ALTERNATIVE ENERGY

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**HYDROGEN & FUEL CELLS**

# HYDROGEN AND FUEL CELL REVIEW

## *The emerging hydrogen economy*

**Hydrogen, a clean burning gas, is emerging as a potential solution to decarbonise difficult to abate transportation and industrial sectors of the economy via conventional electrification strategies. Across a wide swathe of the process industries coal, natural gas and oil are used as heat sources, feedstocks, reductants and fuels. In the transportation field the shortcomings of battery-based electrification strategies in applications such as long-distance trucking, the 'heavy' end of the light vehicle sector, remote location operation and aviation are becoming increasingly apparent. Hydrogen potentially offers a viable alternative to carbon based reductants and feedstocks in the industrial process field. Fuel cell technology has application in automotive and in off-grid power generation. The emerging viability of hydrogen reflects the declining cost of electrolysing water using renewable power and the adoption of high-volume techniques in the manufacture of fuel cells and equipment for the production and distribution of renewable hydrogen**

- **Hydrogen production:** Globally, the production of hydrogen is currently around 70m tonnes a year of which approximately 95% is produced from coal and natural gas. The balancing 5% mainly results from the electrolysis of sodium chloride to produce chlorine and caustic soda. Small volumes of hydrogen are produced via the electrolysis of water, an energy intensive process. Based on IEA (International Energy Agency) data, hydrogen costs between $1-3/kgH using natural gas as a feedstock and $3.5-7.5/kgH via electrolysis using renewable power.

- **Hydrogen demand:** Global hydrogen demand is presently dominated by two applications, petroleum refining and ammonia production. These two, account for 52% and 41% of demand respectively, according to the IEA. Most of the balance is used in methanol production and steelmaking. Potentially hydrogen demand could grow strongly through the 2020s and beyond driven by new applications as a heat source, reductant and feedstock in the process industries and for fuel cell power generation for transportation applications and remote off-grid facilities.

- **Hydrogen economy**: The Brussels-based Hydrogen Council, estimates that hydrogen can account for 8% of world energy demand by 2030 assuming production costs of $2.50/kgH. The share could be 15% at $1.8/kgH, according to the Council. The former would be equivalent to $4.5/kgH at the pump based on prospective distribution costs of $2/kg, a sharp reduction from current levels of about $8/kg reflecting scaled-up operations and higher utilisation.

- **Long distance trucks**: One of the most interesting applications of hydrogen fuel cell technology is long distance trucking, a major user of diesel. For this application, fuel cell electric vehicle trucks have major advantages over lithium-ion battery technology in terms of range, payload, refuelling times and all-weather operation. McKinsey sees the total cost of ownership for an FCEV heavy truck reaching approximate parity with diesel by 2028.

- **Aviation**: Aviation is particularly difficult to decarbonise reflecting the vastly superior energy intensity of aviation fuel vis-à-vis the alternatives. Fuel cell power generation or injecting hydrogen into turbo-jet engines would require far too much fuel tank space for a viable long-range aircraft. Airbus has indicated that it is investigating launching a short-range hydrogen fuelled aircraft by 2035. Long range aircraft may have to continue with turbojets for the foreseeable future, although possibly using low carbon synfuels.

- **Fuel cell plays:** Fuel cell plays such as Ceres and AFC Energy have performed powerfully over the past year reflecting enthusiasm for the secular new technology energy story. Valuations are challenging. Johnson Matthey offers a modestly valued alternative play on the hydrogen economy given its considerable technological strengths in catalysis, fuel cells and advanced materials and well-established automotive links.

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**EQUITY RESEARCH**

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## HYDROGEN OVERVIEW

### PROPERTIES

**Light and abundant but low energy density/litre**: Hydrogen (symbol H) is a colourless and highly flammable element. It is the lightest of all elements in the periodic table and the most abundant element in the universe. Compared with conventional fuels such as diesel, hydrogen has a much higher energy density per unit of mass (kilogram) but a substantially lower energy density per unit of volume (litre). The energy density of hydrogen/kilogram is about 3.1X that of diesel. By contrast, diesel's energy density/litre is about 3.8X that of hydrogen. The adverse variance for hydrogen per litre implies a significant disadvantage where space is limited as for some transport applications, notably aviation.

**Ultra-low melting and boiling points:** Hydrogen rarely exists in elemental form, given that it readily bonds with other elements. Rather, it occurs as a simple diatomic (two atomic) molecule with the symbol $H_2$ in water and most organic compounds, including petroleum and methane gas. Each atom comprises a positively charged proton and a negatively charged electron. Reflecting weak intermolecular forces, hydrogen has extremely low melting and boiling points of -259°C and -252.8°C, respectively. Molecular hydrogen can be stored in liquid form at very high pressure in tightly sealed cryogenic tanks.

**Reactive at elevated temperatures in presence of catalysts**: At room temperature molecular hydrogen is largely non-reactive. This, however, changes at elevated temperatures and in the presence of catalysts as the bonds between the atoms in the molecule are broken. Hydrogen combines with most elements to form hydrides and acts as a reduction agent in the case of metal oxides to leave the metal in its elemental state. The reductant role has particular relevance for high-volume metallurgical sectors notably steel and aluminium which use oxide feedstock for the smelting process.

**Reaction between hydrogen and oxygen to form water**: Typically, hydrogen does not react with oxygen at room temperature. An explosive reaction can, however, take place in the presence of a flame or catalyst associated with a breaking of the bond between atoms in the hydrogen molecule. As a result of the chemical reaction between hydrogen and oxygen, water is formed. Significantly, the combination of hydrogen and oxygen does not give off carbon or toxic emissions, unlike hydrocarbons, when ignited.

### TRADITIONAL APPLICATIONS

**Key applications are petroleum hydrocracking and ammonia:** Molecular hydrogen is light, storable, relatively easy to transport in gaseous form, energy dense, reactive in certain conditions and gives off no pollutants or greenhouse gases during chemical reactions. Despite this range of properties, two applications dominate the production mix. These are the hydrocracking of heavy sulphurous oil in petroleum refining and the production of ammonia, principally for fertiliser production. Hydrocracking enables high molecular weight hydrocarbons in crude to be converted to a full slate of valuable light products including gasoline, diesel and jet fuel. In the case of more advanced two-stage crackers sulphur and nitrogen impurities are first driven off or hydronated as hydrogen sulphide ($H_2S$) and ammonia ($NH_3$).

Based on IEA (International Energy Agency) data globally for 2018, hydrocracking and ammonia account for 51% and 42% respectively of the production mix respectively. A large part of the balancing 7% comprises hydrogen used in steelmaking and methanol production. Relatively small quantities of hydrogen are also used to produce hydrochloric acid, as a reduction agent for processing oxide ores, as an energy source for fuel cells and as a coolant for power station generators.

### PRODUCTION

**Production is currently around 70m tonnes pa**----Based on IEA data, hydrogen demand globally in 2018 was 73.9mm tonnes. Given short lead times, we can say this was also equivalent to production. We believe production in 2019 was similar to 2018 while in 2020 it could fall 3 or 4 % to about 72mm tonnes driven by declining petroleum demand and refining industry activity.

**-------but could rise to 100m tonnes by 2030**: Between 1975 and 2019 hydrogen demand/production globally grew by about 3.4% pa. This was driven by the upward trend in petroleum consumption, the growing use of heavy sulphurous crude feedstock in refineries and rising fertiliser usage. In broad terms, industry studies point to hydrogen demand/production increasing to about 100mm tonnes in 2030 and 500mm tonnes in 2050. Implied growth rates would be 3.5% pa between 2020 and 2030 and 6.7% pa between 2020 and 2050. Growth is expected to be driven by the substitution of carbon intensive fuels, feedstocks, heat sources and reductants in transportation and power generation and in the process industries. Key examples of the process industries where substitution will potentially take place include aluminium, steelmaking, foundries, cement, fertilisers, refining, glass and ceramics. In terms of the process industries, coal and hydrocarbon-based products are used both as a source of heat and where oxide ores are being processed as a reductant.

## TECHNOLOGY

**Hydrogen is currently mainly produced from natural gas-----**Hydrogen can be obtained from fossil fuels, biomass and water; all contain the requisite hydrogen molecules. Currently, according to the IEA, around 75% of the world's hydrogen supply is extracted from natural gas using the steam reforming process. This involves treating natural gas with steam at high pressure over a nickel catalyst at 650ºC-950ºC. In addition to molecular hydrogen, the process generates carbon monoxide and carbon dioxide. According to the IEA, hydrogen production accounts for about 6% of world natural gas usage and is therefore a significant contributor to carbon dioxide emissions.

-------**and coal**: A further 20% or so of hydrogen is produced using coal or oil as a feedstock in a two-stage gasification process. Firstly, coal is reacted with steam and oxygen under high pressure and to form syngas which largely comprises carbon monoxide and hydrogen. The carbon monoxide then reacts with the steam to produce carbon dioxide and hydrogen with the latter separated from the gas stream. Carbon dioxide can either be captured and stored or vented off into the atmosphere. The coal gasification process is mainly used to produce hydrogen in China.

**Small quantities are produced via the electrolysis of water**: Most of the balancing 5% or so of hydrogen is derived from the electrolysis of sodium chloride solutions in producing chlorine and caustic soda. In principle, hydrogen can also be obtained from the electrolysis of water. The process involves splitting the water molecule into hydrogen and oxygen gas. Without the addition of an electrolyte water electrolysis is energy intensive (1kg of hydrogen requires about 55kWh of electricity and another 15 kWh for compression) and therefore significantly more expensive than producing hydrogen via steam reforming. Electrolysing water does, however, have the virtue of not generating by-product carbon dioxide which commends it to green politicos and others as environmentally sound.

## HYDROGEN TYPES

There are three types of hydrogen in production. These are denoted grey, blue and green.

**Grey hydrogen:** Grey hydrogen is currently easily the most common form of the molecular gas and is mainly produced using natural gas steam reforming. Coal based hydrogen and the electrolysis of sodium chloride solutions using power obtained from fossil fuels would also fall into the grey category. Grey hydrogen is distinguished by the use of fossil fuel intensive processing and an absence of mitigating carbon capture and storage measures.

**Blue hydrogen**: Blue hydrogen is produced using the same carbon-intensive processes as for the grey product. Processing of blue hydrogen, however, also includes a final carbon capture and storage stage. According to the IEA and industry sources, 80-90% of carbon emissions can be captured although there is a significant cost penalty. Blue hydrogen is effectively a low-carbon source of the gas.

**Green hydrogen:** Green hydrogen is produced through the electrolysis of water using renewable power such as wind, solar and hydro. Historically, this was prohibitively expensive but has become more feasible as the price of renewable power has dropped in recent years. Interest in green hydrogen projects using renewable power by oil and gas concerns, utilities and renewable energy groups has increased sharply of late partly in anticipation of further declines in power costs and partly in support of decarbonization objectives. According to the Oslo-based energy consultancy Rystad Energy, there are currently over 60 GW of utility-scale (>1 MW) green hydrogen projects planned globally. Interestingly, the pipeline of projects is dominated by Europe and Australia.

## HYDROGEN PRODUCTION COSTS

### Grey and blue

**Cost structure is weighted to natural gas and coal feedstock**: For conventionally produced grey hydrogen, the largest element of cost is typically natural gas or coal where they are used as feedstocks. According to the IEA, natural gas accounts for 45% to 75% of production cost depending on sourcing. Facility capital costs are the next largest cost contributor followed by general operating expense, principally in the form of labour. Based on IEA data, we believe CAPEX accounts for roughly 15% to 30% of cost leaving about 10% to 20% for OPEX.

**The low end of cost curve is around $1/kgH**: Given the above weightings, grey hydrogen competitiveness is very much a function of natural gas feedstock costs. This is borne out by the IEA's 2018 study which showed the US, Russia and the Middle East, all of which have among the world's lowest gas prices, at the low end of the international cost curve. For these three regions grey hydrogen production costs were put at about $1/kgH. By contrast, costs for Europe and China were around $1.75/kgH. It should be noted that these costs are unabated and exclude carbon capture and storage. Including this factor, costs would increase by about $0.5/kgH in all regions. Blue hydrogen costs would therefore be about $1.5/kgH in the US, Russia and the Middle East and $2.25/kgH in Europe and China.

## ELECTROLYSIS AND RENEWABLES

**Green hydrogen competitiveness is determined by renewable power costs**: The key determinant of the competitiveness of green hydrogen electrolysis is power costs. The Brussels-based Hydrogen Council, a coalition of industrial and other interested parties promoting the use of hydrogen, presently puts the average cost globally of green hydrogen at $6/kgH. This is considerably above the cost not only of grey but also blue hydrogen. Significantly, however, over the past ten or so years costs have fallen sharply. Furthermore, they are expected by the Hydrogen Council and others to remain on a pronounced downward trend through 2030 and beyond.

**Green hydrogen costs have fallen sharply driven by renewable power costs**: According to the Hydrogen Council, the production cost of green hydrogen in 2010 was $10-15/kgH. The subsequent decline of 50-60% to $6/kgH has been driven by the falling cost of renewable power as large scale wind and solar facilities have come on-stream and manufacturing economies of scale have been unlocked. Broadly speaking, renewable wind and solar power costs have dropped about 80% since 2010. With costs now below $0.05/kWh in some cases, renewable power from solar and wind has emerged as being fully competitive with fossil fuel generated power over the past few years. In particularly advantaged locations such as North Africa power can, in fact, be generated for as little as $0.02/kWh, according to the Hydrogen Council.

**Further declines are expected**: The Hydrogen Council in a January 2020 report (McKinsey original source) suggested that green hydrogen costs could fall by a further 60% to

$2.5/kgH between 2020 and 2030 based on a hypothetical German project with power generated from a dedicated offshore wind facility. The variance is explained as follows:

- **CAPEX:** Savings of $1.6/kgH by scaling up, efficiency gains, learning curve and technological advances and manufacturing economies of scale as high-volume methods are applied. Part of the scaling up involves increasing the size of the electrolyser from ~2MW-90MW.
- **Efficiency:** Plant efficiency improvement from 65-70% contributing $0.4/kgH.
- **Energy costs:** Savings of $1.3/kgH reflecting a decline in power costs from $0.07/kWh to $0.04/kWh and a fall in grid fees from $0.015 to $0.010 kWh.
- **O&M costs:** Miscellaneous operational savings, including spare parts cost $0.2/kgH

Note, the above cost estimates are based on a 50% load factor and exclude gas compression and storage.

**Green probably still above blue hydrogen costs in 2030 in low natural gas price locations**: The Hydrogen Council's 2030 cost estimate for green hydrogen remains above that currently prevailing for blue hydrogen in the lowest cost locations such as the US but is nevertheless close to imputed European blue levels assuming carbon capture and storage. It is also quite possible that carbon taxes to allow for the externalities (emissions) of burning fossil fuels will be widely implemented by 2030, thereby boosting the cost of blue and especially grey hydrogen. In our view, carbon taxes of $50/tonne or even $100/tonne would not be surprising by 2030. The advent of renewables and the hydrogen economy are unlikely to be a recipe for low- cost energy.

## THE HYDROGEN ECONOMY

### HISTORICAL CONTEXT

**Fossil fuels still account for 84% of primary energy needs**: Since the first industrial revolution in the late 18th century, the world has functioned as what might be termed a fossil fuel-based economy. Energy and industrial processing needs have largely been met firstly with coal and then from the third decade of the 20th century with a mixture of coal and hydrocarbons in the form of petroleum and natural gas. Since world war two fossil fuels have been supplemented to a modest extent by nuclear and renewables. Despite the ballyhoo surrounding renewables, hydrocarbons and coal still accounted for 84% of primary energy sources in 2019 based on BP Statistical Review data. Collectively hydrocarbons had a weighting of 57% with petroleum and natural gas contributing 33% and 24% respectively while coal's contribution was 27%. The balancing 16% was split nuclear 4%, hydro 7% and non-hydro renewables 5%. The fossil fuel age is, however, likely to wane during the 2020s and beyond to be replaced by the renewable power and the hydrogen economy.

**Prof John Bockris first coined the term hydrogen economy in 1970**: The term hydrogen economy was first coined in 1970. It was made in a speech at the General Motors Technical Centre in Warren, Michigan by the sometimes-controversial John Bockris, then a Professor of Chemistry at the University of Pennsylvania. At various times Professor Bockris claimed that he had discovered a way of freeing hydrogen from water using sunlight and later claimed to have devised a method of separating hydrogen and oxygen in water with a secret catalyst. The claims proved far-fetched but Professor Bockris did extoll the virtues of hydrogen as a clean fuel across a wide range of applications. In 1970 Lawrence W Jones, a Professor of Physics at the University of Michigan, also presented a technical paper promoting the concept of the hydrogen economy.

### WHAT IS THE HYDROGEN ECONOMY?

**The hydrogen economy involves expanding applications more widely**: The concept of the hydrogen economy involves expanding applications from the relatively narrow base currently in petroleum refining and the production of ammonia and methanol. The aim is to use hydrogen as a fuel, heat source and process industry feedstock and reductant, particularly where existing hydrocarbon-based technologies are difficult to replace on either technical or economic grounds. In so doing, hydrogen will potentially play a major part in establishing a low-carbon economy.

**Hydrogen can potentially unlock 8% of world energy demand by 2030**: The Hydrogen Council in its January 2020 report estimated that hydrogen can unlock 8% of world energy demand by 2030 assuming a production cost of $2.50/kgH. At $1.80/kgH a 15% share of global energy demand would be possible, according to the Hydrogen Council. Based on its model, production costs of $2.50/kgH would translate into about $4.5kg/H at the pump. The $2/kg spread compares with about $8/kgH currently and assumes a sharp decline in distribution costs mainly reflecting a scaling-up of operations, much higher utilisation of facilities and the industrialising of equipment manufacture. Compared with a gallon of diesel, $4.5/kgH would be 108% higher on an energy equivalent basis than the current average US retail price for diesel of $2.56/gallon, including taxes (1kgH is the energy equivalent of 0.845 of a gallon of diesel). The variance would be significantly less in regions, notably Europe, where diesel is highly taxed.

**Focus is on several areas of transportation and the process industries**: The key areas being considered by policy makers and industry groups as potential applications for renewables-based hydrogen as a fuel, heat source and feedstock are as follows:

- Long distance heavy-duty trucks and buses
- Pickup trucks, SUVs and large sedans
- Regional trains

- Heat and power for buildings
- A heat and feedstock source for the process industries. Key examples are steelmaking, cement, non-ferrous metal smelting, chemicals, foundries and forges, glass, ceramics, bricks and petroleum refining.

**The fuel cell is the relevant technology to replace diesel in transportation**: In the case of the automotive and train fields the relevant technology to replace diesel is the hydrogen fuel cell. The competing low or zero-carbon technology is lithium-ion batteries or in the case of railways, conventional overhead catenary electrification. Fuel cells have advantages over battery technology in terms of range, recharging/refuelling times and all-weather operation. Compared with catenary electrification, fuel cells offer significantly lower capital costs. Hydrogen fuel cells and batteries would both use the power generated on-board on trains to drive electric motors to achieve propulsion.

**Hydrogen can be used for space heating----**Hydrogen gas can be used directly in existing natural gas boilers for space heating. Existing natural gas pipeline infrastructure could also be used but there may be an issue with hydrogen metal embrittlement and ultimately fatigue. Heat pumps are the alternative low carbon technology. Hydrogen-based heating may be more suitable for older buildings given the avoidance of the heavy refurbishment costs associated with installing heat pumps.

**------and power generation**: Power generation is a potential application for hydrogen, although probably more in back-up than base load facilities. In principle, hydrogen can be used to fuel gas turbines while fuel cells can be used to replace diesel and natural gas-powered generating sets. The competing low or zero-carbon technology is on-site renewables power generation in conjunction with large-scale vanadium flow or possibly lithium-ion batteries. Where climate conditions are optimal for either solar or wind, renewables are likely to be the lowest cost solution for power generation, although there may also be a role for hydrogen fuel cells in back-up power applications.

**New industrial applications as a heat source, feedstock and reductant**: A major new market is emerging for hydrogen in the industrial feedstock and heat source fields. This reflects the absence of other viable alternatives to carbon-based thermal smelting, reduction agents and hydrocarbon feedstocks. The potential markets are to a considerable extent in metallurgical and chemical processing but also exist across a swathe of applications in metal forming (foundries, forges, rolling mills and re-heat furnaces), engineering and building materials. Note, metallurgical processing furnaces often operate at temperatures in excess of 1,500° C.

**Changeover from carbon-based technologies to hydrogen is likely to a lengthy process**: For many of the process industry applications we would not expect a quick changeover to hydrogen from carbon-based technologies, given that they have been tried and tested over many years, are very effective and in the absence of carbon taxes, cost-effective. There is also the issue of heavy upfront capital costs. Replacing coking coal by hydrogen as a reductant in blast furnace-based steelmaking could also pose a risk in producing high performance steels for demanding applications. Low-carbon ductile steel strip is a case in point.

**STEELMAKING**

**Blast-furnace/oxygen steelmaking is a carbon intensive process**: Steel is produced by one of two methods. Responsible for the largest tonnage is the basic oxygen route which according to the IISI (International Iron and Steel Institute) accounts for 72% of the world total. The technology uses iron-ore as a blast-furnace feedstock to produce the intermediate product pig iron. Metallurgical coke, sometimes supplemented by fuel oil and pulverised coal, is used both as a furnace fuel and iron-ore reductant (via the carbon monoxide generated in the furnace) to release metal from the oxide ore. Pig-iron is further refined in a basic oxygen furnace by blowing in oxygen to drive-off impurities particularly in the form of carbon, phosphorous, nitrogen and sulphur. Unavoidably, blast-furnace/basic oxygen steelmaking directly generates sizeable amounts of carbon dioxide during the process. Carbon dioxide is also generated in the earlier stages of steel making via iron-ore fines sintering/pellet production and coke manufacture.

**Electric-arc steel making is less carbon-intensive but much depends on how electricity is generated**. The alternative technology accounting for 28% of steel production is based on electric-arc furnace smelting. Scrap constitutes the bulk of the feedstock but in some locations where supplies are in short supply, direct reduced iron or pig iron can be used as a substitute. Electric-arc furnace steelmaking thanks in large part to the use of metallic feedstock generates much less carbon dioxide than basic oxygen steelmaking. The process, however, is power-intensive with around 500 kW/hour required to produce a tonne of steel. Carbon intensity, therefore, very much depends on how the electricity is generated. Overall, the steel industry generates about 8% of world carbon dioxide emissions which points to it being one of the larger industrial emitters.

**SSAB has a programme to replace blast furnace steelmaking----**The Swedish steel group SSAB probably has the most advanced programme to replace blast-furnace/oxygen furnace-based steelmaking using coke as the reductant and furnace fuel. The route being researched is applying technology analogous to producing DRI (direct reduced iron). DRI is produced by converting iron-ore pellets or lump (ferrous oxide) to a hot-briquetted product using a reductant either in the form of natural gas or syngas. The briquets are subsequently converted to steel in an electric-arc furnace.

**-----using a technology analogous to DRI with hydrogen as a reductant**: SSAB, with its HYBRIT technology, is aiming to produce DRI using hydrogen rather than natural gas or syngas as the reduction agent. The company has a HYBRIT pilot plant at Luleå in Sweden and is planning to have a larger facility in operation by 2026 to coincide with the closure of its Oxelösund blast furnace. By 2040 SSAB is scheduled to phase out its blast-furnaces at Luleå and Raahe in Finland. Converting a conventional blast-furnace based steelmaking site to a DRI/electric arc furnace facility with an integrated hydrogen electrolysis plant would clearly be a costly undertaking. There would, however, be some significant operating cost savings not least of which would be the elimination of coking coal purchases and the costs of operating a coke plant.

**Large-scale adoption new technology unlikely before 2030 and probably 2035**: In our view, the large-scale adoption of DRI technology in conjunction with hydrogen as a reduction agent is unlikely to happen on a large scale before 2030 and probably 2035 or beyond. The constraints are the effectiveness of current technology particularly for high-volume steel production and the heavy upfront costs and long lead times of conversion. There is also uncertainty as to the effectiveness of the DRI technology for high performance steel applications.

## DIFFICULT TO DE-CARBONISE SECTORS

Broadly speaking, the easiest sectors to decarbonise are power generation, heat for buildings and process industry feedstock and reductants. This view is subject to the caveats that the economics are in line with long term predictions made by the Hydrogen Council and others and that the new technologies are as effective technically as claimed by the promoters of renewable energy.

### Aviation

**Aviation is particularly difficult to decarboni**se: The most challenging sector to decarbonise is transportation. Within this context the sub-sector of aviation presents particular challenges which will be very difficult to overcome. The underlying issue is that in many ways, petroleum-based fuels in general and diesel and aviation fuel in particular are ideal technically for transportation applications. They have high energy densities per unit of volume, low weights and are easy to transport and store. Refuelling is also easy and quick. In the case of aviation, there is no other form of propulsion than the modern turbo-jet using aviation fuel capable of carrying 300 or so passengers over a distance approaching 10,000 miles at an average speed over 500mph. Furthermore, there is not likely to be for the foreseeable future.

**Airbus exploring hydrogen fuel cell technology for short-range aircraft**: Airbus is reported to be investigating the use of hydrogen fuel cell technology as part of an aircraft propulsion system. Given the low energy density of hydrogen per unit of volume, it would seem, however, there is little chance that fuel cell technology will be suitable for anything other than short range aircraft at best. The underlying problem is severely limited fuel tank capacity and therefore range related to the energy density issue. As the Hydrogen Council has also suggested, we believe that an alternative to conventional jet fuel will probably have to await the development of an aviation synfuel which can be used in existing engines. The synfuel would be a cocktail of hydrogen, bio-kerosene and conventional kerosene and therefore a low-carbon product.

**Remote locations**

**Remote off-grid locations are the province of diesel gen sets and difficult to decarbonise**: We see remote locations as presenting a challenge to decarbonisation measures including the application of hydrogen technology. We are thinking here of mine sites, farms and small settlements remote from major highways and grid power. In these circumstances diesel and propane are the fuels of choice for a wide range of equipment, including generating sets for power. This reflects in large part the ability to transport diesel reliably and safely including along unpaved roads. By comparison, shipment of hydrogen either in gaseous or liquid form is far more hazardous, difficult and therefore expensive. Furthermore, there is the question of dispensing hydrogen in remote locations. As a liquid, diesel can be dispensed easily anywhere.

While fuel cell technology can have application in remote areas wind or solar power facilities would also need establishing to create a carbon free gen-set operation. Creating a fully integrated site with renewable power generation, hydrogen production and fuel cell power generation might be feasible for a long-life project such as a mine. This would probably not be the case, however, for a short-life project or an intermittently used facility.

**Marine**

**Long distance shipping poses a problem due to low energy density/unit of volume for batteries and hydrogen**: Marine is another difficult sector to decarbonise particular for long distance shipping such as container lines and tankers. The underlying problem again is the low fuel density per unit of volume of hydrogen and particularly lithium-ion batteries. Fuel tank capacity would therefore be too small for long distance operation or alternatively it would take up too much cargo space. There may, however, be 'openings for fuel cell technology in short distance, quick turnaround applications such as ferries. Compared with battery power, fuel cell technology in ferry applications has a major advantage in terms of speed of refuelling times. Fuel cells also operate independently of grid connections, an advantage for some of the more remote ferry routes.

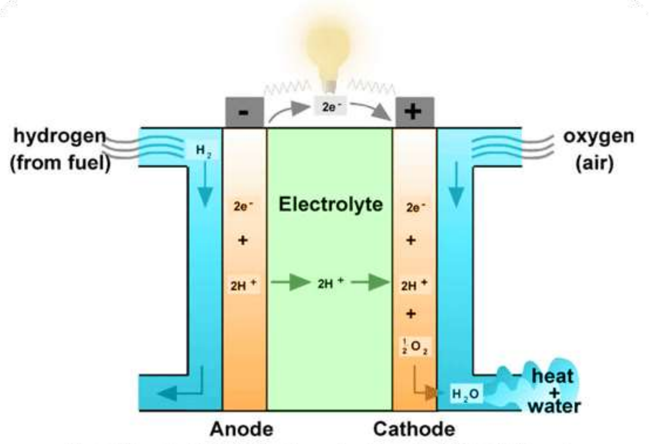
**Synfuel in conjunction with existing diesel engines could provide a partial answer**: The decarbonisation of long-distance shipping will probably ultimately require the use of synfuel in existing diesel engines as described above for aviation. This is not the perfect solution in terms of carbon abatement but is as close as can be expected given our current state of knowledge. Compared with diesel, synfuel would also imply some loss of energy intensity which entails more frequent refuelling stops than currently.

## FUEL CELL TECHNOLOGY

### PEM CELL OPERATION

**A fuel cell generates electricity through electrochemical reaction:** The critical technologies behind the hydrogen economy are the electrolysis of water and the fuel cell. A hydrogen fuel cell generates electricity through an electrochemical reaction involving hydrogen and oxygen rather than thermal combustion. In simplistic form a cell comprises graphite anodes and cathodes and an electrolyte membrane located between the two. Fuel cells are defined by membrane type. The most common, accounting for about 90% of production, is the PEM (proton-exchange membrane) fuel cell which uses a polymer electrolyte membrane. Compared with other types, the PEM operates at relatively low temperatures of about 80 C and is light and robust. Each side of the membrane contains a platinum coating which functions as a catalyst. The other principal commercial fuel cell types currently are solid oxide and phosphoric acid. UK-based AFC Energy is in the early phase of introducing alkaline fuel cells.

**Exhibit 1: PEM fuel cell operation**




Source: World Fuel Cell Council

**Hydrogen is separated at the anode under catalysis to create electricity, by-products are heat and water vapour**: Hydrogen typically provides the fuel for a PEM cell and enters at the anode. Here, in the presence of a platinum catalyst, the hydrogen is separated into positive hydrogen protons and negatively charged electrons. The membrane only allows the positively charged protons to flow through to the cathode thereby forcing the negatively charged electrons to flow along an external circuit to create DC current. At the cathode, the negatively and positively charged ions combine with atmospheric oxygen to form water vapour in the presence of a platinum catalyst. Assuming the fuel is hydrogen, the only other by-product of the fuel cell is heat. Fuel cells continue to function as long as there is a supply of hydrogen. They are, therefore, unlike lithium ion-batteries which provide a store of energy in the form of electrical power. The fuel cell is more analogous to a mini-power station.

**400 cells stacked sufficient to generate 120 kW of power**: Fuel cells are typically only a few millimetres thick and generate modest amounts of power. To increase power availability cells are stacked together to form a module. According to Bosch, the German automotive components and electrical engineering major, roughly 400 cells deliver 120 kW of power or 163 bhp. This is broadly equivalent to a naturally aspirated (non-turbo-charged) 2 litre or a 1.5 litre turbo-charged gasoline internal combustion engine (ICE). As far as energy efficiency is concerned, a PEM hydrogen fuel cell rates about 40-50% against nearer 80% for a BEV and approximately 30% for a diesel engine. The variance against the BEV reflects the two-stage process with an FCEV involving firstly hydrogen production and then the electrochemical reaction in the fuel cell.

**PEM is the fuel cell technology of choice for auto applications**: From the fuel cell, current having first been converted from DC to AC using an inverter, is transmitted to an electric motor or motors which then provide mechanical drive. Fuel cells can be used as a source of power across a wide spectrum of machinery both static as in electricity generation and mobile as in highway transportation, railroad motive power and marine. In the case of automotive applications, PEM is the fuel cell technology of choice, reflecting low operating temperatures, the quick start capability, the use of atmospheric oxygen and relatively low weight.

## HEAVY TRUCK APPLICATIONS

**Long distance heavy trucks a suitable hydrogen fuel cell application**: Hydrogen fuel cells are at an early phase in their commercial development. The situation now is arguably analogous to the emergence of diesel power in the 1930s. In our view, one of the most interesting and suitable applications for hydrogen fuel cells is long distance heavy trucks as characterised by US Class 8 (GVW of >15 tons). The competition to FCEVs in this application is the high-powered diesel truck with engines of over 12 litres and power outputs >400 bhp and battery electric trucks with over 350 kW or about 450 bhp. The mighty Tesla Semi, in fact, has nearer 1,000 bhp.

**Diesel trucks remain competitive but likely to lose viability in coming years both on economic and regulatory grounds**: Interestingly, on some parameters, the heavy-duty diesel truck still compares favourably with prospective battery electric and fuel cell trucks. The initial capital cost at about $120,000 is likely to be much lower against what we believe will be over $200,000 for BEV and FCEV trucks. Compared with BEVs, at least, diesel trucks for a given GVW have higher payloads, greater driving range and refuelling/recharching times that are in a different ballpark. In addition, the diesel truck is tried and tested technology and is both durable and reliable with engine life to major overhaul of >500,000 miles the norm and >1m miles not uncommon.

At this stage we have few statistical insights into BEV and FCEV reliability and durability but anecdotal evidence such that it is good and that some of the earlier problems in terms of fragility may have been overcome. The problem for diesel is pending tightening emission regulations and outright bans in some places. Diesel powered trucks could also come under pressure from BEVs and FCEVs in the coming years on fuel consumption and total cost of ownership grounds.

Conceptually, FECV trucks have five key advantages over BEVs as follows:

- An operating range before refuelling which could be over 1,000 km against 600-800 km for a BEV. This reflects the higher energy density of hydrogen than lithium-ion batteries.
- A refuelling time of 10-15 minutes against several hours for a BEV truck. The refuelling experience with a FECV is, in fact, very similar to a diesel truck.
- An ability to function in practically all temperature conditions. The functioning of BEVs by comparison can be adversely impacted by extreme temperatures.
- Higher payload potential reflecting the superior power:weight ratios of FCEVs. Nikola Motors the Phoenix, Arizona embryonic truck maker puts the FCEV payload advantage at about 6% (57,000 lbs vs 54,000 lbs).
- No sudden demands on local power distribution systems during refuelling. Given their heavy power requirements during recharging, this could be a serious issue with BEV trucks.

**Major FCEV performance advantages**: It might also be added that FCEV trucks share all the advantages of BEVs vis-a-vis diesel powered trucks in terms of near instant torque availability, acceleration, hill climbing ability and superior fuel consumption.

**HOW WILL FCEV TRUCKS BE REFUELLED?**

**For the moment BEV and FCEV recharging/refuelling facilities inferior to diesel:** Refuelling/recharging is an issue for BEV and FCEV trucks. The existing arrangements for both are vastly inferior to diesel trucks reflecting the lack of suitable infrastructure. Urban based trucks, whether BEVs or FCEVs, can be relatively easily refuelled/recharged from a central base, although for the former, there may be an adverse impact on the local power distribution system. Conceptually, FCEV truck depots could be supplied by truck with bottled hydrogen or a dedicated onsite hydrogen facility. For long distance FCEVs, however and particularly those operating in remote regions this might not be feasible logistically or could be prohibitively expensive.

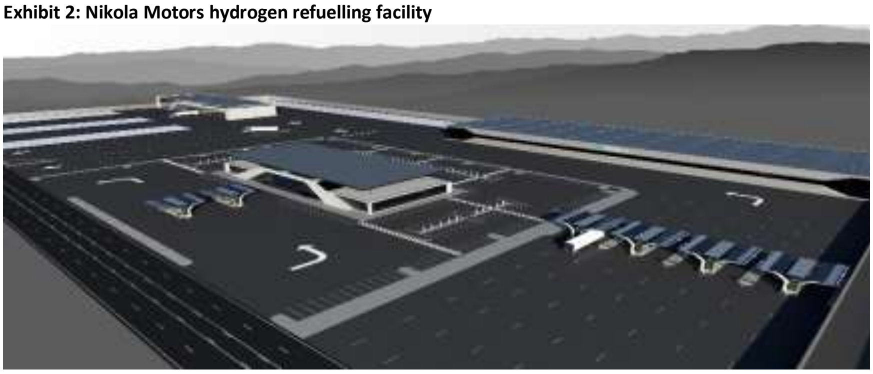
**Network of hydrogen refuelling stations planned for major truck routes**: A solution proffered by Nikola Motors for refuelling long distance FCEV trucks involves establishing a network of hydrogen refuelling stations along key trucking routes with onsite power generation and electrolyser facilities. The key items of equipment would be as follows:

- Renewable power generation facilities in the form of wind turbines or solar panels
- An electrolyser to convert water to hydrogen.
- Hydrogen storage facilities.
- Rapid hydrogen dispensing facilities.

The footprint of the planned hydrogen refuelling stations would be considerably larger than traditional gasoline/diesel stations and the cost would also be far greater. Nikola Motors estimates the cost of a station at $16.6m presently but they think this could be reduced to about $15m by 2025. It might also be possible to use some sites as a hub for making hydrogen deliveries over a radius of around 400 km. We believe, the proposed hydrogen stations could be three or four times the cost of a conventional gas/diesel station. The variance reflects the greater footprint and scope of hydrogen stations plus the much tighter engineering standards for storing and dispensing hydrogen as opposed to diesel.

**Viability will require high rates of utilisation and a sharp drop in hydrogen production costs**: Clearly, to be viable the proposed hydrogen stations will need to meet at least two conditions. These are very high rates of utilisation and a sharp drop in hydrogen production costs through electrolysis from current conceptual levels. Fuel costs for FCEV trucks could, in fact, be more favourable than implied by standalone fuel stations given the ability for a truck to refuel to some degree at central depots.

**Exhibit 2: Nikola Motors hydrogen refuelling facility**



Source: Nikola Motors

**FCEV TOTAL COST OF OWNERSHIP**

We believe truck owner's take-up of FCEV heavy trucks will be driven by three key factors. These are as follows:

- Regulation regarding NOX, particulate and CO2 emissions.
- Truck operator confidence in the new technology.
- Prospective total cost of ownership (TCO).

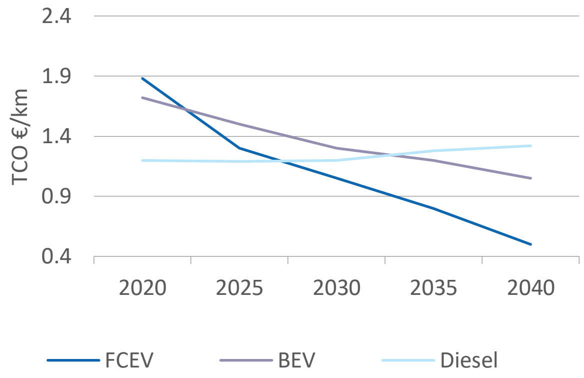
**Diesel prohibitions a possibility**: Unlike for light vehicles, broad prohibitions on the sales of diesel-powered heavy freight vehicles have yet to be made in any major jurisdiction. We believe, however, that localised bans on diesel trucks are a possibility over the next few years while action will probably be taken by governments to tighten diesel emission standards. These are likely to increase the costs of ownership both from the perspectives of the initial purchase price and fuel consumption. In our view, an outright legislative ban on diesel powered trucks in many parts of the world is a very real possibility by 2040 in support of decarbonisation objectives.

**TCO is the key metric:** Normally the key metric used by heavy truck operators to switch supplier is total cost of ownership/mile (TCO). TCO reflects all variable and fixed costs of operation minus the resale value/total miles expected to be driven during the operator's ownership. Simplistically, a TCO below the owner's existing truck encourages a switch subject to any concerns about the viability of new technology. In practice, new technology will only be adopted with a lag following the gathering of information both statistical and anecdotal on its performance.

**FCEV TCO expected to breakeven with diesel by 2028**: Not surprisingly, FCEV heavy duty truck TCO is substantially higher than for a diesel truck. According to a McKinsey 2020 study, the premium would be about 60% currently reflecting a cost/km of €1.9 against €1.2. The study was based on a Class 8 truck with a 35ton gross vehicle weight. The McKinsey study showed the FCEV cost/km falling sharply through 2030 and breaking even with BEVs by around 2022 and diesel by 2028. Based on the study, costs would be down to about €1.1/km in 2030 at which time they would be about 8% below diesel. The trend remained downward over the following ten years to around €0.5/km.

**Costs to be driven down by hydrogen fuel and fuel cell/fuel tank capital costs as operations are scaled up**: In the McKinsey study two key factors drove down the cost of FCEV ownership between 2020 and 2030. These were the cost of hydrogen fuel and the cost of the fuel cell stack and the fuel tank. Between 2020 and 2030 McKinsey was looking for a drop of 50% in the delivered price of hydrogen from $8-10/kg to $4-5/kg assuming the scaling up of production and distribution facilities. In the case of the fuel cell stack and the fuel tank McKinsey believed that cost reductions of approximately 70% and 60% respectively should be possible between 2020 and 2030 respectively. McKinsey's argument is that stacks and fuel tanks are currently being produced on a labour-intensive bespoke basis, so costs are high. Once production is switched to a high-volume industrialised basis costs, it is argued, should fall sharply. For the purpose of the exercise, McKinsey based its manufacturing cost estimates on an annual volume of 150,000 trucks.

**Exhibit 3: HDT total cost ownership scenario by powertrain**




Source: McKinsey & Co and Ballard Power Systems

Note: HDT: heavy duty truck. Data relate to TCOs (total cost of ownership) for heavy duty long-haul trucks in Europe (35 t GVW). FCEV (fuel cell electric vehicles) and BEV (battery electric vehicle).

**McKinsey estimates of declining costs could prove overly optimistic**: While the McKinsey study on FCEV economics is interesting, it should be noted that it is a paper exercise and inevitably dependent on a host of assumptions which may or may not prove valid. We would also argue that fuel cells are complex to manufacture and may not be so amenable to high volume manufacturing techniques in the time frame suggested by McKinsey. Establishment of high-volume FCEV component manufacturing and final assembly operations will necessitate a lead time of several years along with sizeable investment across the auto industry probably in the billions of dollars. Intensive testing and product development will also be required.

Finally, we think it should be remembered that diesel is often heavily taxed especially in Europe. In our view it is likely that hydrogen will also have to be taxed once FCEV trucks appear in earnest on highways in Europe and elsewhere. It is not clear if this issue has been allowed for in McKinsey's study.

**WHAT ABOUT LIGHT VEHICLES?**

**Only Toyota, Honda and Hyundai sell FCEV light vehicles commercially**: Several auto OEMs have experimented with FCEV light vehicles over the past 10-20 years but currently there are only three producers selling cars with fuel cell technology commercially. These are Toyota (Mirai), Honda (Clarity) and Hyundai (Nexo). All three OEMs currently are using low volume production techniques. Based on the trade press, we believe that world production of fuel cell cars was around 7,500 units in 2019 and may have approached 10,000 units in 2020.

**High manufacturing costs and a lack of a refuelling network have been constraints**: Fuel cell technology has had difficulty in gaining traction in light vehicle applications. This has primarily reflected high manufacturing costs vis-à-vis lithium-ion batteries and an absence of a hydrogen refuelling network in most parts of the world. Packaging limitations associated with bulky fuel tanks have also been perceived as a drawback as have the complexities of manufacturing a sophisticated product. Auto OEM's have preferred lower cost lithium-ion battery technology for their electrification needs. According to McKinsey's 2020 study, costs/km for light FCEV cars would be about twice those for BEV equivalents while the premiums for medium and heavy FCEV SUVs and cars would be about 60% and 35% respectively.

**Interest in FCEV technology has increased of late for the heavier end of light vehicle applications:** Interest in fuel cell technology for light vehicle car and pickup truck applications has increased of late. This has been led by Toyota and Hyundai, both of which also have major fuel cell development programmes underway for truck and industrial applications. Interestingly, General Motors has developed its own Hydrotec fuel cell technology. This will be used in its substantial light and medium truck operations and possibly at upstart electric truck maker Nikola Motors. Ford and FCA (Fiat Chrysler Automobiles) have both suggested that they need to develop or buy-in fuel cell technology for trucks and vans and probably SUVs. BMW has also expressed a continuing interest in fuel cells but VW and Daimler have suggested that they are focusing on BEVs, at least for their car operations. Growing interest generally in fuel cell technology for cars and light trucks reflects the following:

- The regulatory push to electrify across product lines.
- The suitability of fuel cells for vehicle propulsion systems for the heavier light vehicles such as pickup trucks, vans, SUVs and large sedans.
- Growing appreciation of the drawbacks to lithium-ion batteries for the heavier applications. The drawbacks revolve around range, recharging times, weight and payload. Note, in an attempt to boost BEV range, ever larger batteries are being used which in turn is increasing weight and recharging times.

**Fuel cell technology could become viable for the heavier long range light vehicles by 2025**: A key finding of McKinsey's January 2020 study was that fuel cell technology economics could become viable for the heavier light vehicles (SUVs, pickups, vans and large cars) requiring long range capability of 600-650 km by 2025. Specifically, McKinsey suggested that breakeven with BEVs in terms of cost/km could be reached in 2025. This conclusion was mainly dependent on unlocking the economies of scale assuming a global production rate of 600,000 vehicles pa. Remembering that FCEV car production is currently running at around 10,000 pa this would appear a very challenging proposition and unlikely to be achieved.

Arguably, 2030 might be a more viable date for breakeven with BEVs. Interestingly, the McKinsey study found that for the lightest cars requiring a driving range of about 200 km fuel cell technology was unlikely to become competitive with BEVs before 2040. This reflects the low cost of batteries relative to fuel cell systems including fuel tanks for low output 30kWh applications which are adequate for a light vehicle with a 200 km range.

As in the case of heavy trucks, the trend improvement in fuel cell technology economics is expected to be driven by two factors. These are a prospective drop in retail hydrogen fuel costs and the adoption of high-volume manufacturing techniques both in the final assembly of fuel cell stacks and other sub-assemblies and in the supply chain. There may also be potential for reducing material design costs with the key move being using smaller platinum catalyst loadings.

**Downward trend in FCEV light vehicle TCO similar to heavy trucks**: Presently, for FCEV light vehicles the hydrogen fuel cell and fuel tank account for about 50% of the TCO while hydrogen fuel accounts for a further 25%. McKinsey is looking for a 50% drop in the light vehicle cost/km between 2020 and 2030. Retail hydrogen fuel costs are expected to decline by about 60% between the two dates to $4.50-5.00/kg as mentioned previously for trucks.

**INTERESTING NEWS FROM TOYOTA**

**New Mirai light FCEV and Class 8 truck development programme**: There has been some very interesting news from Toyota of late on the automotive fuel cell front. This relates, firstly, to the recently launched and acclaimed second generation Mirai sedan and secondly to a Class 8 heavy truck development project.

Regarding the Mirai, the key point of interest has been the upgraded fuel cell stack. Compared with the previous unit the new one provides higher power output, higher output density (an excellent 5.4 kw/litre up from 3.5 kw/litre), greater refinement, longer driving range and most significantly a sharp reduction in costs. According to industry sources, power is up by 19% to 134 kW, driving range is increased by 30% to over 600 km and the cost of producing the stack has declined by no less than 70%. The cost reduction reflects several factors as follows:

- A decline in the number of cells in the stack from 330 to 370.
- A reduction in the amount of platinum used by 58%.
- A shortened manufacturing cycle for producing the cells.
- A reduction by two thirds in the time required to wrap the hydrogen fuel tanks in carbon fibre.

**Costs are expected to continue declining as capacity utilisation rises at newly expanded plant**. Toyota is looking for further declines in unit cost as capacity utilisation at the Honsha plant in Toyota City increases. Interestingly, Toyota has also announced a hefty tenfold increase in cell manufacturing capacity at Honsha to 30,000 units a year. This is a clear vote of confidence in its fuel cell technology. For comparison, first generation Mirai sales in the six years to 2020 were 11,365 globally.

**Toyota poised to commence trials with fuel cell powered Kenworth semis**: Significantly, Toyota recently announced that it will soon be undertaking trials of Class 8 Kenworth semi-trucks at the Ports of Los Angeles and Long Beach using its proprietary fuel cell technology. The trucks will use the Mirai fuel cell system but with two stacks rather than one. This is indicative of the versatility of the technology. Toyota has also indicated that in 2021 it will be trialling in Japan fuel cell powered light duty trucks. The intention is to apply its proprietary fuel cell technology to a range of other products including fork-lift trucks, trains, ships and gen-sets.

**Trucks a key to expanding the hydrogen refuelling network**: Interestingly, Toyota believes capitalising on the technical and economic strengths of fuel cells in heavy long-distance trucking will be the key to expanding the hydrogen refuelling network. Once this reaches critical-mass, Toyota argues that this should help stimulate the light vehicle market. Presently, Toyota estimates there are only 160 hydrogen refuelling stations in Japan, 74 in the US and 177 in Europe.

### HYUNDAI MOVES INTO SWITZERLAND

**Shipment of fuel cell powered trucks to Switzerland commenced in October 2020**: In one of the most dynamic moves so far in the FCEV medium/heavy truck field in Europe, Hyundai commenced in October 2020 shipments of its Xcient fuel cell powered trucks to Switzerland. In the fourth quarter of 2020 shipment of 50 trucks was planned which is the first tranche of 1,600 trucks scheduled to be delivered by 2025. The Xcient trucks are powered by a 190 kW fuel cell system with two 95 KW stacks and seven hydrogen fuel tanks. The driving range is modest at 400 km and was devised as a compromise between the driving cycle in Switzerland and the local refuelling infrastructure. The Xcient trucks for the moment, at least, are probably more geared to regional/cantonal transportation operating from a central depot rather than truly long-distance transportation from, for example, southern Spain to the UK (2,200 km).

**Trucks will be leased on a pay-per-use basis**: Marketing of the Xcient trucks will be handled by Hyundai Hydrogen Mobility (HHM), a joint-venture between Hyundai Motor Co and the Swiss energy company H2 Energy. All trucks will be leased on a pay-per-use basis. Significantly, HHM has linked with Hydrospider a joint-venture between Lausanne-based power company Alpiq and the industrial gases major, Linde. A hydrogen refuelling network has been established by the joint-venture in Switzerland.

**Further expansion planned in Europe and elsewhere**: Hyundai has grand plans for expanding FCEV truck sales elsewhere in Europe. According to statements by the company, the focus will initially be on Austria, Germany, Netherlands and Norway. A major roll-out of FCEV heavy trucks is also planned by Hyundai in North America and China. The former is a non-traditional heavy truck market for Hyundai.

**EUROPEAN HEAVY TRUCK MAKER FUEL CELL INITIATIVES**

**All leading truck makers have announced FCEV product development programmes**: The leading European heavy truck makers have all announced major FCEV product development initiatives over the past year or so. Significantly, Daimler Trucks and Volvo Trucks in April 2020 announced a joint-venture to develop and produce fuel cells. Note, the joint-venture excludes truck development and manufacture.

**Daimler GenH2 high-powered, sophisticated FCEV powertrain**: The FECV trucks, in the pipeline, like the Daimler GenH2 which was premiered in September 2020 as a concept, will have genuine heavy-duty characteristics. The GenH2 fuel cell module is rated at 300 kW (402 bhp) using two stacks while a large battery provides another 400 kW (536 bhp) on an intermittent basis for extra torque and acceleration as needed. Significantly, the battery and powertrain have a regenerative braking feature. This enables the energy generated during braking to be captured and stored in the battery thereby improving efficiency. The battery can also be recharged from the fuel cell when surplus energy is being produced.

**E-axle contains two integrated electric motors**: The combination of the fuel cell and battery enable the performance of the truck to be optimised according to road conditions and the needs of the operator. Electrical power is transmitted to an e-axle containing two integrated electric motors rated at 2X230 kW continuous and 2X330 kW maximum power. The powertrain, including the cooling and heating system, is managed by a powerful computerised control system. Cooling requirements are significantly greater than with a diesel engine while liquid fuel needs to be converted by heating to the gaseous form for use in the fuel cell.

**1,000 km range, 25 tonne payload and refuelling time similar to diesel**: The GenH2 has a GVW (gross vehicle weight) of 40 tonnes and payload capability of 25 tonnes which is typical for heavy-duty diesel trucks currently. It has a long-range capability of 1,000 km reflecting the use of liquefied hydrogen which provides higher density fuel than in gaseous form. Use of liquefied fuel also enables lighter (lower pressure) and smaller fuel tanks than with gaseous fuel which are positive characteristics for payload and providing space for the battery unit. The GenH2 has fuel tank capacity of 80 kgH using two stainless steel tanks. Refuelling time will be similar to a heavy-duty truck.

**Potentially superior performance and lower operating costs:** On a positive note, the Daimler GenH2 along with similar offerings by other OEMs, we believe, will have superior highway performance particularly in terms of acceleration and hill climbing capability vis-à-vis a diesel truck reflecting the near instant torque availability of electric power. Operating costs will probably also be significantly lower owing to reduced maintenance requirements and possibly in due course cheaper fuel. The former stems from fewer moving parts in the FCEV powertrain and the elimination of oil and filter changes. An intensive testing programme with customers is planned from 2023 to identify any reliability and durability issues. As noted earlier, the key disadvantage, at least initially, of the GenH2 to diesel powered trucks, will probably be capital cost.

**Exhibit 4: Daimler Truck GenH2 tractor unit and fuel cell module**

Source: Daimler Trucks

**Exhibit 5: Daimler Truck GenH2 fuel cell module**

Source: Daimler Trucks

**High-volume FCEV truck production in Europe will probably only commence post 2025**: FCEV heavy duty trucks are at the development and testing stage in Europe presently. High volume production will probably only begin post 2025. The park of heavy-duty trucks in Europe will still be overwhelmingly diesel powered in 2030. Interestingly, an alliance of seven leading European truck makers indicated in December 2020 that they intend ceasing the sale of diesel-powered trucks by 2040. This is a decade earlier than originally planned. The seven are Daimler, Volvo, Scania, MAN, DAF, IVECO and Ford.

**WILL THE AUTO OEMS MAKE THEIR OWN FUEL CELLS?**

**Inhouse fuel cell production likely for high volume OEMs**: We believe the high-volume auto OEMS will develop and manufacture their own fuel cells should they decide to adopt this technology. The likes of General Motors, Toyota, Hyundai and Honda have already gone down this route. It would seem to us unlikely that the major OEMs would be prepared to leave such a key item of technology and cost in the hands of third parties other than as part of a joint-venture. For legacy auto companies there is also a major financial incentive to convert existing powertrain operations to fuel cell and/or battery and electric drive components production. In the absence of plant conversions cash restructuring costs for the auto OEMs could be hefty indeed. Fuel cell and battery manufacturing operations will become analogous to present day inhouse engine plants.

We believe some insights can also be drawn from trends in battery vertical integration in the auto industry. Tesla has always made a virtue out of being vertically integrated into battery development and production in conjunction with Panasonic. Indeed, it sees battery technology as a core competence. General Motors has followed a similar path with its highly regarded Ultium batteries produced in a joint-venture with LG. Furthermore, it is manufacturing electric motors and drive line components as part of an integrated package. As we have noted, General Motors has developed its Hydrotec fuel cells and so has a presence in both vehicle electrification camps.

**Ford certainly has the volume for inhouse fuel cell manufacture**: Interestingly, Ford has recently suggested it is considering reversing its decision of a few months ago to buy-in battery technology rather than set up an inhouse development and manufacturing operation. For the moment, however, Ford's chosen route to electrification including for its upcoming F150 pick-up truck and Transit van, will be bought-in lithium-ion batteries. We believe that if there is one company that can justify developing fuel cell technology on volume grounds it is Ford. With production globally in a normal year of 1.8m, Ford is the world's largest producer of light and medium trucks and vans. In addition, Ford produces globally around 1m SUVs a year.

**CUMMINS MOVES INTO FUEL CELLS**

**One of the largest independent producers of diesel engines----**Columbus, Indiana-based Cummins (CMI:NYSE)is one of the world's largest independent producers of diesel engines covering a wide range of automotive, industrial and marine applications. Historically, it has ranked as one of the top two suppliers of diesel engines to US producers of Class 8 trucks and has a strong position in industrial markets both in North America and internationally.

**--------has built a significant presence in fuel cells**: In recent years Cummins has developed a significant presence in the fuel cell and hydrogen technologies arena partly organically and partly by acquisition. Cummins presence in the sector was given a major boost in 2019 with the acquisition of an 81% stake in Mississauga, Ontario-based Hydrogenics Corporation. This enabled it to form a joint-venture with the Paris-based industrial gases major, Air Liquide. During 2019 and 2020 Cummins also acquired a stake in the Burnaby, British Columbia-based Loop Energy, a specialist in fuel cell range extenders for bus and truck operators using battery powered vehicles.

**Fuel cell joint -ventures with Hyundai and Navistar**: Cummins announced two highly significant joint ventures in the fuel cell field in 2019 and 2020. The first was with Hyundai and involved the joint development and commercialisation of electric and fuel cell powertrains initially in the North American commercial vehicle market. The second joint-venture was with Navistar a leading producer of medium and heavy trucks in the US and concerned the development of a hydrogen fuel cell powered Class 8 truck. Interestingly, Cummins sees its electrolyser business expanding rapidly over the next few years with revenues growing to about $400 pa by 2025.

**Cummins expectation for the share of FCEV trucks in 2030 is 2.5%:** Cummins does not appear to foresee a dramatic breakthrough for fuel cells in the highway truck business near to medium term. This, we believe, reflects a combination of factors. Chief among them include product development lags, a likely slow build-up in the hydrogen production and refuelling infrastructure and the technical and financial challenges of pushing down the total cost of ownership for hydrogen fuel cell powered trucks.

Cummins believes that fuel cell powered trucks will have a share of only 2.5% of the heavy truck market globally in 2030. Its expectations for buses and trains are somewhat more bullish with shares by the same date of 10% for both modes of transport. Note, in the case of trains the share relates only to the diesel-powered market. Cummins outlook for fuel cell penetration of the truck market contrasts sharply with that implied by the McKinsey report referred to earlier. Maybe the oil companies do not have too much to worry about near to medium-term after all.

## FUEL CELL PLAYS

Below we briefly review three fuel cell plays. All have performed powerfully in 2020 but are at an early stage in their development and have little by way of revenues and EBITDA. Investors looking for exposure to hydrogen and the fuel cell sector should also consider the industrial gases majors and the specialty chemicals and high-tech materials producers. The industrial gases plays are all large capitalisation stocks and include the likes of Linde (LIN:NYSE), Air Liquide (AIRP:PA), Air Products (APD:NYSE) and Iwatani Corporation (8088.T). Examples of the specialty chemicals and high-tech materials plays are Johnson Matthey (JMAT: LSE) in the UK, Umicore (UMI: BR) in Belgium and BASF (BASFn:DE) in Germany. Significantly, all three have well established links with the automotive industry and are Tier 1 or 2 suppliers. We take a brief look at Johnson Matthey in the following pages.

Compared with the junior fuel cell plays, the industrial gases and specialty chemicals and high-tech material plays are, of course, all well established and have considerable technical resources and expertise. From an investment perspective they have the virtue of modest valuations in the context of the current marketplace.

## BALLARD POWER SYSTEMS (BLDP:TSX AND NASDAQ)

**Background**

**Leading producer of PEM fuel cells**: The name Ballard is synonymous with fuel cells. The company, listed on the TSX and NASDAQ and headquartered in Burnaby near Vancouver, British Columbia, has around 40 years' experience in designing and manufacturing hydrogen fuel cells. We believe Ballard is comfortably the world's leading producer of PEM fuel cells by cumulative installations and has the most developed PEM manufacturing infrastructure. Presently, Ballard technology powers around 45% of the 7,200 FCEVs deployed in China, the world's largest such market.

Long-term, Ballard has pointed to the possibility of achieving a 20% share globally of its core heavy duty motive power fuel cell market for truck, bus, train and marine propulsion applications. The company has two strategic shareholders, Weichai Power and Zhongshan Broad Ocean Motor which own 17.7% and 3.9% of the stock, according to Refinitiv data.

**Operations**

**Market focus California, Europe, China**: Geographically, the key market focus presently is California, Europe and China. Ballard has six manufacturing facilities with three in Burnaby and one each in Bend Oregon, Southborough Massachusetts and Hobro, Denmark. The company also has manufacturing joint ventures with Weichai Power Co (major diesel engine producer) and Guangdong Nation Synergy (fuel cell producer for truck and bus applications) in China. Importantly, however, all MEAs (membrane electrode assemblies), or the technological core of the fuel cell stack are supplied from Burnaby. Ballard also has several technical joint-venture arrangements with major auto OEMs and component suppliers. One of the more important is with one of the largest German auto component producers, Mahle. Headcount across the business is around 900 with almost 50% being in technical functions.

**Competitive strengths**

**Deep PEM engineering expertise**: Ballard's key competitive strength is its deep technical knowledge and applications engineering expertise in the field of PEM fuel cells. Ballard has recently launched new next generation, high-performance fuel cell modules for heavy duty automotive and stationary power applications. The new product lines offer the potential for advances in the total cost of ownership as well as operational performance gains.

Historically, Ballard's manufacturing, in common with the rest of the fuel cell industry, has been based on low-volume labour intensive techniques. Following a major facility upgrading programme, Ballard now boasts the infrastructure for high volume production. Presently, given Ballard's long experience, pre-eminence in terms of PEM installations and technical expertise in FCEV development we believe it has few, if any, independent competitors. Long term, we believe competition in the automotive field will stem largely from auto OEMs. GM's development of inhouse technology is indicative of the road ahead.

**Financials**

**Still modest revenues and significant EBITDA losses but trends are possibly poised to strengthen**: Ballard's revenue base is still modest compared with the US$6.6bn market capitalisation and the long run trend of significant EBITDA losses continues. In 2019 revenues came in at US$106m while the EBITDA loss was US$27.4m. Based on Refinitiv data, consensus revenues are forecast to be similar in 2020 before trending significantly higher in 2021 and 2022 to US$133m and US$194m respectively. The increase in forecast revenues in 2021 is to a considerable extent underpinned by the high order backlog and shipment deferments in 2020 due to the covid crisis.

According to Refinitiv's consensus data, EBITDA losses are expected to be US$33m in 2020 and US$22m in 2021. Approximate breakeven is forecast for 2022. Based on its FECV market size and share assumptions Ballard has pointed to the potential for revenues of over US$5bn in 2030. Assuming a margin of 25% this would imply EBITDA of US$1.25m.

**Muscular balance sheet due to recent sizeable equity raises**: Ballard has a muscular balance sheet thanks to two sizeable equity issues in September and November 2020 which raised US$653m gross. The November raise was US$403m and was undertaken at US$19.25/share or about 17% below the late December 2020 price of US$23.3/share. The cash position was US$362m at the end of the third quarter of 2020 and we believe could be around US$830m at end year. Debt is marginal at about US$17m so net cash could still be over US$800m. This will probably be largely equivalent to shareholders' equity, according to our calculations.

**Share price performance and valuation**

**Powerful performance, market capitalisation US$6.6bn**: Ballard stock has performed powerfully over the past five years with a gain of around 11X to US$23.3/share. Over the past year the stock has risen about 3.5X despite a 20% increase in shares outstanding and continuing significant losses at the EBITDA level. The performance reflects overwhelming investor enthusiasm for new technology energy plays regardless of other factors. In late 2020 market capitalisation was US$6.6bn while the enterprise value was about US$5.8bn. Clearly, much like the tech sector the market is valuing Ballard on the basis of perceived growth potential rather than current financial performance.

**Market capitalisation reflects bullish expectations for the world's leading fuel cell play**: If, heroically, we assume that Ballard's does indeed grow powerfully over the next few years and generates revenues in 2025 of perhaps US1bn and an EBITDA margin of 20% or US$200m, the EV/EBITDA multiple would be 29X. While this might be considered a demanding rating for a mature industrial it is possibly not the case for the leading play in the voguish fuel cell sector. Much will depend on the speed of the build-up in revenues over the next year or two.

**Exhibit 6: Ballard Power Systems share price**


Source: Thomson Reuters

## CERES POWER HOLDINGS (CWR:AIM)

**Background**

**Leading fuel cell play on the London market**: Arguably Crawley, West Sussex-based Ceres Power is the leading fuel cell play on the London market with a market capitalisation of circa £2.2bn or US$3.0bn. Ceres was floated on AIM via an IPO in 2004 to commercialise intermediate temperature solid oxide fuel cell (IT-SOFC) technology originally developed by Imperial College, London. The stock is closely held. Two strategic shareholders, Weichai Power and Bosch GmbH own 19.8% and 17.6% of the stock, respectively.

**SOFC technology**

**Unique SOFC technology**: Ceres' SOFC technology is unique reflecting the use of a ceramic solid-state electrolyte, ceria gadolinium oxide, supported by a ferritic stainless-steel substrate. This arrangement has greater ionic conductivity and lower operating temperature characteristics than the ceramic material normally used for SOFCs. As a result, operating efficiency is enhanced while capital costs are reduced thanks to the use of relatively low cost stainless as the substrate. Unlike PEM, SOFC fuel cells do not have platinum catalysts and rely on much higher operating temperatures to trigger the electrochemical reaction in the fuel cell. Typically, SOFCs operate at 700° C to 800° C whereas Ceres technology can run at 500° C. By contrast, PEM fuel cells typically operate at 70°- 80° C. Energy efficiency can be as high as 85%.

**Technology particularly suited for distributed power applications**: Ceres' technology is also more robust than standard SOFC designs and capable of running on a range of fuels including natural gas and hydrogen and any mix of the two. In terms of applications the characteristics of robustness, relatively low capital cost and fuel flexibility point to the key market for Ceres' IT-SOFC technology as being stationary power generation. It is particularly useful for distributed power applications where there is no connection or a weak connection to the grid and reliability is of paramount importance. Data processing facilities and vehicle charging infrastructure are cases in point. The fuel flexibility characteristic also suggests application as an energy transition technology. Interestingly, Ceres is looking to apply its solid oxide technology to the electrolysis of water. Apparently initial results have been encouraging.

**Business strategy and competitive strengths**

**Ceres looks to licence technology and receive royalties**: Ceres business strategy has two strands. Firstly, the aim is to be asset light. Rather than manufacturing and installing complete power plants Ceres looks to licence technology and receive royalties once facilities are operational. The approach is analogous to that of ARM in semiconductors. Despite the asset light strategy, Ceres opened a new fuel cell manufacturing facility in Redhill in early 2020. The second strand to the strategy is the formation of joint-venture and licensee arrangements with leading engineering companies internationally. The key relationships are with Bosch in Germany, Weichai Power in China, Doosan in Korea and Miura Co Japan.

**Bosch connection looks particularly interesting**: We see Ceres's key strengths as being its unique SOFC technology plus its strategic technical and licensee relationships. Near term, we think the relationship with Bosch looks particularly interesting. Bosch is now moving from the prototype development stage with Ceres' SOFC technology to mass production at several sites in Germany. The aim is to produce 200MW of capacity by 2024. The project is expected to be worth £23m to Ceres between 2021 and 2023 of which £6m is conditional on meeting certain performance indicators.

**Financials**

**Modest revenues and EBITDA losses**: Ceres currently has modest revenues and trades at a loss at the EBITDA level. For the year to June 2020 revenues came in at £18.9m while the EBITDA loss was £7.3m. Refinitiv consensus forecasts show revenues trending up to about £28m in 2021, £35m in 2022 and £39m in 2023. The Refinitiv forecasts reflect a widening of EBITDA losses to around £9m in 2021 and £12m in 2022. Approximate breakeven is forecast for 2023. It should be noted that the cost structure is heavily leveraged with G&A and R&D currently running at about £25m annually.

**Hefty cash position**: Ceres balance sheet is in excellent shape. At end June 2020 a gross cash balance of £108m was reported. After allowing for modest debt the net position was £103m, equivalent to a hefty 80% of equity. The already strong cash position was boosted in 2020 by £49m of new equity investments by Weichai Power and Bosch. Further cash outflows relating to operations and capital spending of perhaps £15-20m annually look like being capable of being absorbed comfortably near term.

**Share price performance and valuation**

**Powerful share price performance**: In common with Ballard, Ceres stock has performed powerfully both over the past five-years and one year. The gain over the past five years has been a massive 21X while the increase over the past year has been an impressive 4.5X. With a market capitalisation of £2.2m, Ceres perhaps can no longer be considered a junior on this definition. The performance has been achieved despite hefty EBITDA losses as a percentage of revenues but with no early prospect of generating significant EBITDA. It is analogous to the Tesla syndrome of perhaps two years' ago.

**Valuation challenging based on any plausible outlook for revenues and EBITDA**: Clearly, investors have great confidence in both the long- term outlook for fuel cell technology and for Ceres' SOFC niche. We believe that to justify the current valuation it would be necessary to contemplate EBITDA of over £100m annually by perhaps 2025. This could imply revenues of possibly around £500m. Although we think there are excellent long-term prospects for SOFC technology in distributed power generation and within this context the Ceres technological niche, achieving £500m in revenues within five years appears decidedly challenging.

**Enthusiasm for the new technology energy story**: An alternative way of looking at Ceres together with other fuel cell plays, is that they will continue to run regardless of valuation driven by enthusiasm for the new technology energy story. Effectively, investors are betting on a major secular trend. The argument is analogous to that dominating the tech sector and indeed Tesla.

**Exhibit 7: Ceres Power share price**


Source: Thomson Reuters

## AFC ENERGY (AFC:AIM)

**Background**

**Leading exponent of alkaline fuel cell technology**: AFC Energy, based in Cranleigh, Surrey, is the world's leading exponent of alkaline fuel cell technology. It is now in the early stages of commercialising its patented technology. The company was floated on AIM in 2007 to acquire and develop the technology from Elenco NV, a consortium including the Belgian nuclear research institute, Beckaert a steel wire producer and the chemical company Dutch State Mines. The pioneering work for alkaline fuel cells was originally undertaken at the University of Cambridge in the 1930s. AFC's stock is broadly held and there are no strategic investors as far as we are aware. Only 0.47% of the stock is not in public hands.

**Alkaline fuel cell technology and applications**

Alkaline fuel cells operate in a similar way to other forms of fuel cell technology. Electricity is generated following an electrochemical reaction at the anode where hydrogen is catalysed. At the cathode negative and positive ions combine to form water vapour and heat. There are no CO2 or toxic emissions in the absence of impurities in the fuel. Alkaline fuel cells can have either liquid or solid-state membranes. The latter largely eliminate the problem of C02 contamination which results in superior electrochemical performance.

**Robust technology with high electrical efficiency and relatively low capital costs**: Alkaline fuel cells can provide a compelling strategy for power generation on both technical and economic grounds. They offer high electrical efficiency of around 70%, are robust, apparently reliable and are tolerant to the use of industrial grade hydrogen, including from cracked ammonia. Once cracked, ammonia provides by volume 75% hydrogen, 25% nitrogen and 200-600 parts per million of ammonia. Significantly, despite the mixed fuel performance is little different than using pure hydrogen according to AFC Energy. The economic advantages of alkaline vis-à-vis other types of fuel cells reflect in part the ability to use low-grade fuel and in part lower capital costs stemming from the alkaline environment negating the use of expensive platinum catalysts.

**So far little commercial use of the technology**: Despite the apparent advantages of alkaline fuel cells, there has been little commercial use of the technology so far. Possibly the major use has been on NASA space missions. The key reasons for the lack of commercial interest have possibly been the CO2 contamination issue mentioned previously and the bulk and weight penalties of alkaline fuel cell installations compared with more compact PEMs. These characteristics tend to preclude alkaline cells for vehicle and other transport applications where compactness and low weight are virtues.

**Key market off-grid remote location power generation**: The most obvious application for alkaline fuel cell technology is power generation. A key target market for AFC Energy is power generation in off-grid remote locations such as mine sites, farms and construction sites and electrolysis facilities for FECV refuelling stations. Another application is as a standby power source for data centres and other critical installations. Currently, the power source of choice for remote locations is the diesel-powered gen-set. According to AFC, this is a $25bn market globally.

**Commercialisation**

**Range of liquid membrane FCs, solid-state FCs under development:** AFC Energy has been developing its alkaline fuel cell technology for ten or more years. It has now developed a range of fuel cells using liquid membranes with power outputs of 20kw, 160kW and 400Kw+. Solid-state membrane fuel cells are also under development including a market leading 2MW product suitable for stationary off-grid power generation.

**First sizeable contract in 2020 from Extreme E World Rally Championship**: Importantly, AFC Energy obtained its first sizeable contracts in 2020. The first involved a collaboration agreement with the organisers of the Extreme-E World Rally Championship to provide their power needs for the upcoming season. Extreme-E is a new rally series for battery powered SUVs which will take place across five locations in demanding conditions starting in early 2021. AFC will be supplying a bespoke H-Power alkaline fuel cell system using renewable hydrogen as a fuel. Involvement in the Extreme-E Series should provide an excellent platform to a televised global audience to pitch its wares in both remote fuel cell power generation and micro-alkaline water electrolysis.

-------**and Julich Research Institute**: The second development on the commercialisation front was an order from the Julich Research Institute in Germany for a 100kW H-Power fuel cell unit. Installation is scheduled for the third quarter of 2021. Financing for the project is mainly being provided by the German federal government. Significantly, a €9bn National Hydrogen Strategy was announced by the government in June 2020.

**Recent major JV with ABB**: In mid-December 2020 AFC Energy announced a major commercial breakthrough. This involved a strategic joint-venture with ABB, the Zurich-based electrical engineering and automation heavyweight, in its BEV charging operations. Significantly, ABB has one of the largest international BEV charging networks. The joint-venture will give AFC the right of first refusal to supply its H-Power fuel cells into the ABB network where either there is no grid connection or where the resilience of the power supply needs upgrading. We believe there are two key implications of the deal as follows:

- It will immediately provide an international footprint with a high-profile engineering concern and BEV charging network. This helps validate AFC's technology and should assist in obtaining further business.
- The potential scale of the business inflow should enable AFC to quickly build-up volume at its recently acquired Dunsfold near Cranleigh plant with positive implications for cost.

Based on intimations by AFC further joint-venture arrangements are in the pipeline.

**Manufacturing strategy**

**Final assembly and commissioning at new Dunsfold facility**: In late November 2020 AFC Energy announced that it had leased a 30,000 ft² manufacturing facility at Dunsfold close to its existing corporate headquarters. AFC intends applying a manufacturing light strategy so the facility will be geared to final assembly and commissioning work. Key components and assemblies such as electrodes and balance of plant will be bought-in from third party suppliers. Initially AFC is planning on establishing capacity for 100 fuel cell systems pa. We believe capacity is likely to be lifted in due course. The Dunsfold facility should be fully operational by end March 2021.

**Financials**

**Development company status has resulted in significant EBITDA losses**: Since the IPO, AFC Energy has functioned as a development company. There have therefore been no systematic revenues, although there have been inflows from EU grants and licence fee income. Despite these, significant losses have been incurred over the past five years. In the year to October 2019 there was a loss at the EBITDA level of £3.3m while for the most recent six months to April 2020 there was a loss on the same basis of £2m. Based on Refinitiv estimates, there could be an EBITDA loss for the year to October 2020 of £5.3m.

**Losses may persist in 2021/22**: Given the recent order intake, AFC should start generating revenues in 2021. Refinitiv is looking for £1.9m followed by £4.5m in 2022. On this basis Refinitiv is forecasting EBITDA losses of £5.5m and £4.8m in 2021 and 2022 respectively. We believe start-up costs at the Dunsfold facility and an upward trend in SG&A associated with an expansion of the business and product development activity point to Refinitiv's forecasts being plausible.

**Balance sheet in good shape following raises in 2020**: AFC's balance sheet should be in good shape following gross equity raises in 2020 of about £34m. Assuming an end October 2020 cash position of around £29.5m in line with our expectations, AFC should be comfortably financed to cover operational cash outflows plus capital spending. We believe, these could be £9-10m in both 2021 and 2022.

## Share price performance and valuation

**Share price performance also powerful in 2020**: AFC Energy has also performed powerfully over the past year particularly considering a 51% increase in shares outstanding. The stock has climbed about 4.4X in the year to end December 2020 when it was trading at 79.4p/share. On this basis the market capitalisation was £537m and the enterprise value £508m. Driving AFC in 2020 have been the secular new technology energy story and particularly in the fourth quarter some very positive news flow on the new business front. This culminated in the ABB joint-venture.

**Valuation again reflects ultra-bullish expectations**: AFC's valuation, as for Ceres, is clearly being buoyed by ultra-bullish long-term expectations for the new technology energy story and for AFC's niche in alkaline fuel cells. In our view, there is little likelihood of positive EBITDA near to medium-term and the enterprise value is not even remotely in the same ballpark as book value of perhaps £34m or 5p/share. Quite possibly AFC, in common with other fuel cell juniors, will continue to be buoyed by sector bullishness but at these elevated valuations performance could be vulnerable to stock specific disappointments.

**Exhibit 8: AFC Energy share price**


Source: Thomson Reuters

## JOHNSON MATTHEY (JMAT: LSE)

**Science driven company with exposure to some interesting technology**: London-based Johnson Matthey describes itself as a global leader in sustainable technologies and is an increasingly rare breed in being a FTSE 100-listed industrial heavyweight. It is probably best known for its expertise in catalyst technology both for petrochemicals and autos and its sizeable platinum/palladium refining and trading operations. Somewhat less well known is its exposure to high-tech materials, including for fuel cells and lithium-ion battery applications. Prospects for the new ultra-high energy density ELON cathode materials look highly promising. Significantly, Johnson Matthey is a science driven company with core competencies in the following:

- PGM (platinum group metals) catalysis and recycling.
- Electrochemistry and surface chemistry.
- Process technology including both grey and blue hydrogen.

**Established and profitable hydrogen and fuel cell business**: Presently, Johnson Matthey has an established and profitable hydrogen/fuel cell-related business with annual revenues of about £100m. This is split roughly £67m hydrogen production technologies and £33m fuel cell related materials/components. The former relates largely to Johnson Matthey's core pgm catalyst technology in which it has an approximate 40% global market share. Johnson Matthey two major business opportunities in the hydrogen field are:

- **Upgraded technology for blue hydrogen**: Introduction of upgraded process technology to produce blue hydrogen which offers the benefits of greater efficiency, lower capital cost and enables 95% of carbon dioxide emissions to be captured at high pressure and purity. The last mentioned, facilitates transportation and storage. Johnson Matthey sees blue hydrogen as being a key transition fuel along the road to net zero CO2 emissions over the next ten years. The addressable market could be £1.5bn-£2.0bn by 2030, according to the company. Johnson Matthey has reported that it is already involved in two major blue hydrogen projects in the UK.

- **Electrolysis of water**: Application of its proton exchange membrane (PEM) and pgm catalysis technologies in the electrolysis of water. Currently, Johnson Matthey's technology is under test with leading producers of electrolysers. According to the company, the addressable market for its PEM technology for electrolyser applications could be £2bn-4bn by 2030.

**Leading position in fuel cell materials/components**: In the fuel cell field, Johnson Matthey focuses on high technology materials rather than the fabrication of fuel cell stacks. The business is still modest in relation to annual corporate revenues of about £4.2bn, excluding the platinum operations but has been growing strongly. Growth averaged 38% pa in the four years to the year ended March 2020. Johnson Matthey also claims a leading market position in fuel cell materials/components. Revenues of £33m in 2020 were split by application roughly 50% stationary power and 25% each for automotive and non-automotive fuel cell applications.

**Full suite of fuel cell components**: Within the fuel cell field Johnson Matthey produces a full suite of components including catalyst coated membranes (CCM), membrane electrode assemblies (MEA) and electrodes and anodes. Its key technical strengths are the catalyst coating process and customised applications engineering. Johnson Matthey believes that its complete fuel cell component product line and applications engineering expertise are key factors in optimising cell performance. Importantly, Johnson Matthey already has strong links with automotive OEMs which is likely to evolve as the largest fuel cell market. The company has also invested in high volume manufacturing facilities in the UK and China.

**JM believes automotive FC market offers excellent business opportunities**: Johnson Matthey believes the automotive fuel cell market offers excellent business opportunities long term. This reflects the following:

- Potential growth in electric propulsion in the sector.
- Its pre-eminent fuel cell technical expertise.
- Potentially very high sales value per vehicle.

In relation to the last point, Johnson Matthey has indicated that it expects the CCM value per car and truck in 2030 to be around £800 and £2,500, respectively. These are multiples of what Johnson Matthey receives today through the sale of auto and truck catalysts. Johnson Matthey has suggested that the auto related CCM market could be around £1bn by 2030 and £10bn by 2040.

**Share price performance and valuation**

**Performance contrasts sharply with fuel cell juniors**: Johnson Matthey's share price performance in 2020 contrasts sharply with that of the fuel cell juniors. At year end the stock was down about 19% from a year earlier at 2,470p/share. This constitutes a slight underperformance against the FTSE 100 which declined 14% on the same basis. Compared with the recent June 2018 high of 3,762p the stock is off 34%. Johnson Matthey's soft share price performance of late reflects weak business conditions in some of its more mature markets along with the broader malaise in large capitalisation industrials.

**Modest EV/EBITDA of 9.0X for year to March 2021 plus 2.0% yield**: Share price weakness has left Johnson Matthey modestly valued on key metrics by contemporary standards. The stock sells on an EV/EBITDA multiple of about 9.0X based on Refinitiv's estimates for the year to March 2021. The prospective EV/EBITDA multiples for 2022 and 2023 are an undemanding 7.8X and 7.1X respectively. Given the current pay out, the stock offers a dividend yield of 2.0% but arguably nearer 2.3% assuming that the earlier precautionary cut in 2020 is restored. The company has indicated that this is its intention as circumstances permit. Given only modest balance sheet leverage, we believe this is perfectly plausible

**Exposure to the hydrogen economy and new energy technology overlooked**: Johnson Matthey can be considered as a pure industrial recovery story at this juncture. This would, however, overlook its very significant exposure to the hydrogen economy and new energy technology. The hydrogen and fuel cell aspects of the business could grow materially between now and mid-decade. Unlike the juniors Johnson Matthey is, we believe, comfortably profitable in this field and already has a manufacturing, engineering and SG&A infrastructure to handle extra volume. Arguably, the current relatively depressed valuation offers an interesting opportunity to buy into Johnson Matthey.

**Exhibit 9: Johnson Matthey share price**


Source: Thomson Reuters

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