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BRILLIANT KNOWLEDGE

ALTERNATIVE ENERGY

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The race towards a lighter-than-air economy

HYDROGEN: RISING FAST IN THE GLOBAL ENERGY MIX

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KEY POINTS

- Renewable 'green' hydrogen will be needed to decarbonize the final 20% of global energy consumption, enabling governments to fulfill their net zero carbon commitments.
- Government investment, subsidies and new policy frameworks are needed to explicitly encourage hydrogen adoption by delivering sufficient scale to lower costs below the point at which subsidies are required. However, the level of support that will be provided is uncertain.
- Widespread availability of electrolysers using surplus power from renewable sources to generate green hydrogen is critical for meaningful green hydrogen adoption. Until green hydrogen is widely available we see scope for fuel cells to be used in heavy duty vehicles and materials handling applications. We also see scope for fuel cells that can run on natural gas or methanol and for off-grid distributed power and back-up generation applications in emissions sensitive areas.
- Longer term, as renewable hydrogen become more widely available, we see potential for deployment in industrial processes, residential heating, shipping and aviation.
- The share prices of many hydrogen exposed stocks have doubled or quadrupled in 2020, making them sensitive to any setbacks in market growth. Most companies profiled are at an early stage of revenue development, few are consistently profitable. Moreover many may require potentially dilutive additional funding. Investors should therefore consider their options carefully.

Companies mentioned in this report:

2G Energy*	>	ENGIE EPS	>	Plug Power	>
AFC Energy	>	Everfuel	>	PowerCell Sweden	>
Ballard Power Systems	>	FuelCell Energy	>	Powerhouse Energy Group	>
Bloom Energy	>	ITM Power	>	Pressure Technologies	>
Ceres Power	>	McPhy	>	Proton Motor Power Systems	>
Doosan Fuel Cell	>	Nel Hydrogen	>	SFC Energy	>

*Edison Investment Research client

EXECUTIVE SUMMARY

Climate change remains at the top of the global political agenda. However the 'net zero' targets committed to by numerous governments cannot be achieved without the use of renewable hydrogen. This is because while cheap renewable power combined with battery storage looks set to address sections of the transport and power sectors, important gaps remain that hydrogen is well suited to fill.

Sectors ripe for hydrogen decarbonisation

'Hard to reach' sectors such as steelmaking, residential and commercial heating, long-distance road freight, shipping and aviation, have no obvious, low-cost, convenient alternatives to fossil fuels, and collectively account for approximately 34% of global energy consumption. Hydrogen's high energy to mass ratio and low losses during storage and transportation make it an ideal fit across these sectors. There is also scope for fuels cells to be used in off-grid generation, distributed generation, and back-up power.

Understanding the hydrogen market

The companies profiled in this report are some of those that will most clearly benefit from the transition to a hydrogen economy. Many of these are at an early stage of revenue development, still require significant additional funding, and few are consistently profitable, yet investor interest has been high, as have valuations. This makes their share prices sensitive to any set-backs causing growth to fail to live up to expectations. An understanding of the key market dynamics is critical for those wishing to invest in the sector.

EXECUTIVE SUMMARY

The tech behind green hydrogen

The key technology underpinning the transition is the fuel cell, which generates electricity from hydrogen. Working in reverse, electrolysers use electricity to generate hydrogen from water. Currently, 99% of the hydrogen produced globally is done so through techniques based on fossil-fuels, so the widespread deployment of electrolysers running off surplus wind and solar power is needed to ensure enough 'green' or renewable hydrogen.

Enabling the transition – pushing down costs of fuel cells and renewable hydrogen

At present, neither renewable hydrogen nor fossil-based hydrogen with carbon capture are cost-competitive with fossil-based hydrogen. However costs for renewable hydrogen are going down quickly. Electrolyser costs have reduced by 60% in the last ten years. For regions where renewable electricity is cheap, electrolysers are expected to be able to compete with fossil-based hydrogen by 2030. The cost of fuel cells is also expected to fall.

Virtuous circle required – government funding and regulatory frameworks key

These cost reductions are predicated on the creation of a virtuous circle that drives hydrogen adoption and triggers the economies of scale required. This requires government investment in infrastructure, R&D, as well as an enabling regulatory framework. Although it is impossible to say how successful investment and policy initiatives will be, the level of support is likely to be the major determinant of how rapidly the market grows.

The report concludes by profiling 18 companies that look set to gain from growth in hydrogen demand. Suppliers of electrolysers and fuel cells such as Ballard Power Systems, Ceres Power, ITM Power, NEL Hydrogen, McPhy and Plug Power appear particularly well positioned but companies engaged in other parts of the hydrogen supply chain such as ENGIE EPS, Everfuel and Pressure Technologies also stand to benefit.

THE HYDROGEN ECONOMY – DECARBONISING THE FINAL 20%

At least 20 countries, collectively representing around 70% of global GDP, are proposing hydrogen strategies or roadmaps as key elements of their decarbonisation plans. This report identifies the sectors where we see the biggest opportunities for hydrogen: industrial processes, heating, fuel cell buses and trucks (not passenger cars), grid and back-up power generation in areas with strict restrictions on emissions and materials-handling equipment. It also identifies the listed companies that are likely to benefit.

Hydrogen essential to achieving 'net zero' targets

'Net zero' targets cannot be achieved, in our view, without green hydrogen. While ever cheaper electricity from renewables combined with battery storage looks set to address large swathes of the transport and power sectors, important gaps remain. Hydrogen's high energy to mass ratio and low losses during storage and transportation makes it suitable for addressing these gaps. Recently published forecasts from the EU, the Hydrogen Council and Bloomberg New Energy Finance (BNEF) suggest hydrogen could grow from 2% of the global energy mix in 2018 to 13–24% by 2050, a c 8% CAGR at the mid-point.

Decarbonising the hard-to-reach sectors

Hydrogen is critical for replacing coal and gas in fossil-fuel intensive industrial processes such as steelmaking. By storing the excess energy generated by renewables until it is needed, hydrogen can help address intermittency in the power sector and provides a potential path for decarbonising heating. Hydrogen's high energy to mass ratio makes it particularly suitable for heavy-duty, long-distance road freight, maritime and aviation applications.

THE HYDROGEN ECONOMY – DECARBONISING THE FINAL 20%

Adoption still dependent on government initiatives

Investment in hydrogen technology and capacity has accelerated in the last year, analysts have lifted long-term forecasts and share prices have soared. Yet hydrogen has a long history of not delivering on its potential. Historically its role has been limited by high production costs and the need for new and adapted infrastructure to support distribution and storage. Falling renewable costs are addressing the price premium for green hydrogen, but governments will also need to provide investment and implement policies that explicitly encourage hydrogen adoption and deliver the scale required to drive down costs.

Investing in the hydrogen transition

This report profiles 18 companies that look set to gain from growth in hydrogen demand. Suppliers of electrolysers and fuel cells such as Ballard Power Systems, Ceres Power, ITM Power and Plug Power appear particularly well positioned but other parts of the hydrogen supply chain will also benefit. While most companies profiled do not depend on an acceleration in market growth to be viable, most of these are at an early stage of revenue development and few are consistently profitable. Therefore significant, potentially highly dilutive, additional funding may be required. Equally, those that establish a technology leadership could prove highly attractive acquisition targets for more established industry players.

> Investment in hydrogen technology and capacity has accelerated in the last year

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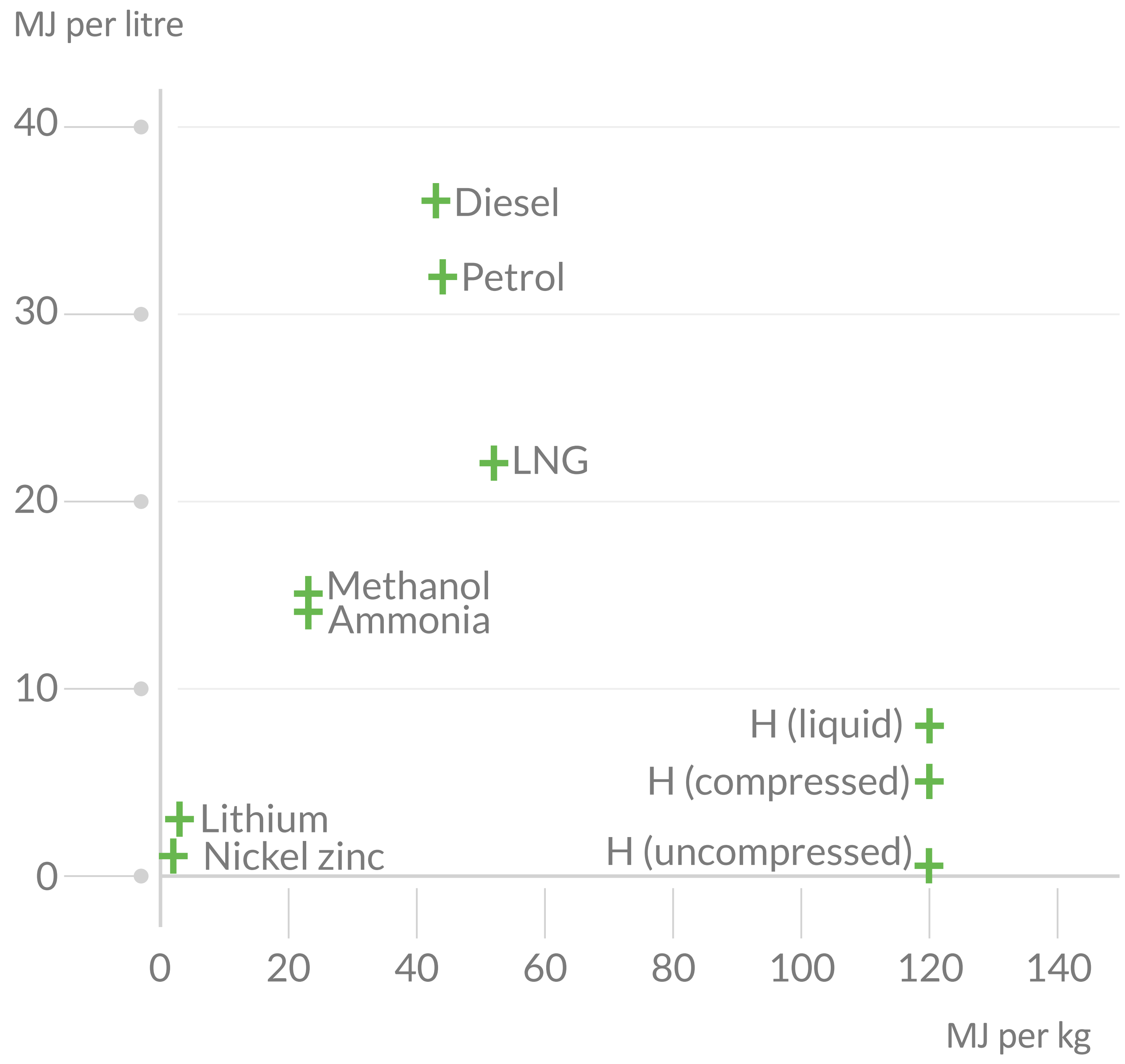
Hydrogen: A unique fuel

Hydrogen has a long history of providing energy for new forms of transport and being touted as the next big thing. It fuelled the first combustion engines and was used in early airships of the 1920s and the lunar rockets of the 1960s. In addition to its role as a transportation fuel, it has potential applications in energy storage, replacing or supplementing natural gas in heating systems and fuelling industrial processes. It has exceptionally high energy per mass, can be transported efficiently and is unique as a high energy fuel in generating no nitrogen oxides or greenhouse gases (GHGs) when burned. Yet its role in the energy system today is peripheral. Currently the vast majority of demand (c 70 Mt/y, 8 million TeraJoules (MTJ) or 2% of global delivered energy) is as a feedstock for oil refineries and manufacture of ammonia for fertilisers.

Exhibit 1: Hydrogen delivers significantly more energy per kg than other energy sources



Source: Edison Investment Research, The Economist DOE; Tran et al.Vaclav Smil Scroder et al; Valera-Medina et al

As it combines readily with other elements, hydrogen does not occur as a stand-alone gas and therefore must be extracted from other sources, typically hydrocarbons such as natural gas, coal and oil, or using electricity to split water (which is a combination of hydrogen and oxygen) in an electrolyser. Like generating electricity from fossil-fuel in a power station, converting natural gas or water to hydrogen consumes energy. Further losses are incurred if the stored hydrogen is used to generate electricity in a fuel cell. These 'roundtrip' losses substantially reduce the useful energy delivered by hydrogen, which means it is relatively expensive (compared to other energy sources) and its widespread use is an inefficient way to supply energy.

The International Energy Agency (IEA) estimates the cheapest way to produce hydrogen at present uses coal and costs c $1 per 1kg, equating to $7 per 1GJ if used directly (rather than converted into electricity).

BUILDING THE HYDROGEN ECONOMY

Using thermal coal as a direct energy source is much cheaper. It supplies 1GJ for c $2.50 on average, while crude oil supplies 1GJ for about $6.50 (both estimates also ignore downstream conversion losses). The IEA suggests the cost of hydrogen produced via renewable electricity is $20 per GJ, substantially above the levelised cost of renewable electricity (ie operating and capital costs amortised over the expected project lifetime).

The choice of feedstock also has environmental implications. Hydrogen production from coal, natural gas and lignite (often described as black, grey or brown hydrogen, respectively) emits GHGs. These feedstocks account for 99% of hydrogen production today and generate 0.8 gigatonnes (Gt) of CO2e emissions. Using electricity produced from fossil fuels to make hydrogen in an electrolyser is particularly emission intensive. Potentially most of the emissions produced can be captured and stored, resulting in blue hydrogen, but Carbon Capture, Utilisation and Storage (CCUS) technologies are relatively unproven at scale and are not cost effective at current carbon prices. Consequently, the focus for governments is on developing 'green' hydrogen made by electrolysers powered by surplus electricity from renewable sources. Later in the note we explore what reductions in costs of renewable electricity cost and carbon pricing are required for green hydrogen to be competitive with other forms of hydrogen.

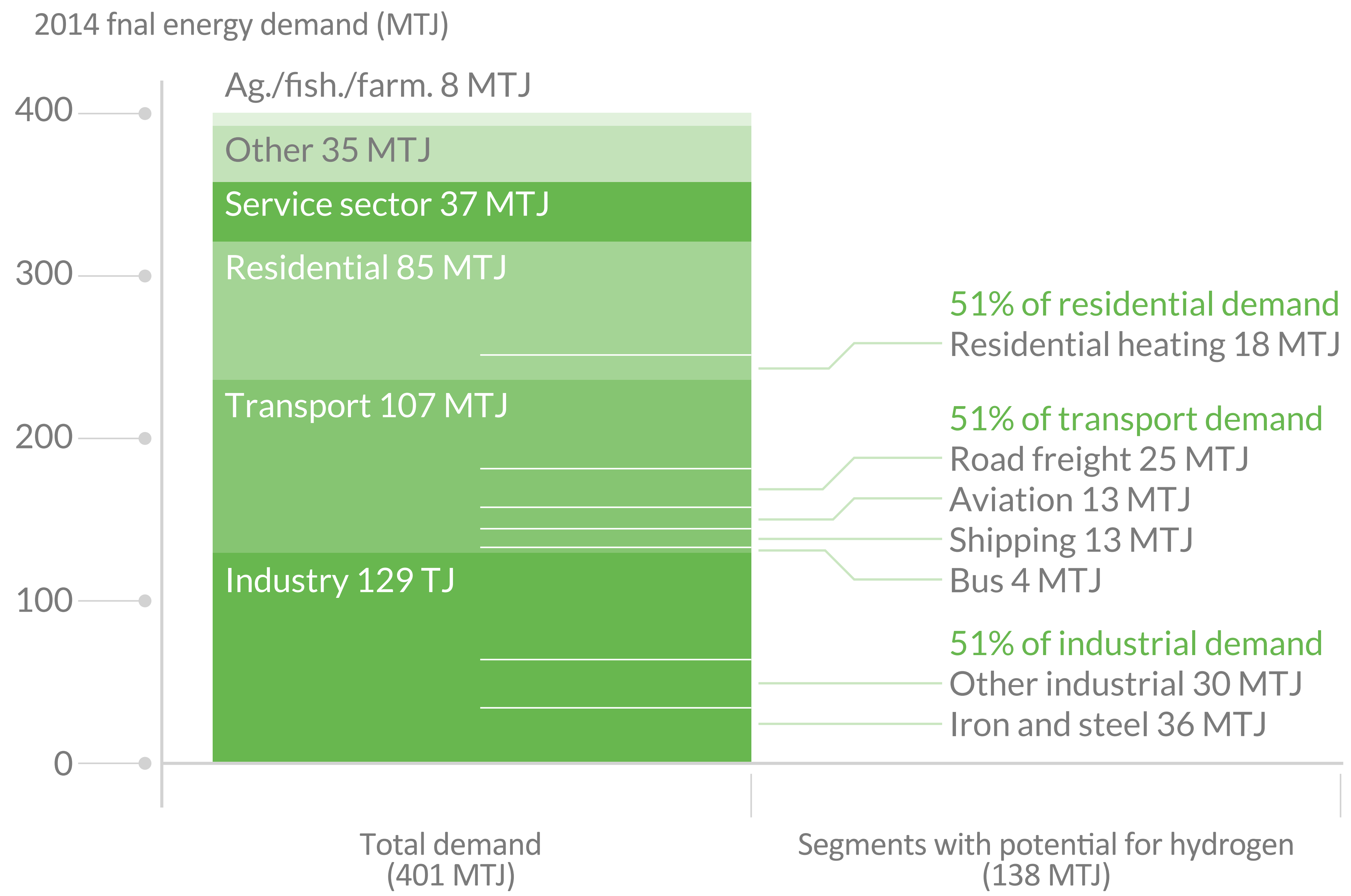
Hydrogen: A key enabler in achieving 'net zero'

Recently introduced legislation looks set to provide the impetus for the growth in green hydrogen. In June 2019 the UK became the first major economy to pass legislation committing to cut GHG emissions to 'net zero' (where any GHGs released are balanced by the amount removed from the atmosphere) by 2050. The EU followed suit with a Climate Law in March 2020, Japan and South Korea recently made similar pledges while China is aiming to be carbon neutral by 2060. At the last count over 70 countries, 14 regions (including five US states), 400 cities and 750 corporations have stated their intention to work towards net zero emissions. At least 20 of these countries, who collectively represent around 70% of global GDP, are proposing hydrogen strategies or roadmaps as key elements of their decarbonisation plans. We believe that the election of Biden in the US is likely to provide additional impetus.

Delivering on these climate change targets requires decarbonising sectors such as steelmaking (9.0% of global energy demand in 2014), residential heating, long-distance road freight (6.2% of demand), shipping (3.2%) and aviation (3.2%), where no obvious, low-cost, convenient alternatives to fossil fuels exist. The weight of the additional batteries needed for long-distances precludes their use for larger electric vehicles. Hydrogen's high energy to mass ratio and low losses during storage and transportation make it a particularly suitable option in some, if not all, of these sectors. Together, these 'hard to abate' sectors account for approximately 142MTJ, or 34%, of energy consumption (equivalent to 998MT of hydrogen).

BUILDING THE HYDROGEN ECONOMY

Exhibit 2: Global energy demand and the potential role of hydrogen than other energy sources



Source: Edison Investment Research, BNEF and IEA

The EU's recently published report, **A hydrogen strategy for a climate-neutral Europe**, suggested hydrogen's share of Europe's energy mix could grow from 2% in 2018 to 13–14% by 2050. The Hydrogen Council (a global CEO-led initiative of over 90 leading energy, transport, industry and investment companies) thinks it could reach 18% by 2050, BNEF predicts 24% globally. Estimates vary but it is difficult to imagine net zero being achieved without significant growth in hydrogen, in our view.

Converting ambition into reality: Policy and economics

To meet these ambitious environmental targets, governments will need to put supportive policies in place. Scale, as the experience of falling renewable energy and battery prices highlights, is the key to sustained falls in production costs. Yet it is difficult to justify the investment in either the R&D or capacity needed to scale-up hydrogen production without greater visibility of demand. Widespread adoption of hydrogen will require co-ordinated investment across the energy industry in new or adapted infrastructure (detailed later in the report). To reduce the need for additional infrastructure and improve the economics, industrial sectors such as steelmaking, chemicals, oil and gas should look to collaborate and co-locate in hubs. Governments will need to play a role in facilitating this co-ordination and establishing sufficient demand certainty in the initial development phase.

BUILDING THE HYDROGEN ECONOMY

Nothing highlights the need for long-term co-ordinated policies to stimulate hydrogen more than the transport sector. According to H2stations.org, at the end of December 2019 there were just 177 hydrogen fuelling stations across Europe (87 of which were in Germany), 177 in Asia (of which 114 were in Japan, 33 in Korea and 27 in China) and only 74 in North America (48 of which were in California). Unlike battery electric vehicles (BEVs), hydrogen fuel cell vehicles cannot be charged at home, but require specialised infrastructure to safely store and release the fuel. The tiny number of fuelling stations significantly limits the number of customers that can consider switching to fuel cell vehicles. This in turn limits the level of investment automotive companies can justify in developing the technology.

Exhibit 3: EU hydrogen roadmap

Phase	Date	Goals
One	2020–2024	Installation of at least 6GW of renewable hydrogen electrolysers and production of <1m tonnes of renewable hydrogen to decarbonise existing hydrogen production and facilitate take up of hydrogen consumption in new end-use applications such as other industrial processes and possibly in heavy-duty transport. Scaling up of electrolyser manufacture. Hydrogen produced close to point-of-use.
Two	2025–2030	Installation of at least 40GW of renewable hydrogen electrolysers and the production of <10m tonnes of renewable hydrogen. Adoption in steel-making, trucks, rail, some maritime transport applications and other transport modes. Use of hydrogen to store energy as part of a balanced renewables-based electricity system. Use of hydrogen to provide heat for residential and commercial buildings in local hydrogen clusters. Planning of pan-European gas grid and establishment of a network of hydrogen refuelling stations.
Three	2031–2050	Massive increase in renewable electricity production a quarter of which might be used for renewable hydrogen production by 2050. Hydrogen and hydrogen-derived synthetic fuels to be adopted more widely across the economy for example in aviation, shipping and industrial and commercial buildings.

Source: Edison Investment Research

BUILDING THE HYDROGEN ECONOMY

The EU hydrogen roadmap (Exhibit 3) sets out how it intends to stimulate the market. It estimates that between 2020 and 2030 investment in electrolysers could range from €24bn to €42bn and investments of up to €65bn will be needed for hydrogen transport, distribution and storage and hydrogen refuelling stations. The report also calls for an enabling regulatory framework (requiring legislation at both a national and European level) plus sustained research into breakthrough technologies and a large-scale infrastructure network. It envisages establishing a series of hydrogen clusters that will become increasingly interconnected. The immediate (Phase 1, 2020–2024) focus of legislation will be technology funding. This will be provided through bodies such as the InvestEU programme and the ETS Innovation Fund and will be directed by bodies such as the European Clean Hydrogen Alliance which includes profiled companies 2G Energy, Ballard, ENGIE EPS, FuelCell Energy, McPhy, Nel Hydrogen, PowerCell and Proton Motor Fuel Cell. The subsequent focus will be the creation of a framework for an open and competitive hydrogen market.

Other governments have also announced their own hydrogen roadmaps. For South Korea the environmental advantages of hydrogen are complemented by a desire for energy security and support for its export economy. The government is heavily subsidising fuel cell deployment to reach its target of obtaining 11% of the nation's primary energy from 'new' (which includes fuel cells) and renewable sources by 2035. It hopes this investment will also create a national fuel cell industry worth US$98bn, employ 175,000 people by 2040 and support Hyundai, which launched its first fuel cell car last year. In the US, while the Trump administration was overtly hostile to investment in green energy and US government-backed R&D funding of hydrogen has halved in the last decade, individual states, primarily California, have adopted more favourable policies and President-elect Biden has a much more positive stance on renewable energy. The UK has yet to announce a co-ordinated plan for hydrogen but is supporting investment in the technology. Construction of ITM Power's 1GW recently completed electrolyser factory, which is the world's largest, was partially funded by grants from the EU and InnovateUK.

Policy initiatives

We believe the introduction of more widespread (and higher) carbon pricing is the policy likely to have the biggest impact on encouraging investment in hydrogen (and other low carbon technologies). At present the cost of fossil-based hydrogen (€1.0/kg in China and €1.5/kg according to the EU hydrogen roadmap) is substantially cheaper than green (€2.5–5.5/kg) and blue (€2/kg) hydrogen. BNEF estimates that, assuming production costs of green hydrogen fall to $1 per kg, a $50 per tonne of carbon dioxide equivalent (tCO_2e) carbon tax would make hydrogen a cost-competitive energy source in steelmaking. At $78 per tCO_2e, green ammonia (a denser fuel formed by combining hydrogen with nitrogen) is a cost-effective fuel source, potentially opening up shipping and aviation segments. At $115 per tCO_2e, hydrogen could provide cheaper electricity than natural gas in peak periods.

Although it is impossible to say how successful policy initiatives will be, the level of support is likely to be the major determinant of how rapidly the market grows. BNEF's forecast of the size of the market by 2050 ranges seven-fold with (from 27MTJ to 195MTJ) with the extent of policy support the main uncertainty. BNEF calculates that subsidies of c $150bn over the next 10 years might be needed to make hydrogen competitive. To put this in context, the IEA estimates that total government spending globally on R&D in hydrogen technology in 2018 was just $724m.

Cost of renewable hydrogen

The other main factor determining the adoption of hydrogen is how quickly the cost of renewable hydrogen falls. As discussed above, hydrogen costs are predominantly driven by the cost of electricity and the capital cost of electrolysers.

Currently the cheapest new renewable energy generation projects have levelised costs of electricity of around $15 per MWh (the average installed price is still closer to $85/MWh). BNEF expects that costs will fall by at least 35% over the next decade.

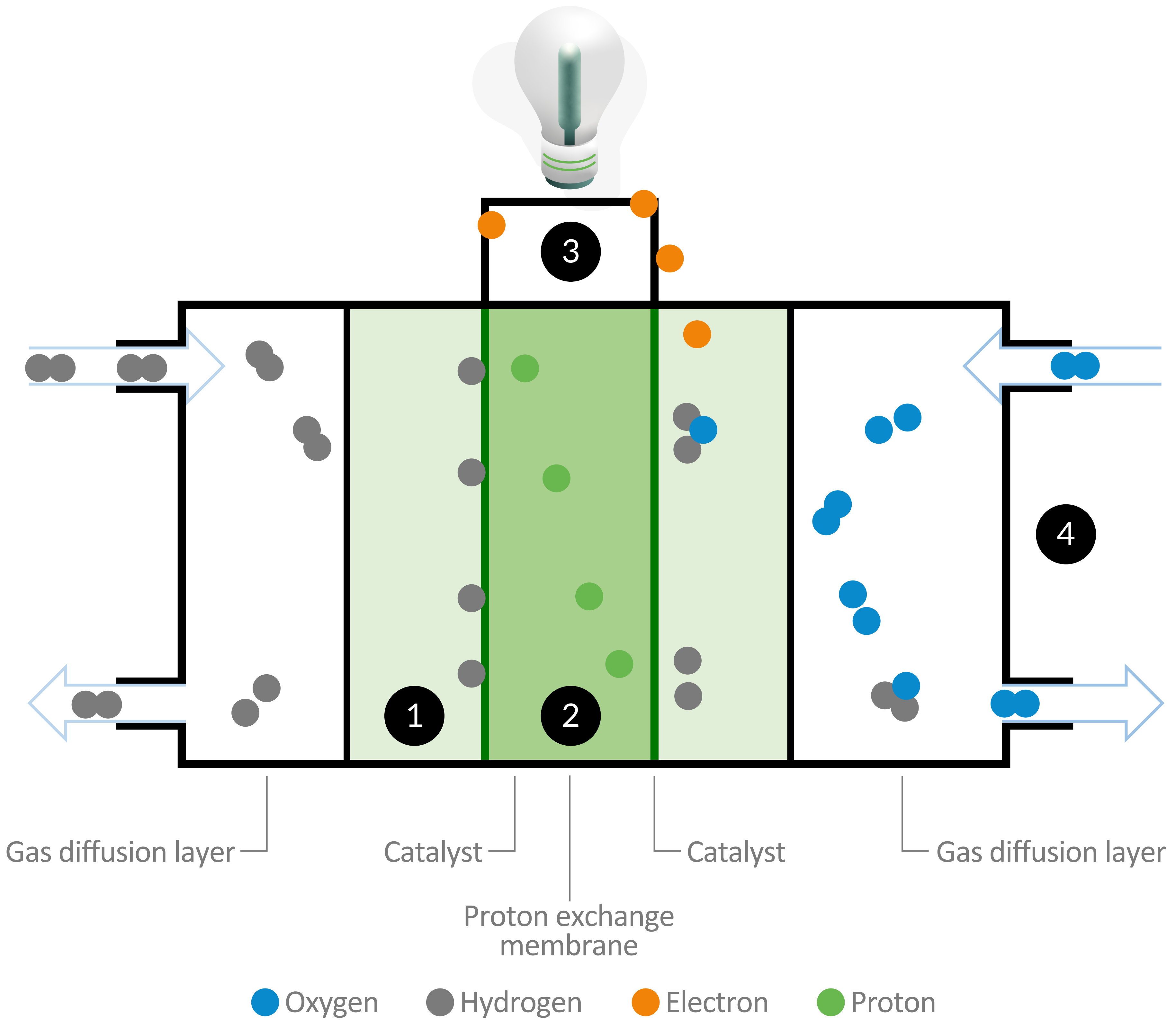
The cost of electrolysers and fuel cells have already fallen 60% in the last 10 years. Improved designs and reduced use of expensive materials as catalysts, especially the platinum used in proton exchange membrane (PEM) technology, which costs $28 per gram, are key to further cost reductions. For example, the average platinum content of the first generation fuel cell cars was c 30 grams (ie $840), while the latest generation uses 70% less (a $588 saving) and alternative technologies such as solid oxide do not require platinum at all. Learning curves, which track the change in costs as a technology scales, suggests the cost of manufacturing hydrogen fuel cells is tracking similar to renewable generation, that is, a 16–21% reduction for each doubling of production volumes. BNEF predicts that the levelised costs of green hydrogen will drop to $1.2–2.6/kg by 2030, the EU is targeting $2/kg. For regions where renewable electricity is cheap, BNEF expects green hydrogen to be cost competitive with fossil-based hydrogen in 2030.

Enabling technology: Electrolysers and fuel cells

The key technology underpinning the transition to a hydrogen economy is the fuel cell, which generates electricity from hydrogen or, if run in reverse as an electrolyser, uses electricity to split water into hydrogen and oxygen. Fuel cells bring about a controlled reaction between hydrogen and oxygen to form water, electrical energy and heat. Because hydrogen and oxygen do not spontaneously react, the electrochemical reaction is effected by bringing them together in the presence of an expensive catalyst such as platinum or heating the gases to a high temperature, in which case the stack (of individual fuel cells), which is where the electrochemical process takes place, must be made from specialist materials. As individual fuel cells produce relatively small amounts of power, they are typically grouped together (often in series) into a fuel cell stack.

BUILDING THE HYDROGEN ECONOMY

Exhibit 4: PEM fuel cell structure



Source: Edison Investment Research.

Note: 1: Hydrogen splits into protons and electrons; 2: protons are conducted through the membrane; 3: electrons are conducted through the electric load; 4: protons, electrons and oxygen combine to produce water.

Fuel cell types

PEM fuel cells are the most widely deployed at present because they operate at relatively low temperatures (c 80˚C, see Exhibit 5). The drawback with PEM systems is that they typically run off pure hydrogen, which is not widely available, limiting deployment to regions where there is an established infrastructure for distributing hydrogen. While they can be adapted to run off natural gas, which is readily available through existing gas networks, this requires adding a complex external reformer that significantly increases costs. PEMs require expensive electrode catalysts such as platinum, which pushes up costs (see left).

Solid oxide fuel cells (SOFCs), which are the second most popular type, are gaining in popularity because the technology offers potentially higher levels of electrical efficiency and does not require a costly platinum catalyst. However, SOFCs depend on high temperatures to get the reaction going. The higher the temperature, the more exotic and more expensive the fuel cell materials become. SOFC systems typically use natural gas, using a simpler, less expensive type of external reformer. Because they are agnostic to fuel type, they are ideal for heating applications as they can run on pure natural gas (whereby carbon dioxide would be emitted), pure hydrogen or a blend of the two. This means they can continue to be used if existing gas pipelines transitions from natural gas to hydrogen as proposed in some roll-out scenarios (see next page).

Exhibit 5: Comparison of fuel cell types

Fuel cell type	000s of units shipped*	MW shipped*	Platinum catalyst	Operating temp	Electrical efficiency	Applications	Companies
Proton exchange membrane fuel cell (PEMFC)	44.1	934.2	Yes	80°C	40–60% hydrogen fuel, c 35% natural gas	Transport, portable, stationary residential and commercial/industrial	Altergy Systems, Ballard, Cummins (Hydrogenics), Doosan, Horizon Fuel Cell Technologies, Hyster-Yale (Nuvera), ITM Power, Nedstack, Plug Power, PowerCell, SFC Energy
SOFC	22.8	78.1		550–1,000°C	45–62%	Stationary utilities, commercial/ industrial and residential, auxiliary power units, portable military	Aisin Seiki, Bloom, Ceres Power, FuelCell Energy, Veissmann (Hexis), Redox Power Systems. SOLIDPower, Sunfire (Staxera)r
Direct methanol fuel cell (DMFC)	3.7	0.4	Yes	50–120°C	<40%	Portable consumer/military, auxiliary power units	Ballard, SFC Energy
Alkaline fuel cell(AFC)	0.0	0.0		90–100°C	60–70%	Stationary industrial	AFC Energy, GenCell
Phosphoric acid fuel cell (PAFC)	0.3**	106.7	Yes	100–250°C	36–42%	Stationary utilities, commercial/ industrial, auxiliary power units	Doosan
Molten carbonate fuel cell (MCFC)	0.0**	10.2		600–700°C	50–60%	Stationary utilities, commercial/ industrial	FuelCell Energy

Source: E4tech, Fuel Cells 2000, LG Fuel Cell Systems, Edison Investment Research.
Note: *2019 estimates; **PAFC and MCFC systems are very high-output power, so small numbers of units shipped equate to high generation capacities.

BUILDING THE HYDROGEN ECONOMY

The other types of fuel cells are not very common. Direct methanol fuel cells are deployed in drones and portable applications such as powering military communications systems where an ultra-compact solution is required. Methanol is a high-density fuel (see Exhibit 1) that carries the hydrogen atoms into the fuel cell where they react. AFC Energy is promoting alkaline fuel-cell technology that it is positioning for large baseload industrial applications longer-term. Doosan has developed a phosphoric acid-based technology that is suitable for large-scale applications, as is FuelCell Energy's molten carbonate technology. Both PEM and alkaline electrolysers are commonly available.

Hydrogen production and distribution

The infrastructure needed to create, store and distribute hydrogen is also essential for the development of the market. In the initial phase of the EU's roadmap (Exhibit 3), hydrogen will be generated close to where it is used by multiple clients on industrial parks or hubs. Such clusters are already forming, for example in Fukushima in Japan, Ulsan in South Korea, San Pedro Bay Ports in California, Pilbara in Western Australia and Hebei, Hunan and Shandong in China. Ports around the North Sea appear particularly active with projects such as Humber Zero and the Tees Valley in the UK and H-Vision Rotterdam and NorthH2 in the Netherlands. These sites could potentially expand to form hubs where electricity from wind farms in the North Sea could generate hydrogen to use in local petrochemical and steel industries. The IEA estimates that North Sea generation capacity is expected to exceed 50GW by 2030, roughly two-thirds the current total electricity generation capacity in the UK.

Beyond these hubs, the economics of hydrogen distribution get more challenging. Hydrogen flows faster than natural gas, making it potentially suitable for distribution through pipelines, but its smaller molecules makes it much leakier. Upgrades to the pipeline network will be needed. The **European Hydrogen Backbone Report** published in July 2020 estimates a total investment of €27–64bn would be required by 2040 to create a 23,000km-long network across western Europe. Three-quarters of this network would use existing natural gas pipelines that have been converted to transporting hydrogen, the remainder would require new stretches of pipeline. The report estimates that this if this network was created, transport of hydrogen would account for only a small part of total hydrogen costs for end users with an estimated levelised cost of between €0.09–0.17 per kg of hydrogen per 1000km^2 compared with future production costs of €1–2/kg for green and blue hydrogen. The report notes that the capital cost of a newly built dedicated hydrogen pipeline is likely to be 10–50% more expensive than its natural gas counterparts and that existing natural gas pipelines need relatively little modification to transport pure hydrogen, such that the capital cost of repurposing existing pipelines is likely to be 10–25% that of building new dedicated hydrogen pipelines.

Hydrogen's low density also makes it expensive to store. BNEF estimates that for hydrogen to displace natural gas entirely would require three to four times the existing storage infrastructure at a cost of over $600bn. While hydrogen can be compressed, the costs of this can exceed production costs and the availability of geological storage options such as salt caverns, which are cheaper, is limited by geography.

HYDROGEN DEMAND BY SECTOR

While transportation applications, particularly passenger cars, have received most attention historically, we believe other sectors such as steelmaking, residential heating, road freight, shipping and aviation, where no obvious, low-cost, convenient alternatives to fossil fuels exist, will be those where hydrogen will be more widely adopted. We see scope shorter term, before the widespread availability of green hydrogen, for fuels cells to be used in off-grid generation, distributed generation and back-up power. As green hydrogen becomes more widely available, we see scope for hydrogen storage and fuel cells to provide a complementary energy storage mechanism to battery energy storage.

Industrial processes

The industrial sector (including chemicals, steel, aluminium and paper manufacturing) accounts for 24% of CO2 emissions globally and is considered to be the hardest to decarbonise. Hydrogen already plays an important role in chemicals as a feedstock and (to a much lesser extent) in steel. In total, 33% of the hydrogen produced globally each year is used in oil refining, 27% is used for ammonia synthesis (predominantly for fertiliser production) and 11% is used to make methanol (a precursor of many polymers). The remainder is used in a variety of industrial processes including the production of carbon steels, special metals and semiconductors.

As hydrogen is a feedstock in chemical processes, it cannot be replaced by electricity for these applications. Assuming hydrogen can be made cost effectively with electrolysers using green electricity (as opposed to fossil fuels) it should be relatively straightforward to decarbonise this production over time.

Steel represents a significant growth opportunity for hydrogen. Steel manufacturing, particularly primary steel making with coal and iron ore in a blast furnace, is highly emission intensive. The IEA estimates steel emits 3.6 GtCO2e annually or 1.9 tCO2e per tonne of steel produced. Shifting from blast furnace production to Direct Reduced Iron (DRI) using gas instead of metallurgical coal can significantly cut emissions. Natural gas is the most economic fuel to use but DRI facilities can be converted to use hydrogen at little extra capital cost. Critically, if renewables are used to generate both the hydrogen used in the DRI and the electricity supplied to the electric arc furnace (EAF), the emission intensity can be reduced 95% to 0.1tCO2e per tonne.

Development of DRI-EAF with hydrogen is still at early stages. Thyssenkrupp stated in June 2020 that it aims to produce c 0.05Mt of zero emissions steel per year using hydrogen in its blast furnaces by 2022 and HYBRIT, a green steel joint venture between Swedish steelmaker SSAB, state-owned utility Vattenfall and state-owned mining company LKAB, started test operations at a pilot plant in August 2020. SSAB is aiming for commercial fossil-free steel production by 2026. If three-quarters of DRI-EAF production is fuelled by green hydrogen by 2050 (implying annual demand for 45Mt of hydrogen), the shift to DRI-EAF could reduce emissions by 1.2MtCO2e.

HYDROGEN DEMAND BY SECTOR

Economics are the key determinant of adoption in this highly cost-competitive sector. The EU estimates that it costs €160–200m in total to convert a typical (0.4m tonnes of steel per year) integrated steel plant coming to end of its life to DRI using hydrogen. Material Economics estimates DRI-EAF using hydrogen in Europe only becomes cheaper than blast furnace production with a carbon price of c $60 per tonne and electricity below $47 per MWh (EU wholesale prices were c $45 in 2019); with no carbon price, electricity has to be below $15 per MWh.

Heating

According to the IEA, heating and hot water accounts for 60–80% of final energy consumption in residential and commercial buildings across Europe. Decarbonising heat has proved difficult, in part because heating demand varies by season and time of day and only fossil heating fuel can provide this flexibility at this scale without investing in energy storage Improved insulation, thermal storage and more efficient heaters could potentially reduce energy demand. However, a study by the Policy Exchange in 2016 predicted this could reduce consumption by 20% by 2050, showing it is not enough on its own.

A fuel cell for residential or commercial heating can be an extremely efficient use of hydrogen or natural gas. Integrating it into a combined heat and power system (CHP), the heat produced as a by-product of the conversion process can provide hot water for washing or central heating, increasing the energy efficiency to 80–95%. There has already been significant uptake of fuel cells for residential micro-CHP applications in Japan. FuelCellWorks estimates that as of April 2019 there were over 305,000 residential CHP systems using fuel cells in Japan under the government-subsidised ENE-FARM project. Despite impressive growth, the project appears unlikely to achieve the government target of 1.4m systems deployed by 2020 and 5.3m by 2030.

Exhibit 6:
Osaka Gas system for ENE-FARM project – power generation unit and back-up heat source unit

Source: Osaka Gas

Exhibit 7:
Osaka Gas system for ENE-FARM project – bathroom remote controller

Source: Osaka Gas

HYDROGEN DEMAND BY SECTOR

Although the current units are using hydrogen derived from fossil fuel or natural gas, the ENE-FARM project still makes the transition to a hydrogen economy more likely. Economies of scale have brought down the average retail price (without subsidy) from 3.0m yen (£22k) in 2009 to 1.1m yen (£8k) in 2017. The price for PEM fuel cells is now low enough not to qualify for subsidies, although SOFC prices still have a way to fall. In addition, the adoption of units has raised awareness of the advantages of the technology. Osaka Gas states that its most recent domestic power-generation unit, the solid oxide ENE-FARM S, reduces annual lighting and heating expenses by about 121,000 yen (£900) and CO_2 emissions by about 2.3 tons compared with a conventional hot-water supply and heating system. The unit has a suggested retail price of 1,320,000 yen (£10k) (excluding tax and optional heat source unit) and has an expected service life of 12 years.

Transportation

According to the IEA, transport accounted for 24% of emissions in 2018 globally. To reach net zero, adoption of battery, fuel cell or biofuel powered vehicles must reach close to 100% by 2050. However, we think hydrogen is unlikely to play a significant role in passenger car road transport, which accounts for almost half the energy consumed by transport, except indirectly as a mechanism for providing fast charging stations. BEVs are substantially ahead of fuel cell electric vehicles (FCEVs) in terms of both deployment and cost maturity (see our **note on batteries for electric vehicles**). A Toyota Mirai or Hyundai ix35 costs roughly three times a Renault Zoe or Nissan Leaf. Further advances in battery density (kWh/kg) and cost are expected to see BEV lifecycle cost ownership outpace conventional cars by the mid-2020s.

Nevertheless, there are other transport segments where hydrogen is likely to deliver a more viable alternative to fossil fuel-based vehicles than batteries. According to *Driving Change: How Hydrogen Can Fuel A Transport Revolution* from the Centre for Policy Studies (June 2020), 'If the UK is to succeed in complying with its ambitions for decarbonising transport, and cleaner air, another solution will be needed for heavier forms of transport. And the most obvious contender – indeed, the only realistic one – is hydrogen'. The 2019 McKinsey report *Roadmap to a US Hydrogen Economy – Reducing emissions and driving growth across the nation* notes 'On a total cost of ownership basis, FCEVs already cost less than BEVs as forklifts and in fast-charge applications above 60 kW'.

Annual sales of fuel cells for transportation applications (which includes on-board heat as well as power generation) have risen from 113.6MW in 2015 to an estimated 907.8MW in 2019 (source: e4tech: The Fuel Cell Industry Review 2019).

HYDROGEN DEMAND BY SECTOR

Buses, trucks and delivery vehicles

The practical range and payload of a BEV is limited by an effect called process mass compounding, where for every kilogram of battery mass added to increase range, the size and weight of other vehicle components must also be increased to maintain the performance and safety of the vehicle and additional batteries are required to shift the additional mass. Extending the range of an FCEV does require the hydrogen tank to be enlarged but this adds significantly less weight per kWh of stored energy. CE Thomas's Sustainable Transportation Options for the 21st Century and Beyond, published in 2015, calculates that even if a Nissan Leaf were to fill all of its 24ft3 of cargo space with Li-ion batteries, it would only have a range of around 350km. A similar-sized fuel cell car would be able to travel 500km and still have two-thirds of its cargo space unused.

This effect is even more significant for heavier vehicles such as delivery trucks or buses. Achim Jüchter of DHL gave a presentation at the Plug Power Symposium in September 2019, which noted that fuel cell-powered delivery vans had almost twice the range of BEVs. He commented that the 200km range achievable for a BEV was insufficient for a delivery truck because a fleet manager would not know until the day whether a vehicle would be required to travel 50km or 500km. While the purchase price of a fuel cell truck is higher than that of a comparable diesel vehicle, Jüchter calculated the total cost of ownership of the two types is similar. This is because the operating and maintenance costs of hydrogen trucks are lower and the service life is longer.

Range is also an issue for buses, even those covering short routes in urban areas. Depending on topography and weather, battery-powered buses have a range of c 360km per charge. This means they have to re-charge about once a day on a shorter route in a dense city. Standard depot-based charging systems cost around $50,000, en-route ones can be two or three times that, excluding the cost of the land. This all adds to the total cost of ownership. Fuel cells can improve the performance of electric buses by generating onboard power from hydrogen to top up the batteries. Increasingly, bus manufacturers offer fuel cell buses to transit agencies as a standard electric propulsion option. Fuel cell manufacture Ballard Power (see below) provides power to more than 1,000 fuel cell electric buses deployed globally.

Exhibit 8: Transit buses in California – to be 100% zero-emission by 2040

Source: Ballard Power Systems

HYDROGEN DEMAND BY SECTOR

Refuelling time is also an area where FCEV score more highly than BEVs. Achim Jüchter's presentation also noted that FCEVs can be fuelled eight to 10 times faster. This has significant economic implications for fleets of buses or delivery trucks that are out of action while they are being charged. In densely packed urban centres, movements inside bus depots have to be tightly orchestrated to accommodate charging. Bus depots often need costly and time-consuming grid upgrades to charge electric fleets. The journal Mass Transit calculated that a bus carrying 320kWh of energy would need recharging with approximately 250kWh of energy over a two- to four-hour period depending on chemistry. Most buses are out of service at night for six to eight hours. A 100-bus fleet would therefore require a minimum power requirement of 5MW, ideally 10–15MW to allow adequate flexibility in charge routines. The alternative would be to distribute 14–16 fast-charge stations along bus routes. Neither option is either simple to execute or cheap.

Maritime

The shipping industry currently uses diesel engines almost exclusively at present, with ocean-going vessels using either heavy fuel oil or marine diesel and inland waterway vessels using commercial diesel fuel. The International Maritime Organisation (IMO) has set a target to at least halve the emissions of GHG from commercial ships by 2050. Considering the long lifetime of ships, this requires zero-emission vessels to be available as early as 2030. The potential switch to fuel cells brings other environmental benefits in addition to a reduction in GHG emissions. The IMO has imposed an 80% reduction in nitrogen oxide (NOx) emissions for the North American and US Caribbean emission control areas, applicable for ships whose keels are laid from January 2016. It is considering regulating particulate (soot) emissions. Deployment of fuel cells would give a reduction in both NOx and black soot emissions.

Fuel cells are being tested as energy providers for the onboard power supply on vessels. The functional capability of fuel cell modules has been proven under maritime conditions; however, using fuel cells for ship propulsion is still at an early design or trial phase. In January 2020 Norway's Havyard Group contacted PowerCell Sweden (see below) to develop the design and technical specifications for a zero-emissions fuel cell system that can be installed on one of its new ships being completed for the Norwegian coastal trade. This will be the most powerful maritime fuel cell system ever built. The new hydrogen fuel cells are expected to be retrofitted to a Havila Kystruten vessel before the end of 2022. Given the volume of hydrogen that would need to be stored for transoceanic journeys, fuel cell vessels may use methanol or ammonia, which have much higher energy densities (by volume), as their hydrogen source (although as shown in Exhibit 1, pure hydrogen has higher specific energy, or energy per unit mass, than methanol or ammonia).

HYDROGEN DEMAND BY SECTOR

Rail

It is not economic for train operators to electrify routes that are less well used, especially if bridges and tunnels needs to be modified to accommodate the catenary cables. Fuel cells represent a mechanism for eliminating diesel powered trains from networks. For example, Transport Scotland intends to decarbonise its rail network by 2035. In February 2020 it announced a project to develop a fuel-cell powered train that can be used on non-electrified routes that are too long for battery-powered trains.

Materials handling

Materials handling is a very small market compared with other transportation sectors, but significant because it is one of the first to adopt fuel cell technology and has done so without the need for subsidies. This is because a forklift is out of action while it is being recharged or refuelled and recharging a hydrogen fork-lift truck in a distribution centre takes one to three minutes compared with

Exhibit 9: Hydrogen refuelling for fuel cell forklifts

Source: Plug Power

a 20-minute minimum for battery charging. In addition, the refuelling infrastructure for hydrogen uses space more efficiently than battery-charging facilities, which require rotating multiple batteries and storing those that are charging, so fuel cell adoption allows companies to maximise their operational space. Walmart operates more than 2,000 forklifts powered by Plug Power's fuel cells across multiple facilities in the US. Plug Power has also supplied fuel cell systems powering over 100 forklifts to French company Carrefour.

Power generation

Decarbonisation of the electric power sector is well underway; substantial progress has been made already, particularly compared with the transportation, heat or industrial sectors. **The World Energy Outlook** published in October 2020 by the IEA states that renewable electricity accounted for more than a quarter of total power generation. The IEA's net zero scenario, which is consistent with the policy objectives of the EU and other countries, predicts a fivefold increase in solar capacity by 2030. In a grid increasingly supplied by renewables, fuel cells are likely to be deployed as a complementary energy-storage mechanism to batteries for off-grid generation, distributed generation and back-up power. However, deployment is starting from a very low base. Global annual sales of fuel cells for stationary power-generation applications

HYDROGEN DEMAND BY SECTOR

(which includes heat and power generation) have grown from 148MW in 2014 to an estimated 221MW in 2019 (an 8% CAGR, source: e4tech, The Fuel Cell Industry Review 2019) but this is less than one-hundredth of 1% total generation capacity in the US.

Balancing variable output from wind and solar-power generation

Exhibit 10: 2G Energy installation in Haßfurter Hafen

Source: 2G Energy

The inherent intermittency of wind and solar power becomes increasingly problematic as the proportion of electricity generated from these sources increases. Utilities seeking to reach net zero can scale renewable capacity so it is sufficiently large enough to nearly meet demand even in prolonged lulls in generation and complement this with investment in storage capacity to cover any shortfall. Additionally, the intermittent generation can be complemented with generation that can be turned on and off as required, ideally from a low carbon source.

Hydrogen can play an important role in balancing out the intermittency of a low-carbon power network. Surplus electricity from renewable sources can be converted to hydrogen, stored for weeks or months until required, then used to power fuel cells or specially adapted gas-powered generators. For example, Städtische Betriebe Haßfurt recently purchased a hydrogen-fuelled CHP gas engine from 2G Energy to do exactly this (see profile below). The hydrogen will be produced in a power-to-gas plant in Haßfurter Hafen using surplus electricity from a nearby wind farm to electrolyse the water. The electricity generated will be fed into the city's grid and the heat taken to a neighbouring malting plant, a school and a kindergarten via a heating network.

Using hydrogen extensively for energy storage is unlikely to be a cost-effective strategy. As highlighted previously, its round-trip efficiency is lower than other storage technologies. Even the most efficient electrolysers and fuel cells give a round-trip efficiency of c 40% compared with c 80% for a battery. This inherently makes electricity delivered from hydrogen storage substantially more expensive even without considering the relative capital costs. Yet batteries suffer from leakage and the cost of hydrogen storage scales more slowly with capacity, which makes batteries poor for providing seasonal storage. The role of hydrogen in power generation therefore is likely to be limited to periods of extreme peak demand and supply shortfall during the winter months.

HYDROGEN DEMAND BY SECTOR

An alternative way hydrogen can be used to balance a low-carbon power system is using fossil fuel combined with CCUS to generate the hydrogen. While not an ideal solution because not all GHGs can be captured, using blue hydrogen is potentially more efficient than building a large fleet of gas power stations to cover short periods of supply shortfalls and therefore have very low utilisation. Moreover, the fuel cells deployed will be able to switch to using renewable hydrogen as it becomes available.

A further option here is using biogas. Biogas is a mixture of methane and carbon dioxide produced from materials including agricultural waste, sewage, food waste and plant materials generated as by-products from industrial processes, such as extracting sugar from cane. It can be used in specially adapted gas turbine engines such as those manufactured by 2G Energy. It can also be used in molten carbonate and SOFCs, although not the more common PEM fuel cells that require very high purity hydrogen. For example, FuelCell Energy's first 250kW system that was located at a Kirin Brewery in Japan operated on digester gas. The potential for biogas may be limited by concerns about the sustainability of supply and competing demand from other sectors. Using biogas is regarded as an environmentally friendly option because otherwise the source materials would go to landfill, where they would decompose to create methane,

Onsite energy generation

Fuel cell technology is already being deployed for power-generation applications even though renewable hydrogen is not yet widely available. The technology is typically deployed as a non-polluting alternative to diesel engines for off-grid applications such as construction sites and telecommunications towers and for back-up applications, particularly in urban areas with strict emission limits. Data centres are another key target sector as the costs of outages are potentially enormous and operators, keen to promote their green credentials, are increasingly looking to replace or upgrade diesel back-up generators. The need for non-polluting alternatives may become more pressing if the suspected link between the severity of COVID-19 and air pollution is proven.

Fuel cells running from natural gas are also being used in distributed generation models where they can improve the energy efficiency of a network and potentially the economics. During 2019 Ceres Powers' SteelCell solid oxide technology achieved a net efficiency of 60% and in December 2018, German research institute Forschungszentrum Jülich recorded an efficiency of 62% for its solid oxide technology. These levels are close to the 64% net efficiency claimed by GE and MHPS for their large turbine engines powered by natural gas used in centralised power stations. Moreover, when comparing a centralised power generation system with a distributed one, the amount of energy dissipated during transmission over the grid, c 8% of the initial energy content in the gas, needs to be included in the comparison, pushing fuel cell technology ahead. We note that deploying fuel cells running on natural gas is supportive of the transition

HYDROGEN DEMAND BY SECTOR

to a hydrogen economy because once the fuels are in place they can begin to run on green hydrogen once it becomes widely available.

In situations where subsidies are available, fuel cells can already be a cheaper source of electricity than the grid. This is because of the differential in price between natural gas and electricity, which is known as the spark gap. For example, in 2015 Advanced Sterilization Products, which was formerly a Johnson & Johnson franchise, installed 500kW fuel cells from Bloom Energy together with uninterruptible power modules to provide reliable and predictably priced power even through grid outages. The installation was expected to provide 25% of the site's daily energy requirements and generate an estimated $10m in savings over the 20-year life of the project. This cost saving met the 15% IRR criteria required to qualify for Johnson & Johnson's carbon reduction funding programme.

INVESTING IN THE HYDROGEN ECONOMY: COMPANY PROFILES

The companies that will most directly benefit from the transition to hydrogen are those producing fuel cells and electrolysers. These companies form the majority of stocks profiled in the upcoming section. We also profile other stocks that are likely to benefit from the transition because they are involved in the production of hydrogen in some way.

Exhibit 11: Key data for profiled stocks

Name	YTD perf (%)	Market cap ($m)	Sales last fiscal year ($m)	EBIT margin last fiscal year (%)	Net assets last fiscal year ($m)	Net debt last fiscal year ($m)	Pure-play hydrogen
2G Energy	93.3	458.1	276.6	6.6	80.2	(0.2)	No
AFC Energy	109.8	308.7	0.0	N/A!	3.7	(1.2)	Yes
Ballard Power Systems	191.6	5,427.2	106.3	(25.8)	250.3	(128.0)	Yes
Bloom Energy	243.1	4,259.7	786.2	3.7	(168.3)	891.1	Yes
Ceres Power Holdings	216.8	1,894.4	24.6	(53.3)	166.6	(134.1)	Yes
Doosan Fuel Cell	480.5	3,189.3	194.6	8.8	146.8	(45.9)	Yes
ENGIE EPS	46.1	198.4	24.1	(74.7)	2.8	9.6	No
Everfuel	254.5	585.9	N/A	N/A	1.1	N/A	Yes
Fuelcell Energy	286.1	2,855.6	60.8	(76.7)	75.7	119.8	Yes
ITM Power	415.7	2,687.0	4.3	(629.3)	72.5	(43.4)	Yes
McPhy Energy	836.7	1,153.3	13.6	(53.5)	19.8	(12.0)	Yes
Nel Hydrogen	179.8	3,835.4	51.9	(49.0)	184.7	(34.8)	Yes
Plug Power	730.4	11,613.7	236.8	(21.1)	135.8	82.9	Yes
Powercell Sweden	75.7	1,650.2	7.4	670.8	62.2	(39.9)	Yes
Powerhouse Energy Group	520.3	163.7	NULL	N/A!	NULL	(0.1)	No
Pressure Technologies	(47.7)	15.5	36.8	N/A	41.7	14.8	No
Proton Motor Power Systems	200.0	672.1	NULL	N/A	NULL	84.7	Yes
SFC Energy	52.9	257.2	68.5	(2.2)	47.1	(7.4)	No

Source: Refinitiv. Note: Priced at 30 November 2020.

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Although all the companies profiled will benefit from growth in hydrogen adoption, most are not dependent on it happening to be viable. This may be because they are involved in other activities. For example, 2G Energy produces CHP systems that run off natural gas or biogas and hydrogen. Alternatively, some are focused on niches where fuel cells are already a viable option. These include back-up power for data centres, materials handling, motive power for buses and trucks, replacements for diesel gensets in environments where NOx emissions are tightly controlled and rapid charging of electric vehicles. Many of the companies profiled are at an early stage of revenue development and few are consistently profitable (see Exhibit 11). Many will require significant additional funding, which may be highly dilutive for existing shareholders. Much of this additional funding so far has been from major players from outside the industry who have realised that fuel cell technology will help them address the challenges presented by the potential phasing out of fossil fuels. Some of these developments are summarised in Exhibit 12.

Exhibit 12: Recent investment from industrial partners

Hydrogen specialist	Partner	Date	Transaction
Ballard Power	Weichai Power (Chinese manufacturer of diesel engines used in vehicles, marine vessels and power generation	2019	Additional investments in manufacturing JV in China
Ceres Power	Bosch	2018	£9m equity investment
Ceres Power	Bosch	2020	£38m equity investment
Ceres Power	Weichai Power	2018	Investment of a further £27.8m in addition to its previous £20.3m investment.
Hydrogenics	Cummins (US manufacturer of engines, filtration and power generation products)	2019	Acquisition for c US$290m
ITM Power	Linde (industrial gases)	2019	£38m investment
ITM Power	Snam (international energy infrastructure operator)	2020	£30m investment
Michelin	Faurecia (automotive technology provider)	2019	Formation of 50/50 joint venture to make fuel cell systems for light vehicles, utility vehicles, trucks and other applications. Michelin and Faurecia to initially invest €140m.
Nikola (fuel cell truck manufacturer)	CNH Industrial (owner of Italian industrial vehicle manufacturer IVECO)	2019	Investment of US$250m
Nikola	Robert Bosch and Hanwha Group (solar panel manufacturer)	2019	Combined investment of US$230m in development of fuel-cell stacks for stationary power applications. Bosch started initial low-volume production of pilot systems in late 2019.
Powercell	Bosch		Co-development of PEM technology with the intention of bringing the new fuel-cell stacks to market by 2022

Source: Edison Investment Research

INVESTING IN THE HYDROGEN ECONOMY: COMPANY PROFILES

2G Energy (2GB:GR)

2G Energy is an international manufacturer of highly efficient CHP plants that are deployed in agricultural, residential, commercial and industrial premises and by public energy utilities and municipal and local government authorities. Historically its systems have been powered by biogas or natural gas, but it has developed variants that are suitable for operation with hydrogen. These may play an important role in the development of the hydrogen economy because the design of 2G's systems means the same equipment can run on either natural gas or hydrogen, with the conversion from one gas to the other taking place at a customer's site.

2G Energy's first CHP system powered entirely by hydrogen was installed in Berlin in 2012. The company's hydrogen initiative was given a boost in September 2018 with an order for a project realised together with the public utility of Haßfurt where 2G Energy's CHP system is fuelled by hydrogen produced by a power-to-gas system that uses surplus electricity generated by a nearby wind park. In July 2019, 2G Energy received an order from Siemens for a similar system for installation in one of the world's largest solar parks, which is situated on the Arabian Peninsula. The installation is a pilot project to test how surplus electricity generated by the solar park can be used in an electrolyser to create hydrogen, which can be stored and either used to generate electricity in 2G Energy's CHP system or utilised in transportation or industrial applications.

In February 2020 APEX Energy Teterow in Rostock-Laage commissioned 2G to supply a highly innovative hydrogen CHP plant that will run on hydrogen produced in an electrolyser powered by electricity from photovoltaic and wind energy plants. 2G's hydrogen cogeneration unit with electrical output of 115kW (129kW thermal) is scheduled to go into operation later in 2020, providing electricity and heat for use at the site. The site, which is effectively a hydrogen park, will house two hotels, production facilities for electrolysers a nd fuel cells and a hydrogen-filling station capable of supplying 200 cars and more than 40 buses.

AFC Energy (AFC:LN)

AFC Energy is commercialising a scalable alkaline fuel cell system (one with an alkaline liquid as the electrolyte) to provide clean energy for stationary on- and off-grid applications. For over a decade it has been refining the technology originally used on NASA space missions and in submarines to give a low lifetime cost of ownership. It has reduced the costs of the original alkaline technology by working at lower temperatures and pressures and adopting manufacturing technologies deployed in other industries such as using injection-moulded plastic plates for regulating the flow of hydrogen. During FY19 AFC appointed key suppliers ahead of being able to move to mass production in calendar year 2020.

AFC is focused on niches where the relative cost of fuel cells compared with conventional power generation is not a barrier. The first is the electric vehicle (EV) charging market as existing electric grids in Europe are not expected to have the capacity to cope with charging the anticipated number of EVs.

Having demonstrated its prototype EV charger based on fuel-cell technology, a world first, AFC signed a collaboration agreement in April 2019 with Rolec Services, Europe's largest EV charge-point manufacture to integrate the technology into the latter's charge point infrastructure. This was demonstrated on a roadshow across the UK during February in which a Tesla Model S 75D drove the 500-mile journey from AFC's HQ in Surrey to Dundee, powered entirely with charge from AFC's EV charger unit. The second is the off-grid power genset market. Together with its partner MSP Technologies, AFC demoed a hybrid hydrogen generator system in February 2020 to UK private-sector construction companies. In June 2020 AFC announced a collaboration with ACCIONA, a Spanish conglomerate involved in construction and renewable energy projects internationally, to field trial AFC Energy's fuel cell platform as part of a strategy to decarbonise construction sites. Large baseload industrial applications where hydrogen is vented, thus generating fuel for free, which changes production economics, remain a longer-term target.

Although the technology has reached a point where it is suitable for deployment in commercial products, which is the priority, AFC is continuing with development work so it can broaden the addressable market. AFC is integrating third-party ammonia crackers with its alkaline fuel cell technology to create fuel cell systems that can run off liquid ammonia. In addition, AFC is working with UK-based HiiROC, which is developing a technique for producing hydrogen from methane or biomethane without emitting GHGs.

In November 2019 AFC demonstrated that an alkaline fuel cell using its proprietary anion exchange membrane technology can achieve similar current densities to those achievable with PEM, but without needing high purity hydrogen as fuel or requiring expensive platinum-based catalysts in the membrane. This potentially opens up e-mobility applications. The membrane could also be used to make more cost-effective electrolysers, in water desalination and in Redox flow batteries. It has recently scaled up and validated the membrane in a commercial sized fuel cell and provided membrane samples for comparative validation to commercial and research institutions in Europe with an emphasis on alkaline water electrolysis applications

Ballard Power Systems (BLDP:US)

Ballard is headquartered in Canada with research, technology and product development, testing, manufacturing and service facilities in British Columbia. It has a sales, assembly, service and R&D facility in Denmark, focused on European customers along with backup power and products for the marine segment and an office in China. It also has a 49% stake in a JV with **Weichai Power** (**SEHK:2388**) in Shandong Province, China. Ballard has already commercialised its technology and is focused on heavy- and medium-duty motive applications including the bus, truck, rail and marine markets where fuel cells offer distinct range advantages over batteries. The c 1,000 buses and 2,200 trucks powered by its fuel cells have driven over 50m kilometres between them. Some of these buses

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have been operating for over eight years in the field and exceeded 35,000 hours of service with no major maintenance on the fuel cells.

Ballard has a two-pronged strategy, deriving revenues from both product sales and sharing know-how. FY19 revenues totalled $106.3m, with 47% derived from the Power Products platform and 53% from the Technology Solutions segment. 71% of Power Products revenues were from the sale of PEM fuel cells for heavy-duty motive applications and 22% for materials-handling applications, most of which is attributable to replacement stacks for Plug Power (profiled below) as older stacks reached the end of their life. The remainder of the Power Product revenues were from fuel cell systems for unmanned aerial vehicles (UAVs), an activity that was sold to Honeywell in October 2020 and back-up power systems primarily sold for emergency services networks in Europe. Technology Solutions includes engineering services, technology transfer and the sale and licence of IP. A total of $22.5m of revenues from this segment were related to technology transfer to the JV in China with Weichai (see below), and $26.7m from an automotive programme with Audi.

Exhibit 13: Ballard-powered commercial trucks deployed in Shanghai, China

Source: Ballard Power Systems

Given the scale of the Chinese government's programme to decarbonise transportation, with a recent target of achieving one million FCEVs on its roads by 2030, it is not surprising China is a key market for Ballard. Ballard appears to already have a significant share of its target sector as management notes its technology is used in around half of the c 7,200 fuel cell buses and commercial trucks in the country. This puts Ballard in a very strong position if fuel cell deployment shifts to widespread commercial adoption. In anticipation of this transition, Ballard formed a JV in 2018 with Weichai Power, a major manufacturer of diesel engines used in vehicles, marine vessels and power generation. In 2018 Weichai also made an equity investment in Ballard, taking a 19.9% ownership position. The JV's fuel cell stack manufacturing facility with an annual capacity of over 1 Gigawatts has been commissioned and is now assembling stacks and power modules for bus, commercial truck and forklift applications in China. The proprietary membrane electrode assemblies (MEAs) used in the stacks are being manufactured in Canada, protecting Ballard's key IP. The company is investing c $20m in its Vancouver facility to increase capacity from c 1m MEAs annually to c 6m by early 2021. The technology transfer agreement alone with Weichai is worth $90m. Weichai intends to build at least 2,000 fuel cell modules to power vehicles in China by 2021.

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Europe is also an attractive market. In FY20 Ballard established a marine centre of excellence at its facility in Denmark, where it is designing and manufacturing heavy-duty fuel cell modules for the marine industry, with capacity for up to 200 modules a year. For example, it intends to deliver three 100kW fuel cell modules in 2020 for a vessel transporting goods between Berlin and Hamburg. In September Ballard announced a collaboration agreement with MAHLE, a Tier 1 supplier to the commercial vehicle and automotive industry, addressing the $100bn global market for commercial truck engines.

Bloom Energy (BE:US)

Bloom is headquartered in the US and has been developing SOFCs around 20 years. It designs, manufactures and sells larger (200kw+) SOFC-based systems for onsite power generation. These run on natural gas or biogas. Its primary focus is fuel cell systems for distributed power generation, initially as back-up power and more recently as part of micro-grid systems where they can be combined with wind and solar power generation sources. Its fuel cell systems produces power for organisations including Apple, Caltech, Google, Walmart, AT&T, eBay, Staples and Kaiser Permanente. In September 2019 Bloom announced a collaboration with Samsung Heavy Industries to design and develop SOFC-powered ships. The majority of sales are within the US, with a small proportion in India and Japan. In September 2019, Bloom formed a JV with Korean company SK Engineering & Construction to establish a light-assembly facility in South Korea to serve the stationary utility and commercial and industrial market in the country. In September 2020 the two partners announced fuel cell deployments totalling 28MW in the South Korean cities of Hwasung and Paju.

Historically, profitability has been directly impacted by whether the US Investment Tax Credit (ITC) was applicable to fuel cells. Fuel cells were removed from the list of applicable technologies at the end of 2016 and have subsequently been reinstated. When the ITC was removed, Bloom lowered the price of its systems to ensure the economic benefit to customers, was unchanged, adversely affecting its gross profit. In addition, financing partners supporting deployments through power purchase agreement or leasing programmes derive a significant portion of their economic returns through tax benefits. There is some debate about whether Bloom installations in California meet Self Generation Incentive Program tax credit criteria with regards to both GHG emissions and cost.

In February 2020 Bloom's auditors decided reported accounts dating back to Q116 had not treated revenues from managed service agreements correctly. Management noted that restating the accounts back to Q218 would result in a decrease in net revenues of $165–180m for the period over which restatement is required, with this revenue now being recognised over the remaining term of the service agreements. The ruling means operating losses are expected to increase by $20–35m over the restatement period and net losses by $55–75m.

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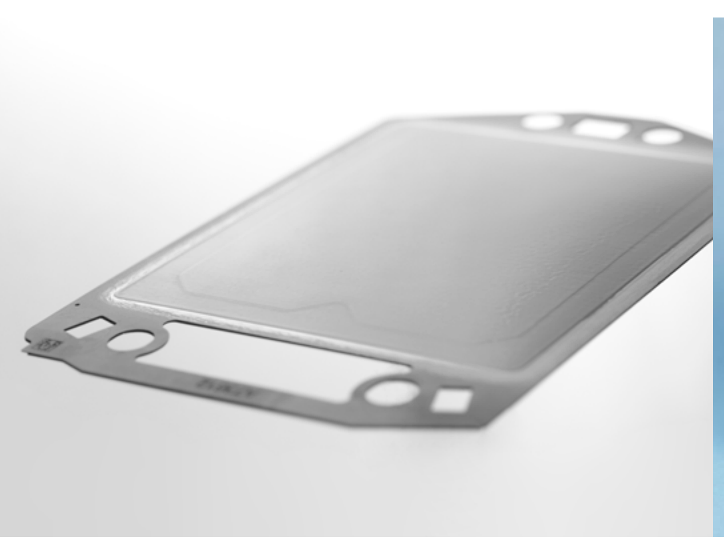
The total cash flows and cash and cash equivalents will not be affected. The company is subject to several class actions for alleged misleading statements or omissions in connection with the IPO although management has stated it believes the complaints are without merit. We also note Bloom has an unusual stock structure, with a 10-to-one voting ratio between its Class B and Class A shares that gives the CEO and other Class B shareholders a substantial majority of voting rights.

Ceres Power (CWR:LN)

Ceres Power has developed a patented SOFC technology known as the SteelCell. This technology is different from PEM and alkaline technology in generating power from widely available fuels such as natural gas and hydrogen, so it is not dependent on the widespread availability of high purity hydrogen before it can be deployed in volume. Additionally, it uses a thin layer of cerium oxide doped with gadolinium as the electrolyte, so it operates at a much lower temperature (c 600°C) than other SOFC cells (800-900°C). This means that, unlike other SOFC technologies, it is manufactured using standard processing equipment and conventional materials such as the ferritic stainless steel (90% of SteelCell by mass) used for car exhausts, and thus be mass produced at an affordable price. The steel foundation means that the fuel cell stacks are more robust than other types of SOFC, making them suitable for transport applications as well as stationary ones, and they are easier to recycle.

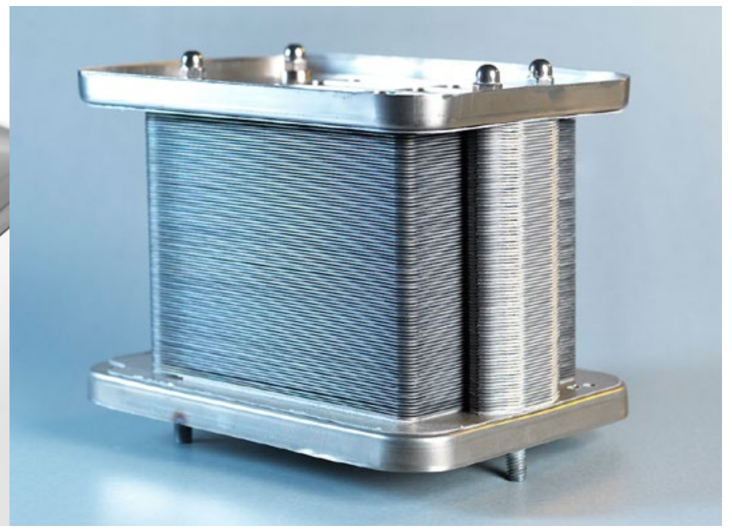
Ceres Power's route to market is through partners such as Bosch, Doosan Fuel Cell (see below) which is based in South Korea, major Chinese diesel engine manufacturer, Weichai Power and Miura, which is Japan's largest industrial boiler company. These partners integrate Ceres' SteelCell technology into their own power generation products. Historically Ceres has monetised its IP through advance licence fees and fees for engineering services as it supports partners during development agreements. Following the commissioning of its new UK manufacturing facility in January 2020, Ceres is also generating revenues from selling small volumes of product, mostly in support of engineering programmes. Longer term, management intends a significant proportion of revenues to be derived from royalties (US$50-100/kW) as partners sell meaningful volumes of systems that include SteelCells they have either made themselves or purchased from a manufacturing partner. In October 2020 Ceres announced that Doosan Fuel Cell had acquired a licence to manufacture its proprietary SOFC stacks at facility yet to be built, which is scheduled to have an initial 50MW capacity by 2024.

Exhibit 14:
Individual SteelCell



Source: Ceres Power

Exhibit 15:
Stack of SteelCells



Source: Ceres Power

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Commercialisation of the SteelCell technology has begun. Miura has launched the first product containing this technology, a CHP system for use in commercial buildings in October 2019. Since signing a strategic agreement in August 2018, Ceres and Bosch have been jointly developing fuel-cell stacks for stationary power applications such as data centre back-up and EV recharging points, following which Bosch has started production of fuel cell stacks and systems at its pilot plant in Germany. In September 2019 Weichai and Ceres announced they had completed the joint development of a protype 30kW range extender for the Chinese bus market. Although the process has been delayed by the coronavirus pandemic, Weichai and Ceres still intend to establish a fuel cell manufacturing JV in China.

Because the business model is based on licencing and royalties, management is keen to broaden the application range to maintain the rate of signing new licensees at one or two per year. In November 2019 Ceres announced the successful development of its first hydrogen CHP system which can run on green hydrogen and the more widely available low-purity hydrogen from industrial sources. It continues to increase power output. Having created a 30kW range extender, it intends to work on 150kW+ systems for trucks and rail applications and is working Doosan Corporation on higher power systems targeting utility scale applications. In January 2020 Ceres stated that early-stage testing of the technology for electrolysis had delivered encouraging results. For example it can deliver efficiencies of 85% compared with c 60% for the incumbent alkaline electrolyser technology. In July the company announced that it intended to invest around £5m in the development of solid oxide electrolysis for hydrogen and potential synthetic fuels over the next 18 months.

Doosan Fuel Cell (336260:KRX)

Doosan Corporation span-out its fuel cell business, Doosan Fuel Cell, in October 2019. The company traces its origin back to the fuel cells installed on the Apollo spacecraft by UTCPower in 1969. It offers fuel cells based on phosphoric acid technology for use in large-scale stationary combined heat/power generation applications. By 2019 the company had delivered aggregated orders of 300MW. Projects include the world's first and largest (30MW) multi-story fuel cell plant for Busan Green Energy and the world's first and largest (50MW) by-product hydrogen fuel cell plant for Hanwha Total Petrochemical. Its operations are based in Connecticut.

ENGIE EPS (EPS:FP)

ENGIE EPS is part of the ENGIE group. Since listing in 2015 it has transitioned from being a pure technology provider to an engineering, procurement and construction (EPC) contractor and manufacturer and supplier of complete solutions. It specialises in standalone utility-scale energy storage systems, thermal power plant retrofitting, large-scale hydrogen and battery storage solutions for commercial and industrial users and microgrids for islands and emerging economies. It also focusses on e-mobility, developing EV charging solutions and vehicle-to-the-grid applications such as stabilising electrical grids with electrical vehicles and reusing EV batteries in stationary storage systems. It has acted as a technology partner to Fiat Chrysler Automobiles since 2016 and in November 2020 the two companies signed a Memorandum of Understanding aimed at creating a Joint Venture offering a full suite of products and solutions such as charging infrastructure and green energy packages to electric vehicle customers across Europe. The company's R&D and manufacturing activity is located in Italy.

ENGIE EPS's HyESS technology platform supports the creation of fully integrated, reliable and safe storage solutions including onsite production of hydrogen through electrolysis and deployment of hydrogen for long-term energy storage in power-to-power configurations. The company believes it is one of only a few system providers that has developed a hydrogen management system and deployed hydrogen-based energy storage in microgrids and storage systems. Since 2005 ENGIE EPS has installed hydrogen based projects totalling dozens of MWh around the globe. In October 2020 it announced the deployment of a 500kWh hydrogen-based storage solution for renewable energy storage in northern Greece. In November the company announced the successful completion of the site acceptance test of a hydrogen-based energy storage system in Singapore comprising an electrolyser, fuel cell system and hydrogen and oxygen storage of c 2 MWh.

Exhibit 16: Hydrogen-based energy storage system in rural Greece

Source: ENGIE EPS

Exhibit 17: Hydrogen -based energy storage system used in a micro-grid in Singapore

Source: ENGIE EPS

Everfuel (EFUEL.NO)

Everfuel provides all-inclusive hydrogen fuelling solutions: manufacturing or sourcing green hydrogen; storing and distributing the gas using trailers; and installing and maintaining refuelling stations. It may be regarded as providing the "missing link" that is holding back wider deployment of fuel cell vehicles by helping ensure that a fleet operator wanting to transition to fuel cells can be certain that the hydrogen it needs will be available when required.

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The company is headquartered in Denmark and currently employs around 20 people. It listed on the Oslo stock exchange in October 2020, having been founded in 2017 by NEL Fuel and then spun-out in August 2019.

At present Everfuel is primarily focussed on providing fuelling solutions for heavy duty vehicles such as buses, trucks and taxis because this is where the mass compounding issues affecting batteries favour the deployment of fuel cells. Moreover, in these applications, the vehicle typically either returns to a depot or passes the same point each day, giving an obvious location for siting a refuelling station so there will be economic levels of utilisation from the start. As markets develop, Everfuel will potentially provide refuelling solutions for delivery vans, trains, marine vessels and private cars as well. The company is also working with industrial users of hydrogen and customers requiring Power-to-Gas solutions. Everfuel's business model is to generate recurring revenues from long-term agreements to supply hydrogen. As of October 2020, the company had a backlog of €34m contracts relating to reserved capacity and committed offtake. It had secured a total of €72.3m of project funding of which €30.3m was direct support for Everfuel infrastructure.

In August 2020, Everfuel announced a contract covering the servicing and maintenance of a refuelling station and provision of green hydrogen for a fleet of over 20 buses in Rotterdam for a minimum of 12 years. The buses are being funded through the EU JIVE2 initiative. The refuelling station is designed for buses but can also be used in the future by other heavy transport vehicles such as trucks because of its scalable design.

In November 2019 Everfuel announced a strategic partnership with Dansk Shell to install 20MW electrolyser capacity and 10 tonnes of storage capacity (equivalent to five days of production) at the Fredericia refinery in Denmark, potentially increasing electrolysis capacity to 1GW longer-term. The refinery already uses hydrogen in its production processes, so powering the electrolysers with electricity from renewable sources will help make the refining processes more environmentally friendly. At the full 1GW capacity, the hydrogen plant will be able to meet the refinery's hydrogen requirements as well as supplying 3-4000 fuel cell buses and trucks with hydrogen each day. The hydrogen stored at the plant may also be used to generate green electricity for local data centres during periods when insufficient energy is being generated from wind and solar sources. The Danish Energy Agency has committed DKK 48m (U$$8m) for the first phase of this project.

Exhibit 18: Minimum 12 year contract to supply green hydrogen to bus fleet in Netherlands

Source: Everfuel

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FuelCell Energy (FCEL:US)

FuelCell Energy is headquartered in the US. It has developed a range of high-power output (over 1.4MW) molten carbonate fuel cells. It designs, builds and operates megawatt scale fuel-cell systems that provide utilities and large industrial and municipal power users with both utility scale and onsite power generation. These plants are providing utilities such as Dominion, Avangrid, PG&E, SCE, Southern Company in North America, EON and EWZ in Europe, and Korea Hydro and Nuclear Power in Asia with power. They also provide heat to district heating systems in the US and South Korea.

As of May 2020 these facilities in the US, Europe and Asia had generated a cumulative 10,052,454MWh energy, which is sufficient to power c 910,548 average size US homes for one year, c 2,275,340 German homes for one year or 2,803,563 South Korean homes for one year. Last year the company decided to start promoting fuel cell products again, relaunching its sub-megawatt products in Europe in July 2019.

Because these systems typically run on natural gas or biogas, which are reformed into hydrogen before entering the fuel cell stack, they can also be used to produce surplus hydrogen for industrial processes, transportation and long-duration energy storage. This reforming process uses a solid-state electrochemical hydrogen separation system that is more energy efficient and requires less water than conventional techniques for producing hydrogen from natural gas or biogas. This technology will be deployed at Toyota's Port of Long Beach facility in California, where the hydrogen will power fuel cell trucks and consumer vehicles.

The company is also working on techniques for using its fuel cell systems as a part of a carbon-capture process for existing coal or gas-fired power plants. In this technique, the exhaust flue gases are directed to the air intake of the fuel cell. The fuel cell generates power as usual, with the carbon dioxide passing from the fuel cell air intake, where it is very dilute, to the fuel cell exhaust stream, where it is concentrated.

Exhibit 19: Construction of 59MW fuel cell park for POSCO in South Korea

Source: FuelCell Energy

This allows the carbon dioxide to be captured more efficiently, while simultaneously producing power. This contrasts with conventional carbon capture technology, which can consume around 20% of the power a plant produces. Fuel cells used in this way also destroy approximately 70% of the nitrogen oxides emitted by the plant. Development of this

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technology is being supported by a two-year joint development agreement with ExxonMobil worth up to $60m in revenues. ExxonMobil also paid FuelCell Energy $10m in licence fees for carbon-capture technology IP in June 2019. The company recently received awards from the US Department of Energy to develop multi-stack electrolysis systems and to develop performance improvements to advance commercialisation of its reversible SOFC systems, that is, systems that electrolyse water to make hydrogen, store the hydrogen, then generate power from that hydrogen.

ITM Power (ITM:LN)

ITM Power manufactures integrated hydrogen energy solutions based on rapid-response PEM electrolysis. These are used for grid balancing, energy storage and the production of green hydrogen for transport, renewable heat and chemicals. Customers and partners include Sumitomo, Ørsted, Phillips 66, National Grid, Cadent, Northern Gas Networks, Gasunie, RWE, ENGIE, BOC Linde, Toyota, Honda, Hyundai and Anglo American and most recently Snam. Management expects that ITM Power's electrolyser factory in Sheffield, England, will be the world's largest when it is completed later this year with a potential capacity of 1GW per annum by the end of 2023.

Exhibit 20: World's first gigawatt scale electrolyser factory

Source: ITM Power

In October 2019 ITM announced the formation of a 50/50 joint venture with industrial gas giant Linde that is focused on delivering green hydrogen to large-scale industrial projects, principally those with an installed electrolyser capacity of 10MW and above. This was a huge endorsement from its long-term partner, which invested £38m in ITM for a 20% shareholding as part of a fund-raising programme of over £52m. It also gave ITM access to Linde's global customer base and enabled ITM to focus on developing and selling electrolysers because Linde is now responsible for EPC activity on projects. In October 2020 ITM announced that international energy infrastructure operator Snam is to make a strategic investment of £30.0m in ITM, with the two companies entering into a commercial partnership agreement under which ITM will be the preferred supplier for the first 100MW of electrolysis projects ordered by Snam between 2021 and 2025. Snam, who owns over 41,000 km of pipelines, is one of the 11 European gas infrastructure companies from nine EU members behind the proposal for an EU-wide hydrogen network discussed earlier.

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ITM's products are proven. It already has a network of 15 public access hydrogen refuelling stations in the UK, nine of which are open to the public and six are in various stages of construction, and has recently started to focus on larger-scale refuelling projects for fleets, buses and trains. Its 10MW refinery project with Shell in Germany is progressing well with all five 2MW electrolysers built and phase one of factory acceptance testing successfully completed.

McPhy (MCPHY:FP)

McPhy offers electrolysers and hydrogen refuelling stations. The electrolysers are based on alkaline and to a lesser extent PEM technology. They are suitable for the production of low volumes of hydrogen on an intermittent basis for metal cutting and metal working or for light industry and of high volumes for applications such as vehicle refuelling and power generation and continuous production for example in steel mills and the chemical industry. For example McPhy's PIEL product range is deployed DIAX's sintering diamond tools line, see Exhibit 21. The PIEL range is typically used by goldsmiths and jewellery manufacturers companies as well as meteorological institutes who use the equipment to produce gas for inflating weather balloons. McPhy has the capacity to produce between 20-30 filling stations per year at its facility in France and up to 300MW of electrolyser capacity annually at its facility in Italy.

Exhibit 21: McPhy's PIEL equipment as deployed in DIAX ' sintering diamond tools production line

Source: McPhy

The focus is on hydrogen fuelling stations and large-scale power to hydrogen energy schemes based on alkaline electrolyte systems, which avoid the need for water purification. It has experienced increased demand for hydrogen filling stations with integrated hydrogen electrolysers as these give security of supply. On-site hydrogen production is also safer because it removes potential issues transferring bulk hydrogen from trucks and storing highly compressed gas. Following the receipt in July of a contract for two hydrogen stations in the Dijon area connected to a 1MW high-power electrolyser and a further two hydrogen stations in August, McPhy references a total of 33 refuelling stations and 43MW of high-power electrolysis.

McPhy is participating in an EU-backed consortium to build a 20MW electrolyser producing up to 3,000 tonnes of hydrogen per year on a chemical park in the Netherlands. The electricity is from renewable sources, so this will be one of the largest zero-carbon hydrogen projects ever undertaken. Nouryon and Gasunie will jointly operate the plant

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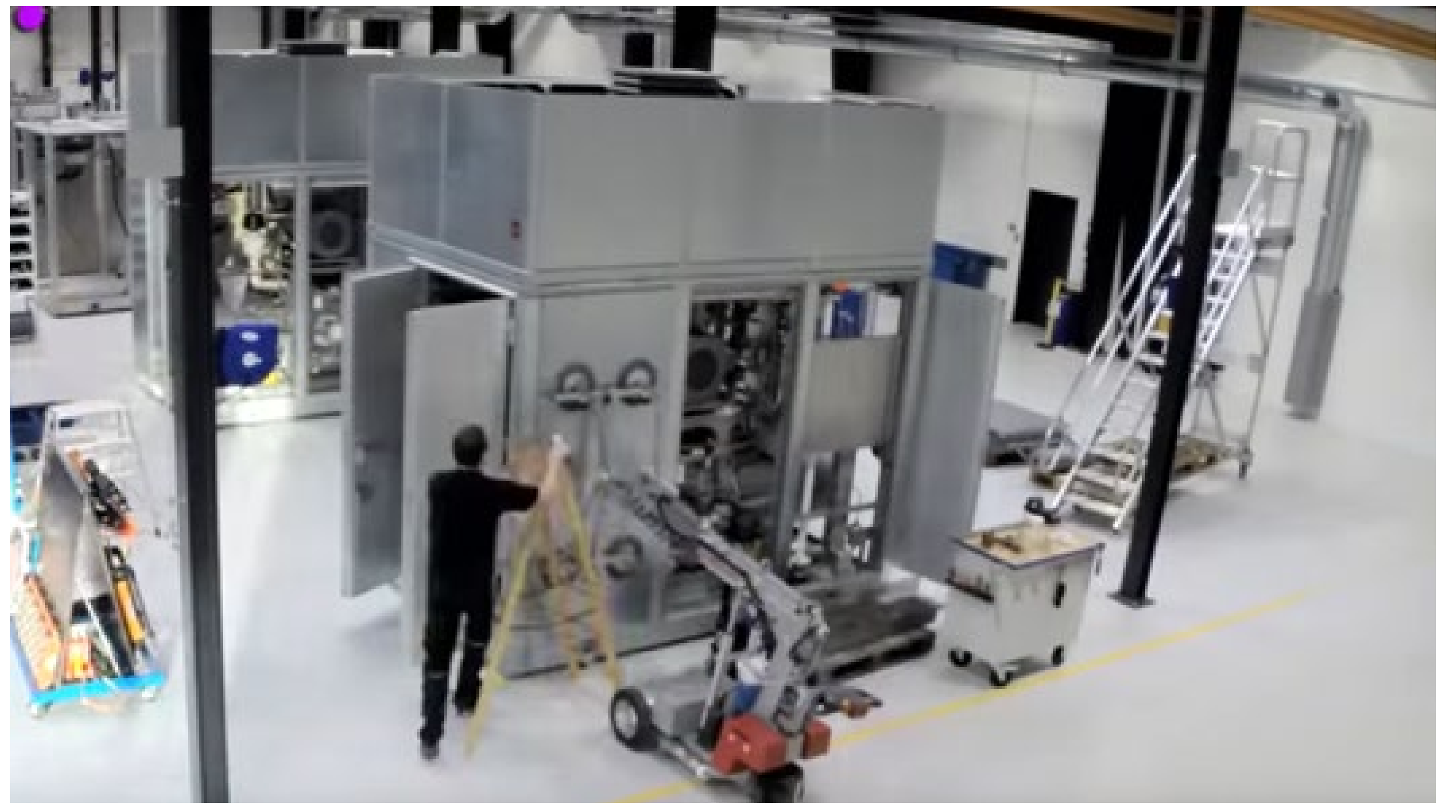
and BioMCN will use the hydrogen to produce renewable methanol. There are discussions about increasing the capacity to 60MW. McPhy will be involved in the pre-engineering phase from this year, and subsequently in the detailed engineering, production and commissioning of the electrolysis platform. This major project marks a change in McPhy's size, confirming its transition to an industrial scale operation.

Nel Hydrogen (NEL:NO)

Nel Hydrogen's electrolyser business goes back to 1927, when Norsk Hydro developed large-scale electrolyser plants to provide renewable hydrogen for generating ammonia that was used in the production of fertiliser. Nel Hydrogen Electrolyser began commercial sales of electrolysers in the 1970s and has since delivered more than 3,500 electrolyser units into over 80 countries. It currently has what management believes is the world's largest electrolyser portfolio, which encompasses both alkaline and PEM technologies. For example, in October 2020 it announced it has signed a letter of intent with Statkraft for the delivery of 40–50 MW of alkaline electrolysers to support green steel production by Celsa Armeringsstål in Norway. The project is targeted for operation by end of 2023. In November, Iberdrola, one of the largest electricity utilities in the world, launched a project with fertilizer manufacturer Fertiberia to establish what it believes will be the largest green hydrogen plant in Europe. The plant will be located in Spain and include a 100 MW photovoltaic plant, 20 MWh of battery energy storage and a 20 MW electrolyser. The hydrogen produced in the project will primarily be used for green fertilizer production. Nel will supply the electrolyser, which is scheduled to commence operations in 2021. Subsequently Nel and Iberdrola announced a memorandum of understanding to collaborate in the development of a green hydrogen production plant with the capacity of more than 200 MW in Spain by 2023. Iberdrola and Fertiberia have plans to develop an 800 MW green hydrogen project for the production of green ammonia.

Exhibit 22: Nel H2Station factory



Source: Nel Hydrogen

Nel has manufacturing facilities in Norway, where it is preparing for a large-scale expansion of production of alkaline electrolysers, and the US. Management believes that the increase in production capacity in Norway, starting with a 0.5GW production line and potentially reaching 2GW/year, will achieve cost reductions sufficient to make renewable hydrogen cost competitive with fossil hydrogen and fossil fuels.

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Nel Hydrogen Fueling manufactures hydrogen fuelling stations. It began manufacturing hydrogen fuelling stations in 2003 and has installations in several European countries as well as in South-Korea and the US. In 2018, Nel opened its new manufacturing plant in Denmark, which has an annual production capacity of 300 hydrogen refuelling stations per year. Noting increased activity in the heavy-duty segment, Nel intends to launch new products tailored for these applications. It is working with US-based hydrogen truck manufacturer Nikola (which it has invested US$5.0m in) and, separately, with Shell Oil Products US on solutions for this segment. In June 2020 Nel announced an order of over US$30m from Nikola for electrolysers at its first five fuelling stations, a €4m order for three more refuelling stations for deployment in Korea, an order of over US$3m for a 2.5MW electrolyser producing green hydrogen for mobility applications in Europe and an order of over NOK150m for multiple refuelling stations for passenger vehicles from a large international company. In November the company received an order worth over US$16m for 14 passenger vehicle refuelling units which will be installed in 2021 on seven sites in California.

Nel Hydrogen has a 33.3% stake in Hyon AS, which is a JV formed to address opportunities in the maritime and marine segments as well as projects to leverage renewable energy resources. The other shareholders are Hexagon Composites and PowerCell Sweden, which each have a 33.3% stake. Nel retains a 17% stake in Everfuel, which it founded to coordinate the H2Bus Consortium, which Nel is part of. Everfuel (EFUELME.NO), which listed in October 2020 (see above), will provide hydrogen fuel to heavy-duty customers such as city buses. Everfuel has signed a long-term exclusive contract with Nel for delivery of fuelling stations and electrolysers.

Plug Power (PLUG:US)

Plug Power's headquarters are in New York. It designs and manufactures PEM fuel cells and hydrogen dispensing stations, initially for the materials handling market. The material handling market was chosen because fuel cells give a superior return on assets to batteries as the on-board energy source can be replenished much more quickly. Plug is the market leader in this niche, having shipped over 32,000 units and built over 90 hydrogen fuelling stations. Customers include Amazon, Carrefour, Home Depot and Walmart. Plug has announced plans to build a manufacturing facility able to output 1.5GW of capacity annually, equivalent to more than 60,000 fuel cell stacks. Management believes that once it is operational, which is scheduled for mid-2021, it will be the world's first PEM fuel cell gigafactory, and the combination of automation, vertical integration and volume leverage will deliver a 50% cost reduction.

Plug has diversified into on-road applications, offering systems with powers up to 125kW for delivery vans, light and medium duty cargo trucks used for on-road middle-mile delivery and heavy-duty trucks used for high utilisation last-mile delivery or long-haul trucking.

Customers include FedEx, Linde, which intends to use the systems in its own delivery vehicles, and MULAG, a German developer of ground support systems for the aviation industry. It also offers lightweight, rugged UAV propulsion systems. In a further diversification, it is partnering with Universal Hydrogen, an end-to-end fuel logistics company, to develop a 2MW hydrogen-electric aircraft powertrain to power commercial regional aircraft. Plug expects that this technology will enable a converted mid-sized regional turboprop aircraft (such as the Dash 8 or ATR42/72 families) to fly missions up to 1,000km. This range serves over 90% of existing routes and is far longer than what would be achievable with battery power alone.

In July 2020 Plug announced the launch of its GenSure HP (high power) platform designed for large-scale, high power backup power applications, taking it into another large market. Initially this platform will be available in power output configurations ranging from 500–1,500kW.

Bringing down the cost of hydrogen is key to achieving the company's growth objectives. In September 2019 Plug signed a three-year agreement with industrial gas supplier United Hydrogen, providing a source of low-cost hydrogen and helping Plug increase the proportion of green hydrogen supplied to materials handling customers. In June 2020 Plug acquired United Hydrogen and electrolyser manufacturer Giner ELX, both for undisclosed sums. Plug calculates that its customers will collectively require 80 tonnes of hydrogen each day by 2024 and has made a commitment to achieve 50% green content by then so locating electrolysers powered by surplus energy generated from renewables at customer sites is a good long-term solution. It is already on its way to achieving this, having announced an agreement to source 100% renewable energy supplies from Brookfield Renewable to manufacture approximately 10 tons of 100% green liquid hydrogen per day at Plug's green hydrogen facility in North America. It has also signed a collaboration agreement with Apex Clean Energy, a developer and operator of utility-scale wind and solar power facilities in North America.

PowerCell Sweden (PCELL:SS)

PowerCell's headquarters are in Sweden. It was founded in 2008 as an industrial spinout from the Volvo Group. It has recently established a sales office in China. PowerCell develops and manufactures fuel cell stacks and systems with an exceptionally high power density for use in both stationary applications where space is at a premium and in mobile applications. Importantly it has expertise in both fuel cell technology and reforming technology, which converts methanol, ethanol, diesel, biogas or natural gas to hydrogen. It believes that its S2 product is the only PEM fuel cell stack that can tolerate high levels of contamination in hydrogen.

In April 2019 the company announced an agreement with Robert Bosch regarding the joint development, production and sale of PowerCell's compact, low-weight S3 fuel cell stack for the automotive segment. Bosch paid PowerCell €50m for an exclusive licence to produce and sell this PowerCell S3 variant for automotive applications such as cars, trucks and buses and a royalty fee for every product sold. Over the last year PowerCell has also received follow-on orders from a global automotive OEM and from companies in China involved in the automotive industry, predominantly with buses. It is participating in EU projects regarding fuel cell electrification of different types of heavy-duty trucks and fuel cell powered refuse trucks. In December 2019 PowerCell received approval from the German authorities for the second phase of the Autostack project, representing up to €4.85m revenues. The project, whose automotive partners include Audi, BMW, Daimler, Ford and Volkswagen, aims to develop a stack suitable for mass production for the German automotive industry.

There is also significant interest in PowerCell's technology for maritime and aviation applications. In February 2020 PowerCell delivered a fuel cell system to Italian ship building company Fincantieri to test fuel cell technology for both propulsion and power generating in marine applications. In April 2020 PowerCell announced a €6.9m contract with a European shipyard for a three-year project involving the development and delivery of a megawatt marine fuel cell system. One of PowerCell's fuel cell systems was an integral part of the powertrain in an adapted six-seater Piper Malibu, which became the first commercial single engine aircraft to make a flight powered by a hydrogen fuel cell. During the eight-minute flight in September 2020 the plane reached an altitude of 1,000 feet and a speed of 100 knots.

Following the joint development and licensing agreement with Robert Bosch last year for the automotive segment, PowerCell has decided to increase its focus on the stationary, off-road and marine segments. As part of this, it has a memorandum of understanding with ABB Power Grids regarding a collaboration around fuel cell based zero emissions stationary power solutions and an memorandum of understanding with Siemens Marine on the development of fuel cell based power solutions for the marine segment. It also has a Nordic cooperation agreement with Soltech Group regarding a joint development of stationary energy solutions where excess energy from solar panels is used to produce hydrogen, which is stored and converted back to electricity in a fuel cell when needed.

Powerhouse Energy Group (PHE:LN)

Powerhouse Energy Group has developed an innovative waste-to-hydrogen reactor technology that converts hydrocarbon waste streams, including unrecyclable plastic, into syngas or hydrogen. Since the technology operates at a higher temperature than conventional gasification techniques and incorporates gas processing and clean-up, it produces only a small volume of residue with no toxic dioxins or furans. The syngas will be used in gas engines to generate electricity. Additionally road fuel quality hydrogen for powering FCEVs will be extracted from the syngas.

The small footprint, modular design of Powerhouse's DMG technology means that it is suitable for waste-to-energy systems located close to where the waste material is produced and collected and where the

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hydrogen or electricity is required. This reduces the costs and energy used for transporting the fuel. Powerhouse's exclusive UK development partner and cornerstone investor Peel Environmental intends to locate DMG technology close to plastic recycling operations so that any waste plastic that cannot be recycled will be used to generate electric power that can used by businesses on the park rather than being sent to landfill. In the longer term, as demand for hydrogen in transport increases, the DMG systems will generate hydrogen to fuel fleets of refuse collection and other vehicles. Peel has a pipeline of around 30 locations in the UK, including 11 of its own sites, where it intends to deploy DMG technology. The first of these is its Protos Energy Park in Cheshire. In March 2020 planning permission was granted for the DMG plant on this site. In August Peel completed the engineering definition stage of the contractors' work for the plant, enabling the delivery contractors to price their contracts for constructing the plant and the associated on site buildings, which will facilitate Peel's completing the project financing ahead of commencing construction at the year end. Peel is also leading the engagement with all potential end-customers in the UK for DMG plants. These include city councils and waste management companies.

Powerhouse intends to monetise its IP through licencing its technology. Under its agreements with Peel, it will earn £0.5m per year for each DMG system once it has been commissioned. There is also the potential for Powerhouse to earn additional fees from providing technical engineering and maintenance services for each project.

Pressure Technologies (PRES.LN)

Pressure Technologies designs and manufactures high-integrity components and systems for safety-critical applications in energy, defence and industrial markets worldwide. Its headquarters are in Sheffield, England, and it operates through two manufacturing divisions: Precision Machined Components (51% of FY19 revenues) and Chesterfield Special Cylinders (49% of FY19 revenues). Chesterfield Special Containers (CSC) provides bespoke, high-pressure gas containment solutions and services and is one of only five companies globally that can compete for ultra large steel cylinder contracts. Its high-pressure cylinders are a critical component for applications including naval submarines, oxygen cylinders in fighter jets, bulk storage of special purpose gases, ultra large air pressure systems used for motion compensation on floating oil rigs and nitrogen storage solutions at nuclear power plants. CSC also provides through-life integrity management services to the operators of safety-critical gas containment systems, including in-situ inspection and recertification.

The group secured its first orders in the hydrogen energy supply chain in FY19, winning two contracts for high-pressure ground storage at new transport refuelling stations in the UK and overseas. Customers in the sector include Haskel and ITM Power. Although sales from the sector were only £0.7m in FY19, representing 2% of the group total, management sees hydrogen storage as a key growth sector.

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Since the end of March 2020, it has signed a five-year framework agreement with Shell Hydrogen, under which CSC becomes the approved supplier of Type 1 steel cylinders to prospective operators of Shell-branded hydrogen refuelling stations across Europe. While the number of potential refuelling stations to be built over the next few years remains uncertain, management sees the selection of CSC as preferred supplier as a significant strategic step.

Proton Motor Power Systems (PPS:LN)

Proton Motor designs, develops and manufactures fuel cells and fuel cell electric hybrid systems. It was formed in 1998 and provided the world's first fuel cell system for a ferry (which operated in Hamburg between 2009 and 2014); the world's first fuel cell powered fork lift truck (which went into operation at Munich Airport in 2001); and the world's first triple hybrid bus deploying batteries, super-capacitors and fuel-cells in 2009 together with Skoda Electric. The company installed an automated fuel cell manufacturing line in calendar Q219 to increase manufacturing capacity from 1,000 to 5,000 fuel cells per year. This investment was financed by an EU agency. The company's headquarters are near Munich, Germany.

Proton Motor's customer base is highly diverse, encompassing power supply solutions for customers in the IT, telecoms, public infrastructure and healthcare sectors in Germany, Europe and the Middle East. It also offers solutions for storing surplus power from solar energy storage. For example, since August the company has received a first order from Shell New Energies for a fuel cell hybrid system intended to power Shell's own line of portable hydrogen refuelling units for buses and trucks, a follow-on order from Fincantieri, one of the world's largest shipbuilding groups, to deliver a fuel cell system with 144kW fuel cell power for installation in Fincantieri's first 25m long demonstrator and testing vessel and has been appointed a preferred supplier of fuel cell systems by Frerk Aggregatebau. Frerk's portfolio includes back-up supply systems for critical infrastructure and decentralised power supply systems. In August 2019, Proton Motor formed a joint venture with Schäfer Elektronik to integrate Proton's larger industrial fuel cells with Schäfer's power electronics, battery and a hydrogen storage system to create a unit supplying over 1MW of power to electric vehicle charging stations.

SFC Energy (F3C:GR)

SFC's headquarters are in Germany and it operates production facilities in the Netherlands, Romania and Canada. Since its formation in 2000 it has sold over 45,000 hydrogen and direct methanol fuel cells, which management believes is more than the combined competition.

Historically SFC has focused on the portable and off-grid power generation markets where the ability to run fuel cells on methanol has been a distinct advantage. This is because the fuel has a very high energy density (see Exhibit 1), enabling two 28 litre fuel cartridges to power a 25W device autonomously for about 15 weeks.

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Exhibit 23: Back-up power for BOSNet radio tower sites (hydrogen fuel cell)

Source: SFC Energy

A portable power pack based on a direct methanol fuel cell (one that does not need additional reforming equipment to convert the methanol into hydrogen) is lighter than a battery pack storing a comparable amount of energy. Consequently, SFC's direct methanol fuel cells are also used in a wide range of end-user applications supplying electricity to

Exhibit 24: Autonomous off-grid hybrid power for remote video surveillance equipment (direct methanol fuel cell)

Source: SFC Energy

mobile homes, sailing yachts, holiday cabins and, as part of a recent cooperation with the boat engine manufacturer ePropulsion, being used as range extenders electric outboard motors.

The group recognised the desirability of providing complete solutions relatively early in its evolution.

To support this integrated approach, the group acquired PBF Group, a manufacturer of power conversion systems, in 2011 and Simark Controls, a systems integrator serving the Canadian oil and gas industry, in 2013. A hybrid solution was used to ensure 24/7 power to a CCTV system integrating a fuel cell with a power management system and battery, with the fuel cell switching on automatically when there is insufficient sunlight. For example, in June 2020 Simark received an order from SiteWatch Safety in Calgary, Canada for fuel cells to power remote video surveillance equipment on 980km of new pipelines during the construction phase of the project. Fuel cells are preferred to diesel generators in environmentally sensitive zones and require significantly fewer maintenance inspections. They are a more reliable source of power than solar only solutions such as panels and battery energy storage systems in regions close to or within the Arctic Circle. In March 2020 SFC announced that its 1,000th EFOY Pro fuel cell had been deployed in Singapore to support public safety and health.

INVESTING IN THE HYDROGEN ECONOMY: COMPANY PROFILES

Historically there was little interest in Germany in fuel cells for back-up power because downtime was not seen as an issue. This has changed now that reducing carbon dioxide and NOx emissions is more of a priority, so organisations are more incentivised to replace diesel back-up generation with fuel cells. Because the price/performance of methanol fuel cells is not appropriate for this sector, SFC has licenced PEM IP from adKor, thus adding fuel cells running on hydrogen to its portfolio. This IP was originally developed or acquired by Heliocentris, which filed for bankruptcy in late 2016. This initiative extends SFC's offer from a maximum output of 1.5kW achievable with methanol variants to 100kW achievable with hydrogen fuel. SFC delivered its first batch of PEM fuel cells in Q419 on a framework contract extending to 2021 to potentially equip over 400 radio tower sites in Germany. In June it received a call-off order worth more than €2.5m under this framework contract to supply systems for more than 100 locations. The programme could potentially equip 1,500 sites. Ballard is supplying the fuel cell stacks for these systems. The German Federal Government is supporting this program by partially compensating for the additional costs that arise from the purchase of a hydrogen fuel cell compared to a diesel generator. This makes SFC one of the first beneficiaries of the German government's national hydrogen strategy. Longer-term, similar fuel cell systems could be used to provide back-up power to 5G radio tower sites as well.

Initiatives to expand the markets served by its direct methanol portfolio are a push to selling to defence forces both within and outside Germany. For example, in September SFC signed a co-operation agreement with VINCORION, the mechatronics producer of technology group JENOPTIK to develop and market a portable energy management system for use by defence, rescue and disaster protection forces, primarily in areas far away from the conventional power grid. SFC is also experiencing high levels of demand from security technology and wind energy markets in Europe and Asia, where it is working with Beijing Green Century Technologies, thus expanding its presence in civil markets. During FY19 the group formed partnerships with several companies in North America to promote integrated solutions to the mining, security, telecommunications, oil and gas, environmental monitoring and rail signal control, water and waste water markets. It has recently signed an exclusive sales and partner agreement with Toyota Tsusho, the trading arm of the Toyota Group. Under the agreement, Toyota Tsusho will be SFC's exclusive partner for promoting and selling hydrogen and methanol fuel-cell products in Japan in all industrial and civilian market segments.

REACH OUT

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