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Hydrogen power
Enabling a virtuous decarbonisation loop

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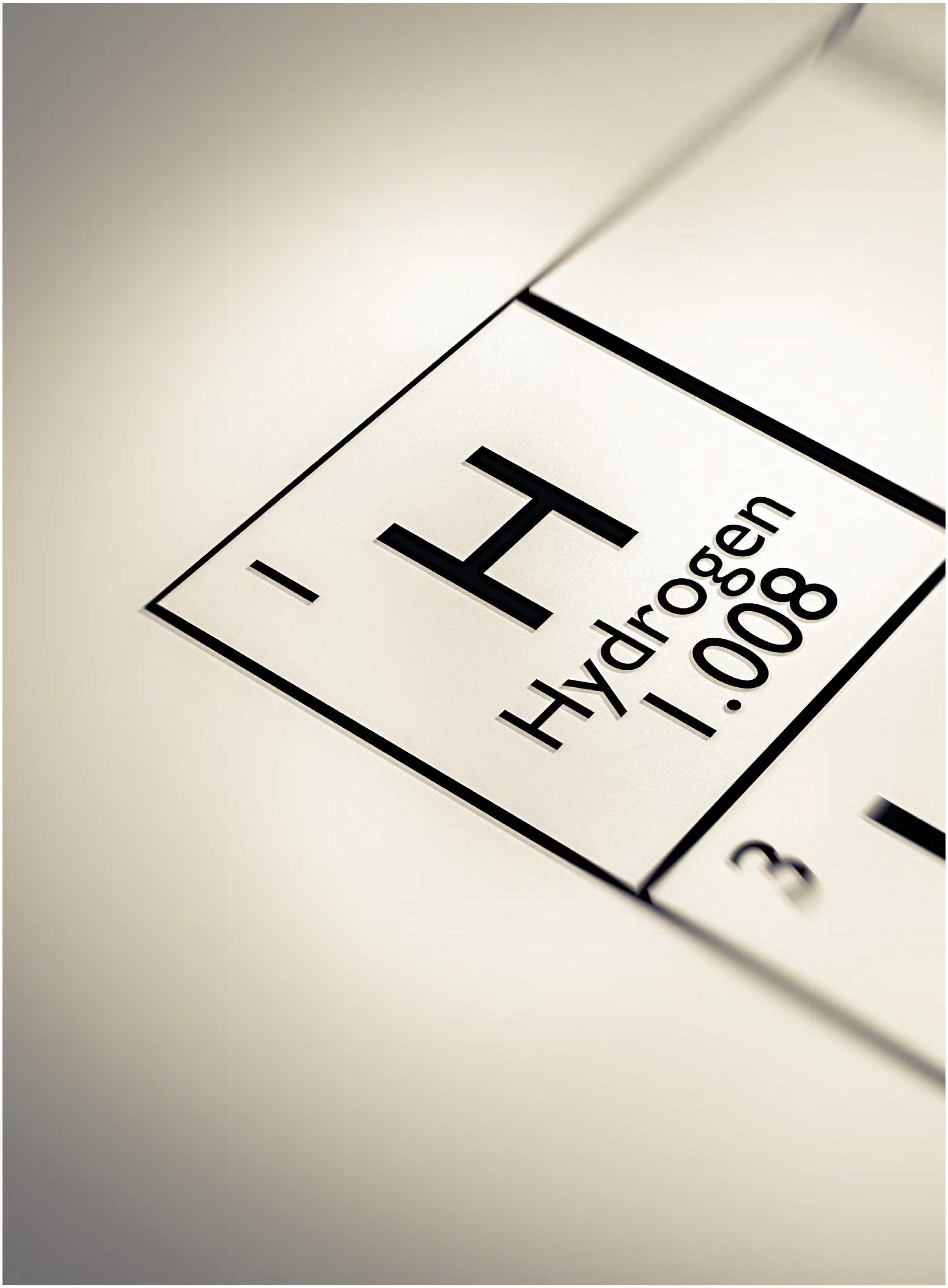

About
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Executive Summary

Hydrogen has long been talked about as a source of energy of the future. However, while scientists had expected hydrogen technology to become an important tool in the provision of "clean energy", technology did not exist to make that happen at an affordable cost and on a wide scale. This is changing fast and governments are moving to support hydrogen-based power with substantial public investment and business incentives, presenting a multitude of opportunities for investors. There has been a significant increase in investor interest in companies focusing on hydrogen technologies. Some key stocks have risen by an average of 300% so far in 2020[1] and brokers have been bombarding their clients with materials about investment opportunities in this area.

Such positive market sentiment no doubt has the effect of boosting hydrogen's short-term market momentum. However, as long-term investors, we give primary attention to key factors such as the scale of the potential hydrogen market and at what stage of its development is each of the projects under consideration. **In this paper, we look at hydrogen technologies from the environmental standpoint, as well as key factors supporting its future development, such as investment, current projects and government support.**

A growing market of diverse opportunities

As you will read in this paper, hydrogen technologies are at different stages of development depending on their application and requirements in different sectors. Some, such hydrogen trains, are already being tried, while others are not expected to be commercially viable for at least another 20 years. For investors, this offers an opportunity to diversify between projects of different timescales and between different hydrogen business types (electrolysis, H2 producers or fuel cell producers).

While commercial application of hydrogen still represents a small part of major players' turnover, a growing market may change things very quickly. For example, Air Liquide, a French supplier of industrial gases, stated that if, in an optimistic scenario, the company had a 1% share of the hydrogen market in 2050, it would represent 100% of its total 2020 turnover.

Powering up for a carbon-neutral world

In the power sector, hydrogen can be regarded a potential catalyst for value creation over the long term. We believe that strong political actions towards decarbonisation should improve the timeframe for hydrogen to become a powerful alternative source for energy. This will also help decarbonise energy-intensive sectors, which have very limited alternative solutions, such as steel production.

Renewable power production and hydrogen are synergetic technologies, with the success of one facilitating the outcome from the other. An increase in the share of renewable energy in the overall supply of electricity will drive the cost of electricity down. This, in turn, will make hydrogen a more competitive option for the storage of electricity, leading to higher potential for renewables development and integration. This creates a strong opportunity for accelerating energy transition in the power sector.

That said, high costs, regulation and technology remain the main obstacles for hydrogen becoming a serious competitive option in the near future. It will also be necessary to increase production capacity of "green" electricity so that the hydrogen produced through electrolysis can be regarded as truly “green”.

Keeping things moving

In the transport sector, hydrogen cannot always provide an alternative to combustion and electric engines. The economic and environmental benefits vary according to the modes of transport. Some modes of transport will benefit from the development of electric batteries to decarbonise at a competitive price but for others they won’t be a practical option, at least in the foreseeable future.

We believe that strong political action towards decarbonisation and lower costs should speed up the process of hydrogen becoming powerful and economically viable alternative source for energy in the next 15-20 years.


H_2
Hydrogen H_2
H_2 HYDROGEN POWER
CLEAN ENERGY OF THE FUTURE

Getting up to scale

In the European Union (EU), 14 member states have already included their strategy for the use of hydrogen as part of their plans to support the post COVID lockdown economic recovery plans. The EU is now looking to create a leverage effect for the private sector by combining national and European funding.

The EU is now looking to create a leverage effect for the private sector by combining national and European funding. For some time now, the European Commission partnered with over 160 companies and about 80 research organisations through Hydrogen Europe, the European Hydrogen and Fuel Cell Association. The EU has also supported the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), a public-private partnership in the field of hydrogen energy research and development[2].

The European Commission is working on the proposals to increase hydrogen-based energy generation, in stages, to 6 gigawatts (GW) by 2024 and 40 GW by 2030. These are ambitious targets: 40 GW is the maximum capacity of 20 Hoover Dams[3], which can also equal to the electric consumption of about 20 million homes. The EU Commission estimated that, by 2050, this will require a remarkable investment of between EUR180bn and EUR470bn.

German and French governments have recently earmarked about EUR15bn for hydrogen technology. Hydrogen is also a key recipient of support under the Recovery Plan for Europe plans because it is seen as a key tool for achieving the EU Green Deal's targets and other objectives relating to Europe's climate-neutrality and strategic autonomy. Across the various funding programmes outlined under Next Generation EU, hydrogen industry could benefit from extra funding support, especially through the Strategic Investment Facility, the Recovery and Resilience Facility, and the reinforced Just Transition Fund[3].

The EU is set to support the installation of at least 6 GW of renewable hydrogen electrolysers, with production is set to will reach up to 1million tonnes.

As a result, from 2025 to 2030, hydrogen is expected to become an intrinsic part of the European integrated energy system. At least 40 GW of renewable hydrogen will be produced through electrolysis, with the overall production expected to reach up to 10 million tonnes in the EU. The expansion of hydrogen use, particularly green hydrogen, will be also supported by the increased use of renewable power in the electricity sector.

What is hydrogen and how can we get it?

Hydrogen (H) is the lightest chemical element in the periodic table and the most abundant substance in the universe. Yet, unlike fossil fuels, it cannot be found and easily extracted in its pure form – the hydrogen gas (H_2) forms only a tiny presence in our planet's atmosphere. However, combining with oxygen, it covers the majority of Earth's surface in the form of water, forming an obvious source for its extraction.

The use of hydrogen in industry is based on its technical characteristics. Hydrogen contains more energy per unit of mass than natural gas or petrol, which makes it particularly attractive as a transport fuel. Moreover, the by-product of combustion of hydrogen is just water.

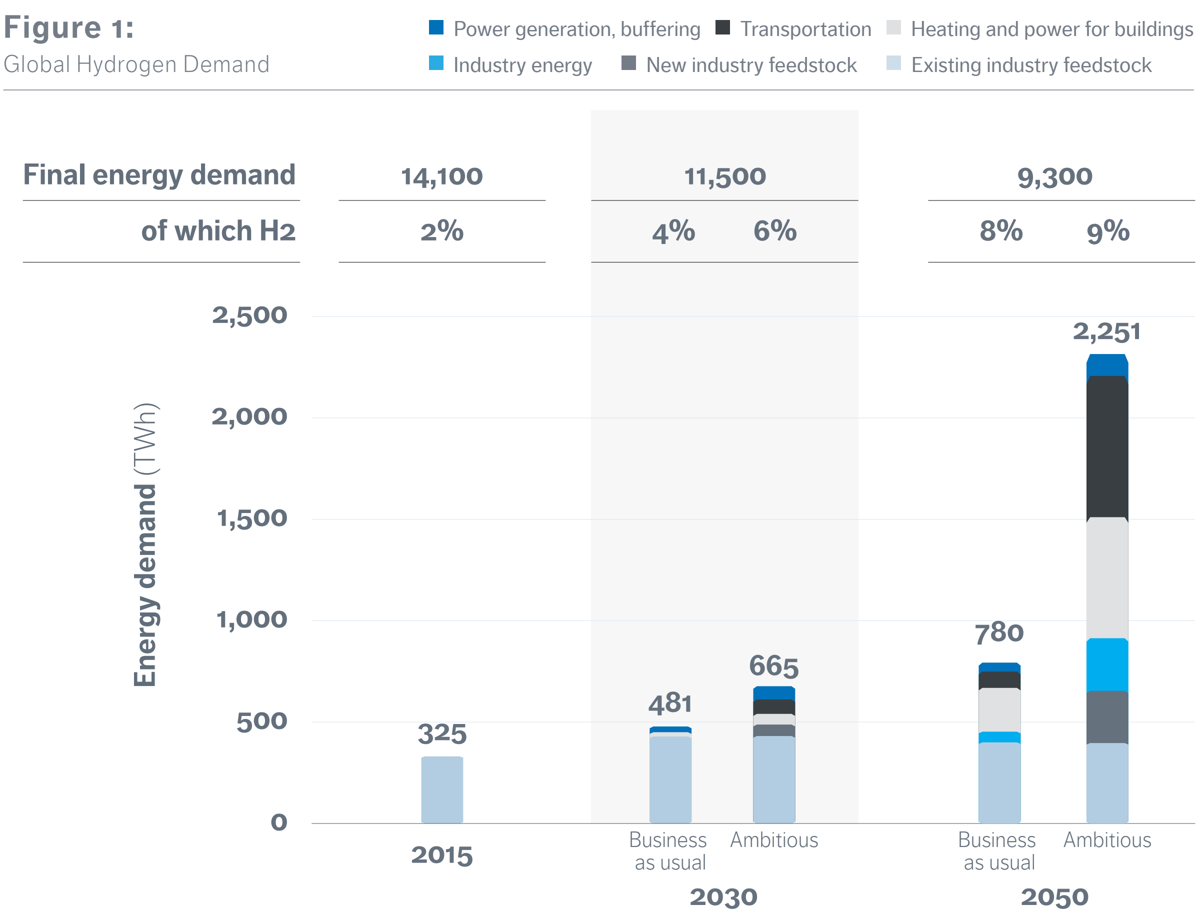
However, given that hydrogen is the lightest chemical element, it also has a low energy density per unit of volume. This means that larger volumes of hydrogen will be required to release the same amount of energy as traditional fuels. For example, producing as much energy as a litre of petrol will require almost five times more hydrogen (4.6 litres compressed to 700 bars - i.e. 700 times the atmospheric pressure). Therefore, transporting and storing hydrogen requires larger or faster pipelines and larger storage tanks. This can be expensive.

Hydrogen can be compressed, liquefied or converted into hydrogen-based fuels that have a higher energy density, but this (and any subsequent conversion) uses predominantly non-green energy, which can be self-defeating.

Industrial consumption of hydrogen in its pure form totals about 70 million tonnes per year (MtH_2/year). Its main user is end-of-pipe transport.

Hydrogen is produced mainly in two ways: extraction from fossil fuels and electrolysis, a chemical decomposition produced by passing an electric current through a liquid (in this case water). It is electrolysis which can bring some environmental advantages.

Figure 1:
Global Hydrogen Demand

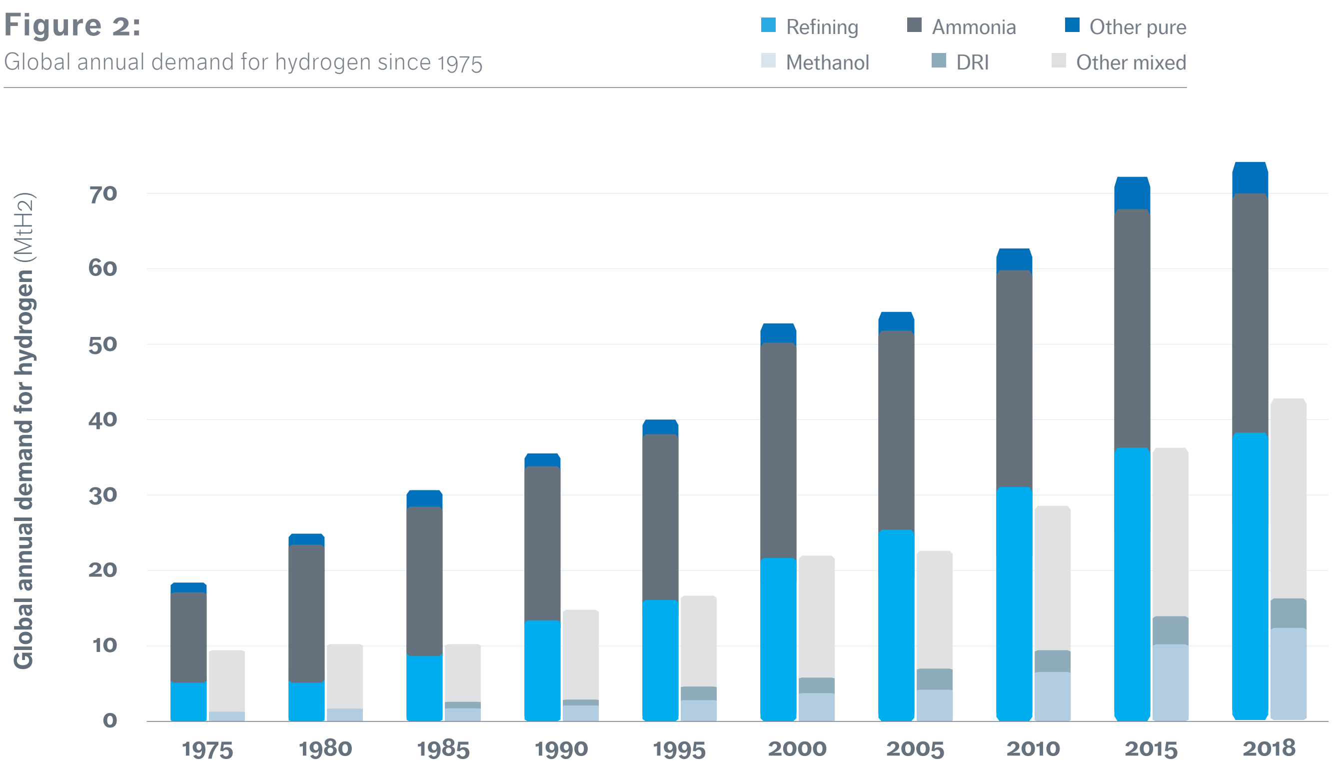


Source: Fuel Cells and Hydrogen 2 Joint Undertaking, 2019

Extraction

Hydrogen is extracted from fossil fuels by high-temperature cracking. This is the main way of producing hydrogen today but it is not a very environmentally friendly one. The energy used to crack the molecule is typically fossil energy, and the process releases CO_2 emissions. This technique accounts for about 6% of the world's natural gas and 2% of coal consumption. It also accounts for the emission of 830 million tons of CO_2 per year, which is roughly equal to those of Indonesia and the United Kingdom combined.

Figure 2:
Global annual demand for hydrogen since 1975



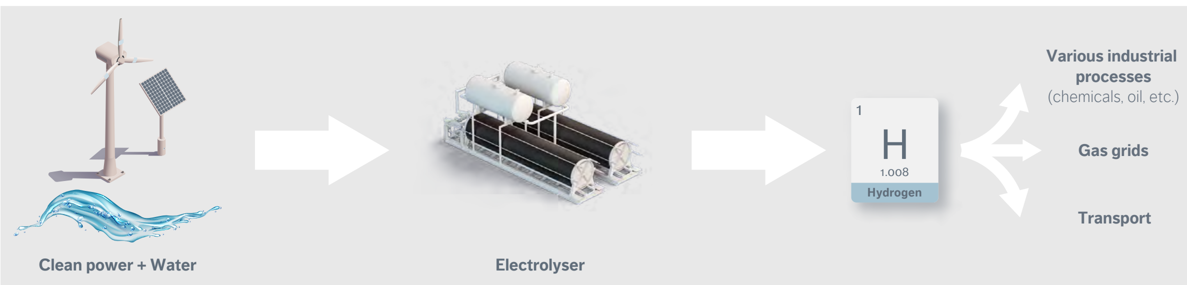
Source: IEA 2019

Electrolysis (decomposition of water)

This method uses electricity to "break" water molecules into its two composite parts: oxygen and hydrogen. This process can utilise renewable electricity, in which case the hydrogen produced at the end of it can be referred to as "green hydrogen".

This technique accounts for about 1.5% of current hydrogen production. Hydrogen can then be used in different ways and in this paper we will look at its use in power generation and transport.

Figure 3:
Electrolysis of water to produce hydrogen for different applications



Source: Morgan Stanley Research

Figure 4:
Different types of hydrogen production and their carbon footprint

Technology	Method	Core estimation ($kg/H2)	CO2 gains
Green	H2 from electrolysis using 100% renewable energies	USD 3-5	None during the production phase but between 1-5 tonnes of CO2 over the life cycle
Grey	Hydrogen derived from methane, usually natural gas, via steam or thermal autoreforming, with CO2 a by-product.	2-3* the production cost of a single unit of natural gas, around USD1.	Direct CO2 emissions of around 9t CO2/H2, and across the whole lifecycle 10-17 tonnes of CO2/H2.
Blue	Uses methane in the same processes as used for grey hydrogen but also by carbon capture and sequestration.	USD 1-2	Direct emissions of around 1 tonne of CO2/H2. Across the lifecycle, this amounts to 3-6 tonnes of CO2/H2 including storage.

Source: JP Morgan

Key to carbon neutral, cheaper energy

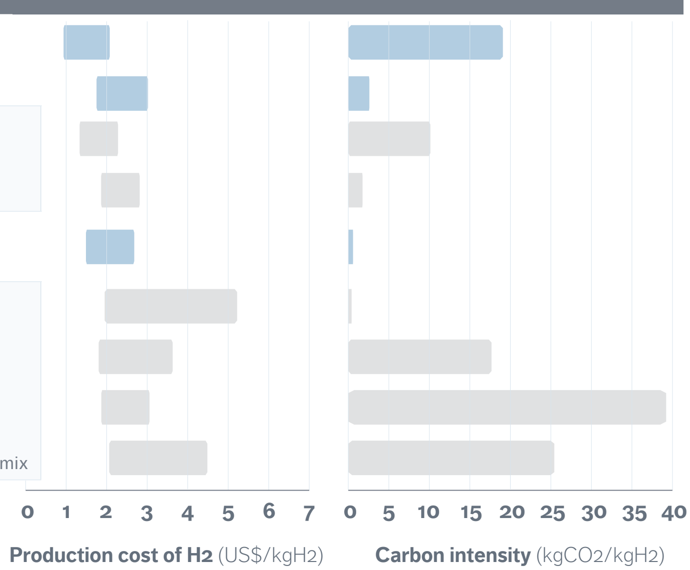
Given that the production of hydrogen using electrolysis requires electricity, the origin of that electrical input will determine the carbon footprint of the process. This footprint can be minimised or neutralised completely through the use of renewable sources of electricity for electrolysis. The resulting hydrogen can then be stored and used in different ways to decarbonise a wide range of energy-intensive industries, including transportation and the production of heating. Hydrogen can also be reconverted to electricity by using a fuel-cell, which is the opposite of an electrolyser.

Electrolysis currently accounts just for 2% of global hydrogen production, with the hydrogen production through renewable-based electrolysis hampered by the relatively high cost of "clean" electricity. According to the IEA, hydrogen made from fossil fuels currently costs between USD1-USD1.8/kg, whereas green hydrogen production costs are today about USD6/kg.

Figure 5: The carbon intensity and cost of production of hydrogen shows a wide variability depending on the source of energy used

Hydrogen producing pathways and associated carbon intensity (kgCO2/kgH2) and cost of production (US$/kgH2)

Primary fuel	Producing pathways	
Coal	Coal gasification (or pyrolysis)	Coal
		Coal with CCUS
Natural gas	Steam methane reforming (SMR) Autothermal reforming Partial oxidation	Natural gas
		Natural gas with CCUS
Biomass	Biomass gasification/pyrolysis	Biomass
Electricity	Electrolysis (water)	Renewable electricity
		Gas-fired generation
		Coal-fired generation
		Global average electricity mix



Sources: IEA, IPCC, Goldman Sachs Global Investment Research

However there is significant scope for electrolysis to provide more low-carbon hydrogen. Not only has the cost of "clean" electricity from wind and solar has fallen significantly over the past couple of decades, but an eventual fall in the average cost of hydrogen process should also be helped by an increase in electrolyser operating hours (driving CAPEX down). Therefore, low-cost electricity available at a level to ensure the electrolyser can operate at relatively high full load hours is essential for the production of low-cost hydrogen.

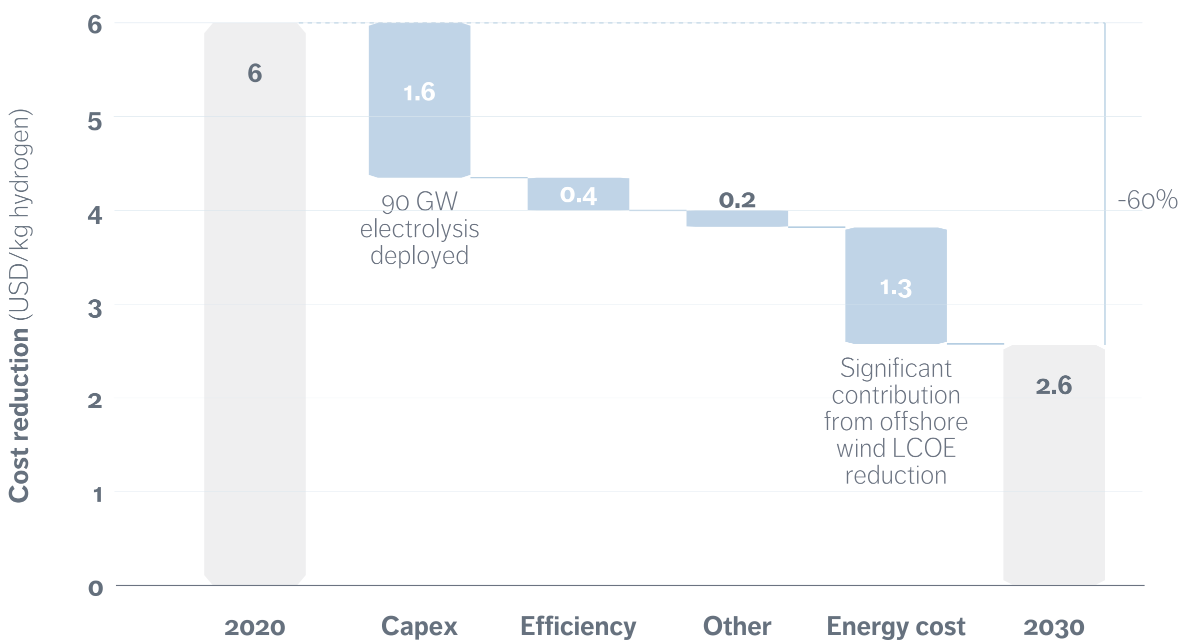
The significant fall in the cost of generating solar and wind energy observed in the last few years have led to renewable energy being the cheapest type of energy in many countries. For example, the cost of electricity from solar PV and onshore wind generation crossed over with thermal generation in 2017/18 and fell by 14% in 2018 alone. Therefore, it isn't unreasonable to conclude that within a decade solar and wind energy generation will be cheaper than continuing to run existing gas and coal power plants in most developed countries. Similarly to wind and solar, the cost of hydrogen-based energy generation may come down to highly competitive levels just as quickly, which points in the direction of hydrogen's future potential.

That said, recent studies showed that the time horizon for green hydrogen becoming competitively priced would differ from other types of renewable energy. This is mainly because the cost of hydrogen is highly dependent on that of electricity, which in turn depends on location, technological advances, as well as the cost of electrolysers.

Mc Kinsey & Co predict that the cost of electrolysis from offshore wind in Europe will fall by 60% in the next 10 years, with decreasing costs of clean energy being the biggest contributing factor to its cost competitiveness.

Figure 6: Renewable hydrogen from electrolysis cost trajectory

Cost reduction level for hydrogen for electrolysis connected* to dedicated offshore wind in Europe (average case)



* Assume 4,000 Nm3/h (~20 MW) PEM electrolysers connected to offshore wind, excluses compression and storage

Sources: H21, McKinsey, Expert interview

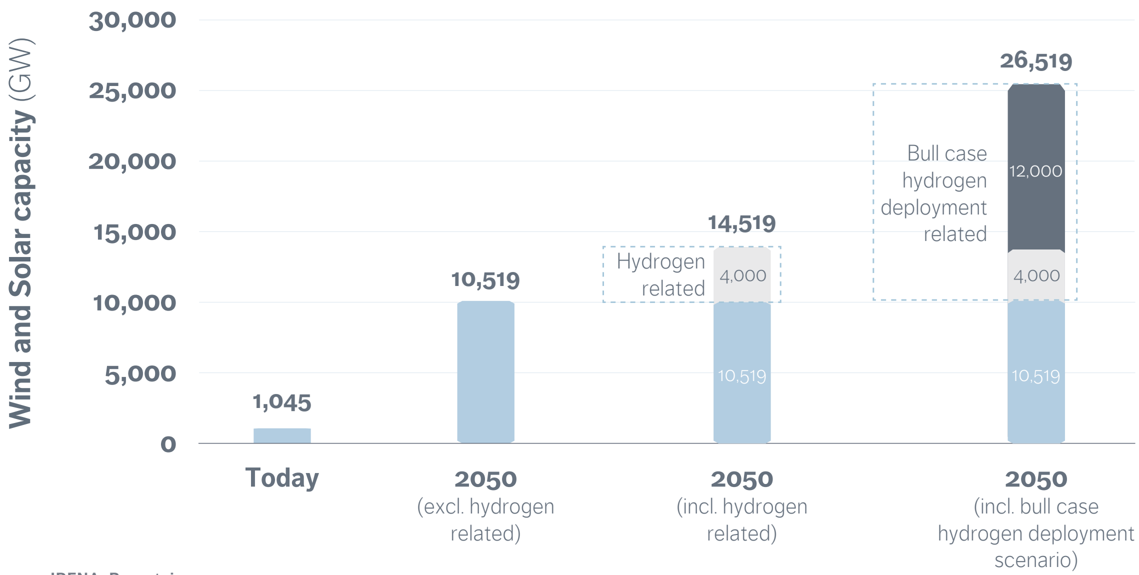
A catalyst to wider renewable energy deployment

As demonstrated, recent technological advancements and falling costs of renewables power production have made green hydrogen more attractive. In other words, both renewables and hydrogen offer synergies in the trend towards a low carbon economy since they are mutually beneficial.

On the one hand, the demand for hydrogen will be driven by technological advances that will enable it to be used to decarbonise energy-intensive industries such as steel cement production. On the other, the use of hydrogen in energy production is expected to grow by four to 16 times from the current level. According to the International Renewable Energy Agency (IRENA) and the Hydrogen Council, this increase will equal about 19-80 exajoules (EJ) by 2050, corresponding to a capacity of 4TW-16TW for solar and wind energy.

Figure 7:

Renewables capacity (wind and solar) scenarios : today versus 2050



Sources: IRENA, Bernstein

Hydrogen can also be used for storage of energy, an important function that would help provide carbon-neutral energy production. Indeed, production levels of renewables change based on weather, resulting in generating too little or too less power required at any one time. For example, according to McKinsey & Co, solar energy generation produces 60% less electricity in winter than in the summer, while consumer consumption is about 40% higher than in summer due to heating requirements, as well as lighting due to shorter days.

Closing the renewable energy supply gap

When renewable energy production is higher than demand, excess power can be fed through an electrolyser for the production of green hydrogen, which in turn can be stored and then reconverted to electricity when renewable electricity production is low. This process makes hydrogen a key solution to the problem of season-dependent intermittency of renewable sources energy as well as a source of production flexibility.

This flexibility is important because without it renewable energy will not achieve the sustainability it requires to become a dominant source of energy. High proportion of renewables in the overall energy provision will create a requirement for long-term and seasonal storage, which can be used to produce electricity during the periods when there is not enough wind or sun.

Currently, hydrogen-based electrical storage technology is not regarded as very efficient. According to the IEA, there is a very significant loss of electricity, about 60%, during the process of conversion using electrolysis into hydrogen and then back into electricity. In contrast, the average loss of storage of a lithium-ion battery is about 15%. It may look to some that hydrogen does not have the characteristics to offer a competitive option for electrical storage. However, in fact, batteries are unlikely to be used for long-term and large-scale storage because they suffer from self-discharge and because it will not be realistic, as well as high environmental risk, to maintain a huge number of batteries required.

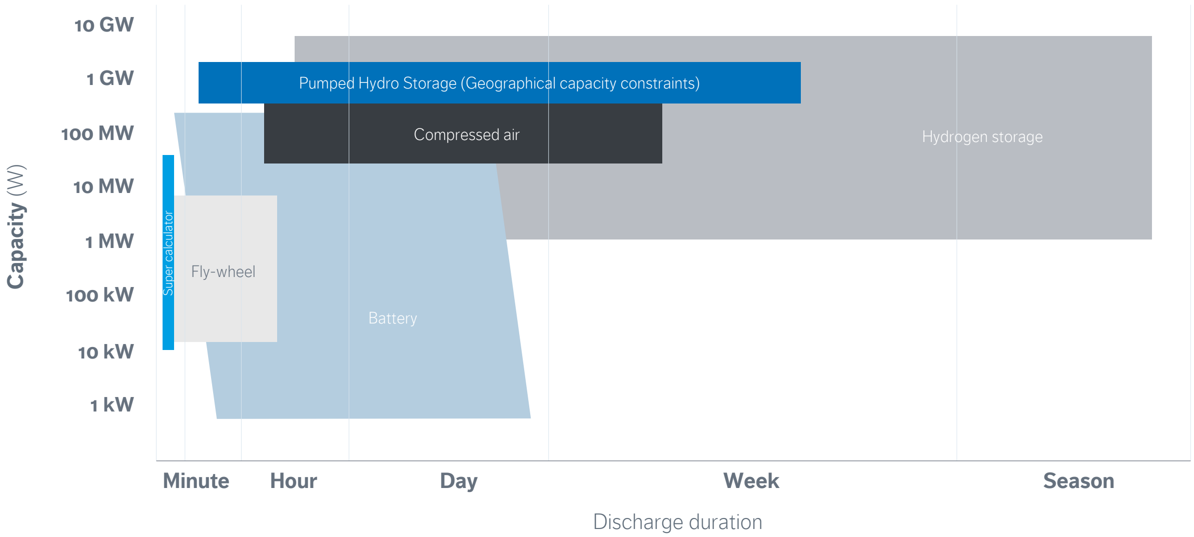
The IEA concluded that hydrogen presents a more competitive solution when electricity can be discharged over longer periods. In fact, depending on the costs of the stored electricity, compressed hydrogen storage can be the cheapest storage option at discharge durations over 20–45 hours. Batteries, super-capacitors, and compressed air can also support balancing but they lack either the power capacity or the storage timespan needed to address seasonal imbalances. IRENA expects the market for seasonal storage for electricity to take off around 2030 and that hydrogen could play a central role.

Hydrogen energy

While hydrogen has long been talked about as an "ideal" pollution-free energy source, only recently has there been a concerted push to kick-start this supply chain. For example, earlier this year in France, a consortium of European companies, research institutes and universities launched the world's first integrated power-to-hydrogen-to-power plant. The steam, a by-product of hydrogen power generation will be used by a paper mill to dry pulp from recycled paper to produce cardboard[5]. Other recent examples include a 1GW green-hydrogen power plant, a USD1.8bn project due to be completed in Australia in 2027[6] and three projects in the US that include the first green hydrogen packages for power balancing and energy storage, with the combined initial investment of over USD3bn[7].

Figure 8: Hydrogen is most promising for long-term carbon-free seasonal storage

Technology overview of carbon-free energy storage technologies

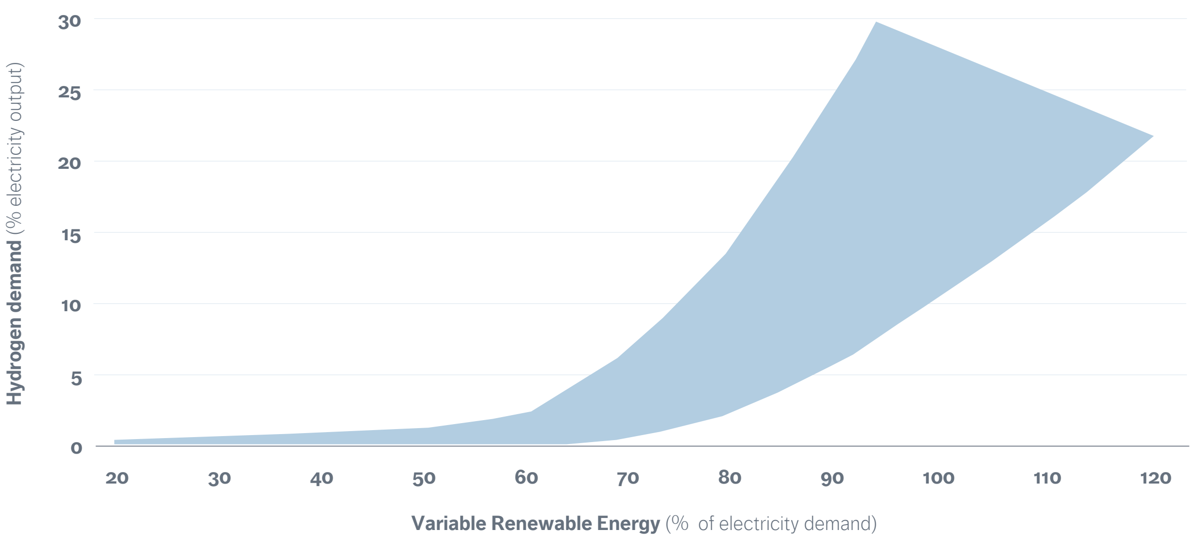


Sources: IEA Energy Technology Roadmap Hydrogen and Fuel Celle, JRC Scientific and Policy Report 2013

Hydrogen will potentially step in as the best long-term storage technology which could balance electricity power demand and supply across both short term and seasonal intermittency in renewed energy supply and increase integration of wind and solar in electricity grids.

Figure 9:

The need for hydrogen storage will increase exponentially with variable renewable energy share

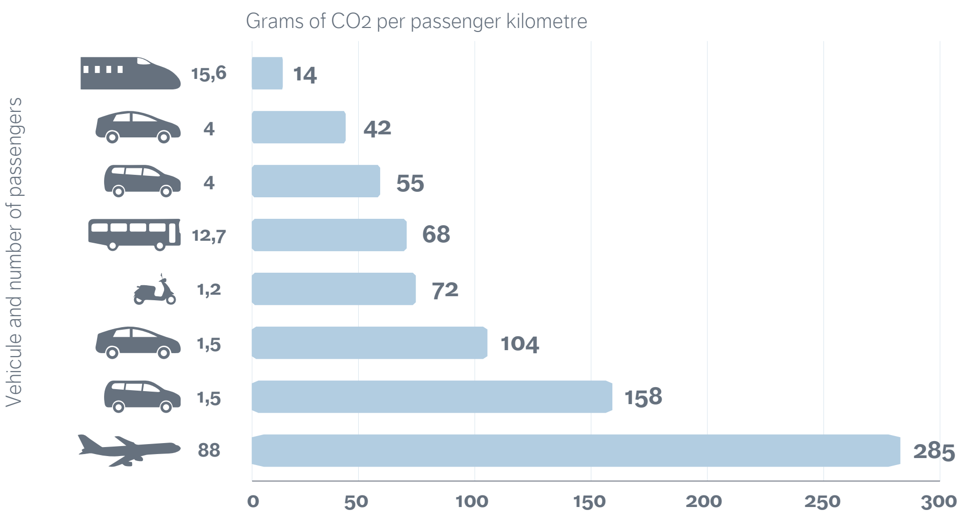


Sources: Fraunhofer Institute for Solar Energy Systems ISE (2017), BMW, RWT Aachen, Sterner and Stadler (2014), McKinsey, Bernstein analysis

Hydrogen for transport: miracle engine fuel?

The transport sector is responsible for 25% of all direct CO_2 emissions on our planet, with cars, buses and motorbikes accounting for three quarters of them. The rest of the pollution comes from aviation and freight transport, the sectors that have experienced some very strong growth recently. Rail transport is the most efficient mode of transport and accounts for only 2% of the energy used in transport.

Figure 10:
CO_2 emissions from passenger transport



Note: The figures have been estimated with an average number of passangers per vehicule

Sources: EEA report TERM 2004

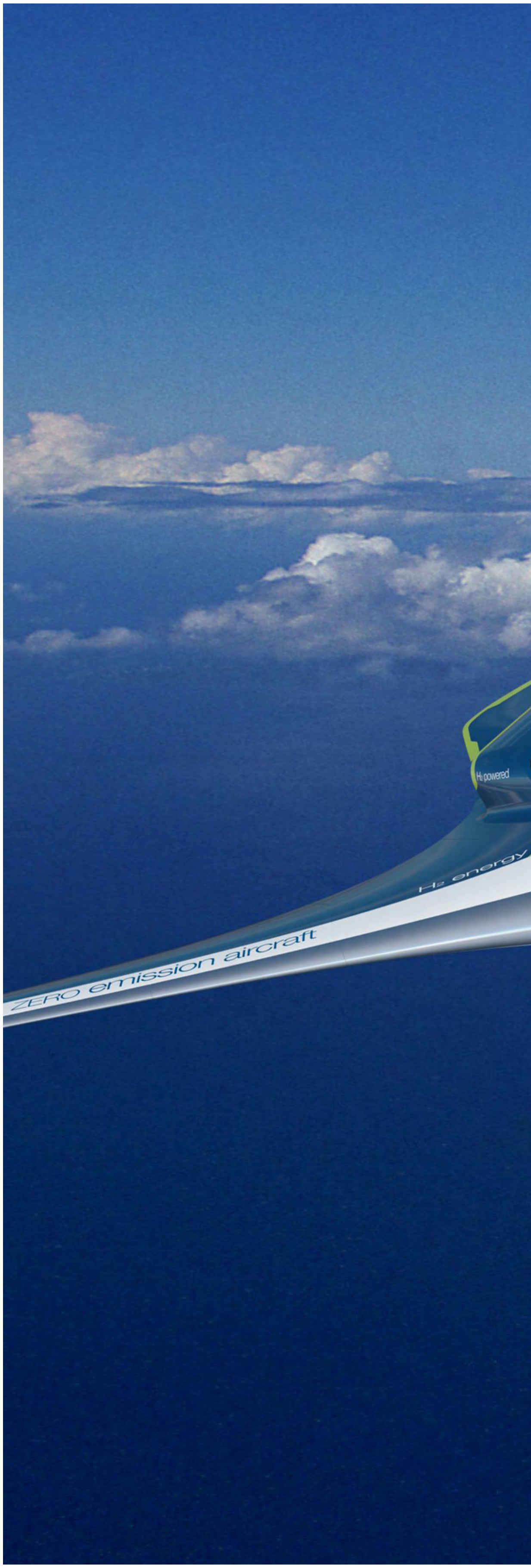
This means that to comply with the Paris Agreement and contain global warming by 2100, governments, industry and investors will need to focus a great deal more on finding alternative energy solutions, particularly in road transport and aviation.

What makes hydrogen so attractive?

- ***Contains more energy per unit mass than natural gas or petrol, which could very useful for transport.***
- ***Integrated within a fuel cell, it releases 140 times more energy than the batteries currently used in electric and hybrid vehicles on the road. Emits no local pollution.***
- ***Hydrogen batteries require much fewer rare materials than traditional batteries***
- ***Longer battery life.***
- ***Recharging time is 15 times faster than electric batteries.***
- ***Its cost could decrease as the price of renewable energies falls and potential government subsidies are introduced.***

That solution, such as hydrogen technology, must be able to provide us with a solution that can reduce CO2 emissions from the transport sector by 75% over that period. Moreover, the future of hydrogen fuel would also depend on how cost-effective it is for all types of vehicles.

In this section, we will look at the current carbon footprint of each mode transport, emission reduction targets and discuss the role of hydrogen in providing a workable solution to the conventional (combustion) engine and current electric batteries.



Hydrogen-based liquid fuels could offer an alternative to aircraft fuel. And while Airbus is already working on a hydrogen plane, its planned launch in 2035 remains uncertain whilst the project is at a very early stage.

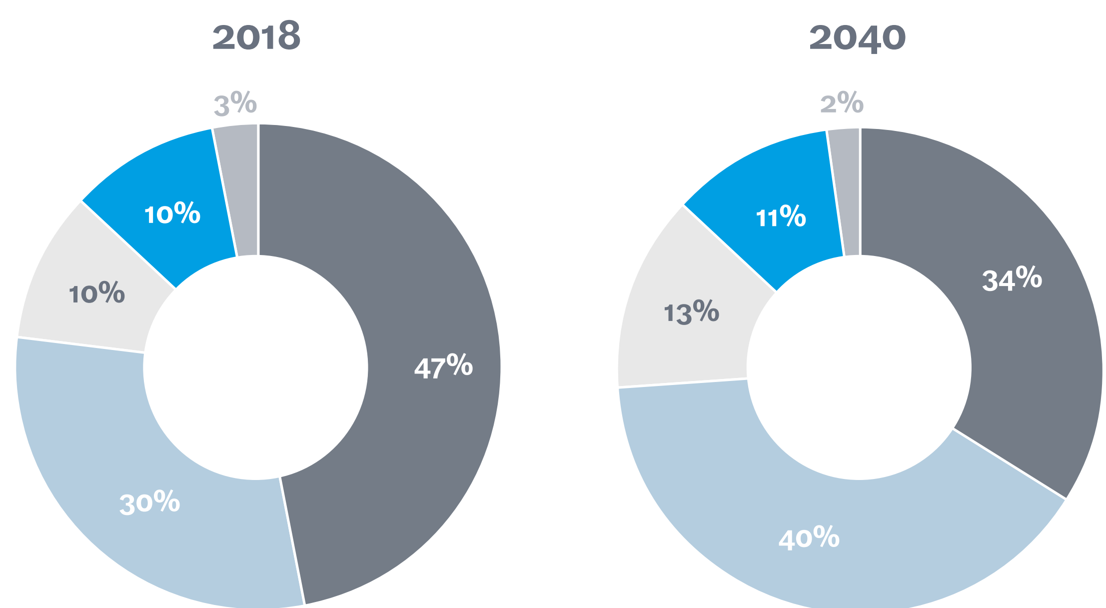
Cars

Despite consumers' significant move towards electric cars, light vehicles are still projected to account for over a third of all transport-generated GHEs by 2040.

Consequently, the European Union (EU) imposes very ambitious intermediate targets to encourage manufacturers to explore different solutions. The average emission rate for the vehicle fleet for each manufacturer must not exceed 95g CO2 per km travelled in 2021. If this limit is not respected, substantial fines are foreseen of €95 per gram of CO2 above the limit, for each vehicle sold.

Will hydrogen be part of them compared to conventional or electric engines? The investment costs for developing new vehicles with combustion engines are currently the lowest but we believe that hydrogen-based engines will offer great potential for cost reduction if we look at the next 10 years.

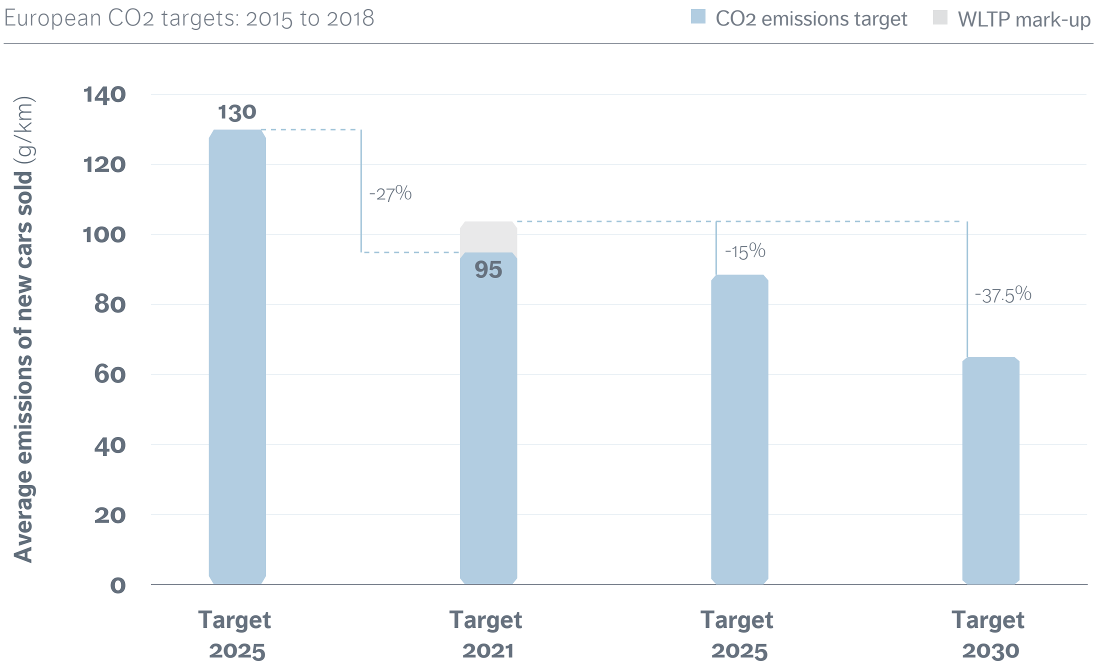
Figure 11:
Global transport-sector greenhouse gas emissions by mode



Source: International Council of Clean Transportation

Figure 12:

European CO2 targets: 2015 to 2018



Sources: FEV Consulting, Bernstein analysis

The financial impact is undoubtedly the most important criterion for the automotive industry today. Today, investment costs for developing new vehicles with combustion engines are still lower compared to other options. Combustion engines involve fewer technological innovations and developments in the types of fuel they use. However, we are convinced that the tightening of environmental standards together with the changes in public opinion will push manufacturers to find workable alternatives to combustion engines. In this context, it is likely that the price of electric cars will continue to fall and become competitive with combustion engine vehicles. We estimate that this will happen around 2022.

Vehicles powered by Hydrogen fuel cells remain the most expensive today. However, we believe that these engines offer great potential cost savings over the next 10 years or so if government aid helps the sector to achieve operation scale. CO2 emissions from fuel cells and electric cars are significantly lower than those from combustion engines.

That said, the degree of fuel cell cars' contribution to achieving carbon neutrality will depend on two factors:

- First, as we discussed earlier in this paper, the method of hydrogen generation. 98% of the hydrogen produced today is produced from fossil fuels.

- Second, in the case of electric cars, origin of the electricity will have an important impact. For example, the electricity produced in France has lower carbon intensity of production than German electricity, meaning that an electric vehicle in France will generate environmental benefits quicker than its peer in Germany.

As things stand now, for cost reasons, the competition for light vehicles is between combustion engines and electric cars and not with hydrogen fuel cells. The production cost of electric batteries is today USD150/kwh compared to more than USD240/kwh for fuel cell. A Toyota Mirai with a fuel cell therefore costs about USD60k, whether the costs for its electric peer are about USD35k.

We do not see hydrogen becoming a workable solution for cars for at least another ten years. In our view, the hydrogen technology is unlikely to meet the challenges of car manufacturers over the short to medium term. In addition, there is a big challenge of developing infrastructure around hydrogen supply to cars. This is due not only to cost issues around manufacture of both hydrogen and fuel tanks but assembling the battery itself. It currently done manually, which is again expensive, but, on the upside, indicates a significant potential for lowering the costs once automation is introduced into the process.

In addition, compressed hydrogen (at a pressure of 700 bars) has only 15% of the energy density of petrol, so storing the equivalent amount of energy in a filling station would require almost seven times as much space. Hydrogen can also be very unstable which may give rise to issues with customer acceptance. The relatively low consumer uptake of liquefied petroleum gas (LPG), except notable examples being Poland and Italy, points to the challenges faced by the hydrogen solutions in the future and the need for mitigation of those risks with further technological innovations.

Aviation

Airlines are working to reduce CO2 emissions by 50% by 2050 from the 2005 levels. However, the International Civil Aviation Organization (ICAO) predicts that CO2 emissions from international traffic are expected to increase by 2.1 to 2.2 times by 2045. While they represent only about 2.5% of global emissions, experts believe that the estimates should be at least doubled. This is because the steam released by planes at high altitudes is also a significant greenhouse gas. Importantly, this target of halving emissions will not bring the aviation sector into line with the Paris agreement.

This is because traffic growth outpaces by far the expected efficiency gains. According to the International Civil Aviation Organization (ICAO), while aircraft fuel efficiency gives us an emissions reduction of 1.37% per year, it is offset by annual growth in air traffic of about 5%. It was weakened by the COVID-19 crisis, but traffic growth is expected to get back on a long-term trend that is higher than achieved efficiency. It is likely that some governments may impose stricter emission reduction measures on airlines in order to keep global warming at levels more compatible with the Paris agreement but they will have a limited effect in our view. The recent government bailouts of Air France and Austrian Airlines show that governments still have a difficulty in putting a foot down when it comes to airlines.

Moreover, while liquid hydrogen-based fuels should be able to offer an alternative to aircraft fuel hydrogen in the future, it is unlikely to happen in the medium term.

To make the hydrogen conversion happen for aircraft, combustion turbines will need to be switched for fuel cells, which currently do not have the power needed to get an aircraft off the ground. In addition, storage would require changes in aircraft design and infrastructure. Assuming that these technical difficulties are resolved, two other obstacles remain:

- Higher hydrogen costs require a carbon price above USD 115/tCO2 to be competitive (source Bernstein)
- Burning hydrogen fuel will produce a large amount of water vapour, which will be a significant contributor to global warming.

Therefore, **hydrogen seems far from being able to replace kerosene, with only the most optimistic scenarios expecting it to become a viable alternative for planes not earlier than 2045.** (Rystad, Bernstein).

Lorries / Buses

Lorries, buses and coaches are responsible for about a quarter of CO_2 emissions from road transport in the EU and some 6% of total EU emissions. Despite some improvements in fuel efficiency in recent years, emissions continue to increase, mainly due to the growth in road freight traffic.

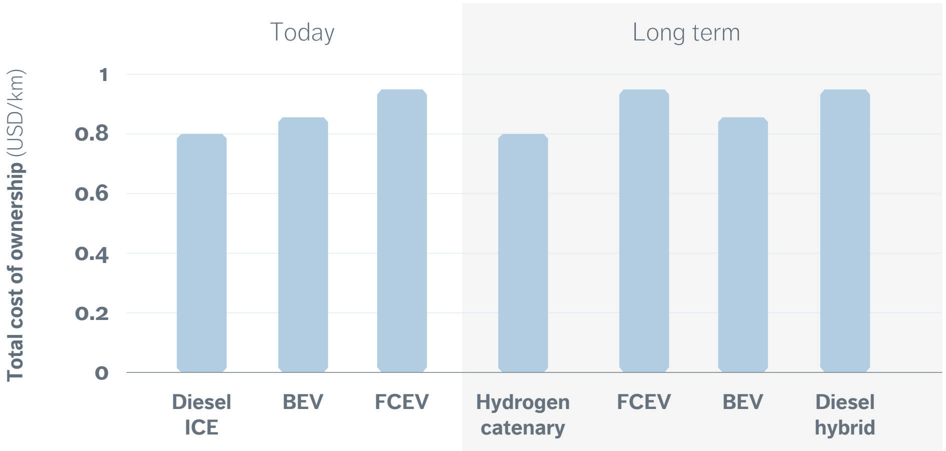
The very first European CO_2 emission standards for heavy goods vehicles (HGV), adopted in 2019, set targets for reducing the average emissions of new lorries by 2025 and 2030. Regulation (EU) 2019/1242 setting CO_2 emission standards for HGVs came into force on 14 August 2019.

The regulation also includes a mechanism to encourage the adoption of zero and low-emission vehicles.

For this, so-called 'heavy', mode of transport, the size of the electric battery makes it less practical. For example, a 40-tonne battery electric truck with a range of 500 km requires eight tonnes of battery power, making it less practical for transporting goods over long distances. Hydrogen providing three times more energy per kg than diesel, even though the tanks are heavier, could be a solution in this case. Several projects for the development of HGV fuel cell vehicles are already underway, and some of them are well advanced.

As shown in the graph below, **in cost terms, hydrogen already offers a competitive solution for the HGV sector comparable to that of light vehicles. Different studies show that between 2020 and 2030 hydrogen will become the most competitive solution to combustion engines.**

Figure 13:
Hydrogen: a cost effective future option for heavy road transport?



Note: Total cost of ownership include battery/fuel cell, operation/maintenance, electricity/furl and refueling/charging.

Sources: IEA, Bernstein analysis

PowerCell Sweden AB develops and produces fuel cells and fuel systems that run on pure or reformed hydrogen and generate electricity and heat without any other emissions than water. In September, its MS-100 fuel cell powered the world's first flight of a hydrogen engine aircraft in September 2020*. During the COVID-19 pandemic, in South Africa, the company supplied fuel cell systems to supply military hospitals in Tshwane to ensure uninterrupted electricity during power shortages. The producer will also participate in an EU project to develop a refuse track for the City of Gothenburg in Sweden. According to PowerCell Sweden AB, hydrogen fuel cell trucks have a comparable driving range, refuelling time and payload capacity to diesel-powered trucks while producing less noise and emitting only water vapor which are welcomed advantages for refuse trucks driving around during morning hours in residential areas.

* https://www.powercell.se/en/newsroom/press-releases/detail/?releaseId=BC32A88394862666, **accessed on 21.10.2020**

Shipping

Ships consume about 5% of global oil demand and contribute about 2.5% of global CO2 emissions, with freight using heavy fuel oil. With the IMO regulations coming into force at the end of 2019, high sulphur fuel oil (HFSO) is no longer allowed, meaning that only low sulphur fuel oil (LFSO) or low sulphur diesel can be used for maritime transport. Some ships may also choose to install a scrubber to remove sulphur, allowing them to continue to use high sulphur fuel oil.

Maersk is the first shipping company to announce its intention to become carbon neutral by 2050. This will require zero-carbon ships to be available by 2030. However, switching to hydrogen is and will continue to be very expensive. According to some estimates, the cost of switching to liquid hydrogen is 30% higher than that of fuel oil or LNG, with a high break-even carbon price, above US$100/tonne, being required for hydrogen to be competitive (Source; Bernstein).

The costs of new infrastructure should also to be taken into account. Marine supply chains will need storage tanks, liquefaction and regasification plants, conversion and reconversion plants, as well as loading and receiving terminals.

Most experts agree that hydrogen will not present a viable alternative for maritime transport. Another carbon neutral alternative, electric ships, is also very poorly developed, for the same reasons as heavy goods transport. According to specialist projections, the tipping point in terms of competitiveness would come after 2030.


NORLED
LMG 80 - DEH2
FUEL CELL
BALLARD
LH2
LMG MARIN
SHIP NAME
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Rail

Rail is one of the most energy-efficient modes of transport, accounting for 8% of motorised passenger movements and 7% of freight worldwide, but only 2% of transport energy consumption and only 0.3% of CO_2 emissions.

Urban and high-speed rail infrastructures have developed rapidly over the last decade, laying the foundation for convenient and low-polluting transport within and between cities.

Rail is already the most electrified mode of transport (IEA, 2018). Although the share of electrified tracks continues to grow in most countries, further electrification of rail networks will result in a diminishing return on investment, as the most frequently used lines were the first to be electrified.

As an intermediate step towards electrification, train manufacturers have begun in recent decades to produce hybrid diesel-electric and electric locomotives. This has improved the coverage of conventional rail passenger transport in areas without electrified tracks.

Beyond the diesel-electric hybrid options, several technologies can offer low CO_2 emissions from non-electrified vehicles. The most innovative technologies that offer low carbon or carbon neutral options to railway transport are battery electric trains and hydrogen fuel cell trains.

Although several companies have developed these innovative technologies, their economic viability with regard to diesel-electric or hybrid diesel-electric trains is still subject to a number of assumptions. They include the type of train, whether it is passenger or freight, distance that needs to be covered, as well as the uncertainties linked to the costs of the system.

The results presented below are those for regional passenger transport with fuel prices representative of the European market, where diesel is highly taxed. Today, half of the European rail network is not electrified and is operated by diesel-powered trains, that are a significant source of chemical and noise pollution.

Figure 14:

Hydrogen in rail transport: cost case studies

	Montréjeau-Luchon, France	Aragon, Spain	Groningen & Friesland, Netherlands
Track length	140 km	165 km	300 km
Rolling stock	3x 4 car trains (bi-mode)	2x 4 car trains (bi-mode)	70x 3 car trains
H2 consumption	0.36 kg/km	0.31 kg/km	0.22 kg/km
Total CAPEX	EUR 25 m	EUR 14 m	EUR 398 m
Characteristics	Partly electrified route with a low utilisation on 36 km	Cross border connectivity and long route without electrification	Fast trains for intercity connections
Total cost of ownership (EUR/km_{train})			
Diesel	18.5	9.3	4.8
FCH	**21.2**	**12.4**	**5.0**
Catenary	27.5	22.6	4.5
Battery	19.9	13.7	5.3
CO2 savings (ton per year)	**1,334 t**	**767 t**	**56,389 t**

Source: Shift2rail.org


© Alstom/Rene Frampe

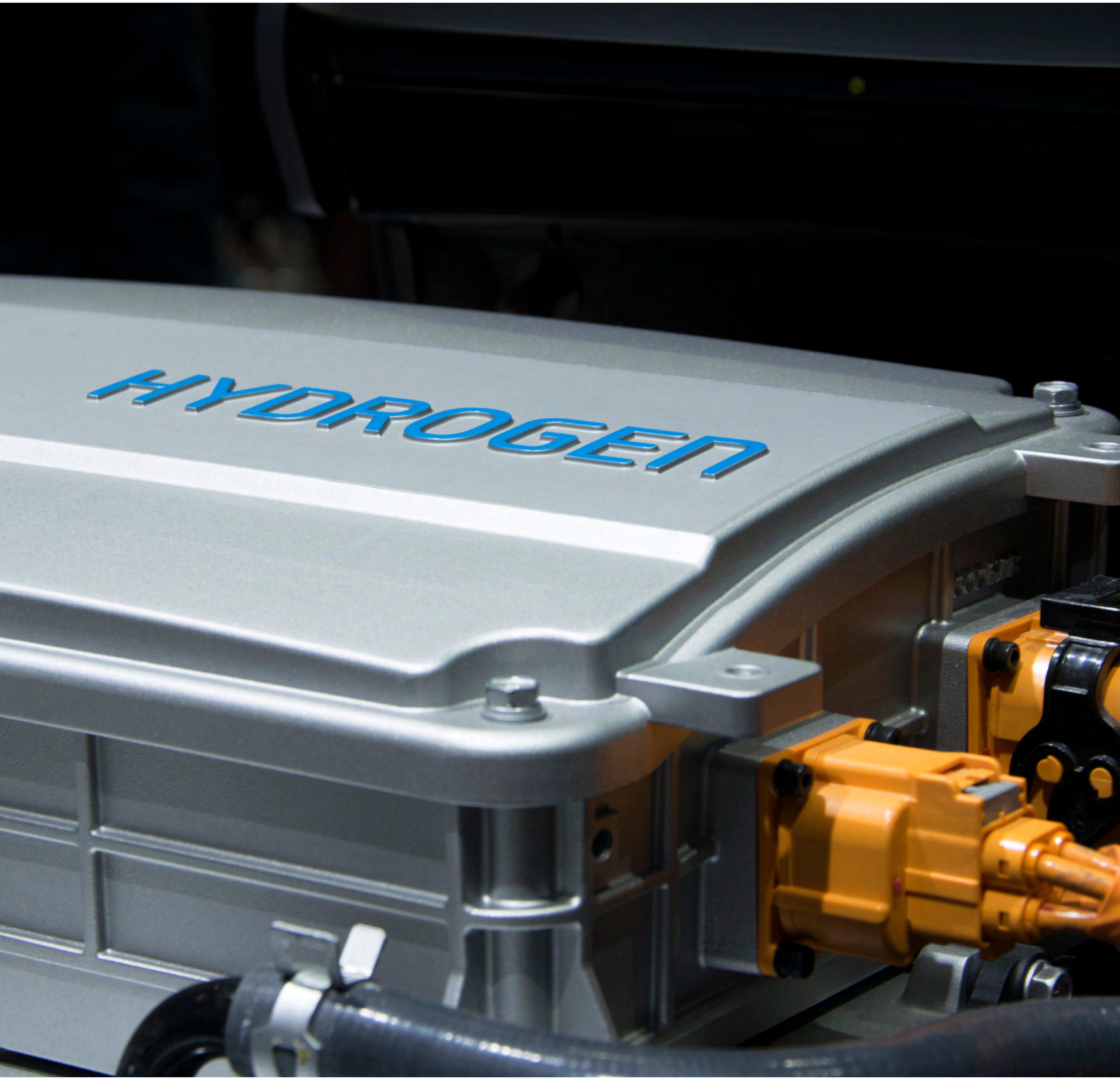
Despite lower maintenance costs than trains with combustion engines, the total operating cost of hydrogen trains remains generally higher than that of diesel trains. However, if the price of the energy needed to produce hydrogen is kept under a certain level, the hydrogen solution becomes competitive relative to the diesel option. If the price of electricity and hydrogen consumed per kilometre is lower (EUR 60 per MWH) with a diesel price of up to 1.35 per litre, hydrogen operation becomes the cheapest alternative. This case reflects the current reality in some European regions such as Scandinavia, where low-cost electricity can be supplied using electrolysis technology to produce hydrogen.

Hydrogen trains can already compete with diesel trains in some cases, depending on several parameters including electrification, distance and electricity price. We believe that hydrogen trains may become a viable alternative already before 2030, well before aviation or maritime transport, assuming some reduction in costs, including that of green energy required for electrolysis, combined with government aid and incentives.

Hydrogen-powered trains have been deployed on an experimental basis or are already under development.

In 2015, the French train manufacturer Alstom and the Canadian fuel cell producer Hydrogenics established a partnership to develop a hydrogen-powered train. Within several years they have developed a hydrogen fuel cell concept, and now have two hydrogen trains in service along a conventional regional passenger railway of about 100 kilometres in Germany's Lower Saxony. Alsthom plans to extend this to 14 trains by 2021.

Similarly in Asia, Toyota announced a partnership with East Japan Railway Company to develop a hydrogen train in Japan.


HYDROGEN

Closing the loop

Hydrogen is set to become a vital link in the alternative energy provision, a crucial part of the carbon neutral world we aspire for the future.

The technology has been around since the 1970s. Despite technological advancement and some government support in the recent years, deployment of hydrogen remains dependent on many factors. They include a favourable environment for reducing CO2 emissions, the price of different types of renewable energy, and a European recovery plan that places a special emphasis on hydrogen in achieving carbon neutrality by 2050. However, this will only happen if we increase significantly the production capacity of green electricity that is used in electrolysis generating hydrogen. Currently Europe aims to produce 40GW of hydrogen through electrolysis by 2030.

The EUR15 billion hydrogen technology investment plan of the French and German governments is driven by the desire to make Europe a world leader in the field and void a situation when emerging markets become the major supplier of technology, such as in the case of photovoltaic panels.

As demonstrated by the transport sector, hydrogen will not be the only way to achieve carbon neutrality for Europe by 2050 but it will have an important role to play. For example, hydrogen can help reduce the heavy carbon footprint of cement and steel production, and other activities that require a continuous and stable energy supply. Heavy transport such as road freight can also benefit from the development of hydrogen.

We believe that strong political action towards decarbonisation should speed up the process of hydrogen becoming powerful and economically viable alternative source for energy. However, even despite all of the progress made on the technological and regulatory side, much of hydrogen's success will depend on costs. The price of electrolysers and the cost of carbon-neutral hydrogen energy are still too high. Moreover, we believe that an increase in hydrogen energy production capacity and more powerful electrolysers can only be achieved based on more intelligent energy networks. Weighing all of these challenges together, it is clear to us that the latest, EUR15 billion, government investment package is only one of the early steps in the right direction, with a lot of investment and opportunities still to come.

Notes & References

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