Bundle | 28 October 2021

Hydrogen: The complete picture

Hydrogen: It delivers both power and heat. So, how does it fit into the global energy mix and the world's environmental ambitions? In this series of articles, we look at the market and the economics, hydrogen's growth prospects, global government attitudes, and the key players in an industry which is becoming increasingly prominent and important

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High gas prices triple the cost of hydrogen production

Increasing the use of hydrogen could be an important part of decarbonising industry and reducing our dependence on gas. But the cost of hydrogen...

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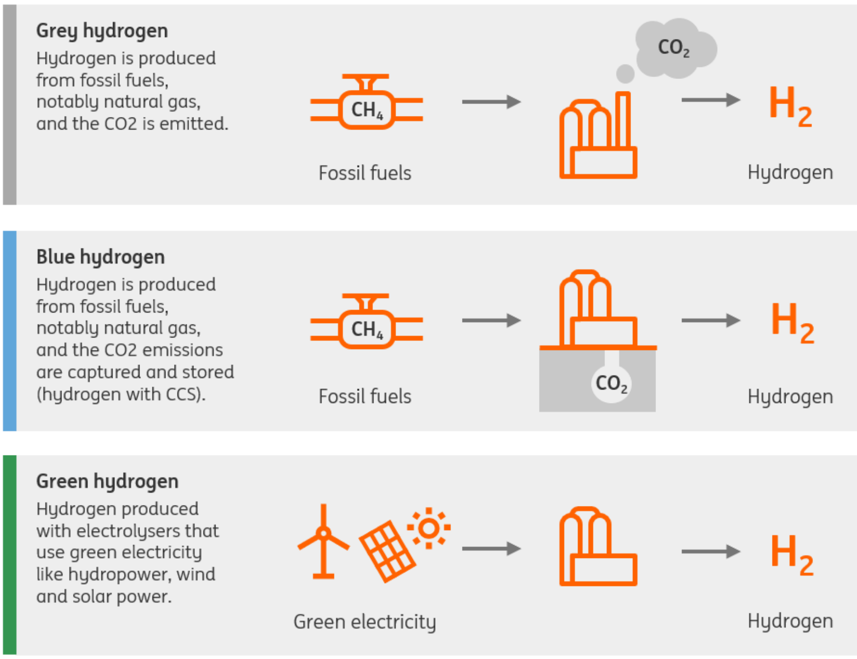
Source: Shutterstock
A hydrogen logo at a hydrogen production facility of the EWE in Elsfleth, northern Germany

Introduction: grey, blue and green hydrogen

There are many different ways of producing hydrogen with grey, blue and green hydrogen, being the most important. Natural gas is the main input for grey and blue hydrogen. Electricity is the main input for green hydrogen. Carbon emissions vary considerably between the different forms of hydrogen, with grey being the dirtiest and green being the cleanest.

Value drives of grey, blue and green hydrogen



Source: ING Research

The economics of hydrogen: gas, power and carbon prices

This article examines the economics of hydrogen, by analysing the impact of gas, electricity and carbon prices on the business case of the various production techniques. In doing so, we examine a **hypothetical project** at an industrial site near the North Sea coast. We assume that hydrogen can be produced 24/7, so the hydrogen plant runs at a high capacity factor. In producing blue hydrogen, we assume the carbon is captured and stored in a depleted offshore oil or gas field. The CO2 is then transported through a 50km pipeline, not by ships (which is more expensive) and not in an onshore field or salt cavern (which meets more social opposition).

These assumptions are similar to those that actually apply in real-life situations in some coastal European countries, notably the Netherlands, Germany, Belgium, the United Kingdom and countries in the Nordics like Norway and Denmark. These CCS assumptions are near-optimal. As a result, the scenario outcomes are likely to represent the lower cost range of a wide variety of hydrogen production possibilities.

In practice, many project-specific factors determine the eventual outcome of a business case. The factors that have a particularly important bearing on the profitability include whether carbon can be captured pre- or post-combustion, the availability of depleted gas fields to store carbon, sea depths, whether or not existing gas infrastructure can be used to transport carbon or if new infrastructure is required. As a result, our calculations are only illustrative and aim to show the general dynamics of gas, power and carbon prices on hydrogen production. They should not be considered as perfect benchmarks. With that disclaimer in mind, let us have a look at the economics of hydrogen production.

Higher gas prices have tripled the cost of grey and blue hydrogen

Grey and blue hydrogen can be made from gas through Steam Methane Reforming (SMR) while green hydrogen can be made out of water and electricity through electrolysis. The different production techniques use different types of energy. SMR uses gas and, therefore the production costs of both grey and blue hydrogen are dependent on the gas price.

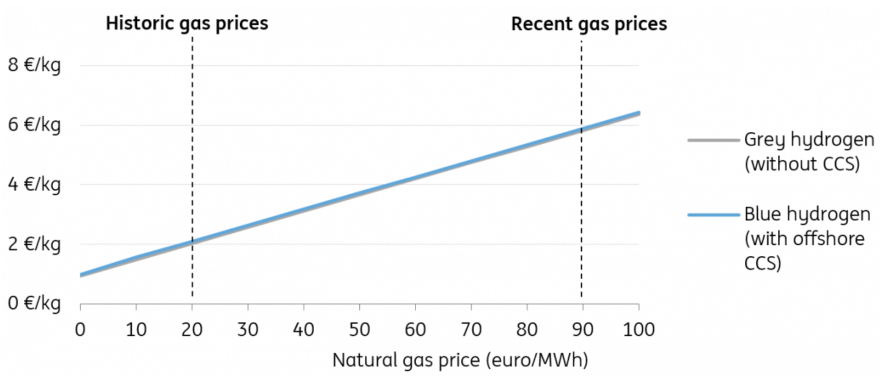
Historically, the natural gas price averages around €20/MWh in North European countries. At €20/MWh, and with the current carbon price of around €65/ton CO2, both grey and blue hydrogen can be produced at around €2/kg in our planning scenario.

During the Covid-19 crisis, gas prices fell to around €3.5/MWh, but recently they have risen to about €90/MWh due to increased demand, low gas reserves and LNG moving to Asia instead of Europe. As a result, the costs of grey and blue hydrogen production have tripled to around €6/kg in our planning scenario.

Note that at current carbon prices of about €60-65 per ton of CO2, the production costs for grey hydrogen (without CCS) and blue hydrogen (with CCS) are almost equal. We will explore the relationship between hydrogen production costs and carbon prices in more detail at the end of this article.

Hydrogen production costs have tripled at current high gas prices

Hydrogen production costs* for different gas prices**



* including distribution and storage of CO_2
** with a carbon price of 65 €/ton/CO_2
Source: ING Research

Green hydrogen is twice the cost of grey and blue hydrogen

Hydrogen can also be made by splitting water (H2O) into hydrogen (H2) and oxygen (O2) through electrolysers that run on power. Unlike hydrogen produced from gas (grey and blue hydrogen), hydrogen produced in electrolysers does not create direct carbon emissions (green hydrogen). There are, however, indirect carbon emissions that are created from the power consumption that is required by the electrolysers. However, if renewable power is used, these carbon emissions can be reduced to zero. In reality, power from the national grid is often used, so a country's power mix determines the actual carbon emissions from power consumption.

There are two main types of electrolysers: PEM and alkaline electrolysers, the last one currently being the cheapest technology (see box).

For our example, we have investigated the range of production costs of green hydrogen. The lower bound is represented by the cheapest technology (Alkaline) using power from the grid. The upper bound is represented by the PEM electrolyser using green power from the grid. Green power is a bit more expensive than grey power from the grid, as the buyer needs to pay for the Guarantees of Origin that proves that the power comes from renewable sources.

Hydrogen costs are c.€3.80-€4.80 with power prices of c.€40/MWh, which is the long year average in the Northwest European power market (Germany and the Netherlands). So green hydrogen is about twice as expensive to produce compared to grey and blue hydrogen (roughly €2/kg).

Power markets are both very tight and volatile

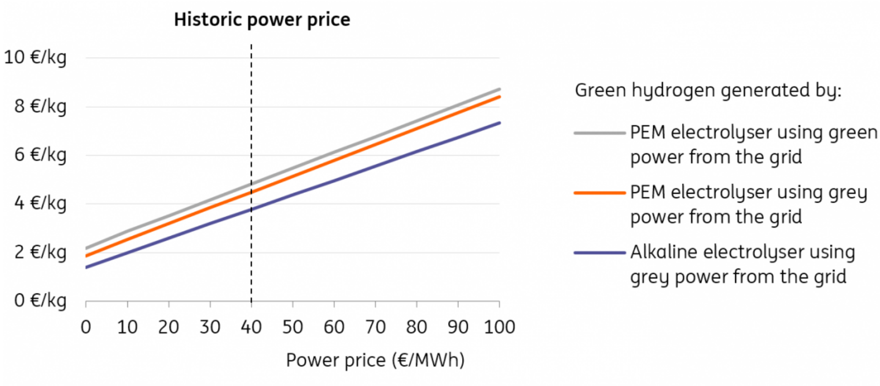
Power markets are currently very tight and volatile. Power prices were trading above €300/MWh at the beginning of October. Hence the costs of green hydrogen have soared because expensive power from the grid is used.

Hydrogen could also be produced with power that comes directly from renewable sources such as offshore wind turbines. A hydrogen manufacturer who owns wind turbines does not run the market risk of volatile power prices, as the effective price they pay is determined by the capital and operational costs of the turbines over the lifespan of the asset. The so-called Life Cycle Costs of Electricity (LCOE) for offshore wind, currently ranges from €45-130 in countries like Germany, the Netherlands and the UK, according to Bloomberg New Energy Finance. So in theory there is a limit to the cost of power if hydrogen producers own renewable assets. However, the technique of directly producing hydrogen from wind turbines is still in its infancy.

Given the large price differential of grey and blue hydrogen with green hydrogen, it is remarkable to see that most governments tend to focus on green hydrogen in their ambitious hydrogen plans. We look more closely at that in this article.

Production costs for green hydrogen are about €3.80-4.80/kg at historical power prices

Production costs of green hydrogen for different power prices



* with a carbon price of €65/ton
Source: ING Research

Alkaline versus PEM electrolysers

Electrolyses is the application of an electrical current to a substance to produce a chemical reaction. Electrolysing water causes the decomposition of water molecules (H2O) into their parts; hydrogen (H2) and oxygen (O2).

There are two main techniques available for the electrolyser.

1. Alkaline electrolysers are the oldest and most established technology. The commercialisation of alkaline electrolyser technology started in the 1920s in Canada. Triggered by rising demand for ammonia, a raw material for fertilisers, many large alkaline systems were built during the 1930-1970s.
2. Polymer Electrolyte or Proton Exchange Membrane (PEM) electrolysis is a newer technology that has some advantages over alkaline electrolyses, such as having a smaller footprint and greater operating flexibility. Both can be useful when the reliability of local green power sources fluctuate depending on solar and wind conditions.

Our analysis is not concerned with the specifics of these technologies other than how they affect the different production costs of hydrogen.

Blue hydrogen becomes cost competitive with grey hydrogen at current carbon prices of €60-65/ton

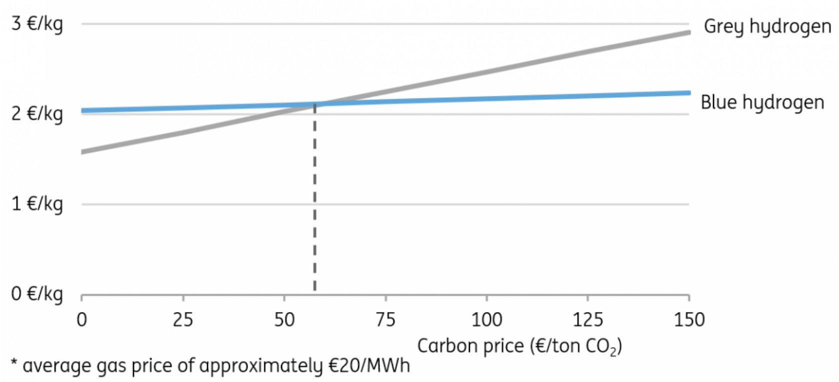
Currently, most of the hydrogen is produced from gas and the resulting carbon emissions are not captured and stored (grey hydrogen). This is not surprising, given the fact that carbon prices were relatively low until 2021. Grey hydrogen was the cheapest form to produce and as a result, most real-life hydrogen production has been very carbon-intensive and accounts for 2.2% of global carbon emissions.

Gas-based hydrogen production can be made less carbon-intensive by capturing and storing carbon emissions (blue hydrogen). The carbon price determines whether it is cheaper to emit a ton of carbon (grey hydrogen) or to capture and store the carbon emissions and to save on the carbon price (blue hydrogen).

We estimate that under normal conditions in energy markets, it becomes cost-efficient to capture and store carbon emissions from hydrogen production at carbon prices of about €60-65/ton. Carbon prices have been trading in this price range recently and we expect prices to stay in this range given the EU Fitfor55 strategy. So, hydrogen producers have a strong incentive to invest in blue hydrogen once the infrastructure to transport and store hydrogen, is in place.

CCS becomes profitable with carbon prices at approximately 60-65 euro/ton and higher

Hydrogen production costs as a function of the EU carbon price under normal gas markets*



* average gas price of approximately €20/MWh

Source: ING Research

Power markets do not support the production of green hydrogen anytime soon

Our main conclusion so far is that green hydrogen (using renewable power) is much more expensive to produce than grey and blue hydrogen (using gas). We therefore further investigated what power price is required to make green hydrogen cost-competitive with grey and blue hydrogen.

The production costs of grey and blue hydrogen are about 2 euro/kg based on the average gas prices of about €20/MWh and a carbon price of around €65/ton. Power prices need to be as low as €1/MWh for extended periods of time to make green hydrogen cost-competitive. Those are unrealistically low levels of power prices for two reasons. First, historical power prices are around €40/MWh in many Northwest European power markets. Second, current power prices are extremely high and recently passed €300/MWh in some European power markets.

Nevertheless, even in current power markets, power prices can be very low during the day, at times when there is a lot of power generation from wind turbines and solar panels. But hydrogen production is a year-round 24/7 business, so a couple of hours of low or even negative power prices, doesn't make much of a difference. Electricity simply won't be free most of the time even in power markets dominated by renewables, as renewables and the backup facilities to store power are capital intensive.

Another complication is the fact that gas and power prices are closely related, as most of the time gas-fired power plants set the power price in European power markets. So, low power prices require low gas prices, but that would make grey and blue hydrogen cheaper compared to green hydrogen.

All in all, it is not likely that power markets will make green hydrogen cost-competitive with grey and blue hydrogen anytime soon. In that respect, it is somewhat surprising that most governments focus on green hydrogen production in their ambitious hydrogen plan. The US is an exception to this practice, with a balanced approach to both grey, blue and green hydrogen.

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Hydrogen: Fuelling the future

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Source: Shutterstock

Demand: a promising alternative to fossil fuels in all aspects of energy use

Our energy transition scenarios show that fossil fuel use is the main cause of the global greenhouse gas emissions that contributes to global warming. We must drastically reduce the use of fossil fuels if we are to reach the Paris Agreement Climate Goals of keeping global warming to well below 2°C and to pursue the even more ambitious goals of limiting the temperature increase to 1.5°C.

Hydrogen based solutions provide huge potential in helping reduce fossil fuel demand in all the major areas of energy use: heating, transportation, electricity and feedstock. It can, for example, be burned to generate the heat necessary to produce cement and steel or for the heating of buildings. In transportation, trucks, aeroplanes and ships could be powered through hydrogen-fuelled engines. And power plants can be designed to run on hydrogen instead of gas. Hydrogen can also be used as a feedstock, in the production, for example, of fertilisers.

Both governments and companies have set ambitious carbon reduction targets which have made hydrogen and its environmental benefits, a very hot topic.

Hydrogen could shake up the energy chain in many ways

Type of energy use	Share in global energy use (2019)	Hydrogen examples
Electricity	19%	Hydrogen fired power plants and production of hydrogen with electrolyses
Transportation	29%	Hydrogen trucks, airplanes and ships
Heating	42%	Hydrogen furnaces and boilers in factories and buildings
Other	11%	Production of fertilisers

Source: ING Research

Hydrogen can meet demand for low carbon electricity…

19% of global energy demand is related to the use of electricity, according to the latest World Energy Outlook from the International Energy Agency (IEA). Most of the power is used in buildings and factories and to a much lesser extent, in transportation.

Proven, mature and low-cost technologies such as wind turbines and solar panels, are already available to generate green electricity. It is therefore relatively easy, both technically and economically, to increase the share of renewable electricity in the power sector. The European Commission, for example, recently increased its renewable energy target for the power sector in its Fit for 55 strategy to 65% by 2030, up from the previous target of 55%. Furthermore, power plants can be built to run on hydrogen instead of gas and thereby produce electricity with almost zero carbon emissions.

…and ‘store’ the power for later use

The problem with electricity is that it is not easy to store in large quantities for long periods. Batteries, for example, can only store relatively small amounts of electricity for short periods of time. Economically, it is really only feasible to store electricity in batteries for up to a couple of days.

Hydrogen could help overcome this problem by playing a major role in the storage of electricity in future energy systems that rely heavily on power generation from renewables. Using hydrogen as a store of energy would involve producing it at times when there is an oversupply of green electricity from wind turbines and solar panels. At a later stage, the hydrogen could then be used to generate electricity again, for example in a hydrogen power plant.

Currently, such processes are not financially competitive compared with traditional fossil fuel power generation. However, technically, hydrogen has the potential to act as a backup facility in future power systems, especially during long periods when the wind is not blowing and the sun is not shining; the so-called ‘dunkelflaute’.

Hydrogen can meet demand for low carbon heat, too

Electricity demand is relatively easy to decarbonise but only accounts for about one-fifth of total energy demand. The real challenge is to decarbonise the other 81% of global energy demand related to heating, transportation and feedstock purposes. These processes require molecules, not electrons, and hydrogen is one of the most promising technologies which are able to provide those 'green molecules'.

For example, fertilisers (NH_3) can be made from hydrogen (H_2) and nitrogen (N_2) molecules. And hydrogen molecules can also be burnt in furnaces to provide high-temperature heat in the steel, cement and glass industries. It could also provide low-carbon heat in buildings, and hydrogen could also be used to power trucks, aeroplanes and ships.

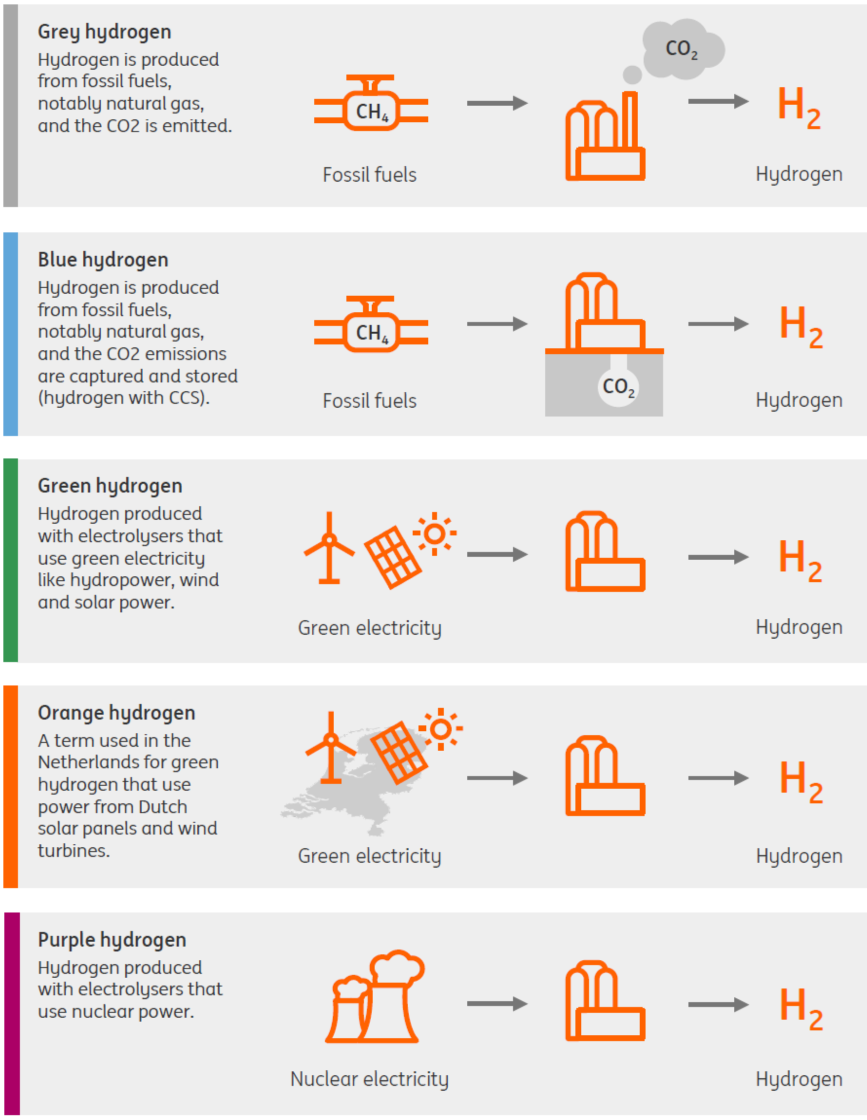
Supply: five shades of hydrogen

To summarise, future hydrogen demand could come from many different sectors and be used for many different purposes. But of course, that hydrogen first needs to be produced, as it does not naturally exist in a pure form.

Despite the fact that hydrogen is a colourless gas, many colours are now used to distinguish the different ways in which hydrogen can be produced. From grey and blue hydrogen which are produced using fossil fuels to green, orange and purple hydrogen which are produced through electrolysis.

A colourful bouquet of hydrogen production techniques

Hydrogen production techniques



Source: ING Research

In theory, hydrogen can also be made from biogas instead of natural gas. If the resulting carbon emissions are captured and stored, this technique would yield negative emissions, meaning that carbon emissions are taken out of the air by plants and stored in the ground during the production of hydrogen. However, this technique is not yet used in practice.

Given the importance of negative emissions in creating the energy transition pathways needed to reach the Paris Agreement Climate Goals, it is remarkable that this option has not yet been assigned a colour. We suggest calling it dark green, indicating the significant potential of the technology to reduce emissions.

Facts on current hydrogen production

- Current global production: about 120 MMT which creates yearly emissions of 830 million tons of CO2 (2.2% of global energy-related emissions).
- Over 95% of hydrogen is made out of natural gas without capturing and storing carbon emissions (grey hydrogen).

- Hydrogen is mostly used for its chemical properties, not for energy purposes. Around 70% of hydrogen production is related to oil refining or the production of ammonia and methanol. Oil refineries use hydrogen for sulfur removal. Ammonia (NH_3) and methanol (CH_3OH) cannot be made without hydrogen (H_2).
- 50% of hydrogen is produced deliberately in purpose-built plants, 40% comes as a by-product of manufacturing processes.
- On-site production and hydrogen usage on large industrial sites dominate. Only 8% of global production is sold on a merchant basis directly between producers and consumers.
- There is hardly any intermediate trading and therefore no market indices or benchmarks exist. Prices of traded hydrogen range between €3-12 per kilogram of hydrogen.
- The size of the hydrogen market is estimated to be about €110bn globally, based on onsite production and usage and the trade in hydrogen.
- While these are big numbers, the size of the hydrogen market is still small in relation to the total energy market. In Europe for example, hydrogen consumption is around 1% of total energy consumption.

Sources: BNEF, CEER, DNV-GL, IEA.

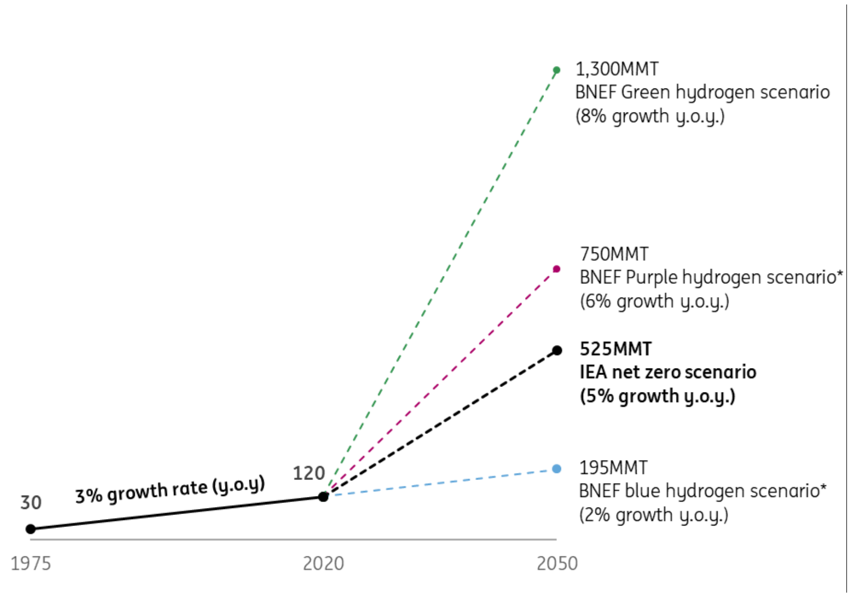
Hydrogen scenarios indicate 2% to 8% yearly growth towards 2050

Global carbon emissions need to reach 'net zero' by 2050 in order to keep global warming in the lower band of the Paris Climate Agreement goals (close to 1.5°C warming). Net-zero refers to the situation in which yearly global emissions equal the natural absorption of carbon by the climate by, for example, oceans and forests.

There are many different scenarios that would create a net-zero economy by 2050. In this section, we discuss some benchmark scenarios for different power systems that make up a net-zero economy.

Hydrogen scenarios indicate 2% to 8% yearly growth towards 2050

Past and future global hydrogen production in million metric tons (MMT)



Source: ING Research based on BNEF

Hydrogen production has grown 3% year-on-year since 1975 and currently stands at about 120 million tons (MMT) globally. Future growth will depend on the energy systems used in creating a net-zero economy. Hydrogen certainly has a large role to play in an energy system that is predominantly based on renewables, as it provides clean energy at times when the supply of renewables is low. In such a world, hydrogen production could reach about 1,300 MMT by 2050, meaning 8% growth year-on-year, according to Bloomberg New Energy Finance and most of that hydrogen will be **green hydrogen**.

Hydrogen also has a big role to play in an energy system that heavily relies on renewables and **nuclear power**. Hydrogen production could reach around 750 MMT by 2050 in a power system where small modular nuclear plants complement wind, solar and battery technology in the power sector. In this scenario, the electricity that drives hydrogen electrolysers comes from dedicated nuclear power plants. In such a world, hydrogen production could reach around 750 MMT by 2050, meaning 6% growth year-on-year.

Hydrogen production could reach around 195 MMT in a world where fossil fuels continue to play an important role in the energy system. Carbon capture and storage (CCS) is an important technology that could be used to mitigate carbon emissions from fossil fuels. In such a world, most hydrogen production will involve **blue hydrogen**. Despite the fact that hydrogen production will almost double from current levels, the growth rate will drop from 3% to 2% per year in this fossil fuel-based scenario.

The IEA Net Zero Scenario takes a more holistic approach and allows for the different energy technologies to co-exist next to each other. According to this scenario, both renewables, CCS and nuclear energy have a role to play in a net-zero economy. While individual countries could focus on one specific technology, it all adds up to a more diverse picture at a global level. In such a world, there is room for all the different shades of hydrogen and hydrogen production to grow to about 525 MMT by 2050, implying a future growth rate of 5%.

Future growth depends on policy support, societal preferences and technological advances

These hydrogen scenarios indicate a wide range of possible outcomes for future hydrogen production. At this stage of the transition towards hydrogen, it is impossible to accurately forecast the future nature and level of hydrogen production. It simply is not clear yet how hydrogen will transform energy use in manufacturing, aviation, shipping, trucking and power systems across the globe. As such, all pathways should be seen as possible scenarios, including the well known Net Zero scenario from the IEA.

Key, but highly uncertain, factors that will determine future growth in hydrogen are:

- Policies from governments and public support from society for nuclear energy and the capturing and storage of carbon (purple and blue hydrogen).
- The pace of technological advances at which manufacturers can lower the cost of electrolysers (green hydrogen) and CCS (blue hydrogen).
- Regulatory frameworks and policy support that gives confidence to investors to finance the hydrogen transition in key sectors.
- Investments in the hydrogen value chain, in particular by the oil and gas majors, utilities and grid operators.
- Market conditions in commodity and energy markets, notably the development of gas, power and carbon prices. The recent rise in energy prices, for example, has doubled the cost of hydrogen production.

The other articles in our series shed light on some of these factors.

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Article | 28 October 2021 Energy | Sustainability

Governments are shaping their hydrogen ambitions

Many governments across the globe have announced ambitious hydrogen plans to decarbonise economies and increase gas independence. Big money is invested in...

Source: Shutterstock
3d rendering of Hydrogen renewable energy production

Governments across the globe present their hydrogen budgets

The Hydrogen Council, an international organisation created by the CEOs of a number of leading companies, believes that hydrogen could meet 18% of total global energy demand in the long term and create a €2 trillion market. But for the moment, the market is still in its infancy and needs a lot of policy support. According to Bloomberg New Energy Finance, as of July 2021, 43 countries have released or are about to release hydrogen roadmaps.

Some governments have announced big numbers, like Germany, Spain, France and the United States. But these numbers are extremely hard to compare, as time horizons are difficult to interpret, some of the budgets involve private investments too. The amounts are often not yet backed with policy instruments and the numbers might target different parts of the hydrogen value chain (infrastructure only versus stimulation of hydrogen production as well as demand).

Announced hydrogen budgets by governments

Country	Allocated budget for hydrogen projects	Indicative timeline
Italy	€10.5bn*	2021-2030
Germany	€9bn	2021-2030
Spain	€9bn**	2021-2030
France	€7.2bn	2021-2030
The United States	€6.7bn	2021-2030
The Netherlands	€1.1bn	2020-2030
Japan	€340m	2021-2030
Australia	€340m	2021-2022

*Preliminary budget
**Mix of public and private investments
Source: ING Research

In this article we take a closer look at hydrogen policies in Europe, Asia and North America.

The European Union aims for 13-14% of hydrogen in energy mix by 2050

In July 2020, the European Commission revealed its hydrogen strategy with the Hydrogen Strategy for a Climate-Neutral Europe publication. The European Union wants to have a net-zero carbon economy by 2050 and believes that, while renewables will account for a large part of the energy decarbonisation in the future, hydrogen has an important role to play.

The goal of the plan is to increase hydrogen's share of the market from less than 2% in 2020 up to 13-14% by 2050. The most optimistic scenario forecasts a hydrogen share within the energy mix of up to 24% by 2050.

13-14%

Hydrogen share in the EU energy mix

By 2050 in the main scenario

The European hydrogen plan includes a three phase roadmap

Phase one: from 2020 up to 2024, the objective is to install at least 6 GW of renewable hydrogen electrolysers in the EU and to produce up to 1 million tonnes of green hydrogen. The European Clean Hydrogen Alliance, which brings together industry, public authorities and civil society, will develop an investment agenda and concrete projects.

Phase two: running from 2025 to 2030, the scale-up of hydrogen production, distribution and use is aiming at the installation of at least 40 GW of renewable hydrogen electrolysers to produce 10 million tonnes of green hydrogen.

Phase three: from 2030 onwards, green hydrogen should reach maturity and should be used in all sectors that are currently harder to decarbonise, such as manufacturing, aviation, trucks, shipping and buildings.

The European Commission believes that the scale-up of green hydrogen will require a total investment of €470bn over the next 30 years.

€470bn

Investment need for green hydrogen

Up to 2050

The exact budget that will be dedicated to hydrogen is not yet well defined. The approach seems to include a mix of incentives and loans. The European Investment Bank and a number of European programmes could be used. Amongst the programmes that directly mention support to hydrogen projects, the InvestEU and the Horizon Europe programmes are, in our view, amongst the most interesting.

- The **InvestEU program**, dedicated to the pandemic recovery, green growth, employment and well-being across Europe, is one of the funding possibilities. An updated programme was launched in March 2021 with a €372bn budget to boost investment, innovation and job creation in Europe over the period 2021-2027. €26.2bn will be backed by a guarantee and the European Investment Bank will be the main financial partner and should deliver on 75% of the EU guarantee. The remaining 25% of the budget will be shared between other partners which will be selected by the Commission. The first wave of approved financing and investment operations will need to be signed by 31 December 2023.
- **Horizon Europe**, a research and innovation programme, could be used to support research to improve existing technologies. The Horizon Europe programme consists of 3 pillars and had a budget of €2.7bn between 2018 and 2020 for the Pillar 1 phase. Pillar 2, with a budget of €53.2bn, will look into bringing forward the transition towards circular and low carbon industries in applied research clusters. The third pillar, with a budget of €10bn, is 70% dedicated to SMEs, and will promote all project innovations and knowledge transfers, including non-technological innovations.

The European countries' planned budgets for hydrogen projects

The approach taken by European countries in terms of subsidies in regards to hydrogen does not offer a homogenous picture. Looking at a few examples, some countries have taken a top-down approach by estimating how much budget or subsidies will be needed for a successful implementation of the new energy source, others have taken a more bottom-up approach, having not divulged any specific amounts but have rather been looking at projects and examining how they can qualify for financial support.

Germany, France and Italy are amongst the European Union members that announced global specific budgets for their national hydrogen development. In May 2021, **Germany's** Economy and

Transport ministry reaffirmed the country's ambitions. The federal government is ready to dedicate €9bn of its stimulus budget to green hydrogen projects. The country has a 5GW electrolyzer target for 2030, of which 2GW was reserved for transport applications. Earlier this year, more than 200 hydrogen projects applications were received.

In September 2020, **France** published its hydrogen strategy and announced a total of €7.2bn budget to develop a decarbonised hydrogen industry by 2030, with €3.4bn to be implemented by 2023.

Italy published its "National hydrogen strategy. Preliminary guidelines" in November 2020. So far, the plan has not been made final, but the Italian Recovery and Resilience plan is allocating a preliminary €10.5bn budget to hydrogen for the period 2021-2030. This include between €5bn and €7bn dedicated to hydrogen production. Distribution, refuelling stations and transport vehicles such as trucks and trains could benefit from between €2 to €3bn over the next ten years. Another financial effort of c.€1bn could be used to research and promote hydrogen. The plan envisages that half of these investments would be provided by European funds, such as the Horizon Europe, the Innovation Fund and the Next Gen EU fund.

Despite ambitious plans for hydrogen, **the Netherlands**' announced budget for the implementation of the new energy source, is rather modest. On September 21st the government announced a budget of €750m to support the gas transmission system operator Gasunie, in developing a hydrogen backbone by 2030. It would connect the main industrial clusters in the Netherlands (total costs equal €1.5bn). We discuss that in more detail here. Earlier in 2021, the government announced a budget of €338m for hydrogen research and production projects. This amount is part of a €20bn fund dedicated to the Dutch economy, education, infrastructure and sustainable energy projects for the period 2020-2025.

Spain plans to install 4GW of electrolysers by 2030, 300MW to 600MW of which could be installed by 2024. In practice, Spain aims at 100 to 150 public access hydrogen fuelling stations, 150 to 200 hydrogen buses, 2 hydrogen-powered trains and 5000 to 7500 light- and heavy-hydrogen vehicles. Spain estimated that a budget of €9bn for its Hydrogen Roadmap over the next 10 years is necessary. However, the government expects the majority of the funds to come from the private sector, although the public sector would also play a role. As of today, Spain has received 502 project proposals corresponding to €10bn of investment needs. In May 2021, Spain secured €1.5bn from the Next Generation EU Fund to finance some of these projects.

The Asia-Pacific region: Japan is already a leading player

Japan is already a leader in hydrogen technology and a large scale green hydrogen plant has already been operating since March 2020 and the country is planning for more. Japan's third and latest version of its hydrogen strategy dates back to 2019. Three main objectives that emerge from the roadmap are:

1. The decarbonisation of the Japanese economy with a net-zero carbon emissions ambition by 2050.
2. The government also sees hydrogen as an energy resource that could increase the country energy self-sufficiency.
3. Reduce hydrogen costs to push the economy's competitiveness and become a hydrogen exporter.

€340m

The Japanese government's budget for hydrogen

Up to 2030

Full-scale hydrogen generation in Japan by around 2030

The plan's expectation is to introduce full-scale hydrogen generation by around 2030. The government has also set a budget of ¥70bn or €340m equivalent, to finance research and development as well as eight pilot projects:

- A hydrogen refuelling station for fuel cell forklifts
- Hydrogen produced from biogas originating from livestock manure to power fuel cell vehicles and fuel cell forklifts
- Using hydrogen to supply electricity to a swimming pool
- A hotel powered by a hydrogen fuel cell
- Hydrogen produced from hydropower used to heat a swimming pool
- Green hydrogen used to power and heat a retail store
- Blending green hydrogen with town gas to fire stoves and other gas devices
- Hydrogen produced using wind power used to generate electricity and heat at a hot spring facility

As far as the transport sector is concerned, Japan has clear objectives, aiming to have 200,000 fuel cell vehicles on the roads by 2025 and 800,000 by 2030. This would be accompanied by 320 hydrogen refuelling stations by 2025 and 900 by 2030. A major investment in fuel cell buses is also planned, with 1,200 of them expected to be operating by 2030.

Australia

In 2016, the Australian government, along with some 20 organisations, started to investigate the challenges and opportunities offered by hydrogen. First of all, Australia has decarbonisation targets that imply cutting carbon emissions by 26%-28% below 2005 levels, by 2030. Secondly, Australia produces natural gas but with depleting reserves, its natural gas production costs have remained high compared to other markets and this poses a challenge for Australian industries to stay competitive.

In 2018, the Australian government published its hydrogen roadmap: "Pathways to an economically sustainable hydrogen industry in Australia". The roadmap looks at the development of a renewable hydrogen supply chain model, a legal framework review and hydrogen storage potentials.

The report also looks at the applications for hydrogen on the Australian territory and the implied economics.

- Stationary electricity: in the Australian context, proton exchange membrane fuel cells are likely to be the most widely used systems due to their global market size due to its, various applications and faster start-up times.
- Hydrogen fuelled transport: passenger hydrogen fuel cell electric vehicles (PFCEVs) are seen

as a complementary technology to battery electric vehicles. As of today, no commercial hydrogen car is for sale in Australia and one of the major obstacles to their development is the lack of hydrogen refuelling points.

- Heat in industrial processes.
- Industrial feedstocks: for the petrochemical industry, treatments of biofuels, glass manufacturing and metal processing.
- Export: the hydrogen roadmap has identified four markets where Australia could take a market share: Singapore, Japan, China and South Korea. However, to be competitive in the Asia Pacific market, Australian hydrogen players would need to be able to produce H2 at under US$2/kg (€1.70/kg).

A series of strategic investments from both the private and public sectors are expected to be on the table. In April 2021, the Australian Federal Government announced investments in clean hydrogen and carbon capture technologies of up to €340m (AU$539m) as part of its 2021/2022 budget. By 2030, the Australian government is planning to invest up to €1.1bn to successfully develop the Australian hydrogen roadmap.

The United States: a mix of green, blue and grey hydrogen

The United States started an Energy hydrogen programme in the mid-2000s. In 2006 it already had a budget of US$153m (€130m) for hydrogen and fuel cell technologies. Led by the U.S. Department of Energy Hydrogen Program, within the Office of Energy Efficiency and Renewable Energy, the programme conducted research and development in hydrogen production, infrastructure, storage, fuel cells, other applications across many different sectors. Between 2006 and 2020, the programme benefitted from an annual budget ranging from between US$95m and US$208m (€81m to €177m).

The United States includes hydrogen in their US$1tr Infrastructure Plan

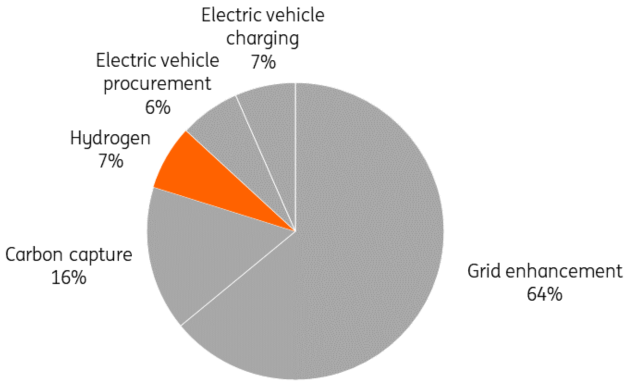
On 28 July 2021, US senators backed by President Joe Bidden agreed on a National Infrastructure Plan worth US$1tr (€841bn) that includes a US$114bn (€100bn) budget for energy transition according to BNEF estimates. The plan still needs to be transformed into law and will need a minimum of 60 senators in favour, to be passed. The global infrastructure plan would be backed up by a federal budget of US$550bn (€463bn) while other financing solutions would still remain to be found.

€6.7bn

The United states will dedicate US$8bn of their infrastructure plan budget to hydrogen

Out of the €100bn dedicated to the country's energy transition plan, €6.7bn will be fully dedicated to hydrogen, representing 7% of the budget for the energy transition.

Hydrogen accounts for 7% of US budget on energy transition



Source: ING Research

Reflecting the country's involvement in energy generation coming from clean and non-clean resources, the United States could include all three types of hydrogen projects into their Infrastructure Plan. The Bipartisan Infrastructure Plan wants to establish a minimum of four regional hydrogen hubs. One hub would use renewable power while the other three would be producing hydrogen from natural gas, fossil fuels and nuclear power. We discuss that in more detail here. Coal is also considered a potential source for hydrogen production.

Reflections on hydrogen strategies

From the many hydrogen plans from governments across the world we conclude:

- There is no shortage of attention for hydrogen. Many countries want to play a leading role in hydrogen. If the hydrogen market remains local, for example, to limit dependence on natural gas, there is room for many players. In a global hydrogen market, not every country can be a market leader and price competition will determine who will be winners and losers.
- Governments bring a lot of money to the hydrogen market. Some start with big numbers and still have to work out the policy instruments and projects (top-down). Others start with projects and instruments and communicate lower numbers as a result (bottom-up).
- Either way, these hydrogen support schemes will scale up the market and bring down costs.
- The main focus in most plans is on green hydrogen. There is relatively little attention to grey and blue hydrogen. That is surprising as the economics of grey and blue hydrogen are better compared to green hydrogen on word economics. The US program is an exception as it aims for a mix of grey, blue and green hydrogen.

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Grid operators, utilities and oil & gas majors invest in hydrogen

Hydrogen could be an important future energy source, but it can only thrive with the support of good infrastructure. A European hydrogen backbone requires...

Source: Shutterstock
A hydrogen production plant of Shell in Wesseling, Germany

It all starts with infrastructure

The establishment of a hydrogen market will not be possible without a network infrastructure in place. Isolated national hydrogen grids will not be viable in the long term because hydrogen procurement will need to be established on at least a European-wide basis, if not even more broadly international than that. Overall, the reconversion of existing natural gas networks, the building of new pipelines, storage capacities and international interconnections, implies the need for substantial investments. In this article, we look at current investment plans by grid operators, utilities and the oil and gas majors.

European hydrogen backbone requires €43-81 bn investment

Published in April 2021, the report “European Hydrogen Backbone”, also called the EHB initiative, offers the vision of 23 European gas infrastructure companies on the future of hydrogen grids. The report was first published in 2020 and included 11 players. The latest version provides analysts and specialists with a vision for the potential development of a European hydrogen grid infrastructure across Europe. The document presents updated hydrogen infrastructure maps for 2030, 2035 and 2040 with a dedicated hydrogen pipeline transport network, largely based on repurposed existing gas infrastructure.

€43-81bn Costs of a European hydrogen backbone

Estimate by 2040

The report also provides the readers with the estimated costs of the development of that 39,700km European hydrogen network infrastructure between now and 2040. Based on using 69% of repurposed natural gas pipelines and 31% new pipeline stretches, the European hydrogen backbone would cost between €43bn and €81bn. The range in costs can be explained by variable parameters, notably the various existing diameters of the pipelines (24, 36 or 48 inch) with smaller pipelines cheaper to repurpose.

European transmission system operators already invest in hydrogen

Natural gas has been a major source of energy for industries and households in a number of European countries. As a consequence, it is not surprising to see countries such as Italy, Spain or the Netherlands to be already testing and investing in hydrogen infrastructure. Although a lot of open questions remain about the future success of hydrogen in Europe and across the globe, Italian, Spanish and Dutch gas transportation network companies have developed an advanced vision of what they want to achieve. We focus on these specific grid operators as they currently seem to be the most active in hydrogen pipeline adaptation. We also only focus on the transition system operators (or TSO's who operate the grid on a national level) as hydrogen use is generally first adopted by the manufacturing sector. Hydrogen is not yet much of an issue for distribution system operators (or DSO's who operate local grids) as it is not yet a significant part of the built environment or transportation sector.

> *Snam is dedicating 50% of its 2020-2024 investment plan to hydrogen*

In Italy, **Snam SpA**, the national gas transportation network company, included a €7.4bn investment target in its 2020-2024 strategic plan. About 50% of these €7.4bn are dedicated to the replacement and development of a gas network compatible with hydrogen. Today, the company has about 70% of its pipelines that can already carry hydrogen. Snam is also cooperating with players contributing to the other parts of the value chain to help enable the development of the supply chain. The company has partnerships with electrolyser producers as well as energy and utility suppliers, like A2A, Hera and ENI, as well as Italian railway operators for transportation capacities.

Enagas' gas grids are already hydrogen compatible and do not require additional investment

In Spain, the Hydrogen Roadmap designed in October 2020, includes an investment of €8.9bn for projects across the hydrogen value chain. The main objectives are the installation of 4GW electrolysis capacity and 25% of industrial hydrogen consumption of renewable origin by 2030. The roadmap also set objectives for mobility services such as a minimum of two commercial train lines powered by hydrogen and 5,000 light and heavy vehicles in circulation.

As far as the Spanish gas transportation grid operator, **Enagas**, is concerned, the company claims to fully utilise the current gas infrastructure for hydrogen and does not need new hydrogen pipelines. Enagas concentrates its efforts on the production of biogas in partnership with various players.

€6.3bn

Amount of combined investments, in which Enagas is participating, to help develop and promote hydrogen production

In collaboration with 60 partners, Enagas plays a role in 55 different projects throughout Spain: 34 green hydrogen and 21 biomethane projects. As such, the Spanish gas transportation company is taking part in a total joint investment plan worth €6.3bn. Some projects have secured funding from the European Union, such as the Puertollano plant, which is also being developed in collaboration with Repsol. The plant will generate hydrogen from solar energy and is capable of producing around 100kg of hydrogen per day. The amount of the funding has not been divulged. The power plant could be operational in 2024.

The Netherlands used to produce a substantial part of its own natural gas consumption. Over time, production has decreased, due to field depletions and the repetitive earthquakes in the region attributed to the gas fields' exploitation. This has led to a substantial gas extraction decline from the Groningen gas fields. After 2022, the Groningen gas fields will be mostly maintained in order to provide a supply backup in case of harsh winters. This means that for the next few years, the Netherlands will be, by and large, dependent on international gas imports.

The energy transition plan of the Netherlands pushes natural gas partially, and potentially totally, outside the energy mix by 2050. Hydrogen is seen as one of the solutions to partially replace that possible natural gas gap.

€1.5bn

Nederlandse Gasunie

Expected investment between 2021 and 2027

Nederlandse **Gasunie**, the national gas transportation system operator, has been mandated by the Dutch government to build a hydrogen network. The company announced an investment plan which includes the adaptation of pipelines to transport hydrogen. The company identified investment needs of €7bn between now and 2030, including €1.5bn dedicated to a hydrogen network that connects the main industrial clusters in the Netherlands. 85% of the hydrogen grid involves the retrofit of existing gas infrastructure, 15% involves new pipelines. The Dutch government announced on 21 September, that it will provide half of the capital (€750 mln).

Furthermore, Gasunie has joined coalitions that focus on increasing the supply and demand of hydrogen, to ensure that the infrastructure meets high utilisation rates. Aligning infrastructure with hydrogen production and demand is therefore important but it is difficult to achieve in practice, as different actors have different investment horizons. Grid operators have to plan 15 years ahead, hydrogen producers 5 to 10 years, whereas the hydrogen users look just 3 to 5 years ahead.

European utilities allocate 3% to 6% of total investment to hydrogen

With current electrolysers capital costs of around €1 million per MW, one can estimate the amount of capital expenditure dedicated to hydrogen by European utilities. However, the electrolysers equipment is not the only cost associated with hydrogen development. Design, site construction, new installation of renewable capacity to feed electrolysers, storage and commissioning also add to the required total hydrogen capital expenditure.

As a result, a base of 100MW hydrogen capacity installation will generally incur a capital expenditure much higher than €100m. One example is Iberdrola's 800MW green hydrogen plant project in partnership with Fertiberia. The project's estimated capital expenditure is €1.8bn for a capacity of 800MW which is due to be ready by 2027.

3%-6% European integrated utilities' average capital expenditure dedicated to hydrogen projects vs. total investment

Looking at some of the European utilities' ambitions (Engie, Iberdrola, Enel and Naturgy), we think that capital expenditure dedicated to hydrogen production remains modest in comparison with the companies' total investment plans. On average, we estimate investments for hydrogen to account for between 3% to 6% of total investment plans per annum in the short and medium-term. Nevertheless, these estimates do not take into consideration support schemes including capex or revenue subsidies, which could account for up to 50% of the companies' dedicated capex for hydrogen.

Hydrogen plans and estimated investments from European utilities

	Hydrogen	Capital expenditure	
	Installed capacity targets and projects	Total company's average yearly gross investments	Estimated portion of hydrogen capex (excluding subsidies) in company's total investments
Engie	• 600MW green hydrogen installed capacity by 2025 and 4GW by 2030 • 170km of transmission pipeline in 2025 and 700km by 2030 • 50 refuelling stations by 2025 and 100 by 2030 • 270GWh of storage by 2025 and 1TWh by 2030	• €5bn per year between 2021 and 2023	• Between 8% and 12%
Enel	• 120MW of green hydrogen installed capacity by 2023 and 2GW by 2030	• €19bn per year between 2021 and 2030	• Between 1% and 3%
Iberdrola	• 600MW of green hydrogen installed capacity by 2025 and 800MW by 2027 in partnership with Fertiberia	• c.€12bn per year between 2020 and 2025	• Between 3% and 5%
Naturgy	• 110MW of installed green hydrogen capacity by 2025, up to 400MW in the longer term • 38 refuelling stations by 2025 and 120 stations in the long term	• €2.5bn per year between 2021 and 2025	• Between 4% and 7%

Source: ING Research

Oil and gas majors only commit small percentage of total investment to hydrogen

European oil & gas majors, such as BP, ENI, Repsol, Royal Dutch Shell and TotalEnergies, are committing investments for low carbon and green energy projects that range from between 15% and 40% of their total investment plans. All five European oil & gas companies are involved in hydrogen (grey, blue or green hydrogen projects). However, we estimate these projects will represent a very small part of the groups' total capital expenditure.

Hydrogen plans for European oil and gas majors

	CO2 reduction targets, clean energy projects and capital expenditure		
	Targets	Renewables/green projects	Hydrogen
BP	• Net zero carbon footprint from operations by 2050 • Net zero on an absolute basis across upstream oil and gas production by 2050 or sooner.	• €50bn of investments in clean energy projects in the period 2020-2030 – representing c.40% of total capex • 20GW of renewable installed capacity by 2025 and 50GW by 2030	• In March 2021, BP announced a feasibility study to build a blue hydrogen plant in the UK for a 1GW capacity. By 2027, the plant could produce one fifth of the country's hydrogen production target
ENI	• Net Zero Carbon Footprint for Scope 1 and 2 emissions from all group activities by 2040. • -15% of net carbon Intensity of energy products sold by 2030 v 2018 and -40% by 2040	• 4GW renewable installed capacity by 2024 and 15GW by 2030 • 80% of upstream production based on natural gas • Bio-refineries in Italy • Petrol stations transformed into sustainable fuels and services stations • Conversion of chemical sites to produce bio specialities	• Hydrogen production mainly used in own biorefineries • Blue hydrogen projects and carbon capture • Waste to hydrogen • Green hydrogen (electrolysers project with Enel 20MW) • Studying hydrogen projects in North Africa
Repsol	• Reduce absolute carbon intensity by 40% by 2040 and be net zero carbon neutral by 2050	• €5.5bn capex dedicated to low carbon projects (30% of total group investment) between 2021 and 2025 • Solar and wind • Carbon capture, hydrogen and storage • Focus on R&D	• Muti-technology approach (electrolysis, biomethane, photo electrocatalysis) • Green hydrogen targets of 400MW by 2025 and 1.2GW by 2030 • Hydrogen production for own consumption and potentially external clients
Shell	• Becoming a net-zero emissions energy business by 2050 by reducing emissions from company operations, and from the fuels and other energy products sold to customers. This is coupled with using technology and offsets.	• Invest c.€2.5bn yearly in renewables and low carbon projects – representing c.15% of the group's total capex	• Increasing the amount of biofuels and hydrogen in the transport fuels sold to 10% in 2030 from 3% in 2021.
Total Energies	• Net zero emissions from Total's operations and products sold to customers globally by 2050 • 35% reduction in carbon emissions (scope 1,2,3) by 2040 and 60% by 2050	• €5bn yearly capex dedicated to clean energy projects in the period 2020-2030 – representing c.40% of the group's total capex • Increase presence in renewables with gross capacity of 25 GW by 2025 • Increase of gas share in portfolio mix	• Partnership with Air Liquide on a blue hydrogen plant in Normandie • 30 hydrogen stations in Germany, the Netherlands, Belgium, France • Partnership with Engie on a 40MW green hydrogen project in the south of France for a TotalEnergies' bio-refinery

Source: ING Research based on company data

Hydrogen could allow for new business positioning

Nobody knows yet how the growth of hydrogen will transform the energy value chain. In this section, we provide possible forces that could lead to new business positioning.

The European oil & gas majors announced major changes in their business models in the last two years. Under the pressure of societies, organisations and shareholders, energy companies are looking towards clean energies. With renewables, carbon capture and storage (CCS), hydrogen and biofuels projects in general, the sector wants to be part of the energy transition. However, compared to integrated utilities, oil & gas major's hydrogen projects are skewed towards blue hydrogen given their historical business footprint in natural gas. That being said, European oil & gas majors have green hydrogen plans in the pipeline as well.

Oil and gas majors also have big pockets as far as investments are concerned and that's another advantage in taking a position in the hydrogen value chain. In the early stage, capital expenditure for hydrogen plants is relatively high compared to lower operational costs. That might give oil and gas majors an advantage. At a later stage, when the technology is more mature and cheaper, operational expenses will become more important which might benefit utilities that excel in running power plants.

> *Oil and gas companies have a competitive advantage in grey and blue hydrogen, utilities in green hydrogen*

While integrated utilities see their role as hydrogen producers that offer solutions to industrials and corporates, European oil & gas majors look at hydrogen first as one of the means to decarbonize their own assets and products with the introduction of hydrogen for the obtainment of cleaner fuels. As such, utilities and energy companies are not necessarily direct competitors and have sometimes partnerships in place to develop hydrogen projects.

Although there are few signs of direct competition at the moment, some projects indicate that things could change in the future. As an example, BP is studying the feasibility of a blue hydrogen plant of a 1GW capacity in the UK with a potential construction green light in 2024 and that could start producing hydrogen in 2027. The Teesside project would capture CO2 and store it under the North Sea. The hydrogen plant would be linked to an industrial zone and the produced hydrogen could also be used for transportation and heating residential homes.

While we do see clear competitive advantages between the different players, it does not automatically means the market ends up in fierce competition. Some players might also choose to leverage each other's strengths and will prefer to co-operate.

So hydrogen allows market players for new business positioning. How this plays out for the sector is still unclear but it is likely to increase market dynamics.

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