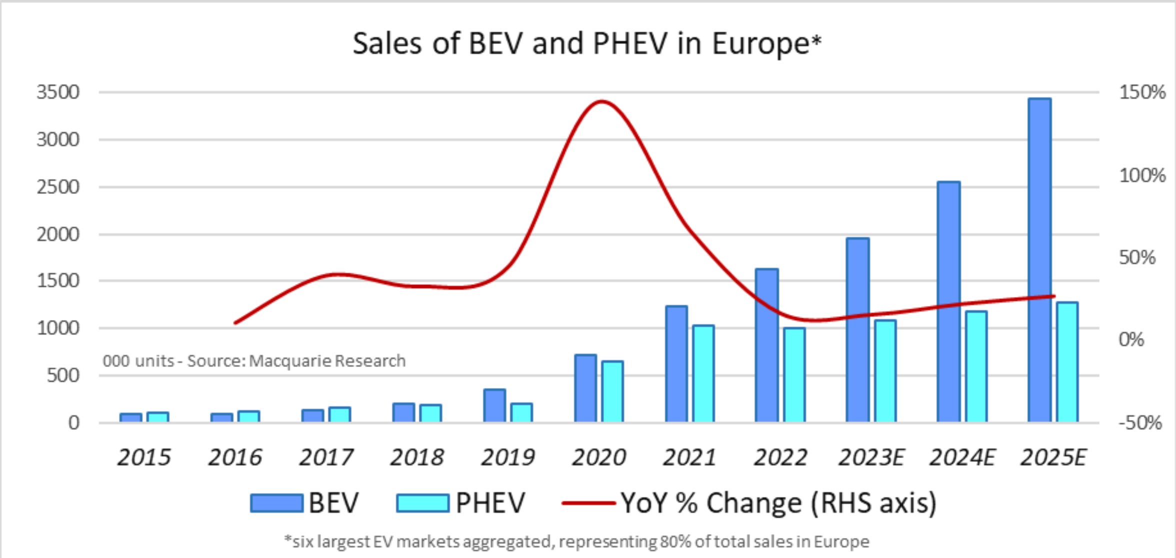
since 2016. The "dual-credit scheme" was aimed at stimulating both industry consolidation and the manufacturing of NEVs with longer electric range, since these would entitle its manufacturers to receiving more credits, which could then be sold to other companies. Consequently, simpler, lower-range models become comparatively less lucrative for Chinese automakers, and this is expected to upgrade the Chinese EV industry via the development and dissemination of more sophisticated (and expensive) models with improved technology and longer electric range.

Despite previous announcements that the government would stop subsidising NEV purchases in 2022 (already an extension from the earlier declared expiry date of 2020) Chinese officials announced in September 2022 that the acquisition of NEVs would continue to be exempt from purchase tax in 2023. This has been interpreted by market analysts as an effort to stimulate the EV industry since new car sales in China over 2022 were negatively impacted by a resurgence of the COVID19 pandemic. Nevertheless, it has become clear that these incentives are on a declining trend, with its base subsidy amount being cut by 10%, 20% and 30% each year between 2020 and 2022. Albeit consumer anticipation of declining subsidies might have positively impacted sales to a certain degree, the fact that NEV sales in China continue to rise substantially in spite of a reduction in government subsidies indicates that this market has reached maturity.

Europe

The combination of stringent CO_2 emission targets for the automotive industry together with generous incentives for consumers to buy greener vehicles has also been proven to be effective in Europe, since sales of PHEVs and BEVs have risen significantly in recent years, being exceeded only by those in China. According to the European Automobile Manufacturers' Association (ACEA), sales of PHEVs and BEVs in the EU rose by 71% and 61% respectively in 2021 with their combined share increasing from 2% in 2018 to 18% of total sales in 2021. In 2022, sales of BEVs rose by a further 32% despite an overall reduction of 5% in new passenger car total sales. According to Macquarie Research Market, the penetration of PHEVs and BEVs is expected to increase further over the next decade, surpassing 28% and 50% of European* car sales in 2025 and 2030 respectively.

Chart 3



EU mandatory fleet-wide average CO2 emission limits have been effective since 2009 with the most recent update having taken place in 2019. Current standards include a goal of up to 81 and 59 grams of CO2 per km by 2025 and 2030 respectively. Despite being amongst the most stringent globally, these will soon be further tightened since an agreement within the European Parliament to formally adopt European Commission's "Fit-for-55" proposal was reached in October 2022. This proposal requires emissions to be reduced by 55% for cars and 50% for vans by 2030 from a 2021 starting point, and by 100% for both by 2035. In practice, from 2035 it will no longer be possible to place cars or vans with an internal combustion engine (ICE) on the EU market, which is a strong signal of regulatory support for BEVs.

Within Europe, most countries run some form of incentive scheme for the purchase of hybrid and electric vehicles. The range and scope are decided on a national level, allowing them to differ significantly from country-to-country and, as a consequence, the rate of adoption of these vehicles has been very different amongst European countries. Norway, the Netherlands and Sweden, where the most attractive incentive packages have been put in place, exhibited a significantly higher market penetration for hybrid and electric vehicles than the European average, accounting for an impressive 89%, 35% and 56% of total passenger vehicle sales in 2022 respectively. In Norway, inducements include the waiving of import duty, reduced VAT, a 10% reduction in weight tax, special free electric vehicle car parks, free charging, the use of bus lanes, the waiving of toll and ferry charges and a 50% company car discount. In the Netherlands, the acquisition of zero-emission cars is tax-exempt and ownership taxes are cut by 100% for pure electric and by 50% for plugin hybrid cars. These vehicles also benefit from significantly reduced rates of income tax on company cars as well as numerous additional subsidies related to the purchase price. In Sweden, up until November 2022 owners of plugin hybrid and electric cars benefited from reduced circulation taxes with the cost of purchase also supported by a comprehensive subsidy scheme.

Sweden's government announced in November 2022 that it would shift its strategy towards vehicle electrification by no longer subsidising the purchase of these vehicles via the following public statement: "The cost of owning and operating a climate bonus vehicle is starting to become comparable to the cost of owning and operating a petrol or diesel vehicle. Therefore, the climate bonus has been removed. This means that anyone who buys or orders a climate bonus car after 8 November 2022 will not receive a climate bonus." It has recently been made public that similar incentives will also be revised and/or significantly reduced in France, Germany and the United Kingdom in 2023, and other European countries could potentially follow this trend in the near future.

Regarding lead-based batteries, their use in vehicles in Europe is subject to increasingly restrictive environmental regulation, most notably the EU Battery Regulation and the End-of-Life Vehicles Regulation, from which lead batteries are currently exempt but subject to revaluation on a regular basis.

Japan

Sales of HEVs, which include the Toyota Prius, in Japan were extremely successful over the past decade, being supported by comprehensive tax incentives and accounting for over 40% of overall Japanese automotive sales in 2021. However, the penetration of PHEVs and BEVs

in the Japanese market has been much slower, with combined sales accounting for only 1.2% of the total in 2021, a very low share compared to those in China or Europe. High prices for these vehicles, short cruising ranges, an inadequate charging infrastructure and a highly competitive HEV market are the main reasons for this discrepancy.
In 2021, Japan put forward a large funding package of 37.5 billion yen (US$ 340 million) aimed at both subsidising the purchase of EVs and expanding public EV charging and hydrogen infrastructure. Current inducements include substantial tax reductions and monetary incentives of up to US$ 3,500 and US$ 7,000 to purchase PHEVs and BEVs respectively. However, this incentive is only granted if all the electricity for charging the vehicles, both at the buyer's home and office, is generated from renewable sources, which might not be achievable for many consumers.

In what regards vehicles' fuel efficiency and CO2 emissions, the standards imposed by Japanese authorities have been ambitious, being equivalent to those in Europe. According to a recent Stated Policies Scenario, combined sales of PHEVs and EVs are aimed at reaching 20% of the total by 2030, when at least 150,000 charging stations should have been made available to drivers. In 2021, the Japanese government announced that would commit to the target of all new cars sold in Japan from 2035 being PHEVs, BEVs or Fuel Cell Electric Vehicles (FCEVs).

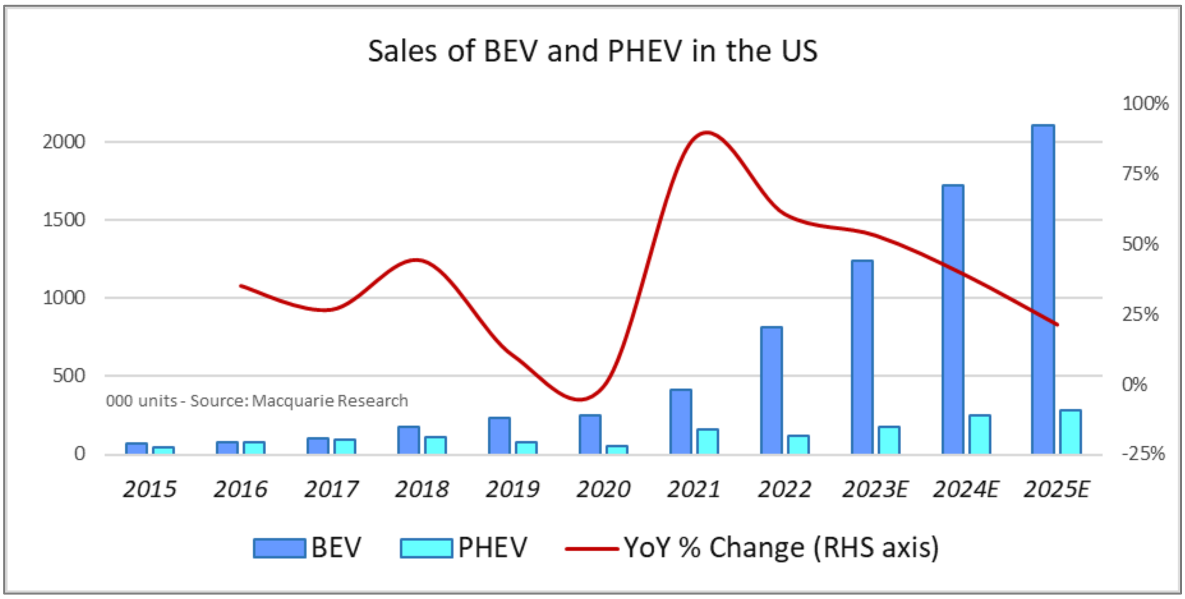
United States

In the US, the penetration of hybrid and electric vehicles has been slower than that in China and Europe, with the combined share of PHEVs and BEVs accounting for just 4% of the total in 2021, despite sales having risen by 188% and 65% respectively compared to 2020. In 2022, BEV sales increased by a further 96%, however those of PHEV's fell by 29% resulting in a combined 6.7% share of total sales. According to Macquarie Research, this share is expected to increase to 16% in 2025 and 30% in 2030, remaining significantly below that anticipated in both China and Europe.

A Federal Government executive order issued in August 2021 denotes a significant change in the policy towards the EV market in the US. It includes the first EV target announced at the federal level: combined sales of PHEVs and BEVs accounting for 50% of total light-duty vehicle sales by 2030. It also includes requirements for fuel efficiency improvements of 8% to 10% for corporate average fuel economy (CAFE) for model years 2024-2026 and a reduction of CO2 emissions by 5% to 10% for model years 2023-2026.

Being underpinned by generous funding packages that include the US$7.5 billion Infrastructure Investment and Jobs Act, recent US federal policies towards vehicle electrification are not only aimed at boosting EV demand but also at building a wide-ranging network of charging and fast-charging stations and encouraging the development and manufacture of EVs and batteries within the US. These objectives are particularly noticeable in the US$ 700 billion Inflation Reduction Act of 2022 that has recently been passed by the Congress and establishes new financial incentives to buy BEVs as well as a list of requirements to be met in order to be legible for the incentives. This legislation package sets tax credits of up to US$ 7,500 for buying a new BEV, provided that both its final assembly takes place in the US and a certain percentage (which will increase gradually over the next few years) of its battery components, particularly those listed as critical materials, are processed in the US or countries with which it has a free trade agreement. Additionally, financial incentives are being conceded to the US auto industry, including a US$ 2.5 billion government loan commitment to be used for EV development granted to General Motors in July 2022.

Chart 4



California has followed its own state level regulations for a number of years, imposing more stringent limits for vehicle emissions than the federal standards whilst offering comprehensive incentives for the purchase of greener vehicles. In January 2022, the state of California proposed a financial package of US$ 6.1 billion, the largest ever budget commitment for EVs at the state level, to be spent on incentives to buy new passenger EVs and build a charging infrastructure as well as other EV market-related inducements. Later in August, the State's Governor signed an executive order that effectively bans the sale of new ICE cars and light trucks from 2035, an ambitious goal that only the state of New York (and the EU) have endorsed up until now, but that is expected to be followed by other north American states in the coming years. More recently, in December 2022, the California Energy Commission approved a US$ 2.9 billion clean transportation investment plan, aimed at adding 90,000 EV charging stations across the state by 2025.

The state of California is by far the most important market for EV's in the US, with current sales surpassing the next 10 states combined and being 7 times higher than the next closest state. Being the state with the biggest economy and largest population in the US, it accounted for 11% of the country's total light-duty vehicles sales in 2021. However, combined sales of PHEVs and BEVs in California accounted for a much larger 38% share of the total, indicating that its policies targeting the EV market, which include more attractive incentives than any other state, have been successful. On a state-level, combined sales of PHEVs and BEVs in California increased by 79% and 38% in 2021 and 2022 respectively, allowing their share to rise from 13% to 18% of the state's light-duty vehicle mark. North American car manufacturer Tesla has clearly taken the lead in the Californian BEV market, accounting for over 70% of total sales in 2022.

3. Types of Vehicle

There are a variety of hybrid and electric vehicles currently under development. The majority fall within one of the following categories:

Micro-Hybrid Vehicle

These vehicles are not "hybrid" in the true sense of the word in that they are driven solely by an internal combustion engine (ICE). The difference between micro-hybrids and conventional ICE vehicles is that micro-hybrids use an automatic stop-start function (ASSF) and regenerative braking technology (RBT) to reduce fuel consumption and emissions.

These vehicles require batteries with improved performance that can handle more frequent starter operations over their lifetime while improving charge recoverability to allow efficient acceptance and storage of the energy generated during braking. The new performance requirements have impelled lead-acid battery makers to improve technology aiming to increase charge acceptance and cyclic durability. The development of 12V advanced lead-based batteries, either Enhanced Flooded Batteries (EFBs) or the more sophisticated Absorbent Glass Mat (AGM) batteries was the industry's response to the new requirements posed by micro hybrid vehicles, providing significant advantages over conventional flooded batteries and allowing adoption by car manufacturers worldwide.

The main attraction of the micro-hybrid system to automotive companies has been that, at under US$300 per vehicle, it provides a relatively low cost means of meeting the new emissions criteria. It is estimated that micro-hybrid vehicles reduce both fuel consumption and carbon dioxide emissions by about 5% on average and by up to 10% in pure city driving. Companies are now installing stop-start systems as standard equipment on an increasing number of models in many regions of the world.

Hybrid Electric Vehicle (HEV)

These vehicles combine an electric motor with a traditional ICE. Depending on the power of the electric motor relative to the ICE and the extent of use of the electric motor, they can be mild-hybrid (lower voltage) or full-hybrid (higher voltage). As in the case of micro-hybrids, HEVs make use of ASSF and RBT functionalities.

Mild hybrid vehicles typically combine a 12V lead-acid battery to start the ICE and power devices including electric windows, central locking and windscreen wipers with a 48 V lithium battery. This unit supports the ICE when additional torque is required, and powers higher energy demanding electronics. Depending on the way the starter/generator is integrated into the powertrain, a small electric motor or an intake air compressor is deployed to boost the ICE during periods of acceleration, reducing fuel consumption and improving drivability.

Full hybrid vehicles also typically combine a 12V lead-acid battery with a lithium battery, but the latest is of higher voltage - above 75 V - which enables it to run an electric power train that allows the vehicle to be driven on electric power only for a relatively short distance. While the ICE remains the major source of power, this additional feature, combined with a more robust propulsion assistance to the ICE when additional torque is needed, allows further fuel reduction compared to mild hybrid technology, particularly in urban driving. In most cases the 12V battery is used for SLI functions, however the higher voltage battery may be used to start the engine, reducing the role of the 12V battery to supplying auxiliary electric devices when engine is turned off, for example by the use of ASSF.

Automakers have been favouring lithium technology over lead-acid for the higher voltage battery in both mild and full hybrids, due to its advantages in terms of dynamic charging acceptance, cycle life and, in particular, energy density, allowing the batteries to be much lighter (around half of the weight) than an equivalent lead-acid unit. However, for SLI and auxiliary functions, a 12V lead-acid battery is considered to be the best solution due to its lower cost, reliability and stability even under extreme temperatures, making it the current standard choice.

Plug-in Hybrid Vehicle (PHEV)

Similarly to full hybrid vehicles, PHEV's typically combine a 12V SLI lead-acid battery with a higher-voltage lithium unit as well as an ICE with an electric drive train. However, the lithium batteries can be recharged through a power outlet or other external charger, allowing them to be larger. This extends the vehicle's ability of running on electric power independently of the ICE to longer distances. At moderate speeds, the vehicle is driven by the electric power train only. At higher speeds or once the lithium battery is depleted the ICE comes into action to drive the vehicle, power the electric motors and recharge the batteries. As in full-hybrid vehicles the ICE is normally started by the 12V battery, however is some cases this function is ensured by the high-voltage unit, limiting the use of the smaller battery to powering auxiliary and safety electric devices only.

Pure Electric Vehicle or Battery Electric Vehicle (BEV)

These automotives do not incorporate an ICE and are powered by an electric motor only. A high voltage (above 75 V) board net supplied by lithium batteries is required for vehicle propulsion. However, a parallel 12V power source is also needed to start the high-voltage circuit and for auxiliary comfort and safety features including central-locking, airbags, emergency lights and window lifters, being in most cases met by a lead-acid battery. This battery is of lower capacity compared to that used in vehicles featuring an ICE because it is not required to perform engine cranking duties.

Fuel Cell Vehicle

Fuel cell technology represents the most radical shift away from the ICE. The fuel cell is an electrochemical device that converts hydrogen and oxygen into electricity, heat and water. Like a battery it can be recharged during use. However, instead of recharging using electricity, a fuel cell uses hydrogen and oxygen. Some automakers have built fully functional prototypes of these vehicles, however its commercial viability remains at a very early and incipient stage.

4. Types of Battery

Lead-Acid

The flooded lead-acid battery has been the source of power for starting, lighting and ignition (SLI) for the automotive industry for over a century and the basic technology behind its operation has remained essentially unchanged. Lead-acid batteries are made of five basic components: a polypropylene plastic container; positive and negative internal lead plates, plate separators, an electrolyte composed of sulphuric acid and water and lead terminals which are the connection point between the battery and whatever it powers.

Although its use remains primarily for SLI functions in vehicles with an ICE, lead based batteries are expanding their scope of utilization to auxiliary duties in both battery electric and hybrid vehicles that convey the ICE starting function to the high-voltage board net. Auxiliary applications require a smaller 12V battery because there is no longer a requirement to perform the engine starting or cranking function. However, these batteries remain critical since they are required to ensure the operation of key safety devices including central-locking, airbags, emergency lights, window lifters, car media systems and the monitoring of the lithium battery. According to the consulting company Ricardo, light-duty auxiliary applications are anticipated to become increasingly important through 2030 and lead-acid batteries are currently the only commercial option for it, since 12V lithium-based batteries are still an emerging product.

The main advantages of the well-established 12V lead based battery technology, which currently provides 75% of all rechargeable energy storage globally, are that they have a proven track record, are low cost, do not require the use of scarce or expensive materials and are easily recyclable. Often referred as the most recycled consumer product globally, lead-based batteries benefit from a well-established and widespread recycling circuit, particularly in developed economies such as Europe, Japan and the US, where recycling rates are close to 95%. Additionally, lead based batteries excel in cold cranking and remain very stable and safe over a wide temperature range, with fire or explosion risks being kept to extremely low levels. Principal disadvantages of this technology are that the batteries are heavy and have a lower power and energy density compared to other battery technologies now being used for propulsion in hybrid and electric vehicles.

The introduction of micro-hybrid technology with ASSF and RBT functions in passenger vehicles and its rapid dissemination, impelled the fabricators of lead-acid batteries to improve performance in terms of dynamic charge acceptance (the rate at which the battery can be recharged) and cycle life (by minimizing the issue of the battery being only partially recharged after discharge). The resulting development of Enhanced flooded battery (EHB), or the more expensive sealed, valve regulated lead-acid batteries (VRLA) in which most of the acid is contained in an absorbed glass mat (AGM) allowed significant improvements in those areas. Furthermore, EHB and AGM batteries are lighter and ensure enhanced reliability, durability and stability under adverse conditions compared to traditional technology.

Numerous projects aimed at further enhancing the performance of lead-acid batteries to raise its competitiveness against lithium-ion and other emerging technologies are currently being developed. These include the Ultrabattery developed by the Australian

Commonwealth Scientific and Industrial Research Organisation (CSIRO), the bi-polar lead-acid battery being developed by Advanced Battery Concepts (ABC) with its most recent enhancement being branded as EverGreenSeal technology and the use of carbon additives to the batteries' positive electrode to improve its cycle life and charge acceptance. A number of these projects are supported by the Consortium for Battery Innovation (CBI) based in North Carolina. ABC's bi-polar technology in particular has been drawing interest from the manufacturing industry, with Gredential Energy and Exide Industries recently announcing partnerships aimed at building and selling batteries based on this technology in the near future.

Nickel-Metal Hydride

In addition to their use in HEVs, NiMH batteries have been widely used in the mobile phone and portable computer markets. They are essentially an extension of the technology used in nickel-cadmium batteries with the substitution of a hydrogen absorbing negative electrode for the cadmium electrode.

In terms of performance NiMH batteries are superior to lead-acid in terms of energy and power density. They also have good thermal performance and are recyclable. Their main disadvantages are cost, heat generation at high temperatures, the need to control hydrogen loss, high self-discharge rate and the fact they suffer from "memory" effect (unless the battery is fully discharged some power is lost when it is recharged).

Sales of NiMH batteries have been widely supported by the commercial success of Toyota's Prius model, which has been using this technology to power its high voltage on board net for more than 15 years. The model also includes a smaller lead-acid AGM 12V battery for SLI and auxiliary power purposes. The first generation of the Toyota Prius was launched in Japan in 1997, becoming world's first mass-produced HEV. It was subsequently introduced worldwide in 2000, being currently sold in over 90 markets worldwide. With total accumulated sales surpassing 5 million units in 2022 according to the manufacturer, it has also become the all-time best-selling hybrid car globally.

However, competition in the HEV market has risen sharply in recent years, with numerous automakers developing models that offer a wide range of hybridization, from mild 48 V torque assisting systems to full PHEV's allowing its motion on electric power only for increasingly large distances. Lower priced BEVs are also become increasingly available in the market. Sales of the Prius have therefore been slowing and, as a consequence, the production of NiMH batteries for automotive use, since Toyota is one of the few car manufacturers that still uses them, with most other manufactures opting for lithium-ion technology for higher voltage batteries. Furthermore, the most recent generation of the Prius model, which was unveiled in November 2022, includes a PHEV model in its range that uses lithium-ion batteries, so it is now widely anticipated that use of NiMH batteries will be phased out in the automotive industry over the medium term.

Lithium-Ion

In this type of battery the lithium ions move from the anode to the cathode during discharge and from the cathode to the anode when charging. Different types of lithium-ion batteries use different chemistries with different costs of performance and safety characteristics. Unlike primary lithium batteries, lithium-ion cells use a lithium compound as the electrode material instead of metallic lithium.

Lithium-ion batteries are commonly used in consumer electronics in particular for portable applications such as mobile phones and laptop and tablet computers. In the automotive sector, lithium-ion batteries have also become the default choice for torque assistance and traction purposes in the large majority of new HEVs and BEVs, even those with 48 V mild-hybrid systems, in the past decade or so. However, despite its clear weight-reduction advantages, this technology remains emerging in 12V SLI and auxiliary applications due to its higher cost and complexity. Remaining issues in terms of safety and sensitiveness to fluctuations in temperature are additional limiting factors for certain types of lithium-ion battery.

The main advantages of lithium-ion batteries are that they have a power and energy density ratio significantly higher than that of NiMH and lead-acid batteries, high dynamic charge acceptance and a long service lifetime if operating within their specified temperature range. Their performance has been enhanced considerably in recent years, particularly regarding low-temperature performance or cold-cranking and durability.

The principal weakness is high cost, as lithium-ion batteries used for starter function typically cost around 2 to 3 times more than lead-acid ones, although this has decreased significantly over the past decade and is expected to continue to fall in the next years. According to Bloomberg NEF, prices were above USD1100 /kilowatt-hour (kWh) in 2010 and fell by 87% in real terms to USD156/kWh in 2019. By 2023/4 prices are expected to be close to USD100/kWh. Reduced power at low temperatures and the fact the batteries are prone to overheating, limiting their safety in extreme conditions are additional known weaknesses of this technology despite recent improvements.

Lithium-based batteries use varying amounts of aluminium, manganese, iron, nickel, phosphate, cobalt and titanium, with manufacturers currently working to develop the most suitable and effective composition. One of the most common lithium-based batteries combines lithium with a cobalt oxide cathode (LCO) and a graphite anode. This type of battery is widely used in mobile phones, laptops and digital cameras. Alternative chemistries include lithium manganese oxide (LMO), lithium iron phosphate (LFP) and lithium nickel manganese cobalt oxide (NMC), which has become the preferred technology for electric car traction batteries due to its high energy density, long life span and improved safety and cost effectiveness. Cost competitiveness has been the main driver for a recent recovery in the adoption of LFP batteries for traction duties in electric cars, particularly in China. Moreover, LFP batteries also perform well in terms cycle life, thermal stability and safety, although cannot match the energy density of NMC batteries. Further alternatives in terms of the composition of the cathode of lithium-based batteries include the combination of lithium with nickel, cobalt and aluminium oxide (NCA). This technology is mainly used by Panasonic and Tesla and shares some similarities with NMC as it offers high specific energy, reasonably good specific power and a long-life span, with the added benefit of aluminium increasing the battery’s stability. More recently, the use of solid-state cells rather than liquid electrolytes and the replacement of the typical graphite anodes with silicon-based ones has also become the subject of intensive investigation and debate. Silicon anodes are considered as one of the most promising anode materials for lithium-ion batteries because they have the potential to significantly increase energy density while improving thermal stability and safety.

The fact that supply chains for some of these materials, most notably cobalt and lithium, still face unsolved challenges may also be considered a disadvantage for lithium-based battery technology. Its product-life circularity and environmental sustainability have also been raising concerns since recycling used lithium-ion batteries is a complex and difficult task. A number of European battery recyclers highlighted unresolved and common issues in terms of safety and efficiency while recycling these batteries at the 2022 AABC Europe: Advanced Automotive Battery Conference.

Sodium-Ion

Sodium-Ion batteries are regarded as a viable alternative for lithium-Ion technology, particularly in the stationary energy storage market. Although inferior in terms of energy density, they are non-flammable and offer advantages in the time needed for charging and performance under low temperature. Additionally, they do not contain lithium, nickel or cobalt, being mostly made of sodium, which is much cheaper and more abundant than these metals. Commercial production of these batteries is expected to start as soon as 2023, and technical improvements are underway aimed at enhancing their energy density and life cycle.

Zinc Air

Zinc-air batteries work by creating an electrical current through a chemical reaction between zinc and the oxygen contained in air and are used in a number of consumer and industrial applications, in particular hearing aids, pagers, and for various medical applications. Apart from some isolated test cases, these batteries have not so far been used in automobiles and are not expected to be in the near future.

Since at least 2019, the Vancouver-based Zinc8 Energy Solutions has been working on a new, low-cost design, patented zinc-air battery technology for utilities, microgrids, and stand-alone commercial and industrial projects. In September 2022, it confirmed plans to build its first commercial manufacturing plant in the United States. Advantages of this type of battery include a high power and energy density, no known safety problems, the fact the batteries are easily recyclable and the materials to build them are cheaper and more easily accessible than those used in lithium batteries.

Other zinc-based battery technologies currently under study include nickel-zinc, silver-zinc, carbon-zinc and zinc-bromine. All of these are currently at an early stage of development.

5. Current and Likely Future Trends in the Automotive Market

Micro-Hybrid Vehicle

Micro-hybrid vehicle sales have risen rapidly over the past decade, particularly in Europe, driven largely by the need to meet CO2 emission standards. According to Avicenne Energy, in 2021 80% of new vehicles sold in Europe were micro-hybrids, whereas in 2015 this share stood at around 60%. The penetration of this technology globally has been slower, with an estimated 20% and 40% share in global sales in 2015 and 2021 respectively.

Over the next decade, it is anticipated that most vehicles using an ICE that is not assisted by an electric motor will progressively incorporate start-stop systems as automakers capitalise on the benefits of adopting a cost effective and proven technology that effectively reduces CO2 emissions. The main driver for this shift is the increasingly stringent emission regulations and fuel-efficiency standards enforced by different legislative bodies across the globe. In the US, where micro-hybrid penetration remains below that in Europe, between 2022 and 2027 the value of this market is anticipated to grow at a compound annual growth rate of between 6.4% and 5.7% according to the consultants ReportLinker and Research & Markets respectively. A similar trend is expected in other countries with large populations including Brazil, India, Thailand, and Indonesia, where improving socioeconomic conditions will result in the growth of demand for premium passenger cars using micro-hybrid technology. It is commonly accepted that virtually all of these vehicles will continue to use a lead-acid battery for at least the next decade. According to Avicenne by 2030 65% of these will be of AGM technology with the remaining 35% simpler EHBs.

Notwithstanding expected rises in the penetration of micro-hybrid technology in ICE vehicles, it has become clear that non-electrified micro-hybrid technology will be gradually shifted to hybrid technology over the next years, with electric batteries in many passenger cars progressively being extended to provide motor assistance to the ICE. Therefore HEVs, PHEVs and BEVs will take some of the micro-hybrid’s share in the market of new passenger vehicles. In the European market and according to the consulting company Ricardo, micro-hybrid’s share of new car sales will decline from 68% in 2015 to 40% in 2025 and 25% in 2030. In November 2022, Macquarie Research published a comprehensive forecast for global vehicle sales, anticipating non-hybrid ICE car sales (whether employing micro-hybrid technology or not) to decline from over 59.7 million units in 2022 (74% market share) to 36.7 million in 2030 (38% share). These estimates are broadly in line with those advanced by other consultants including IHS Markit so there is a consensus on an expected market share reduction of non-electrified ICEs over the next years. However, this will be a reasonably slow process since nearly 40% of all new cars sold in 2030 are still expected to continue to use this technology.

Hybrid Electric Vehicle (HEV)

Global sales of HEVs have increased rapidly in the past decade or so, since they offered improved drivability, fuel consumption and lower CO2 emissions compared to non-electrified ICE technology in exchange for a moderate increase in price. Over the period 2010 to 2022 annual sales of HEVs increased from about 785,000 to 10.4 million units globally with their market share rising to 13% of the total.

This market was for many years dominated by the Toyota Prius, whose global sales peaked in 2010 at more than half a million units, progressively declining in subsequent years to around 86,000 units in 2021. This reduction, combined with a rapid rise in the offering of alternative HEV models by Toyota and many other automakers, drastically cut this model's share to less than 2% of global HEV sales in 2021. On a battery demand perspective this reduction is relevant, since the Prius model has been one of the few HEV's using NiMH batteries, whereas all the other HEVs have favoured lithium-ion technology. Therefore, demand for NiMH batteries has declined significantly over the past decade, whereas that for lithium-ion batteries has grown sharply, also benefiting from rises in PHEV and BEV sales. The Toyota Prius use a 12V lead-acid battery in addition to the higher voltage NiMH unit. However, its use is limited to auxiliary and safety duties as the starting function of the ICE is performed by the NiMH battery. In most other HEVs the energy needed to start the ICE is supplied by a 12V lead acid battery, with most analysts anticipating a limited penetration by lithium-ion technology in the 12V battery market over the next decade.

According to Macquarie Research, global sales of HEVs rose by 32% to 10.4 million units in 2022, capturing 13% of the new vehicles market. This share is expected to rise to 20.5% in 2025 and 23.4% in 2030, when over 22 million units are anticipated to be sold, which means that between 2023 and 2030 sales of HEV's are expected to increase by over 21% each year on average.

Plug-in Hybrid Vehicle (PHEV)

Plug-in Hybrid Vehicles are generally more expensive than HEVs and were introduced firstly in premium segments of the market, with annual sales globally remaining below 1 million units until 2020. However, this technology is becoming more popular amongst mid-priced vehicles and as a consequence, affordable for a much larger number of consumers. According to Macquarie Research, sales of PHEVs globally rose by 87% to almost 2 million units in 2021 and are expected to grow by 13% on average ever year until 2030, when nearly 6 million units are expected to be sold. Avicenne predicts a more moderate 10% average annual growth in PHEV's sales between 2021 and 2030.

Battery Electric Vehicle (BEV)

Annual BEV sales grew from 325,000 to 4.5 million units over the period 2015 to 2021, boosted by abundant legislation or incentives favouring the purchase or utilization of zero-emission vehicles in a number of countries, regions or cities where pollution is of particular concern. The overall market share of these vehicles rose from 0.4% to 5.6% over the same period. In terms of regional market breakdown, China accounted for nearly 60% of global sales in 2021, Europe 26%, the US 10% and Japan less than 1%.

In 2015 only a small number automakers offered competitively priced BEVs with Tesla, Renault and Nissan accounting for over 50% of total sales. Since then, this market has changed drastically. Twenty three times more new EV models were available in 2021 than in 2015, with most car brands currently offering a number of BEVs in different segments for a wide range of prices, increasing the attractiveness for consumers. The largest producer of EVs globally is China's BYD, followed by Tesla, the VW Group and GM. Regarding the number of BEVs circulating and according to data compiled by the International Energy Agency (IEA), in 2021 6.2 million BEVs were circulating in China, 3 million in Europe and 1.3 million in the US. The EIA estimates that in 2015, the number of BEVs did not surpass 0.2 million in each one of these markets. Investment in the construction of both "Gigafactories" to supply the market with increasingly sophisticated lithium batteries and stations to recharge them is also crucial and has been increasing rapidly in many regions of the world.

A number of market consultants have put forward medium term forecasts for BEV sales globally. Macquarie Research anticipates that they will grow from 7.6 million in 2022 to over 31 million units in 2030, which implies a substantial annual average growth of 19% over this period. In terms of market share, it is forecast to rise from 9% to 32%. The IEA, however predicts that a more modest 22 million units of BEVs will be sold in 2030. Avicenne's most recent estimates are closer to the IEA figures, anticipating sales of 25.5 million BEVs in 2030. While the pace of growth is up for debate, the broad trend anticipated for this market is clear and generally consensual amongst experts. In terms of regional breakdown, according to the IEA sales of BEVs in China will rise by 16% on average annually between 2021 and 2030 to 10 million units. A similar average annual growth is anticipated for Europe, where sales of new BEV's are predicted to reach 4.8 million units in 2030. In the US, sales are expected to rise by 20% on average each year between 2021 and 2030 to 2.3 million units.

The 10-year outlook for BEVs is promising, however the price and availability of some of the main materials used in lithium batteries, including lithium, nickel and cobalt could pose some risks to growth.

Fuel Cell Vehicle

Fuel cell technology that converts hydrogen and oxygen into electricity has the advantages of being both free from emissions and raw material restrictions, with some manufactures currently investing in the development of a few fully-functional yet non-commercial prototypes. However, the recent commercial success of BEVs, particular in China and Europe, indicates that the market is moving towards a battery-based vehicle electrification, with most industry experts anticipating only a small penetration by fuel cell technology for at least the next decade. According to the IEA around 16,000 hydrogen-powered fuel cell electric vehicles were sold globally in 2021, and by 2030, it is anticipated that only 2% of cars sold will use this technology.

6. Empirical Predictive Analysis for Lead Usage in 12V Batteries used in Light Duty Vehicles over the period 2023-2030

It is estimated that the battery industry accounts for more than 80% of the total demand for refined lead metal globally. According to Avicenne, most lead-acid batteries are used to perform SLI duties in vehicles, with 71% of the total lead-based energy storage capacity produced in 2020 being SLI batteries. The International Organization of Motor Vehicle Manufacturers (OICA) estimates that light duty vehicles (LDVs) currently account for more than 70% of vehicle sales globally, making the LDV industry the major consumer of lead acid batteries and, consequently, a key driver for lead demand.

Lead-based 12V batteries are used in conventional ICE vehicles, micro-hybrids, hybrids, plug-in hybrids and pure electric vehicles, with most consultants anticipating a negligible penetration of lithium-ion technology in the 12V battery market over the next decade. Avicenne forecast that no more than 3% of this market will be captured by lithium-ion technology, with the remainder continuing to be supplied by lead based batteries. However, the rising penetration of hybrid and electric vehicles in the LDV market will likely affect the demand for lead acid batteries and as a consequence global demand for lead metal. This is because all BEV's and a portion of HEV's and PHEV's limit the use of 12V batteries to auxiliary comfort and safety features only. Since these batteries are no longer required to perform engine cranking duties, their capacity is lower than the typical SLI unit. Consequently, auxiliary batteries contain up to 50% less lead than those used for SLI duties.

In this section of this report, we have anticipated the volume of lead used in 12V batteries fitted in each type of LDV and, in particular, annual percentage changes, over the period 2023 to 2030.

Chart 5 clearly illustrates that the composition of the LDV market is expected to change rapidly over the next few years, with sales of HEV's, PHEV's and BEV's rising substantially and those of ICE vehicles declining. As a result, hybrid and electric vehicles will capture a significant share of the new vehicle market, whereas the relative weight of ICE vehicles will progressively fall.

Chart 5

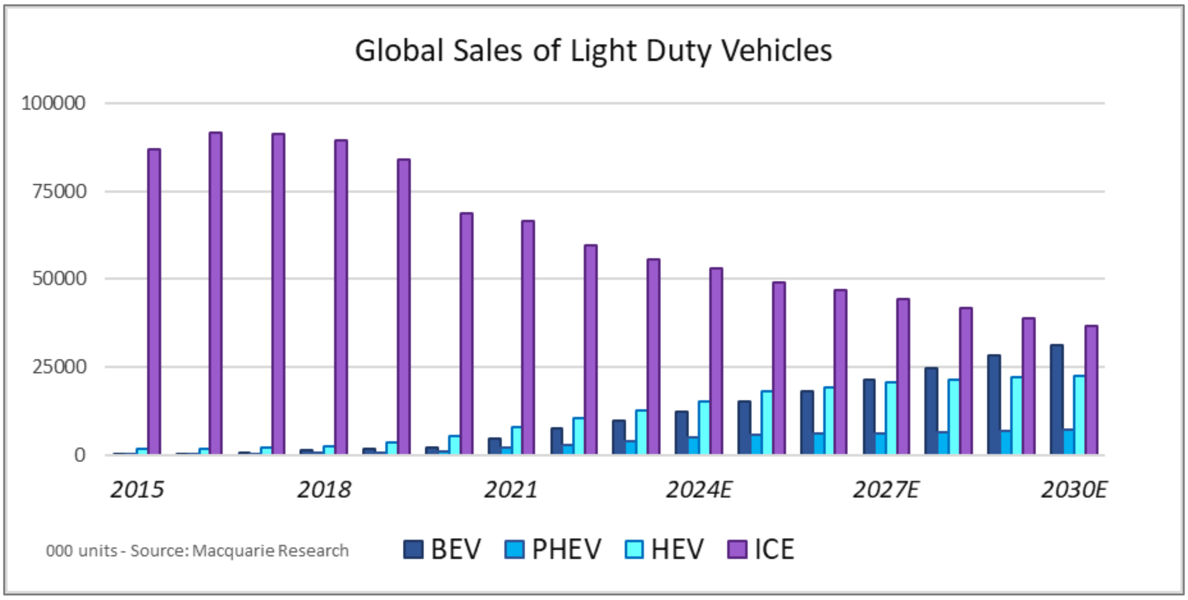


Table 1 includes global sales of LDV's by type of vehicle, their annual percentage growth and share of total sales. Actual data and projections were sourced from Macquarie Research for the period 2015 to 2030 and from the IEA's Global online EV Data Explorer for 2010 to 2015.

Table 1

New Light Duty Vehicle Sales

Source: Macquarie Research, IEA

000 units

	ICE	% Change	Market Share %	BEV	% Change	Market Share %	PHEV	% Change	Market Share %	HEV	% Change	Market Share %
2010	68,327			-			-			977		
2011	71,416			40			-			891		
2012	73,773			59			61			1,726		
2013	77,792	5%	97%	110	86%	0%	92	51%	0%	1,811	5%	2%
2014	81,819	5%	97%	190	73%	0%	130	41%	0%	1,793	-1%	2%
2015	86,908	6%	97%	325	71%	0%	227	75%	0%	1,705	-5%	2%
2016	91,472	5%	97%	469	44%	0%	298	31%	0%	1,751	3%	2%
2017	91,204	0%	97%	778	66%	1%	429	44%	0%	1,993	14%	2%
2018	89,544	-2%	95%	1,280	65%	1%	631	47%	1%	2,370	19%	3%
2019	83,924	-6%	93%	1,685	32%	2%	587	-7%	1%	3,607	52%	4%
2020	68,676	-18%	89%	2,275	35%	3%	1,062	81%	1%	5,498	52%	7%
2021	66,558	-3%	82%	4,513	98%	6%	1,949	84%	2%	7,846	43%	10%
2022	59,658	-10%	74%	7,570	68%	9%	2,744	41%	3%	10,391	32%	13%
2023E	55,621	-7%	68%	9,636	27%	12%	4,014	46%	5%	12,843	24%	16%
2024E	53,176	-4%	62%	12,259	27%	14%	4,954	23%	6%	15,348	20%	18%
2025E	49,185	-8%	56%	15,226	24%	17%	5,767	16%	7%	18,131	18%	21%
2026E	46,982	-4%	52%	18,257	20%	20%	6,079	5%	7%	19,323	7%	21%
2027E	44,359	-6%	48%	21,344	17%	23%	6,303	4%	7%	20,563	6%	22%
2028E	41,873	-6%	44%	24,765	16%	26%	6,494	3%	7%	21,395	4%	23%
2029E	38,804	-7%	40%	28,178	14%	29%	6,834	5%	7%	22,276	4%	23%
2030E	36,716	-5%	38%	31,162	11%	32%	7,137	4%	7%	22,630	2%	23%

Sales of ICE LDVs accounted for 97% of the total in 2017, however this share fell to 74% in 2022 and is anticipated to decrease further in coming years, accounting for only 38% of the total in 2030. Sales of BEVs, in contrast, grew by over 60% on average every year between 2015 and 2022 and are forecast to continue to rise significantly over the next few years, accounting for a substantial 32% of all LDV sales by the end of the current decade. After increasing substantially in recent years, sales of new HEVs and particularly PHEVs are also anticipated to rise more rapidly than those of ICE vehicles over the next few years.

The combined market share of BEV's and PHEV's rose from only 1% in 2015 to 13% last year and are forecast to account for up to 39% of the market by 2030. Avicenne's projections are slightly more conservative, at 30% to 35% of total LDV sales by 2030. However, and despite some differences in the projections, the vast majority of consultants and experts agree that the composition of the LDV market is going through a profound transformation, with ICE LDV's being forecast to account for a gradually smaller share of the total new vehicle market, and all other types of LDV's expanding their relative share of the market.

The LDV sales data included in Table 1 provides the basis for estimating the demand for lead used in LDV's 12V batteries over the next few years. However, in order to develop a realistic forecast, it was also necessary to the take into consideration the following factors:

1. The number of times a 12V battery will be replaced over the life cycle of each vehicle, which is determined by the average lifespans of both the battery and the vehicle;
2. The share of HEV's and PHEV's that rely on the higher voltage battery system to start their ICEs therefore use smaller sized 12V lead acid batteries;
3. The amount of lead contained in each type of battery – larger sized units that perform SLI functions and smaller sized ones that are used for auxiliary duties only.

Estimating the yearly demand for original equipment manufacturer (OEM) 12V batteries fitted in LDVs is a straightforward process, with this number equal the vehicles sold each year. However, the average life span of a lead acid battery is shorter than that of a car. A number of factors affect the life span of a battery, including the manufacturing process, temperature in which it operates and the level at which it is charged or discharged; however, it is commonly accepted that it needs to be replaced every 3 to 5 years. Assuming average life spans of 4 and 15 years for a 12V battery and a LDV respectively, each vehicle will utilize on average 3 replacement batteries over its life in addition to the battery that was originally fitted in the vehicle. Therefore, the number of batteries needed for replacement purposes in a given year was estimated by summing up the number of vehicles that had been sold 4, 8 and 12 years earlier, in each one of the LDV categories considered in this analysis.

It was assumed that 80% of HEVs and PHEVs make use of the 12V lead acid battery to perform full SLI duties, with the remaining 20% making use of the higher voltage lithium-ion based battery system to perform ICE crank duties. For the sake of simplicity, it was also assumed that all 12V batteries issued in LDVs up until 2030 will be lead-based since as mentioned earlier, the penetration of lithium-ion technology in this market is forecast to be insignificant.

Regarding the amount of lead contained in each type of 12V batteries, it was assumed that, on average, those required to perform engine starting duties contain 10kg of lead, whereas those used for auxiliary and safety purposes contain 5kg of lead.

Table 2

Lead Usage in LDV SLI/Auxiliary 12V Batteries

	SLI Full Sized (10Kg Pb) 12V Batteries						Aux Smaller Sized (5Kg Pb) 12V Batteries					
000 tonnes	ICE	BEV	PHEV	HEV	TOTAL	% Change	ICE	BEV	PHEV	HEV	TOTAL	% Change
2022	2,993	0	28	124	3,146		0	45	4	16	64	
2023E	2,979	0	39	152	3,170	1%	0	58	5	19	82	28%
2024E	2,871	0	51	195	3,117	-2%	0	75	6	24	106	29%
2025E	2,847	0	66	238	3,152	1%	0	103	8	30	141	33%
2026E	2,780	0	77	271	3,128	-1%	0	136	10	34	180	27%
2027E	2,708	0	89	310	3,107	-1%	0	165	11	39	215	19%
2028E	2,552	0	102	352	3,006	-3%	0	199	13	44	256	19%
2029E	2,458	0	120	402	2,979	-1%	0	243	15	50	309	21%
2030E	2,329	0	133	438	2,899	-3%	0	291	17	55	363	17%

Data included in Table 2 shows that the demand for lead used in SLI full sized batteries is anticipated to fall by an average 1% every year between 2023 and 2030. This is primarily a consequence of a reduction in the demand for SLI batteries used by ICE LDV's, which is expected to offset an increase in those used by 80% of the hybrid (HEV + PHEV) vehicles. But it also shows that the amount of lead used in auxiliary batteries fitted in all BEVs and 20% of the hybrids is expected to rise by 24% on average each year between 2023 to 2030. This means that the demand for lead used in auxiliary batteries is forecast to be nearly 6 times higher in 2030 compared to 2022.

Whether or not the forecast rise in demand for lead used in auxiliary batteries will balance the reduction in SLI batteries, despite the fact that on average they contain only half of the lead used in larger batteries, becomes the focal question that this empirical predictive model aims to answer.

Table 3

Lead Usage in LDV 12V Batteries

SLI Full Sized + Auxiliary Smaller Sized Batteries

000 tonnes	ICE	BEV	PHEV	HEV	TOTAL	% Change
2022	2,993	45	32	140	3,210	
2023E	2,979	58	43	171	3,252	1.3%
2024E	2,871	75	57	219	3,223	-0.9%
2025E	2,847	103	74	268	3,293	2.2%
2026E	2,780	136	86	305	3,308	0.5%
2027E	2,708	165	100	348	3,322	0.4%
2028E	2,552	199	115	396	3,262	-1.8%
2029E	2,458	243	135	452	3,288	0.8%
2030E	2,329	291	149	492	3,262	-0.8%
Average Annual Change 2023E - 2030E						**0.2%**
Overall Change 2022 - 2030E						**1.6%**

Table 3 includes yearly projections for lead demand from both SLI and auxiliary 12 batteries, which is forecast to rise by an average 0.2% every year between 2023 and 2030. Therefore, the amount of lead metal required to supply the 12V LDV battery market globally in 2030 is expected to be 1.6% higher than that in 2022.

This analysis indicates that despite substantial rises anticipated in the sales and market share of hybrid and electric vehicles over the next few years, the large[1] replacement market of batteries used in ICE LDVs, combined with the rapid rise in the demand for auxiliary batteries, is forecast to balance losses originating from the decrease in ICE LDV's sales and resulting fall in the demand for original equipment SLI batteries.

[1] According to this analysis, the replacement market accounts for 83% of the total ICE battery market over the period 2022-2030E.

7. Potential Impact on Lead Demand

The main conclusions of this Insight Report are as follows:

- All current and planned micro-hybrid and conventional ICE vehicles, as well as most HEV's and PHEVs, incorporate a lead-acid battery that operates in conjunction with the internal combustion engine to supply starting, lighting and ignition functions.

- Lithium based battery technology has become the standard choice for torque assistance and traction purposes in hybrid and electric vehicles, however virtually all these vehicles also incorporate 12V lead-acid batteries for non-propulsion auxiliary features including central-locking, airbags, emergency lights and window lifters.

- New vehicles are steadily including more complex and sophisticated electronic devices, including autonomous driving functions, that rely on a 12V electrical circuit in order to operate. 12V batteries are also required to back up hybrid and electric vehicles' high voltage circuit in critical safety functions and for monitoring the lithium battery.

- Lead acid batteries are the only technology capable of meeting all major 12V requirements, with AGM technology allowing weight saving and enhanced reliability, durability and stability under adverse conditions.

- Further technical advances in lead-based batteries include the Ultrabattery developed by CSIRO, the use of carbon additives to the batteries' positive electrode and Advanced Battery Concepts' bi-polar EverGreenSeal technology.

- Despite an anticipated negligible penetration of lithium technology in the 12V battery market, batteries that are used for auxiliary duties contain up to 50% less lead than those used for SLI purposes, negatively impacting the intensity of lead per vehicle in BEVs and a small percentage of hybrid vehicles.

- This fact, combined with the rising penetration of hybrid and electric vehicles in the new vehicle market has been perceived as a threat to the future of the lead industry, since the 12V battery industry is a key consumer of lead metal.

- However, according to recent market projections and under certain realistic assumptions, the large replacement market of batteries used in ICE LDVs, combined with an increasing demand for auxiliary 12V batteries should balance losses due to a reduction in the demand for new SLI batteries over the period 2023-2030.

- Therefore, up until 2030 the rising sales of hybrid and electric vehicles are unlikely to result in a decline in the demand for refined lead metal.

- Evidence indicates a slower electrification of the heavy-duty vehicle market, which includes large vans and trucks that use much larger lead acid batteries, postponing any eventual negative impact on the demand for new SLI batteries. Moreover, it is anticipated that lead auxiliary batteries used in electric trucks will remain substantial, with little difference in weight to the current SLI units, due to the heavy duty cycle imposed on batteries of large commercial vehicles.

- Other important lead consuming industries, including E-bikes, telecom backup systems and in particular the rapidly growing market for stationary energy storage used in the renewable energy sector or charging stations for electric vehicles are also expected to continue to support the demand for lead in the future.

- Although lithium-ion batteries are capturing a significant share of the stationary energy storage market, there are several reasons why this market could be supportive to a growth in the demand for lead-acid batteries over the next few years. These include cost effectiveness, safety and recyclability, with weight and power density not being critical issues for stationary applications.

- Despite their superior performance in terms of power and energy density, high dynamic charge acceptance and a long service lifetime if operating within their specified temperature range, lithium-based batteries still cost around 2 to 3 times more than lead-acid ones. Further disadvantages of this technology include reduced power at low temperatures and the fact the batteries are prone to overheating, limiting their safety in extreme conditions.

- Supply chains for some of the materials used in lithium-based batteries, most notably cobalt and lithium, still face unsolved challenges. Additionally, lithium batteries' product-life circularity and environmental sustainability have been raising concerns as recycling this type of battery is a complex and difficult task.

- The well-established 12V lead based battery technology is low cost, does not require the use of scarce or expensive materials, performs well in cold cranking, remains very stable and safe over a wide temperature range and is easily and widely recycled.

In the longer term any threat to the usage of lead remains dependent the following issues:

- Even though prices of lithium-ion batteries remain significantly higher (on average between 2-3 times more for a 12V battery) than those of lead-acid they are falling rapidly.

- Despite its recyclability the image of lead remains negative among both the public and policy makers.

- The volume of both public and private investment in lithium battery technology far exceeds that available to further develop lead-acid batteries.

- The adoption of more stringent environmental legislation, particularly in Europe, aimed at reducing the use of lead for automotive applications.

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