

OIL & GAS

OIL & GAS MACRO OUTLOOK

The spectre of peak oil demand

The concept of peak oil has once again come to the fore. However, unlike 10 or 15 years ago the issue today concerns demand rather than production. The peak oil advocates base their case on the need to achieve compliance with the United Nations protocol on limiting global warming to under 2°C above pre-industrial levels over the balance of the century. Based on global warming theory this will require a sharp drop in fossil fuel usage and hence GHG emissions starting imminently. According to the advocates, a combination of public policy initiatives and technological developments will facilitate the desired drop in emissions. The implications for fossil fuel demand would, of course, be dire in such a scenario and clearly raise the prospect of stranded assets. We believe, however, a scenario reflecting a sharp drop in oil and gas demand over say the next 20 years is unlikely in the absence of extreme public policy initiatives. Governments will increasingly find themselves caught in a dilemma between decarbonising energy supplies and economic reality.

- **Radical peak oil demand scenario:** There are a wide range of views when oil demand will peak. One of the more radical views is that expressed by the Oslo-based consultancy DNV GL. This calls for demand peaking in about three years, plateauing until around 2030 and declining sharply thereafter. DNV's radicalism reflects an assumed very rapid uptake in the use of electric vehicles and a cautious view of petrochemicals demand growth.
- **Consensus view:** Mainstream scenarios as represented by the IEA (OECD's energy policy adviser) and the oil majors point to an oil demand peak between 2030 and 2050 followed by a plateau for a few years and then a decline with varying degrees of steepness. The consensus scenarios usually reflect demand growth of 1.0-1.5% between 2020 and 2025 driven by income per capita and population growth. On the consensus view slower growth post 2025 stems from the lagged effect of technological advances and public policy initiatives designed to curb fossil fuel usage.
- **The ExxonMobil view:** ExxonMobil is forecasting modest gains in both primary energy and oil demand globally between 2017 and 2040 of 0.8% and 0.6% pa respectively. Both reflect a significant slowing compared with the 2000-2017 growth rates of 2.1% pa for energy and 1.2% pa for oil. The 2017-2040 forecast is based on GDP growth of 2.8% pa against 2.9% pa between 2000 and 2017. Energy intensity therefore declines markedly in the forecast period thereby continuing a trend that has been apparent since the first oil crisis and price surge in 1973. Interestingly, on the ExxonMobil scenario oil still represents 30% of the energy mix in 2040, only slightly down on the 32% of 2017.
- **ExxonMobil reality check:** Arguably, the ExxonMobil oil demand forecast is optimistic given the apparent desire of politicians and others to consign petroleum companies to the ash heap of history. Based on ExxonMobil's review of alternative scenarios produced by other forecasters its forecast of oil demand between 2017 and 2040 is within the consensus range of modestly positive to modestly negative growth.
- **Battery electric vehicles (BEVs):** Battery electric vehicles still have a very low share of the light vehicle park and sales mix at about 0.5% and 2% respectively. In our view, the uptake of BEVs is likely to be constrained near to medium term by the availability of product, the limitations of rechargeable battery technology in terms of range, recharging times and the availability of charging infrastructure. In terms of medium and heavy trucks, the constraints on uptake are even more pronounced than for light vehicles. Upfront cost penalties vis-à-vis diesel trucks and lower payloads due to heavy battery packs are further drawbacks to the early uptake of long-distance battery powered heavy trucks.

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PETROLEUM INDUSTRY VOLUME TRENDS AND SCENARIOS

LARGEST MARKET POTENTIALLY UNDER THREAT

Vehicle electrification threat: Medium to long-term, the greatest threat to petroleum demand is vehicle electrification. The dominance of gasoline and diesel internal combustion engines as the power source of choice for on-highway and indeed off-highway vehicles has provided the petroleum industry with its largest market over many years.

Transportation fuel almost 60% of the mix: Presently, based on ExxonMobil data, transportation fuels in total account for about 58mm boe/d or almost 60% total petroleum usage of 100mm boe/d. Transportation demand is split broadly as follows: light duty vehicles 25mm boe/d, heavy duty vehicles 23mm boe/d, aviation 5mm boe/d, marine 4mm boe/d and rail 1mm boe/d. On-highway transportation accounts for approaching 50% of total petroleum usage. Overall, gasoline and diesel account for around 95% of highway transportation energy sources with the balance being ethanol, bio-diesel, CNG (compressed natural gas) and electricity.

Strong growth in highway transportation-----: Highway transportation petroleum demand has grown strongly, in an energy context, over many years. Growth has been about 3% pa since 2000 driven by gains in personal vehicle ownership, an upward trend in the heavy truck fleet, particularly in the non-OECD world and the increasing presence in the light vehicle mix of pickup trucks, SUV's (sports utility vehicles) and CUV's (crossover utility vehicles). The key underlying drivers are rising income per capita, lengthy supply lines in many parts of the non-OECD world and the advent of e-commerce which has stimulated demand for light commercial vehicles. It should be noted that in many parts of the world there is no alternative to using long-distance diesel-powered trucks. Additionally, trucks and vans offer the virtues of versatility, flexibility and a competitive cost base for non-bulk transportation. Rail can't match the competitiveness of highway transportation for non-bulk applications.

-----and aviation and petrochemicals: Excluding on-highway transportation, the major growth sectors for petroleum have been aviation and petrochemicals. Since 2000, demand for both categories has grown by about 3.5 % pa. Partly offsetting growth in on-highway transportation has been a decline in petroleum usage in the power generation, residential and commercial segments and broadly flat trends in industrial usage excluding petrochemicals and in rail. Marine usage has shown modest growth since 2000. Overall, petroleum demand has grown by 1.2% pa since 2000 based on ExxonMobil data.

ExxonMobil scenario reflects modest oil demand growth 2017-2040-----ExxonMobil's scenario for world oil demand between 2017 and 2040 reflects an increase of 0.6% pa assuming GDP growth averaging 2.8% pa (OECD 1.8% pa, non-OECD 4.1%) and population growth of 23% to 9.2bn. Energy demand in total over the same period is expected to be modestly higher at 0.8% pa. The broad picture is for oil demand to rise 12% between 2017 and 2030 and then to trend essentially flat to 2040. Energy-related GHG (green-house gas) emissions on the ExxonMobil scenario would increase 5% between 2017 and 2040. However, the energy intensity of the world economy would fall sharply between these two dates thereby continuing a longer-term trend that has been apparent since the first post-war oil crisis and price surge in 1973/74.

-----by heavy-duty trucking, petrochemicals and aviation: Helping buoy oil demand over the next 20 years or so, according to the ExxonMobil scenario, will be on-highway heavy-duty trucking, petrochemicals and aviation. Note, in the case of petrochemicals key feedstocks are naphtha and natural gas liquids such as ethane, propane and butane. Interestingly, the ExxonMobil's scenario shows oil demand for light vehicles peaking in the mid-2020s but the subsequent dip is modest through the balance of the forecast period to 2040. The decline from the peak is about 15%.

ExxonMobil scenario appears optimistic: ExxonMobil's energy outlook scenario at first glance appears optimistic from a petroleum industry perspective. Pressure is clearly intensifying from politicians and others to reduce carbon emissions and therefore fossil fuel consumption in support of the UN goal to limit global warming to under 2°C during the balance of the century. ExxonMobil's scenario, however, is not out of line with other forecasting bodies. We believe the absence of a decline in either energy or oil consumption in the ExxonMobil scenario is symptomatic of an extremely challenging backdrop. Key features are significant population growth, expectations of rising per-capita incomes and no easy technical solutions to decarbonising the economy in general and the transportation sector in particular, at least without deleterious side effects. It is not for no reason that the energy sector functions as it does.

Underlying conflict between climate policy and economic objectives: There is, in our view, a clear conflict between economic objectives including access to low-cost energy and climate policy. To reconcile the conundrum energy policy will probably need to increasingly focus on negative carbon emissions through carbon capture and storage (CCS). Nuclear may also be part of the solution. The alternative approach is state direction of the economy a la Greta Thunberg, including severe restrictions on mobility in the noble cause of emissions reductions. Wave goodbye to economic growth and personal freedom.

OUR OIL VOLUME SCENARIO

Oil demand threat from electrification not significant near-term: We believe oil demand is under no significant near-term threat from electrification and public policy initiatives to decarbonise energy supply. The petroleum industry remains dominant in its key markets of highway transportation, off-highway machinery, aviation, marine and petrochemicals. Transformational technological changes in these industrial segments can neither be implemented easily or instantaneously. Indeed, regarding transportation in general and aviation in particular, alternative technologies to thermal combustion engines using fossil fuels are at an early stage of development. It should also be noted that there is a very large park of about 1.4bn vehicles globally powered by internal combustion engines. These are likely to remain in use for many years given average vehicle lives of 15-20 years.

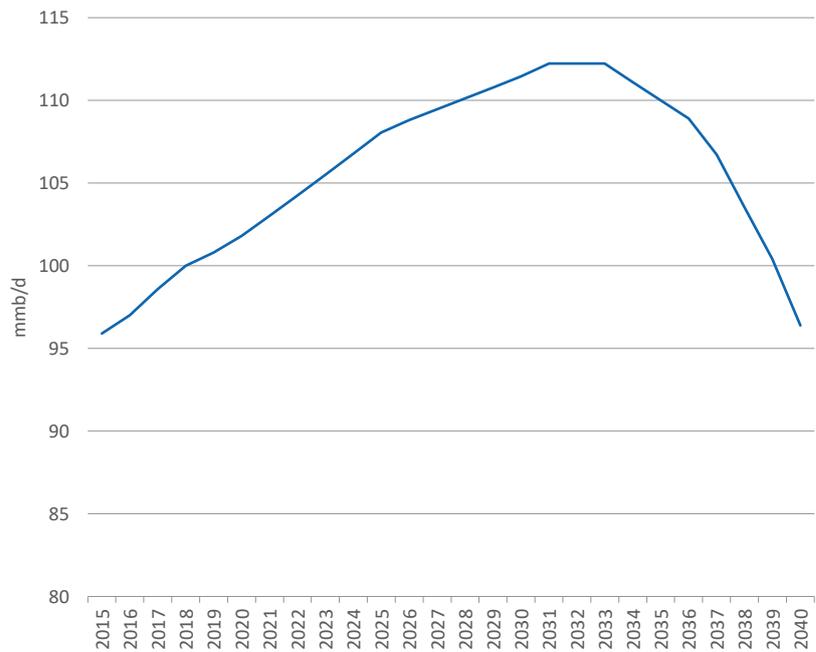
Peak demand in the early 2030s: In this context we define near-term as being the next five years or so to the mid-2020s. Over this period, we would expect petroleum demand to rise by about 1.2 % pa or in line with the recent pace, assuming global economic growth of around 3% pa. We would look for world demand of around 108mm b/d in 2025 against an estimated 101.8mmb/d in 2019. During the second half of the 2020's we expect growth to slow as electrification takes hold in light vehicle transportation and the fuel efficiency of conventional vehicles continues to improve. We believe the oil consumption trend will level-off in the early 2030's at about 112mmb/d and move down thereafter. This we think will mainly reflect rising EV penetration in the light vehicle sector but will probably be given added impetus by the emergence of electrification trends in medium and heavy trucks. By the mid-2030s we believe demand could have drifted down to about 105mm b/d.

We believe the key risks for oil consumption over the next 15 to 20 years are as follows:

- **Political initiatives:** Political initiatives in support of climate policy. Any action to tighten emission legislation over and above what has already been announced could result in a significantly weaker trend post 2025 than currently envisaged. Potentially the EU's recently announced Green Deal which tightens emissions policy could be a case in point.
- **Technological innovation:** Technological innovation particularly in the battery and hydrogen fuel cell fields which could advance the pace of electrification in transportation applications. In our view, the key potential technological development that poses a risk for the petroleum industry is a breakthrough in the

commercialisation of solid-state batteries. Solid-state technology offers the potential to revolutionise battery performance but high-volume production has proved technically very challenging. Toyota is the leading exponent of the technology. However it does not expect to have achieved commercialisation before 2025. News from Toyota on solid-state will be a key leading indicator for oil demand long-term.

Exhibit: Global oil demand scenario



Source: EIA & Allenby Capital

VEHICLE ELECTRIFICATION

REVIEW OF THE TECHNOLOGY

Principally rechargeable lithium-ion battery technology: Vehicle electrification is currently undertaken principally by applying rechargeable battery or hybrid ICE/battery propulsion technology. Typically, rechargeable batteries use lithium-ion technology. This comprises a lithium oxide cathode such as lithium cobalt, a graphite anode, chemical-based electrolyte and a separator between the cathode and anode to prevent short circuits. During charging lithium ions move from the cathode to the anode via the electrolyte and vice-versa during discharging. An electrochemical reaction enables electrons to be discharged to an external circuit.

The alternative EV technology to lithium-ion rechargeable batteries is hydrogen fuel cells.

Battery electric propulsion

Electrical energy stored in a battery converted to mechanical energy by an electric motor: In the case of pure battery propulsion systems electrical energy is stored in the battery (analogous to storing gasoline or diesel in a fuel tank) and released on command to power one or more AC electric motors. These convert electrical into mechanical energy which is then used to drive the wheels much as for an ICE (internal combustion engine) powertrain. The generator acts in reverse and converts mechanical energy from regenerative braking to electrical energy for storage in the battery.

Instant availability of torque therefore no multi-speed gearbox: Unlike ICE powertrains, pure battery electric propulsion systems do not generally have a multi-speed gearbox due to the instant availability of torque with an electric motor. A recently announced exception is the Porsche Taycan which incorporates a two-speed gearbox for more relaxed high-speed cruising. The number and output of the electric motors determine such parameters as acceleration, driving range and load capacity.

Advantages: Rechargeable battery technology for vehicles has been advocated by politicians and increasingly in automotive engineering circles mainly on environmental but also partly on performance and operating cost grounds. Tesla is perhaps the leading advocate of rechargeable lithium-ion battery technology but other automotive groups such as General Motors, Volkswagen and Ford are increasingly applying the technology.

While BEV's do offer advantages in several fields they also have major drawbacks for some applications notably, medium to long distance driving. The strong suit of BEV's is clearly short distance urban driving where re-charging is relatively easy and there are none of the fuel consumption penalties associated with ICEs. Providing, of course, the electricity used for battery charging purposes is generated from renewables, BEVs are emission free both in terms of CO₂ and nitrogen oxide (NOX) and particulates (soot).

In addition to the emission issue, BEVs have significant advantages over ICEs in two other areas. These are acceleration and potentially cost of ownership. Thanks to the instant availability of torque and the absence of gear changes BEV's have lightening acceleration, particularly in the lower speed ranges. The drawback is that if anything like full performance is used the battery charge will be rapidly rundown without the ability to recharge. The performance advantage may therefore be more academic than real.

BEV's potentially have significant operational cost advantages over ICEs. This reflects two factors. First and foremost, BEV's use a much cheaper energy source in the form of electricity. The advantage is compounded by electricity being lightly taxed vis-à-vis diesel and gasoline. The second potential operational cost advantage of BEV's relates to servicing and spares. The key points here are a BEV propulsion system contains many fewer moving parts than an ICE and does not require oil and filter changes. Furthermore, the battery is

theoretically maintenance free over its lifetime and BEVs require neither clutches or gearboxes.

The preceding, however, probably overstates the potential BEV operational cost advantage given the reliability and durability of modern ICE's, the potential for high cost electrical repair work on BEVs once warranty periods expire and the high cost of replacing batteries. Broadly, batteries account for approaching 50% of the cost of a BEV. Even for low-price vehicles such as the VW ID3 the impact could be around \$15,000.

Disadvantages: BEV's have several drawbacks which pose major barriers to adoption in the short term. We see the key one's as follows:

- **Range and recharging times:** First and foremost, among the disadvantages of BEV's are limited range and lengthy recharging times. These two factors seriously compromise the use of BEV's for medium to long range driving compared with ICE's. The fundamental issue concerns the low energy density in terms of both weight and volume of lithium-ion batteries compared with gasoline and particularly diesel. Broadly, gasoline has an energy density about 100 times that of a lithium-ion battery. In the case of diesel, the multiple is nearer 120 times.

The ultra-high energy density of gasoline and diesel implies small storage requirements in terms of fuel tank capacity vis-à-vis battery storage. This in turn has positive implications for ICE vehicle weight and package. These considerations are of particularly relevance for vans and trucks where payload is an important consideration.

Helping to narrow the energy density gap is the greater efficiency of an electric motor in converting electrical energy to vehicle movement than an ICE. The efficiency of an electric motor is about 70% while an ICE is nearer 20%. Nevertheless, the ICE retains a significant advantage in terms of range, although the gap is narrowing. With the latest BEV's the theoretical driving range is around 250 miles in standard form. This extends to 320-350 miles in long range specification. Earlier BEV's had ranges more like 100 to 150 miles. Interestingly, the recently announced Ford Mustang Mach-e CUV (crossover utility vehicle) has a range of a highly creditable 370 miles in its most advanced form.

In reviewing published specifications, it should be noted that actual ranges are likely to be significantly lower at high speeds and when the auxiliaries such as air conditioning are in use. Ranges in practice might be 50 to 100 miles less than published. Interestingly, the US Environmental Protection Agency's (EPA) assigned range for the new \$150,900 Porsche Taycan is a mere 201 mpg which is adequate for little more than commuting. Porsche had previously been talking of range of around 265 mpg.

Arguably, the key drawback with BEV's now is recharging times rather than range. Typical recharging times are around 12 hours using a 240 volt/AC charger. Admittedly, using a fast charger, the time can be cut to about 30 minutes but this is only for an 80% charge. Furthermore, excessive use of rapid chargers can compromise battery life.

Outside the range and recharging time limitations with lithium-ion battery technology, an absence of recharging infrastructure is also likely to severely constrain usage. This applies most notably to long haul medium and heavy trucks but also includes off-highway agricultural and earth moving machinery operating in remote locations. Note here that diesel, in contrast to electricity, can be very easily transported to most locations without the need for expensive infrastructure.

- **Battery durability:** Battery durability is a function both of age and recharging cycles. Battery recharging creates considerable heat which reduces battery life and performance. To help mitigate the heat issue BEV's incorporate cooling systems but these add weight and consume power. The issue of battery durability has been addressed by auto OEM's typically warranting 70% of battery life over eight years or 100,000 miles. For comparison ICE engines are generally extremely reliable and durable and capable of mileages of over 150,000 or even 200,000 miles before major overhaul.
- **Power distribution and re-charging infrastructure:** The adoption of BEV's involving the substitution of large quantities of high-energy density gasoline and diesel by electrical power would necessitate a major upgrade of the power distribution system in both urban and rural areas. The power distribution system is the final stage in the supply of electricity from the high-voltage transmission network to the final consumer. It comprises equipment such as busbars, transformers, protective devices and the underground ducting and pole network needed to carry the power to the final consumer.

Supplying power for BEV's will also necessitate the widespread installation of battery chargers. Upgrading the power distribution network to cater for large-scale BEV usage is likely to cost billions of dollars in a country the size of the UK. A further drawback in terms of power distribution concerns the potential for heavy congestion at vehicle charging centres. The issue here is the time required for recharging. The throughput will be much lower than at a gas station where the time required to 'gas-up' is a matter of a few minutes.

Logically, the widespread adoption of BEV's will also substantially boost the demand for electrical power which will necessitate an expansion of generating and transmission capacity. Politicians and other BEV advocates, however, argue that vehicles will be largely recharged at night which will obviate the need for capacity expansion. In our view this is implausible in the event of widespread substitution of gasoline and diesel. Furthermore, the new capacity would need to be based on renewables to be compliant with emission objectives.

Solid-state batteries

The holy grail of rechargeable battery technology: Solid-state is the holy grail of rechargeable battery technology. The distinguishing characteristic of solid-state batteries is the use of solid electrodes and a solid electrolyte. This contrasts with conventional lithium-ion batteries which use a graphite powder anode and a wet chemical or polymer gel electrolyte. Significantly, the electrolyte is flammable. Solid-state batteries use a non-flammable ceramic electrolyte and a lithium metal anode. In principle, solid-state batteries broadly double energy density compared lithium-ion batteries and remove fire risk.

Potentially eliminates the drawbacks to lithium-ion batteries: The application of solid-state technology to rechargeable batteries would eliminate or substantially mitigate the drawbacks to conventional lithium-ion batteries and thereby facilitate the rapid adoption of BEV's. In particular, it would increase driving range potentially to 500 miles or over, sharply reduce recharging times, increase durability and lower the cooling requirement along with the fire risk. Higher density would facilitate the use of smaller batteries with consequent benefits in terms of weight and space utilisation. Alternatively, larger batteries could be used to enhance range and performance. So far, solid-state battery technology has only been applied in low-volume applications. Constraining application more widely has been the difficulty of mass-producing solid-state batteries and the susceptibility of solid-state batteries to dendrite crystal formation in the lithium anode. These crystals can grow through the solid electrolyte resulting in a rapid loss of battery

performance and ultimately the complete failure of the battery. In extreme cases the crystals can result in short-circuits and fires.

Toyota the most advanced exponent of solid-state battery technology: Presently, solid-state batteries are not economic for automotive applications. We believe the difficulties of mass-producing solid-state batteries were a key factor behind Dyson's recent decision to abandon its BEV project. Given the potential advance in battery performance, however, many automotive companies are attempting to perfect solid-state battery technology. The most advanced would appear to be Toyota. The company is planning to show-case solid-state battery technology in a prototype vehicle at the Tokyo Olympics in 2020. However, Toyota has indicated that it does not expect to commence solid-state mass-production before 2025. Given the technical challenges and potentially long lead times required to perfect solid-state technology, it will possibly be the early 2030's before it becomes a serious threat to gasoline and diesel ICEs. An early breakthrough in solid-state technology would clearly have profoundly negative implications for the petroleum industry.

Hybrid

Hybrid technology involves using two power sources. Typically, an ICE (diesel or gasoline) is combined with an electric motor, generator and a small rechargeable battery. The purpose of hybrid technology is to enhance the efficiency of the ICE by optimising its functioning according to driving conditions. Enhanced efficiency is reflected in lower fuel consumption and emissions. Optimisation centres around:

- Converting kinetic energy generated during braking and coasting to stored electrical energy in a battery.
- Dual sources of power that can be used as appropriate depending on driving conditions.
- Reduced idling due to the fitment of automatic start/stop devices. Such devices are also fitted to unconstrained ICE's but their functioning is simpler when used in conjunction with an electrified vehicle. Note, hybrid batteries are smaller than those installed in pure electric vehicles.

There are three distinct vehicle hybrid technologies. These are full-hybrids (HEV), plug-in hybrids (PHEV) and 48-volt mild hybrids (MHEV).

Full-hybrids: Full-hybrid powertrains have been made famous by the Toyota Prius which was first launched in 1997. Subsequently, however, the technology has been widely adopted by other OEMs, albeit less successfully than by Toyota. In addition to the ICE, an HEV contains the following components:

- **Electric motor-generator:** An electric motor and generator unit used to convert electrical to mechanical energy in the case of the former and vice-versa in the case of the latter. There are various alternative locations but the most common for a transverse engine and front-wheel drive the motor-generator is usually located inline with the engine. The power output for the electric motor is typically 20-40 kwh.
- **Lock-up clutch:** A lock-up clutch mechanism to provide direct drive to the wheels when the engine is in ICE mode.
- **Central processor:** A central processor controlling the different functions of the HEV powertrain.
- **High voltage battery:** A 300-400-V lithium-ion rechargeable battery.

Fuel saving 20-30%: Full-hybrids can drive the wheels either via the electric motor or the ICE depending on driving conditions and the battery charge. For high-speed cruising HEV's operate in ICE mode. They are capable of boosting fuel economy by 20% to 30% compared with an ICE powered vehicle of equivalent package, although much depends on the driving cycle. The hybrid fuel economy advantage is most pronounced in the case of urban driving.

If the cycle mainly involves high-speeds the fuel savings will probably be more modest than indicated above. During electric mode HEV's have the virtues of low noise and instant torque from step-off.

Approximate \$3,000 cost premium to an ICE: The disadvantages of full-hybrids are manufacturing complexity, weight, performance, carrying capacity and the space occupied by a relatively large battery. Performance and carrying capacity are all adversely impacted by the weight penalty vis-à-vis a pure ICE powered vehicle. According to industry estimates, the incremental manufacturing cost of an HEV compared with an ICE powered vehicle is about \$3,000. In the UK a HEV broadly sells at a 25-30% premium to an ICE powered vehicle of equivalent package size and performance.

Plug-in hybrids: The distinguishing feature of the plug-in hybrid is that it can be charged either by plugging into an external power source or by an onboard ICE/generator. The advantage of plug-in technology is that it provides many of the benefits of a BEV in terms of fuel consumption and emissions but without the range constraints. PHEV's use high voltage 400-V batteries and an electric motor-generator with a power output of 50-90 kwh, significantly more than an HEV.

A plug-in hybrid, depending on specification, can operate in one of three modes. Firstly, the vehicle can be driven in electric mode until the charge is exhausted. Subsequently the vehicle is powered by the ICE only.

Fuel saving compared with an ICE 50%-75%-----: The second option is a dual mode system whereby the vehicle can switch seamlessly between electric and ICE modes depending on driving conditions and the available battery charge. On the move, battery charging is undertaken automatically by capturing regenerative energy during braking and coasting. This technology enables high performance without range restrictions to be combined with excellent fuel economy. It has been adopted by the likes of Audi, Mercedes, BMW and a wide array of mainstream OEM's such as Ford.

Approximate \$7,000 cost penalty to a HEV: On the fuel economy front, dual-mode operation with regenerative braking can generate fuel consumption savings of 50% to 75% compared with an ICE, although much depends on the driving cycle. The dual-mode system, however, is complex and requires sophisticated electronic control equipment. Reflecting engineering complexity along with the use of bulkier components, the incremental cost impact of a dual-mode PHEV compared with an HEV could be \$7,000 or more, according to industry estimates.

Electric mode only PHEV with ICE range extender: The third alternative is a plug-in that always operates in electric mode. When the charge expires the ICE starts and powers an electric generator which in turn drives the wheels. Good examples of this type of plug-in are the new LEVC TX taxi and the new PHEV Ford Transit Custom van. Both vehicles are highly suited to urban start/stop environments where there are strict limits on emissions and the vehicles return to a base most nights where charging infrastructure is readily available. They are, however, not suitable for long distance high-speed applications and have poor performance compared with ICE vehicles of equivalent package. Indeed, the LEVC TX has a range restriction of 377 miles before re-charging. A further disadvantage is the substantial initial price premium of the electric mode plug-in. The Ford Transit PHEV sells for about £43,000, a premium of 65% to a diesel-powered van. The LEVC TX sells for about £57,000, a premium of about 40% to its predecessor.

Typical range on full charge 25-35 miles, LEVC TX 80 miles: Typically, plug-in vehicles have a range on a full charge of 25-35 miles (much depends on the size of battery), significantly more than with an HEV which is less than 10 miles. Interestingly, the LEVC TX can travel around 80 miles on a full charge. This covers about 70% of a typical daily driving cycle for a London Taxi. With any PHEV the key to achieving impressive economy is to regularly

recharge the battery thereby maximising the use of electric mode. Interestingly, many owners of PHEV's apparently fail to use the plug-in facility. The result is likely to be inferior fuel economy and performance to an ICE powered vehicle, given in part the weight penalty and in part the use of less powerful ICE's in some dual-mode PHEV's.

48-V mild hybrids: 48-V mild hybrid technology offers a cost-effective method of enhancing the efficiency of an ICE which in the process improves fuel economy and lowers emissions. The technology, unlike that for a HEV and particularly a PHEV is compact, relatively simple in scope, does not involve a major weight penalty compared with a pure ICE powertrain and does not involve structural changes to the vehicle. Importantly, because of the relative simplicity of 48-V powertrains manufacturing facilities do not have to be retooled. A 48-V mild hybrid ICE powertrain incorporates the following components:

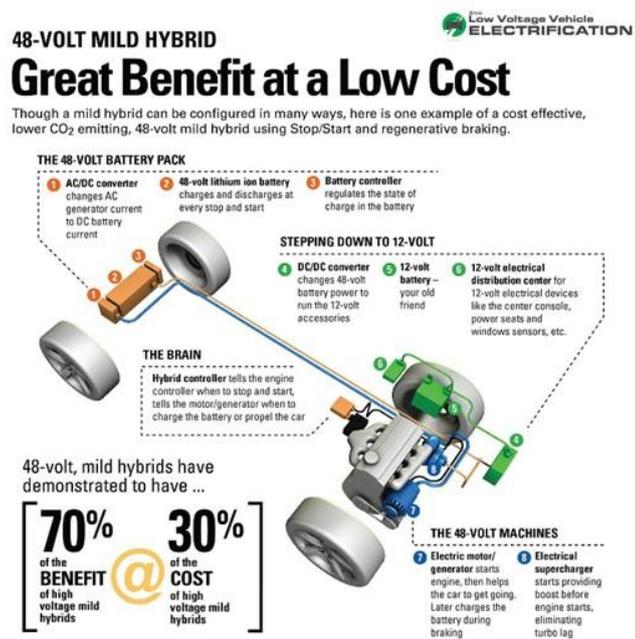
- **Belt driven motor-generator:** A combined electric motor-generator typically driven by a belt off the crankshaft and located at the front of the engine. The motor is used initially to start the engine and provide extra torque, compared with a standard 12V system, for enhanced performance and lower fuel consumption on step-off. Later the motor-generator captures regenerative energy during braking for conversion into electrical energy and storage in the battery. Typically the power output of a 48-V propulsion system is 20 kWh, well up on the 5 kWh of a conventional ICE.
- **Lower voltage than HEV or PHEV:** A 48-V lithium-ion battery which both charges and discharges at every stop and start and collects regenerative braking energy. Significantly, improvements in the tolerance of battery cells to heat has reduced cooling needs and hence the complexity and size of the cooling system. Batteries are now of modest scale and roughly fit within a shoe box, according to auto component producers such as Continental.
- **Electrically operated supercharger:** An electrically operated supercharger which starts operating before the engine fires, thereby eliminating turbo lag. This feature can enable smaller ICE's to be used than previously with potential benefits for fuel consumption. Alternatively, the technology can be used to boost performance by eliminating turbo lag.
- **Hybrid controller:** A hybrid controller which signals to the engine management system when to start and stop and when to operate the motor and generator.
- **AC/DC converter:** An AC/DC converter which changes AC generator current to DC battery current and vice versa.
- **DC/DC converter:** A DC/DC converter which changes 48-V battery power to 12-V to operate the auxiliaries. Note that with a mild hybrid a parallel 12-V system is maintained for the operation of the auxiliaries such as air conditioning, power steering, engine fan, heater system, catalytic converter and windscreen wipers. The greater power of the electrical system enables the load on the engine to be considerably reduced thereby boosting fuel economy.

Typical fuel saving 10-15% but around 20% with the latest technology: The tangible benefits of a 48-V mild hybrid system compared with a 12-V ICE powertrain are a 10 to 15% reduction in fuel consumption and emissions, 25% more low-end torque and more power to operate a growing array of electrically operated auxiliaries. Recent advances in electric motor technology by the German component producer Continental AG, which has boosted power output to 30 kWh may, in fact, have increased the 48-V fuel saving to about 20%. The key breakthrough reflected a new electric motor cooling system. As a result of the higher power output, electric mode operation can be maintained for longer.

Relatively low incremental cost of \$1,000: The incremental cost of a 48-V mild hybrid system vis-à-vis an ICE is relatively low at about \$1,000, according to industry reports. This is approximately 30% of a 300 to 400-volt HEV system for 70% of the benefits. The 48-V mild hybrid cost advantage reflects less demanding insulation protection requirements with the considerably lower voltage and more compact and lighter components. A major element behind the cost saving relates to the use of a smaller lithium-ion battery.

Reflecting the attractive cost-benefit ratio of 48-V mild-hybrid systems vis-à-vis HEV's, many auto industry observers expect that the powertrain technology will dominate in the coming years. Bosch, for example, suggests that the share of 48-V technology will rise from 5% of light vehicle production globally in 2020 to 20% in 2025. This could imply about 20m vehicles. The consultancy IHS believes that roughly 50% of the hybrid market in 2025 will be 48-V mild hybrid. We believe these expectations may prove conservative such is the competitiveness of the 48-V technology and the pressure to boost fuel economy.

Exhibit 2: 48-Volt hybrid schematic



Source: Automotive-IQ Delphi Technologies

Hydrogen fuel cell electric vehicles (FCEV)

An alternative vehicle electrification technology: An alternative route to vehicle electrification involves using hydrogen fuel cell technology. In this application the fuel cell effectively performs the function of a mini on-board power station. Hydrogen provides the fuel which produces electricity through a catalytic reaction. The fuel cell comprises a platinum coated anode which acts as the catalyst, a nickel coated cathode and a polymer proton exchange membrane which separates the two. Hydrogen is broken down at the anode into electrons (the basic unit of an electrical charge) and protons. The membrane prevents the electrons separated from the ions passing through to the cathode, thereby forcing them along an external wiring circuit. Meanwhile, the protons pass through the membrane and combine at the cathode with the electrons to form water. The electric circuit is used to power an electric motor much as in the case of a BEV or hybrid. Unlike a battery which depends on stored electrical energy, a fuel cell keeps functioning as long as there is a supply of hydrogen.

Scalable energy efficient technology: Fuel cells are eminently scalable. Cells can be combined in parallel to form stacks for extra power generation capability. Reflecting the reactive characteristic of hydrogen and the use of electric motors, fuel cell electric vehicles are highly energy efficient

Advantages: Interest in hydrogen fuel cells for auto applications reflects several factors. The key ones are as follows:

- The high energy efficiency of the technology. Broadly, fuel cells are around 60% energy efficient or similar to BEVs and much higher than the 15-20% of ICE's.
- The ability to refuel in much the same time as for diesel and gasoline powered vehicles.
- Similar or better fuel consumption than ICE powered vehicles.
- No battery charging and range restrictions unlike a BEV.
- Hydrogen's high intrinsic energy density per unit of weight (volume is a different story) vis-à-vis other fuels reflecting the lightness of the gas. The advantage of FCEV's is compounded, given that fuel cells weigh significantly less than lithium-ion batteries. The BEV therefore requires more energy per mile than a FCEV. This translates into potentially superior FCEV acceleration, range and payload.
- No carbon dioxide or toxic emissions during the functioning of the fuel cell unlike for an ICE.
- Hydrogen fuel is renewable if derived from water by electrolysis.
- Reliable technology.

Disadvantages: The disadvantages of FCEV's largely revolve around the following factors:

- Virtually all hydrogen gas is presently produced via the steam reforming process using natural gas as the feedstock. FCEV's presently are, therefore, not emission free on a 'well to wheel' basis. Nevertheless, industry reports suggest that FCEV's using natural gas-based hydrogen generate only about 50% as much carbon dioxide as ICE's. Hydrogen can also be produced from water through electrolysis. This process generates no harmful by-products but is highly energy intensive and prohibitively expensive. FCEV's supplied with hydrogen produced from power generated by renewables would be emission-free on a full-cycle basis.
- High manufacturing costs, compared with ICE vehicles and indeed BEV's due to the use of platinum, an expensive catalyst, and the absence of mass-production. Presently, FCEV prices of £60,000 plus are not competitive with either ICE powered vehicles or BEV's of comparable package and performance.
- Hydrogen has low-energy intensity by volume in comparison with diesel and gasoline. This necessitates compression for transportation purposes which adds to cost and complexity of storage.
- Reflecting the energy intensive nature of the production process and the need for compression for transportation purposes, hydrogen is an expensive fuel vis-à-vis diesel and gasoline. In the US hydrogen costs roughly five times that of diesel at \$15/kg.
- Hydrogen gas is less convenient to transport than gasoline and diesel liquids and needs to be compressed at high-pressure in specialised containers when transported and stored. Specialised containers add to distribution costs compared with gasoline and diesel. In recent years onboard tanks have been developed that are small enough to fit in the back of a vehicle while still having sufficient capacity for at least 300 miles of driving range. The tanks, however, are expensive compared with those for gasoline/diesel.

- The hydrogen distribution network is undeveloped and so far, mainly located in California, Japan and South Korea.

FCEV's still at an early stage of development

Key challenges emission-free source of hydrogen and storage/distribution: Hydrogen FCEV technology has been explored by both automotive OEMs and fuel cell specialists such as Vancouver-based Ballard for many years but without breakthroughs to large-scale production. This reflects in part the all-round capability of ICE's, in part the automotive industry's development focus on BEV's and in part some major technical challenges. The most significant of the challenges are obtaining a competitive emission free source of hydrogen and the storage/distribution complications. We believe however, the pace of development is speeding up driven by the tightening regulatory environment for ICE emissions and rising taxes particularly on diesel in some parts of the world.

Leading light vehicle FCEV players Toyota, Honda and Hyundai: Hydrogen fuel cell development for light vehicles is being led by Toyota, Honda and Hyundai. These three, in fact, are the only mainstream auto OEMs with light vehicle product in the field via the Mirai, FCEV and IX35 respectively. Volume, however, is marginal presently at under 5,000/year worldwide. Driven by recent new product introductions, FCEV production looks like gaining momentum over the next year or two, although volume will probably remain decidedly modest in terms of world light vehicle production of about 95m units/year.

Toyota has indicated that it is looking for FCEV volume of about 30,000 units by 2021 while Hyundai has been pointing to a capacity near-term of 40,000 units following the start-up of a new plant. Worldwide volume of FCEV's, we believe, could comfortably top 50,000 units (light vehicles) in the early 2020's. Interestingly, Hyundai has an objective of producing around 500,000 light and heavy commercial FCEV's per year by 2030. If Hyundai and Toyota were to achieve volumes of anywhere near these levels by this date, it would seem likely that more OEM's would enter the FCEV fray.

Heavy truck opportunity: Arguably, the greatest opportunity for hydrogen fuel cells is in heavy trucks rather than light vehicles. This reflects the following:

- **Long range:** The advantage of FCEV's in terms of energy density per unit of weight vis-à-vis BEV's. As we have noted, this translates into major benefits in favour of FCEV's in terms of payload and range. Significantly, the range for FCEV heavy trucks (US Class 8) of 500 to 750 miles is double that for BEV counterparts, according to data provided by the Phoenix-based electric truck start-up, Nikola Corp. The payload potential of a FCEV is also higher than for a BEV, given the approximate 20% lower weight.
- **Excellent performance:** Bearing in mind a higher power to weight ratio, FCEV trucks should also be able to out-perform BEV trucks, although Nikola provides identical acceleration times to 60 mph. Nikola's prototype FCEV semis have tremendous horsepower and at 1,000 bhp and 2,000 ft lbs respectively and can accelerate at twice the pace of the larger diesel trucks with around 500 bhp. Furthermore, a speed of 65 mph can be maintained with a full load of 36 tonnes on a 6% grade, a truly outstanding performance.
- **Quick refuelling:** The ability of a FCEV to refuel in 10-15 minutes which is similar to a diesel truck and in a different ballpark to the several hours for a BEV. It should also be noted that FCEV's avoid the hefty drain on the grid imposed by BEV trucks during recharging. FCEV's considerably longer driving ranges and much shorter refuelling times, imply a smaller heavy truck fleet than with BEV propulsion.

Currently a considerable FCEV price premium: For the moment, at least, fuel cell powered heavy trucks are considerably more expensive to buy than either BEVs or diesel trucks. According to industry commentary, the Nikola Class 8 semi in the US is expected to retail for \$375,000 when it goes into production in 2022. This compares with \$180,000 for Tesla's Class 8 BEV (roughly half the range of a Nikola Class 8) and approximately \$120,000 for a Class 8 truck. Helping to mitigate the fuel cell premium should be lower operating cost.

Nikola Corp

Leading proponent of FCEV trucks: The leading proponent of FCEV heavy trucks is arguably Nikola Corp, a privately held company that was only founded in 2014. The company has already produced two hydrogen fuel cell powered prototype semis, the Nikola One and Nikola Two and a BEV product the Nikola Tre. It has an order backlog of 14,000 trucks and is in the throes of constructing an assembly plant near Phoenix, Arizona.

Joint-venture with CNH-IVECO: Importantly, Nikola has also formed a joint-venture with the Turin-based IVECO heavy truck manufacturing arm of CNH Industrial along with its powertrain division, FPT. IVECO is one of the big-four European truck businesses along with Mercedes Benz, Volvo and Triton (Scania, MAN and VW) and also has major operations in South America. The first fruits of the joint-venture were recently seen in the Nikola Tre, which uses the architecture of the highly acclaimed IVECO S-Way truck. The plan is to commence production of the BEV version of the Tre in 2021 and to follow this with a fuel cell powered version in 2023. As part of the joint venture, CNH has contributed \$250m in loan and equity financing. This follows an earlier \$230m financing round by the auto component major Bosch and Hanwha, the Seoul, South Korea-based (technology headquarters Thalheim, Germany) solar cell and photovoltaic technology specialist.

Major hydrogen refuelling network planned in the US: Significantly, Nikola intends rolling out 700 hydrogen refuelling stations along key highway arteries across the US by 2028. Apparently, these will contain their own hydrogen electrolysis and storage facilities. The intention is to use solar power as the primary energy source for electrolysis. This is a very ambitious and costly programme but one that it is necessary, if fuel cell trucks are to have wide application. In the US Shell is also active in promoting FCEV's and is working with Toyota, Kenworth and UPS.

Hyundai is also entering the arena.

Recent 1,600 FCEV truck order in Switzerland: Hyundai has an ambitious hydrogen fuel cell heavy truck development programme. In recent months the company announced a highly significant order for 1,600 trucks in Switzerland to be delivered between 2020 and 2025. The customer is Hyundai Hydrogen Mobility, a joint-venture between Hyundai Motor Co and Zurich-based H2 Energy AG. The joint-venture called Hyundai Hydrogen Mobility (HHM), will lease the vehicles to trucking concerns in Switzerland using a refuelling infrastructure being developed by H2. Significantly, H2 along with the Lausanne-based power concern Alpiq AG and Linde the industrial gases specialist, announced a joint-venture in April 2019 to produce electrolytic derived hydrogen. Primary energy will be sourced from Alpiq's Gosgen hydro plant.

Onerous Swiss regulatory and tax regime on diesel: Hyundai's decision to commence operations in Switzerland with its fuel cell powered trucks has been inspired by the increasingly onerous regulatory and tax regime surrounding the use of diesel trucks in the country. Based on company statements, it is likely that HHM will roll-out its hydrogen refuelling infrastructure elsewhere in Europe. Interestingly, the Federal Transport Ministry in Germany has an objective of 400 refuelling stations by 2025. This compares with 70 as of late 2019. The Japanese transportation authorities are looking for 900 hydrogen refuelling stations by 2030.

EV PRODUCTION SCENARIO 2019-2030

LIGHT EV PRODUCTION SCHEDULED TO GATHER PACE IN 2020

PHEV and BEV share increasing but still marginal: Light EV (PHEV and BEV) production globally has grown rapidly in recent years but has remained marginal in share terms bearing in mind total industry light vehicle (cars, pickups and vans) output of about 95m in 2018 and 92m in 2019. According to third party industry assessments by organisations such as Bloomberg NEF, world EV production was around 2m units in 2018 for a 2.1% share of world production. We believe it could be about 2.6m in 2019 based on year-to-date September sales trends (we assume that sales are roughly equivalent to production). Assuming industry production of 92m the EV share would be 2.8%.

EV sales pace has softened of late driven by the US and China: Based on third party reports, EV sales globally through the first nine months of 2019 were 1.61m units up about 26% on a year earlier. Compared with 2017 and 2018, the sales pace has slowed significantly of late. This reflects softening trends in China and the US following cuts in government price subsidies in both locations. Enthusiasm for EV's in China and particularly the US also seems to be waning with range limitations being seen as a key drawback. In the US the recently launched Jaguar I-Pace and the Audi E-Tron crossovers have both sold below expectations while Mercedes Benz has decided to delay for one year the launch of its first BEV, the EQC crossover.

China accounts for about 55% of EV sales: Interestingly, sales were down globally year-on-year in both August and September 2019. Partly offsetting the weakness of late in China and the US has been growth in Europe. Presently, China accounts for about 55% of world EV sales followed by North America and Europe both on around 20% while Japan contributes the bulk of the balancing 5%. China is comfortably the largest producer of EV's accounting for 55-60% of world output.

2020 could reflect the beginning of the EV age: We believe EV production will show strong upward momentum in 2020 abstracting from major recessionary forces. Indeed, we believe 2020 will mark the beginning of the high-volume EV age. The key positives for production will probably be several auto OEMs coming on-stream with electrified product for the first time and sizeable manufacturing capacity additions.

VW has the most ambitious EV programme based on its MEB platform: Driving the electrification process will be the Volkswagen group, which arguably has the most ambitious electrification programme of any automotive OEM. Its development programme is now coming to fruition. Volkswagen has recently launched its ID3 compact car (similar in size to a VW Golf or Ford Focus) based on its modular high-volume MEB (a German acronym meaning modular electric-drive) platform. Note, platform in this context includes both the vehicle chassis and powertrain. Production of the ID3 will commence in 2020 at a rate of 100,000-150,000 pa at its Zwickau, central Germany plant. The capacity is 330,000 pa which is very much in line with the automotive mainstream.

The ID3 is the first of the MEB derivatives, platform shared with Ford: The ID3 is the first of five derivatives to be launched on the MEB platform over the next few years. VW plans to commence operations at several other dedicated electric vehicle plants in the US, China and Europe using the MEB platform by 2022. By this time the plan is to produce over 1m BEV's/pa on this platform. VW has also licenced its MEB technology to Ford as part of a wide-ranging joint-venture relating to electric vehicles, automated driving and light trucks/vans. Ford is reported to be planning three BEV's in Europe using MEB technology by 2023. This could imply a further 0.3-0.4m units annually by this date. Ford is planning 16 plug-in electric vehicles worldwide by end 2022.

Recent launch of the Ford Mustang Mach-e to critical acclaim: In the US Ford, using its own CE2 technology, has recently launched its Mustang Mach-e, a high-performance, long range CUV (crossover utility vehicle) that will be sold globally and sourced from a facility in Mexico. The car sells for between \$52,000 and \$85,000 depending on derivative and has received highly favourable reviews in the trade press. Order intake has also been strong. Industry reports suggest production of about 50,000 in 2020 and perhaps 100,000 at full capacity.

Mid-market ID3 price point: Unlike the Tesla product line, which until the Model 3 focused on premium vehicles, the ID3 will be competing much closer to the middle of the market. For a base version the price will be around \$30,000 pre-incentives, which is competitive for a BEV. For large premium Audi and Porsche BEV's VW has developed the PPE platform. The first application of this has recently been launched in the form of the Porsche Taycan, a powerful four-door coupe similar in package to the gasoline powered Porsche Panamera or indeed the Tesla Model S. The price point for the Taycan is very different than the ID3 at about \$151,000.

Several other major EV product launches and capacity additions in 2020: In addition to the developments at VW, 2020 is scheduled to see several major EV product launches in Europe by the likes of PSA, Volvo/Polestar, Mercedes, BMW while in the US Tesla will be unleashing its new Model Y crossover. Production will also be gathering momentum at Tesla's new 250,000 units pa Shanghai facility in the first quarter. Tesla's planned 150,000 pa facility near Berlin will follow with a start-up scheduled for late 2020/early 2021. Potentially some of the most influential electric vehicle launches scheduled near to medium-term will relate to GM, Ford, FCA and Toyota.

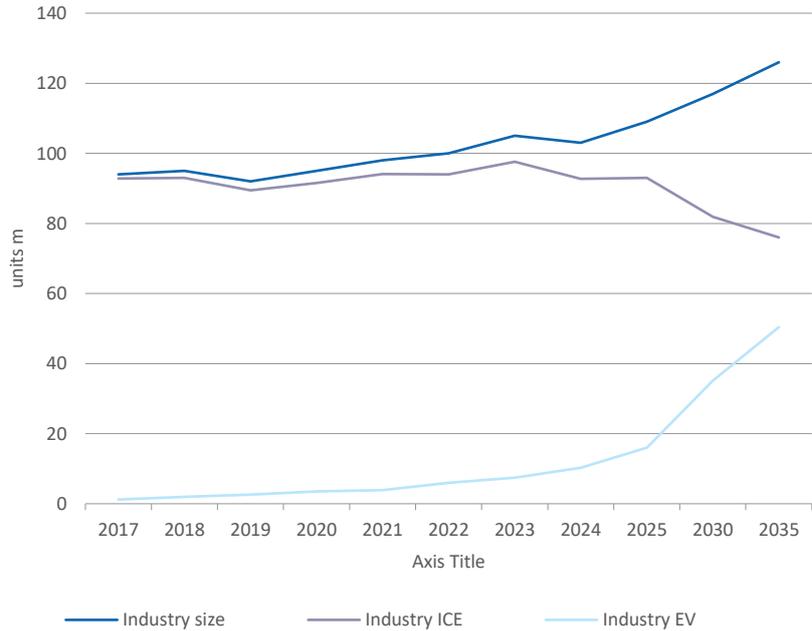
EV share possibly 15% by 2025 and 30% by 2030

Potential surge in new product launches and capacity expansion 2020-2025: For 2020 we are forecasting global light vehicle EV production of 3.5m units based on industry volume of 95m units. The gain from the previous year would be 35% which implies the EV share rising to 3.7%. Reflecting what is likely to be a surge in new EV product introductions and a continuing upward trend in manufacturing capacity, we believe EV production could rise to about 16m units in 2025. This would imply a share of approximately 15% assuming industry volume of 109m units. For this purpose, we have assumed the industry grows by 2% pa on average between 2018 and 2025.

Post 2025 a high degree of uncertainty inevitably surrounds the EV trend. However, a consensus is possibly evolving in industry circles around a 30% share by 2030. If we assume industry growth between 2025 and 2030 of 1.5% pa to 117m units, this would imply EV production of 35m units. Key potential constraints on EV production growth over the next ten years or so are the following:

- The rate of EV take-up by vehicle owners with key factors being acceptance of the limitations of BEV technology for long-distance driving, the availability of re-charging infrastructure and price premiums.
- The lead time and cost to convert plants from ICE to EV technology. Note, to convert a large plant will probably take a year and a half and cost well over \$1bn. A case in point is GM's Hamtramck plant in Detroit, one of company's newest, where the conversion process is scheduled to start in the first quarter of 2020.
- The availability of battery materials and battery cell manufacturing capacity.

Exhibit 3: Global light vehicle trend and scenario



Source: Trade data & Allenby Capital. Note: EV is BEV plus PHEV

ICE bans could boost the light EV share to over 50% post 2030

EV share could be boosted by tightening regulatory environment including ICE bans and compulsory scrappage: Post 2030, EV production could receive a boost from bans on the sale of ICE powered highway vehicles in certain jurisdictions notably Europe. Public policy on this matter is vague presently particularly regarding the status of hybrids and is contentious. If the bans begin to be implemented post 2030 rather than 2040 as has been mooted, the EV light vehicle share could rapidly rise to over 50% of the mix post the former date. Compulsory scrappage schemes for older gasoline and diesel vehicles combined perhaps with punitive registration taxes could also force the pace on electrification.

WHAT IS DRIVING ELECTRIFICATION?

Tightening emission standards in all major jurisdictions: The underlying driver behind both light vehicle and medium and heavy truck electrification is tightening emissions and fuel consumption standards on gasoline and diesel engines. Emissions relate in part to CO₂ and in part to particulates, NOX and SOX (sulphur oxide). The tightening trend applies to the three main emission standard jurisdictions, Europe, US and China. Chinese regulations are broadly based on Euro standards. Compliance with the tightening standards is inevitably proving challenging technically and leaves no alternative to the introduction of a large element of electrification into the fleet. Initially this can be achieved to a considerable extent using hybrid technology but given the spectre of outright bans on the sale of ICE’s between 2030 and 2040 there is no alternative in practice to applying BEV and/or FEVCV technology.

EU emission standards are particularly challenging: In the case of the EU, the 2021 (to be phased in during 2020) new regulations call for CO₂ targets of 95 g/km (3.8 litres/100 km) and 147 g/km (5.6 litres/100 km) for passenger cars and light commercial vehicles respectively. These targets are about 22% and 18% under current emissions of around 121 g/km and 180 g/km respectively. Importantly, the EU regulations call for a further cut by 2030 of 38% to 59 g/km in the case of passenger cars and by 31% to 101 g/km for light commercial vehicles.

US fuel economy standards are presently in a state of flux given President Trump's desire to roll back earlier Obama era standards and integrate California into the Federal mainstream. According to earlier Trump proposals fuel economy objectives across light vehicles could be 33 mpg (7.1litres/100 km) in 2025 and 37 mpg 2035, with all standards expressed in US mpg (85% of imperial mpg). Presently US fuel consumption is running at about 29 mpg (8.1litres/100 km). US OEMs also have a need to introduce a substantial element of electrification into the mix partly to comply with tightening emission standards and partly prospective bans on the use of ICE's in urban areas, particularly on the eastern and western seaboard.

Enforcement mechanism via punitive fines: The enforcement mechanism for the EU, China and US is via a system of fines. In the case of the 2021 EU target a fine will be levied of €95 for each g/km over the target of 95 g/km multiplied by unit sales. Clearly, the financial penalties have the potential to be punitive in the event of serious non-compliance.

HEAVY TRUCK AND OFF-HIGHWAY MACHINERY EV SHARE MARGINAL NEAR TO MEDIUM TERM

Powertrains for heavy trucks and off-highway machinery continue to be near 100% diesel: Powertrains for medium/heavy trucks and off-highway earth moving and agricultural machinery continue to be close to 100% ICE diesel. Standby and base-load power generation and stationary, portable compression equipment and fork-lift trucks for outside use also continue to be diesel powered. For all these applications diesel engines provide a well tried and tested power generation solution that will be difficult to dislodge by electrification. Key attributes are superior range or hours of usage, quick refuelling times and the ease of transporting liquid fuels to remote sites with minimal infrastructure.

BEV's are practical for short-haul urban applications: Prototype BEV trucks are in use for testing purposes and some truck OEMs, such as Daimler Benz have introduced battery electric vehicles for urban operations. As we have noted previously, prototype hydrogen fuel cell powered trucks are also under test with high-volume production pending in the early 2020's. BEV trucks are a practical proposition for urban delivery applications where range and refuelling times are considerably less significant than for long distance trucking. For urban applications a range of 100 miles might be adequate given the ability to readily recharge at a central depot. Short range also means that relatively small batteries can be used which limits the payload drawback to BEV trucks. Large numbers of BEV trucks operating in urban areas will, however, subject the grid to a heavy draw which implies the need for major infrastructure upgrades.

Long-term FCEV's may become the powertrain of choice for long haul, trucking operations: Long-term we believe that short and medium distance trucking may become the province of BEV trucks. For long distance trucking, however, where range and refuelling times are of critical importance, FCEV's may well become the powertrain of choice in due course. In principle, trucking companies are interested in electrification, given the potential cost savings vis-à-vis diesel in terms of fuel and maintenance. It should be noted, however, that in many parts of the world long distance trucks are operating in remote areas where it would be very difficult to justify economically establishing hydrogen processing and refuelling infrastructure as described earlier.

As far as off-highway machinery and compressors are concerned, we again need to differentiate between urban and non-urban applications. While in an urban environment machinery can, in principle, be easily connected to the mains this is not the case for remote mining, construction and agricultural locations. Establishing a hydrogen infrastructure will also not be economic in such circumstances. In the case of urban applications, the issue of a heavy draw on the mains again applies.

EV market share for medium and heavy trucks likely to remain marginal near-to mid-term: We believe that the EV share of global medium/heavy truck production will remain marginal near to medium term. This reflects the early stage of technical development in transitioning away from diesel, the innate advantages of diesel particularly for long range trucking applications and the absence of either a recharging or hydrogen refuelling infrastructure. The same conclusion applies to off-highway machinery and equipment. We believe it will be post 2025 and maybe post 2030 before EV technology, either battery or hydrogen fuel cell, gains traction in the market place for long range trucks. Medium range truck electrification will probably become apparent at an earlier stage.

A LARGE PARK OF ICE POWERED VEHICLES IS LIKELY TO REMAIN INTO THE 2030s

Consideration also needs to be given to the park of vehicles: EV production growth is only part of the story from an oil consumption perspective. Even with strong growth and a rise in the EV share globally from about 2% presently to 30% by 2030 the park of ICE powered vehicles will remain substantial looking out into the 2030's and maybe beyond. This is a function both of the scale of the vehicle park at over 1.4bn globally, according to industry data and vehicle lives which average 15 to 20 years. Presently, we estimate the EV park, including commercial vehicles, is about 9m for a share of 0.6%.

The park of EV's will rise substantially over the next few years but the share will remain modest:

The EV park is likely to rise substantially over the next ten years or so, albeit from a low base. IEA's scenario calls for a park of about 100m in 2025 and 250m in 2030. These are sizeable absolute numbers but in share terms are comparatively modest at 6% and 13% respectively based on our expectations of a total park of around 1.7bn in 2025 and 2bn in 2030. The implication of the above is that despite the falling share, the absolute ICE park would actually continue to trend modestly higher between 2019 and 2030. We would, however, expect much of the ICE park, particularly post 2025 to use hybrid technology. The combination of a rising EV share and significant efficiency gains in the ICE fleet probably points to fuel usage peaking in the second half of the 2020s.

Gasoline and diesel usage could trend down significantly post 2030: We believe the EV share will trend sharply higher post 2030 as a combination of ICE bans in some countries and tightening emission standards take hold and ICE production capacity continues to grow. Gasoline and diesel usage could therefore trend down significantly post 2030.

WHAT ABOUT AVIATION?

High growth sector of the petroleum fuel mix: Aviation constitutes a high growth segment of the petroleum fuel mix as oil companies and others have noted. ExxonMobil is looking for aviation fuel demand to grow by 2.2% pa between 2017 and 2040 driven by expectations of rising economic activity and per capita incomes, the widespread desire for greater mobility and the availability of low-cost air travel. It should be noted that the ExxonMobil forecast takes into account advances in aircraft fuel efficiency. We believe the ExxonMobil view is highly plausible subject to the caveat that no draconian government restrictions or punitive taxes are placed on air travel.

Large turbofan jets well insulated from competing technologies: We believe that existing aero engine technology, based on large turbofan jets using aviation fuel (a middle distillate similar to diesel) for medium and large airliners, is well insulated from competing technologies. There would, in fact, appear to be no alternative technology, particularly for long-haul applications, that can displace turbofan jet propulsion systems for the foreseeable future. We would define this as being mid-century at the very least.

High energy density is critical for aviation applications: The task of an aircraft propulsion system is technically challenging. The underlying requirement is to provide sufficient thrust to enable a 100 tonne plus aircraft to take-off over a relatively short distance and then to cruise reliably at high-speed over several thousand kilometres before landing safely. This requirement necessitates use of a high-density energy source which can be stored efficiently on-board an aircraft and without carrying excessive weight. There is also a need to provide quick refuelling and to be able to transport fuel rapidly and cost effectively. At this juncture the only propulsion system suitable for technically demanding aviation applications is the turbofan jet using aviation fuel. Conceptually, a renewable fuel such as bio-diesel could be used but this would lower energy density thereby reducing the range and/or the payload.

Turbofan drawbacks in terms of emissions and thermal efficiency: As in the case of other types of thermal-propulsion systems such as ICE's, turbofan jets have drawbacks in terms of thermal efficiency (major heat losses to the exhaust) and particularly emissions both in the form of CO₂ and NO_x and particulates. Reflecting this, the aviation industry has been exploring the potential for electric propulsion. There is, however, a fundamental drawback and that is the low energy density of lithium-ion batteries per unit of weight and volume relative to aviation fuel.

Electric propulsion systems infeasible for aviation applications: With current technology electric-propulsion would be infeasible for a long-range aircraft on weight and space utilisation grounds. Energy storage via lithium-ion batteries would, in fact, probably be insufficient to achieve lift-off on take-off. Even if it proved possible payload and performance would be vastly inferior to thermal turbofan propulsion while heavy batteries could pose a problem on landing. According to Airbus, 1 kg of liquid aviation fuel is equal to 25 kg of lithium-ion batteries. Note, issues of battery weight and volume are far more critical for an aircraft than a vehicle due to the more direct adverse consequences for payload, performance and range.

Hybrid propulsion systems may prove feasible in due course: Hydrogen fuel cells would appear to be an unlikely aviation propulsion technology on account of difficulties with storage. This reflects weight and volume penalties vis-à-vis aviation fuel and storage at high pressure. A technology that may have application down the trail is hybridisation involving the use of a turbofan jet in combination with an electric motor-generator much as in the automotive industry. Given the greater complexity of the propulsion system, this may impose a weight penalty compared with conventional turbofan jet technology. Turbofans probably have further development potential which will help boost fuel efficiency but this is not a limitless process. Over the next 20 to 30 years we are probably

looking at incremental improvements rather than quantum change in turbofan jet fuel efficiency. The key issue facing the aviation industry is the possibility that draconian measures will be introduced to drastically restrict aircraft use either by rationing or punitive taxation.

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