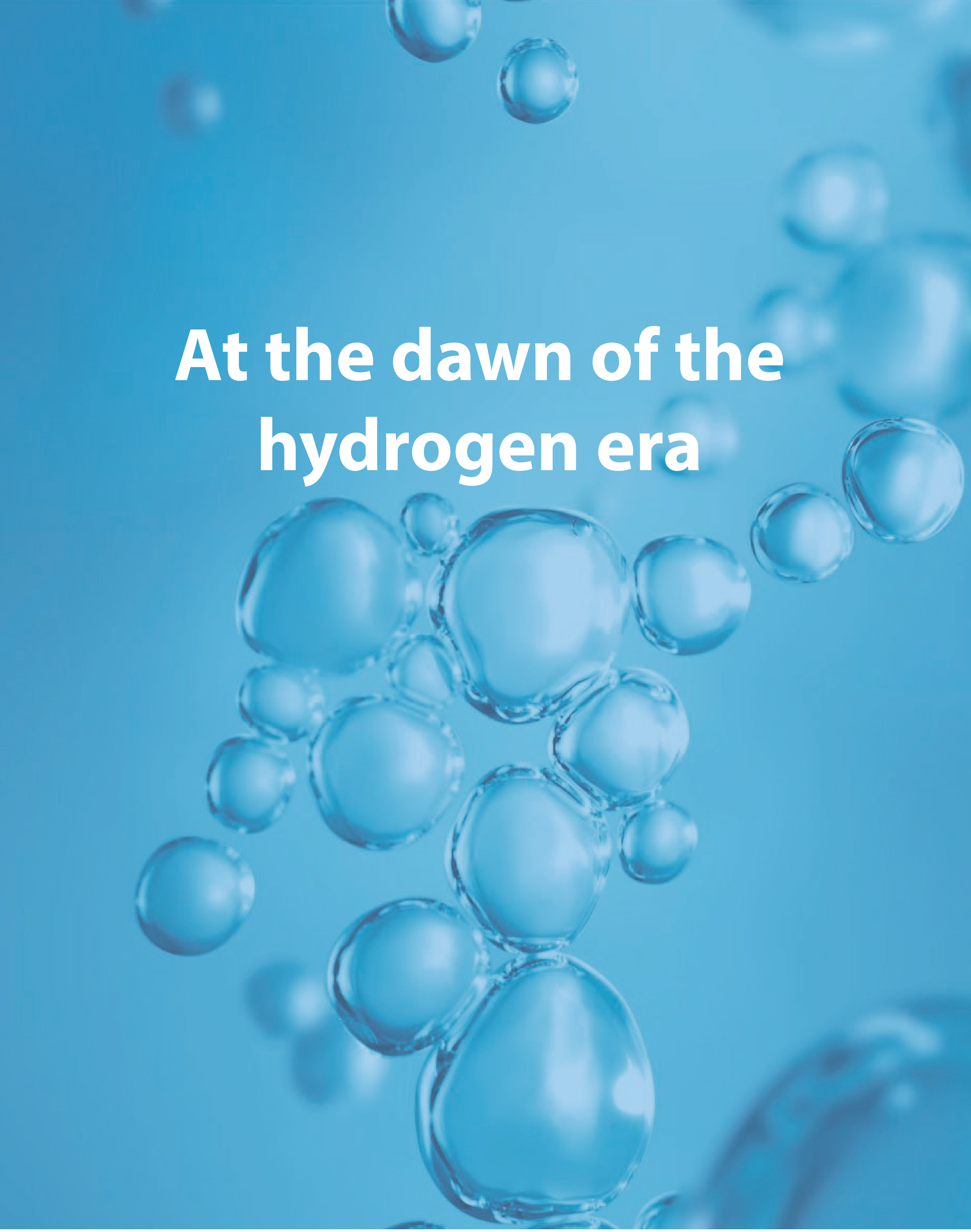
At the dawn of the hydrogen era



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Summary

In the last two centuries, the earth's temperature has risen by 1.1°C.[1] Efforts to limit this rise to 1.5°C by 2100, as agreed in the 2015 Paris Agreement, are way off track, despite the growing frequency and severity of natural disasters caused by anthropogenic global warming.

At present, the world is on track for a 2-5°C rise above pre-industrial temperatures by 2100.[2] Global carbon dioxide emissions are still rising annually – in 2022, around 37.5 billion tonnes of CO2 were emitted, up 1% from 2021.[3] According to the United Nations, these emissions must fall by around 45% by 2030 in order to hit the 1.5°C target, an ambitious goal which now is surely out of reach.[4]

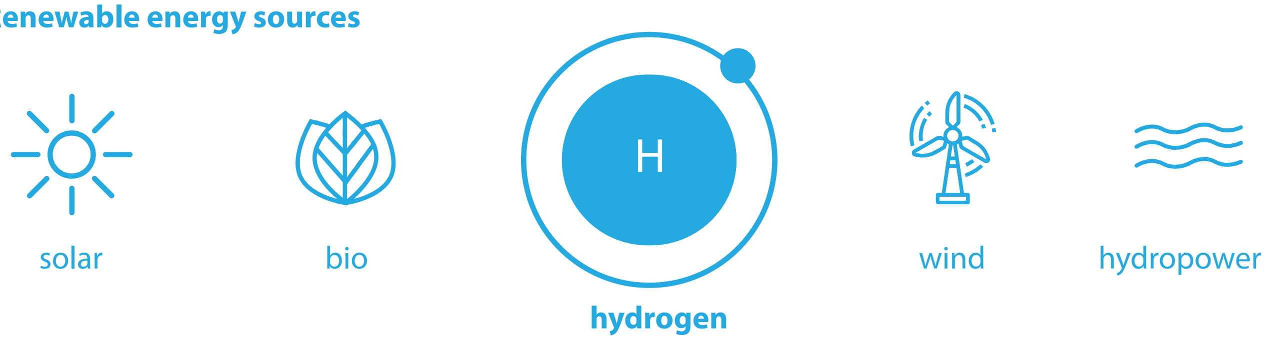
Evidently, there has been a widespread failure to meet the commitments of the Paris Agreement. This is due to a range of factors, including inadequate policies and infrastructure, slower than expected rates of progress, and changes in priorities to address new security or geopolitical concerns. Certain sectors are also lagging behind more than others, particularly those which are difficult to decarbonise, such as heavy industry and transport.

One solution to this shortfall is clean hydrogen, which can serve as both a fuel and a chemical reducing agent to dramatically lower the carbon emissions generated by industries such as steelmaking, cement production and chemical manufacturing. While most hydrogen produced today is not "green", it will likely become a zero-carbon power source as innovation grows, investment rises and prices fall. White or geological hydrogen, which occurs naturally underground, is touted as the cleanest and cheapest form of hydrogen and could become the leading energy source in the hydrogen market.

Hydrogen technologies are constantly evolving, and this is reflected in an array of recent changes to hydrogen policies and infrastructure around the world. As awareness of hydrogen's green potential grows, countries are granting it more prominence in their strategies for a clean energy transition, adopting different approaches depending on their economies, resources and priorities. These policies and infrastructure will no doubt continue to change as the hydrogen industry develops.

As the window for preventing the worst consequences of climate change squeezes to a close, the actions of countries across the globe are signalling that hydrogen will be a key tool for accelerating the shift to a zero-carbon world.

Renewable energy sources



References:
[1] https://www.un.org/en/climatechange/science/key-findings
[2] https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature-projections
[3] https://www.nature.com/articles/d41586-022-03657-w
[4] https://www.unep.org/resources/emissions-gap-report-2022

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Falling short

One reason why hydrogen is increasingly in focus among policy makers is the inadequate progress that has been made with regards to climate targets, particularly in sectors which are difficult to decarbonise, such as heavy industry and transport. As countries come to realise that they are not on track to meet their commitments, it makes sense to ask two questions: why, and what can be done about it?

Three main explanations for this shortfall present themselves: Firstly, **the speed of progress that many countries are making is slower than expected**. None of the globe's biggest emitters – China, USA, Europe and India – have reduced their carbon emissions sufficiently to meet their Paris Agreement goals. The USA, for example, aims at a 50-52% emissions reduction from 2005 levels by 2030, but in 2022, emissions reached only 15.5% below 2005 levels, meaning that far more aggressive policies are needed to hit their target. [1]

Secondly, **some countries have changed their priorities since they made their commitments**, addressing new concerns related to security or geopolitics which they feel are more urgent. In Europe, for example, most countries have been racing to find new fuel sources in order to reduce their reliance on Russian supply. Germany recently increased coal mining and coal imports to augment fuel reserves for the winter, a move reflecting how energy security concerns caused by geopolitical events have taken short-term priority over climate targets.

A third explanation is that **the strategies put forth by certain countries were not strong or ambitious enough to meet their targets**, perhaps compounded by a lack of the required infrastructure. Such cases can be rectified by changes in policy, where realistic goals are set and the correct infrastructure is put in place to facilitate their achievement. Some sectors also encounter more obstacles to decarbonisation than others, and this can slow overall progress towards climate targets. Heavy industry in particular is one sector that is lagging behind in this regard. Conservative estimates suggest that it is responsible for around 20% of global carbon dioxide emissions, although other estimates go above 40%.

So why is heavy industry proving especially difficult to decarbonise? Many heavy industries – including steelmaking, cement production and chemical manufacturing, which are the highest emitters in the sector – either require very high temperatures during production, which would be costly and impractical to achieve with renewable electricity, or generate carbon emissions during the chemical process, which means a completely new production method is required. There are also economic hurdles to overcome: for example, thin profit margins make it hard to fund an investment in clean electricity, and moving from competitive markets like steelmaking into a low-carbon market could undercut profits.

Global carbon dioxide emissions share per sector

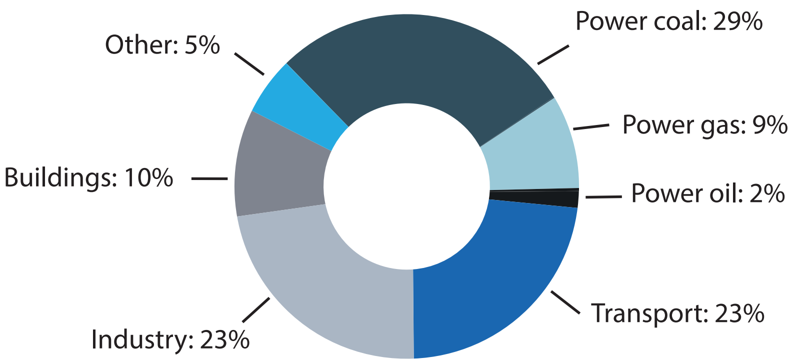

Chart source:
https://www.iea.org/data-and-statistics/charts/global-energy-related-co²-emissions-by-sector

References:
[1] https://rhg.com/research/us-greenhouse-gas-emissions-2022/

Given that it generates roughly a quarter of global carbon emissions, it's clear that heavy industry must rapidly reduce its dependence on fossil fuels.

Clean hydrogen could present one means of accelerating the sector's decarbonisation in the long term. Specifically, it could offer a solution to two of the key problems facing heavy industry: the dependence on carbon-emitting fossil fuels, and the release of carbon dioxide during chemical processes.

How? **Hydrogen can serve as both a fuel and a chemical reducing agent, releasing only water vapour and eliminating carbon emissions.**

In **steelmaking**, for example, hydrogen could be used as an auxiliary reducing agent in the Blast Furnace-Basic Oxygen Furnace (BF-BOF) process, which is used in 60% of steel production in Europe.[1] Carbon usually serves as an ingredient in blast furnaces as part of a reaction which turns iron oxide and carbon into iron and carbon dioxide. Producing 1 ton of steel in this way emits roughly 1.85 tons of CO2 – it's estimated that replacing carbon with hydrogen could help to reduce the industry's carbon emissions by up to 20%.[2]

While the use of hydrogen in steelmaking could initially drive up the cost of steel by a third, this price gap could be eliminated by 2030 as the cost of renewable energy falls, hydrogen-based steelmaking processes become more efficient and the price of coal rises due to carbon and carbon-emission pricing. [3]

In **cement production**, on the other hand, hydrogen has the potential to be used as a fuel in kilns to produce clinker, which serves as a binder in many cement products. Several pilot projects are already underway – in England, for example, a cement kiln at Hanson UK's Ribblesdale plant has been successfully operated using a climate-neutral fuel mix, consisting of hydrogen, biomass and glycerine. [4] The trial, funded by the UK's BEIS (Department for Business, Energy and Industrial Strategy), was carried out following a feasibility study by the same government body, which concluded that this zero-carbon fuel mix could eliminate 100% of the carbon dioxide emitted in cement production.

Finally, in **chemical manufacturing**, hydrogen can serve as an ingredient to create a range of chemical products. It's main use in the industry is as a feedstock to make ammonia, which is used to make fertilizer and household cleaning products. To a lesser extent, it is also used to produce methanol, a chemical building block used to make other chemicals as well as additives and fuels.

Obstacles to decarbonising heavy industry

Steelmaking

The steel industry faces several barriers to decarbonisation, including the lack of an affordable renewable energy supply; limited industry policies and the need for greater global regulation; a shortage of skilled labour; the need for large-scale funding to decarbonise the value chain; low (but growing) demand; and the need for off-take guarantees to derisk investment decisions.[5]

Cement production

It is currently not feasible to electrify cement making due to the high kiln temperatures needed for clinkering. Moreover, aside from its reliance on fossil fuels, cement making also produces carbon dioxide as a result of the chemical reduction of limestone, one of the core ingredients. Solutions include producing cement using non-limestone raw materials, and limiting carbon emissions with carbon capture and storage (CCS). However, most technologies to decarbonise the industry are still in the pilot stage.

Chemical manufacturing

The chemical industry is different from cement and steelmaking in that it uses fossil fuels not only as an energy source but also as feedstocks which are turned into end products. This means that oil, coal and gas are likely to continue their use in the industry even in a zero-carbon future. Furthermore, the complex manufacturing plants used for chemical production will need to be completely redesigned to enable the use of clean fuels.

Hydrogen therefore has the potential to be integrated into a range of industrial processes. The central role of heavy industry in most economies, together with the urgent need to move away from fossil fuels, makes hydrogen investment and development a logical and necessary next step. Moreover, as investment in hydrogen infrastructure increases, there will be more money to drive innovation in the industry and develop greener and more efficient technologies, while gradually reducing the cost.

References:
1 https://www.rolandberger.com/en/Insights/Publications/Europe%27s-steel-industry-at-a-crossroads.html
2 https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel
3 https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/641552/EPRS_BRI(2020)641552_EN.pdf
4 https://www.heidelbergmaterials.com/en/pr-01-10-2021
5 https://www.shell.com/shellenergy/marketingandtrading/

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Getting greener?

In the past, hydrogen didn't receive much attention in climate policy frameworks, primarily due to the high proportion of non-green hydrogen production (95%) [1] – but this is changing. **The technology required for a green hydrogen revolution already exists, although currently the cost is high.**

While hydrogen may not be green enough at this early stage, this does not mean it will not become significantly greener in the future. At their inception, renewable energies such as solar, wind and hydropower were similarly costly and inefficient, and not a viable short-term solution, but their long-term potential was recognised. Similar potential exists for hydrogen. Once the investment and infrastructure are in place, there is a wide scope for further improvement.

Aside from its high cost, hydrogen production faces other challenges. Firstly, hydrogen has a very **low density**, which means it occupies a very large volume when stored, making it unsuitable for use in mobility unless liquified or highly pressurised. However, hydrogen condenses at a very low temperature (-253°C), so liquification is expensive; equally, pressurising hydrogen increases the chance of leakage, which could be especially problematic as hydrogen is a greenhouse gas with twice the warming potential as carbon dioxide.

Besides its low density, hydrogen is **highly reactive**, meaning that extensive safety measures are needed to mitigate the risk of explosion, and hydrogen pipelines must be coated with a polymer to prevent corrosion.

The hydrogen spectrum

- **Green hydrogen** is produced via electrolysis using electricity from renewable sources
- **Blue hydrogen** is produced from natural gas via steam methane reforming or from coal via gasification, using carbon capture and storage (CCS) to eliminate some of the carbon dioxide emitted
- **Grey hydrogen** is produced from natural gas via steam methane reforming, without CCS
- **Brown hydrogen** is produced from coal using gasification, without CCS
- **White hydrogen** (or geological hydrogen) occurs naturally in underground deposits and can be extracted without emitting carbon dioxide

Challenges related to storage can be overcome by converting hydrogen into a carrier, such as ammonia or methanol. Ammonia, for example, is easier to store than hydrogen, as it can liquify at a higher temperature and occupies a smaller volume per unit of energy. Equally, methanol is liquid in ambient conditions and therefore easy to store and transport; it is also highly versatile as it can be converted back into electricity.

Despite these challenges, **demand for hydrogen is growing** – in 2020, global demand reached 87 million metric tons (MT) and is expected to rise to 500-680 million MT by 2050.[2] Moreover, the falling cost of renewable energy and electrolysers, coupled with improved electrolyser efficiency due to technology enhancements, have all boosted the commercial viability of green hydrogen production. From 2020 to 2021, the hydrogen market was valued at $130 billion [3] and is projected to grow up to 9.2% annually through 2030.[4] In short, the enormous green potential of hydrogen, together with the rapid growth in demand and improvements in technology, is making the industry increasingly attractive to investors.

How do you make hydrogen?

Different types of hydrogen have different production methods. Green hydrogen is produced using a process called electrolysis, which separates the hydrogen from the oxygen in water using an electrical current. When the electricity used in this process is obtained from renewable sources, no carbon dioxide is emitted and "green hydrogen" is produced. However, green hydrogen accounts for less than 5% of all hydrogen in use today – most is sourced from natural gas and coal and therefore generates carbon emissions.

References:
1 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_Hydrogen_breakthrough_2021.pdf
2 https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf
3 https://www.marketsandmarkets.com/Market-Reports/green-hydrogen-market-92444177.html
4 https://energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf

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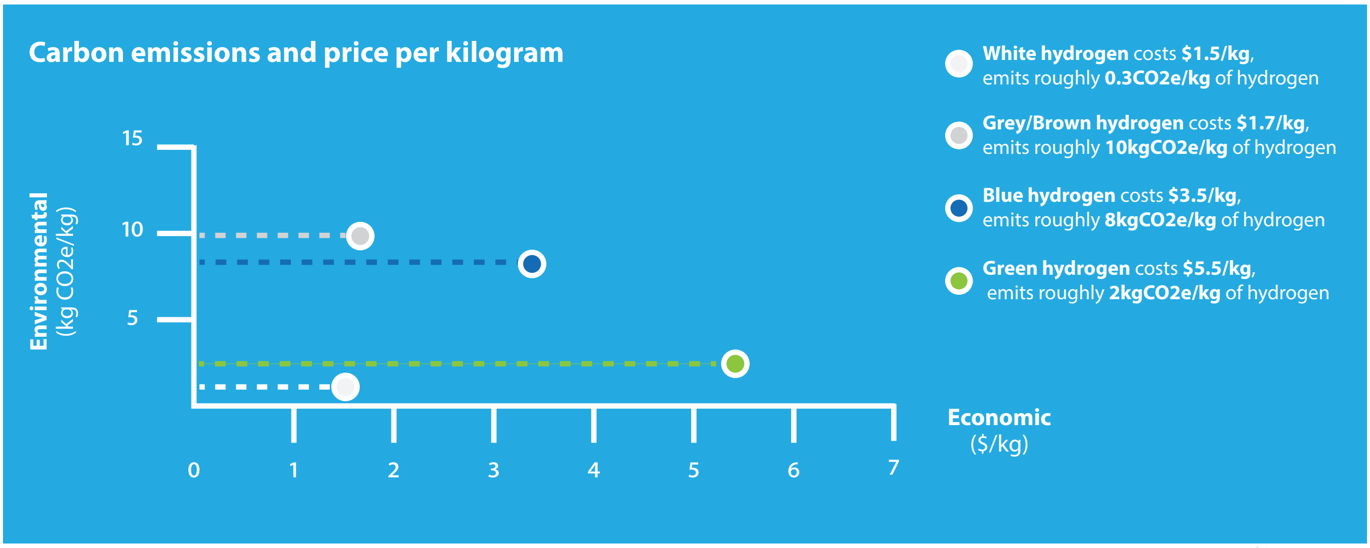
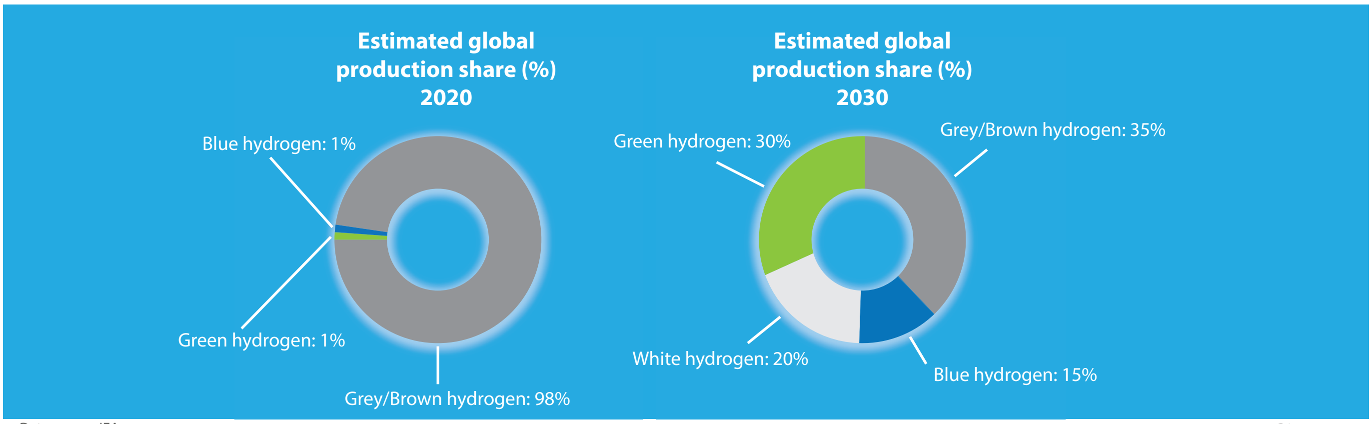


Diagram 1



Data source: IEA

Diagram 2

The rate and scale of hydrogen development are dependent not only on demand but also on government support and the infrastructure currently in place. As most countries only started to pay attention to hydrogen recently, their policies and infrastructure are still limited, but likely to become more advanced as demand grows. For this reason, any projections we have for the growth of the hydrogen sector that are based on current progress may be conservative.

The emerging potential of white hydrogen

Naturally-occurring white or "geological" hydrogen is perhaps the least understood form of hydrogen. It was long thought to be extremely rare and therefore ignored as a potential energy source – however, recent exploration projects have shattered this historical misconception, finding flows of white hydrogen all around the world, from Africa and Brazil to Canada, the USA, Europe and the UK.

White hydrogen is produced naturally underground and flows to the surface through natural subsurface geothermal processes in the earth's crust, where it can simply be collected. Although we have much more to learn about where and how it is produced, there is growing recognition among experts of its potential as an energy source.

Moreover, it is becoming evident that **white hydrogen is the only truly clean hydrogen form that can compete with fossil fuels**, as its production is **less expensive, less carbon intensive and less energy intensive than green and blue hydrogen.** White hydrogen is therefore expected to disrupt the hydrogen sector in the coming years and is likely to be a vital tool in the transition to a carbon neutral world.

References:
Diagram 2: https://www.iea.org/data-and-statistics/charts/global-hydrogen-production-by-technology-in-the-net-zero-scenario-2019-2030

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New changes in policy and infrastructure

There have been many new shifts in hydrogen policies and infrastructure in recent years, with countries taking different approaches in alignment with their economic structures and natural resources. Japan, for example, has been focusing on hydrogen for several years and in 2020 launched a comprehensive hydrogen energy infrastructure operation, aiming to increase the country's self-sufficiency, improve its industrial competitiveness and decarbonise the economy – as well as position Japan as a fuel cell technology exporter.

Japan's early focus on hydrogen has seen it progress much faster than other countries, perhaps driven by its large heavy industry sector and the need to diversify power sources. Today, it produces 2 million tons of hydrogen each year, and has over 160 hydrogen refuelling stations – more than any other nation.

Policy changes have also been influenced by the abundance of native resources. For example, some countries which use large amounts of natural gas in heavy industry, such as Germany, not only have a greater incentive to move away from fossil fuels, but also have adequate resources with which to produce low-carbon blue hydrogen using CSS.

The table below offers a snapshot of the hydrogen-related policies and infrastructure of five countries. For more information on other markets, please don't hesitate to contact us at **info@clotavarde.com**

	Germany	UK	Japan	Netherlands	USA
Policy	Subsidy of $1bn for green hydrogen production in non-EU countries for import to Germany [1]	Subsidy to help fund projects up to 1GW green & 1GW blue hydrogen [4] Funding of £100m for Scotland's Hydrogen Action Plan, with aim of 5GW low-carbon hydrogen by 2030 [5] Funding of £4.8m for Wales' Holyhead Hydrogen Hub production plant [6] EU & UK funding of €9.4m for Northern Ireland's GenComm pilot project [7]	Subsidies of over 7trn yen over next 10 years to establish a hydrogen & ammonia supply chain [9]	Subsidies of up to €15m for research & development pilot projects Funding of €35m per year to scale-up production & reduce green hydrogen cost Subsidy for electrolysis production up to 2000 full load hours [12]	Tax credits for 10 years of $0.60/kg of clean hydrogen if construction begins before 2033 [15] Funding of $750m to reduce cost of clean hydrogen technologies [16] Funding of $7bn to create 6-10 clean hydrogen hubs across USA [17]
Infrastructure	Around 30 small- scale green hydrogen projects underway [2] Demand of almost 60TWh annually [3]	Almost all hydrogen sourced from natural gas without carbon capture 10-27TWh produced annually, mainly for oil refining & chemicals sectors [8]	Produces 2m tons of hydrogen annually [10] Over 160 refuelling stations [11]	Over 1,000km of hydrogen pipelines [13] Refuelling stations & hydrogen buses operating in country's north Europe's first Hydrogen Valley in the north Empty gas fields & salt caverns for hydrogen storage [14]	10m metric tons of hydrogen produced annually Main demand for petroleum refining & ammonia production [18] Over 90% is grey hydrogen More than 150 operating fuel stations [19]

As we can see from this table, government funding and subsidies are popular policies. Germany, Japan, the Netherlands and the UK are all subsidising new projects to boost green hydrogen production, while the US government is providing $750 million to reduce the cost of clean hydrogen technologies. America also aims to lower the price of clean hydrogen itself to $1/kg by 2031, and is issuing 10-year tax-credits of $0.60 per kilogram of clean hydrogen to projects which begin construction before 2033.

In the UK, Scotland, Wales and Northern Ireland have significant potential for hydrogen production and use, thanks to their abundance of wind and wave energy, strong gas networks and interconnectedness. They are home to several pioneering hydrogen demonstration projects, aided by government support of research, innovation and low-carbon hydrogen technologies. In Scotland, for example, the European Marine Energy Centre in the Orkney Islands has a £65 million portfolio of clean hydrogen projects, while Northern Ireland's GenComm project received funding from both the EU and UK government to pilot hydrogen production for use in buses.

Case study: The Netherlands

The Netherlands is well-positioned to become one of Europe's leading hydrogen hubs.[1] Favourably situated near the North Sea's offshore wind farms, it has extensive gas and electricity grids which are already being adapted for the transport of clean hydrogen. It also has substantial carbon storage capacity, thanks to the country's salt caverns and the empty gas fields in the North Sea, along with sufficient demand from its industrial clusters and trade opportunities from its large ports.

The Dutch energy system is changing, with efforts underway to reduce the use of natural gas and augment demand for electricity. At present, electricity accounts for 20% of total energy consumption, but the country aims to increase this to 50% by mid-century, with gaseous carriers accounting for 30% of overall consumption. As a result, focus on the development of clean hydrogen is growing, with the gas set to play a vital role in this transition.

In its 2020 National Hydrogen Strategy, the Dutch government highlighted the importance of hydrogen in efforts to decarbonise the energy system, emphasising the need for **upscaling, innovation and cost reduction**. Several projects are already underway across the country: the Hystock plant, for example, is a 1MW plant in the northern village of Zuidwending which converts solar energy into hydrogen using electrolysis. The city of Groningen has also been recognised as Europe's first "Hydrogen Valley", hosting an entire value chain, including hydrogen production, distribution, storage and end-use.

The Netherlands is also coordinating the development of electricity and hydrogen grids, given the dependence of clean hydrogen production on renewable energy. The Dutch gas infrastructure company Gasunie, together with transmission system operator TenneT, is producing a study on integrated infrastructure in Germany and the Netherlands, with the aim of determining the best locations for electrolysers. Gasunie is also investing €7bn until 2030 in the green energy transition, much of which will be used to refit existing natural gas pipelines for hydrogen transport. This will become **Europe's first nation-wide hydrogen infrastructure**, connecting all of the country's five major industrial clusters.

Hydrogen is already in use in several sectors across the Netherlands, including public transportation. In the north, refuelling stations and hydrogen buses are currently in operation, as part of ambitions to produce 50 refuelling stations, 15,000 fuel cell vehicles and 2,000 heavy vehicles by 2025.

Hydrogen is also being used in ports and industry: for example, Porthos, the first carbon storage project in the country, aims to capture and transport carbon dioxide from industry in the Port of Rotterdam and produce blue hydrogen on a large scale. In addition, hydrogen is becoming prominent in buildings and heating, as the Netherlands moves away from natural gas, as well as in electricity plants and in heavy vehicles for agriculture.

Despite the significant progress made by the Netherlands, it is still faced with certain challenges, including the development of demand, storage, supply and infrastructure. In particular, upscaling hydrogen and creating demand will be essential in reducing overall costs.

References:
1 https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/netherlands

- Hydrogen has enormous potential as a clean energy source, particularly in industries which are difficult to decarbonise, such as steelmaking, cement production, chemical manufacturing and heavy transport
- While most hydrogen currently in use today is not "green" and not cost-competitive with fossil fuels, it will become greener and cheaper as investment and innovation in the industry continue to grow
- Recent changes in hydrogen policies and infrastructure worldwide reflect the growing recognition of hydrogen's importance in the transition to a zero-carbon world
- White or geological hydrogen, which has long been overlooked due to a historical misconception, may be the only clean hydrogen form that can compete with fossil fuels

If you would like to learn more, please contact us at **info@clotavarde.com**

References for table on page 8:
1 https://www.rechargenews.com/energy-transition/germany-s-1bn-scheme-to-subsidise-green-hydrogen-projects-in-non-eu-nations-gets-green-light/2-1-1133158
2 https://www.gtai.de/en/invest/industries/energy/green-hydrogen
3 https://hydrogen-central.com/the-government-germany-regions-committed-green-hydrogen/
4 https://www.rechargenews.com/energy-transition/uk-opens-world-s-first-national-clean-hydrogen-subsidy-scheme-as-it-aims-for-10gw-by-2030/2-1-1263576
5 https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/
6 https://www.gov.wales/sites/default/files/consultations/2021-01/hydrogen-in-wales-consultation.pdf
7 https://www.nweurope.eu/projects/project-search/gencomm-generating-energy-secure-communities/
8 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf
9 https://thediplomat.com/2023/01/japan-looks-to-promote-a-hydrogen-society/.
10 https://www.csis.org/analysis/japans-hydrogen-industrial-strategy
11 https://www.lexology.com/commentary/energy-natural-resources/japan/nishimura-asahi/hydrogen-update-and-outlook-in-japan-2022
12 https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen
13 https://hydrogen-central.com/the-netherlands-fueling-a-green-hydrogen-future/
14 https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/netherlands
15 https://www.law.cornell.edu/uscode/text/26/45V#c_3
16 https://www.energy.gov/articles/biden-harris-administration-announces-750-million-accelerate-clean-hydrogen-technologies
17 https://www.energy.gov/oced/regional-clean-hydrogen-hubs
18 https://www.energy.gov/eere/fuelcells/hydrogen-production
19 https://www.shearman.com/perspectives/2021/10/hydrogens-present-and-future-in-the-us-energy-sector

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