Sector Briefing:
Hydrogen sector
May 2023

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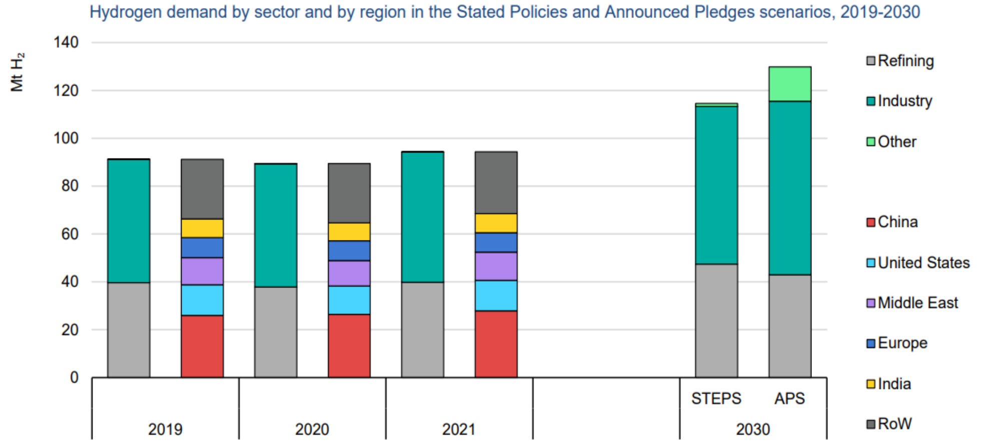
MARKET DEFINITION

- Hydrogen can be produced from a variety of sources, including natural gas, biomass, and renewable energy sources such as solar and wind. It is used in a variety of applications, including transportation, power generation, heating, and industrial processes such as refining and chemical production. There are several different types of hydrogen, distinguished by their production methods and purity levels:
  - **Grey hydrogen** - is the most common type of hydrogen produced today, typically from fossil fuels like natural gas through a process called steam methane reforming. Grey hydrogen is the cheapest to produce but also the most carbon-intensive and therefore not environmentally friendly.
  - **Blue hydrogen** - is produced using the same steam methane reforming process as grey hydrogen, but with carbon capture and storage (CCS) technology to capture and store the carbon dioxide emissions. Blue hydrogen is more expensive than grey hydrogen but still cheaper than other low-carbon alternatives.
  - **Green hydrogen** - produced through the electrolysis of water using renewable energy sources like wind or solar power. Green hydrogen is the cleanest form of hydrogen and has no carbon emissions, but it is also the most expensive to produce.
- According to the International Energy Agency's (IEA's) 'Global Hydrogen Review 2022' low-emission hydrogen includes blue and green hydrogen while grey hydrogen is not a low-emission source.
- McKinsey (Oct-22) said that by 2050, clean hydrogen could help abate 7 gigatons of CO2 emissions annually, which is about 20% of human-driven emissions if the world remains on its current global-warming trajectory. Complementing other technologies, such as renewables and biofuels, hydrogen has the potential to decarbonise a variety of sectors, including industry (steelmaking, ammonia synthesis for fertilizer production); long-range ground mobility (as a fuel for heavy-duty trucks); maritime shipping and aviation (to produce synthetic fuels for vessels); and building heating.

Sector analysis

- The IEA says most of the hydrogen demand came from traditional uses in refining and industry (see image below). Demand for hydrogen in new applications, such as in heavy industry, transport, power generation and the buildings sectors or the production of hydrogen-derived fuels, was very low in 2021 (about 0.04% of global hydrogen demand).
- Use mostly in road transport, which observed a significant increase (60%, albeit from a very low base) reflects accelerated deployment of Fuel Cell Electric Vehicles (FCEVs), particularly in heavy-duty trucks in China.



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Notes: Mt H_2 = million tonnes of hydrogen; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. *Other* includes transport, buildings, power generation sectors production of hydrogen-derived fuels and hydrogen blending.

Source: IEA 'Global Hydrogen Review 2022'

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In its 'Global Hydrogen Review' (Sep-22), the IEA sets out the major sector applications for hydrogen:

Refiners

- Global hydrogen demand in 2021 was 94 Mt, with, according to IEA, almost all of it concentrated in refining and industrial applications, with very little demand in other sectors. Refineries use hydrogen to remove impurities, especially sulphur, and to upgrade heavy oil fractions into lighter products.
- Almost all hydrogen used in refineries is produced from unabated fossil fuels[1]. Nearly half of global hydrogen demand for refining in 2021 was in two regions - North America and China.
- The IEA's outlook suggests global hydrogen demand in refining will rise strongly to reach around 47 Mt by 2030.

Industrial uses

- Industry is the sector in which hydrogen can deliver the largest fossil fuel savings by 2030. Some governments have announced plans to adopt quotas and mandates for industrial applications.

Transport

- Hydrogen demand in transport totalled over 30 kt in 2021, more than +60% higher than the previous year says the IEA. As a share of total hydrogen demand, however, transport represents only 0.03%, and as a share of total transport energy, hydrogen represents only 0.003%. Road vehicles, by far, are the major source of hydrogen demand in transport. Most of this is consumed in trucks and buses due to their high annual mileage and heavy weight relative to the larger stock of fuel cell electric cars.

Power

- Hydrogen use in the power sector plays only a negligible role as a fuel in the power sector today. It accounts for less than 0.2% of global electricity generation and mostly uses mixed gases with high hydrogen content from steel production, refineries, and petrochemical plants as well as off-gases from the chlorine-alkali industry.
- Electricity generation technologies that can use hydrogen are commercially available today. Some current designs of reciprocating gas engines, fuel cells and gas turbines are technically capable of operating on hydrogen-rich gases or even pure hydrogen.

Building

- Hydrogen accounts for a negligible share of energy demand in the buildings sector, with no significant increase from the previous year. Technologies that use natural gas for heating and cooking account for nearly one-fourth of worldwide energy demand in the buildings sector.
- In the context of the current energy crisis and national commitments to achieve net zero emissions, several countries are introducing bans on fossil fuel use in new buildings such as France from 2022 and Austria from 2023.

Geographic analysis

IEA's Global Hydrogen Review 2022 goes on to make the following observations:

- In terms of regions, China is the world's largest consumer of hydrogen with demand in 2021 of around 28 Mt (30% of total), up +5% from 2020.
- The US is the second-largest and the Middle East slightly behind as the third-largest consumer at around 12 Mt each (13% of total), with demand in 2021 increasing by +8% and +11% respectively relative to 2020.
- Europe is the fourth-largest consumer with demand of more than 8 Mt H2 in 2021, practically the same level as 2020.

[1] Unabated fossil fuel use is fossil fuel combustion without the application of carbon capture and storage (CCS) technology.

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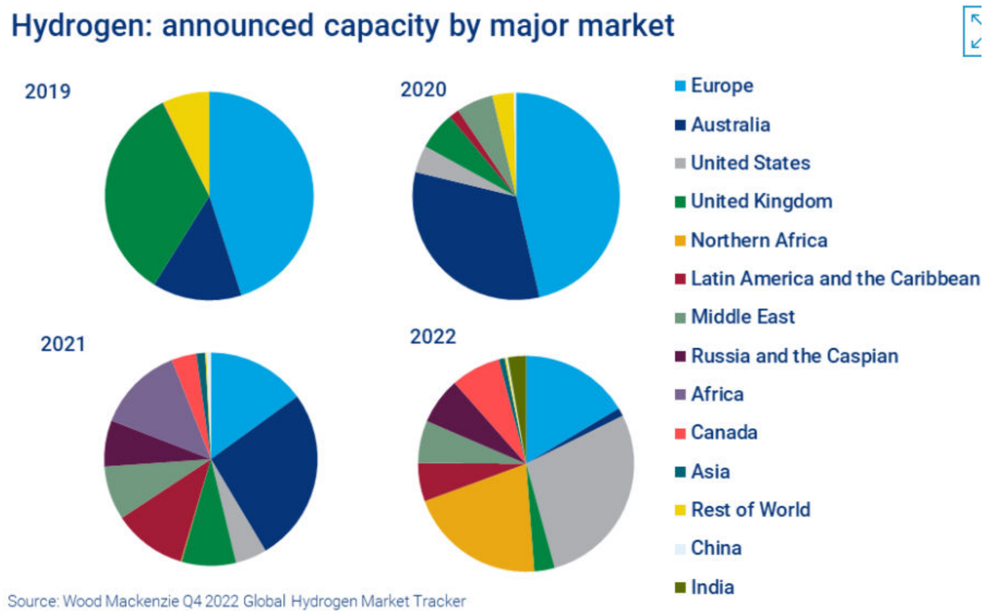
MARKET SIZE

- In terms of market value, according to Grand View Research, the global hydrogen generation market size was valued at US$155.4bn in 2022 and is expected to reach US$316.4bn by 2030, growing at a compound annual growth rate (CAGR) of +9.3%.
- Regarding green hydrogen, Grand View Research (2022), said the global green hydrogen market was valued at US$3.2bn in 2021 and is expected to expand at a CAGR of +39.5% from 2022 to 2030 to reach US$19.9bn.
- The IEA (Sep-22), made two forecasts for hydrogen demand: The IEA Stated Policies Scenario (STEPS) reflects current policy settings based on a sector-by-sector assessment of the specific policies that are in place, as well as those that have been announced by governments around the world.
  - The outlook in the *STEPS* forecast suggests hydrogen demand could reach 115 Mt by 2030 (94 Mt in 2021).
  - The IEA *Announced Pledges Scenario (APS)* assumes that all climate commitments made by governments around the world, will be met in full and on time. The outlook for hydrogen demand in the APS is 130 Mt by 2030, of which only about 25% would be for new applications and the use of low-emission hydrogen in traditional applications.

Project pipeline

- Wood Mackenzie (Feb-23) revealed total announced capacity reached 71.4 Mpta in 2022, adding the year was marked by the energy crisis and a slew of policy announcements, leading to a plunge in the number of project announcements. Only 19 low-carbon projects were announced in Q4 2022, with a total of 0.96 Mtpa in hydrogen production – the fewest since mid-2020. No mega projects were announced from October to December either.
- The slowdown in project announcements was counterbalanced by record electrolyser manufacturing announcements says Wood Mackenzie. A year ago, electrolyser manufacturing looked like a bottleneck. That no longer seems to be the case, with a record 45 GWe announced in 2022. Interestingly, while 95% of operational manufacturing capacity is in Europe, China, and the US, 41% of announcements are heading to Africa.



Source: Wood Mackenzie (Feb-23)

- McKinsey (Oct-22) said more than 680 large-scale hydrogen projects have been announced globally as of May 2022 amounting to US$240bn in direct investments (c. 80% have announced full or partial commissioning before 2030, with the remainder coming online after 2030 or not having announced a commissioning date as of yet).
- In Europe, which accounts for 314 of announced projects, hydrogen is expected to play a significant role in meeting decarbonisation targets, with usage across industrial applications, transportation, and power generation. Within Asia, China accounts for roughly half the total announcements. Among announced projects in China, most focus on hydrogen use in transportation. In North America, hydrogen production should help boost the region's domestic supplies of low-carbon energy across multiple applications.

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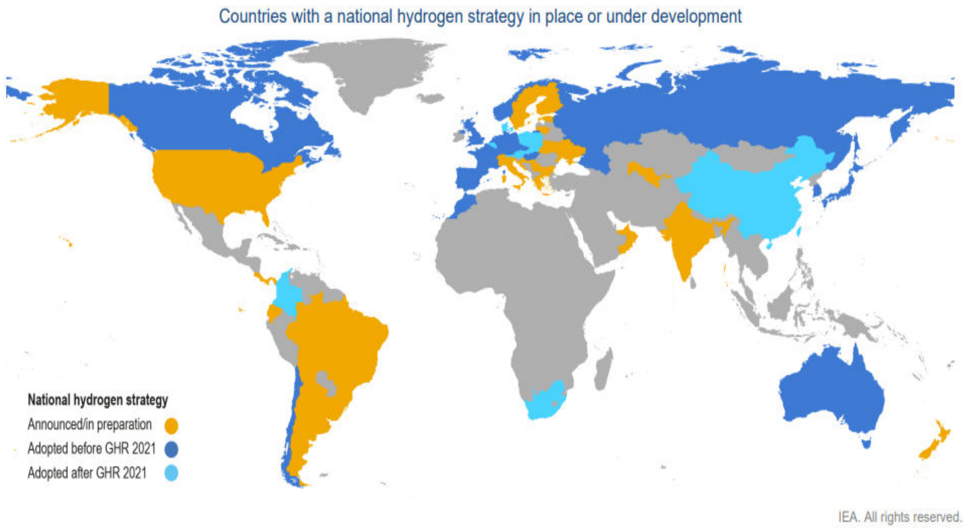
- Norwegian consultancy Rystad Energy (Apr-23) says hydrogen pipeline projects could expand by as much as +700% over the next 12 years. It said that more than 4,300 km of pipelines already transport hydrogen, with more than 90% of them in Europe and North America. It estimates there are about 91 planned pipeline projects throughout the world, with 30,300 km set to go online by around 2035.

TRENDS

Government support and targets

- According to the IEA's 'Global Hydrogen Review 2022', the adoption of hydrogen as a new energy vector is a complex endeavour that requires government intervention if it is to be realised at the pace required to help meet climate ambitions.
- 25 countries plus the European Commission have released national hydrogen strategies. Most of the strategies are in Europe.



Source: IEA's 'Global Hydrogen Review 2022'

- Also, since the last IEA report, other countries adopted a hydrogen strategy. For instance, India released its plan in March 2023, while the US unveiled a draft in September 2022.
- In addition to the strategies already adopted, more than 20 governments have announced they are working on a national hydrogen strategy.

- The IEA says targets to deploy hydrogen technologies are increasing in ambition, particularly to produce low-emission hydrogen. National targets for electrolysis capacities by 2030 were 74 GW globally in the IEA's 'Global Hydrogen Review 2021', whereas national targets for electrolysis capacities targets have more than doubled to reach 145-190 GW in IEA's 2022 Review. More ambitious targets, in part, were triggered by Russia's invasion of Ukraine.
- In May 2022, the EU launched RePowerEU, setting more aggressive targets for 2030. The bloc aims to import 10 Mtpa of hydrogen, 4 Mtpa of that as ammonia. It also doubled its domestic hydrogen production to 10 Mtpa.(Wood Mackenzie, Feb-23)
- In July, the UK doubled its 2030 ambition to 10 GW and, for the first time, declared that at least half would come from electrolytic projects.
- The US passed the Inflation Reduction Act in August, announcing a 45V production tax credit (PTC). Qualifying hydrogen facilities can obtain a 10-year PTC of up to US$3/kg, the most generous tax incentive to date. The move has prompted some markets to develop similar incentives in an effort to remain competitive.
- Canada plans to develop a similar subsidy scheme with up to 40% in tax credits. The EU, in contrast, launched the US EU Task Force on the Inflation Reduction Act in October and has submitted an official response requesting a modification to the PTC to limit its potential effects on EU projects.
- India's National Hydrogen Mission sets out the government's specific strategies for the short-term (to 2030) and broad-strokes principles for the long-term (10 years and beyond) for green hydrogen production. However, the government has scaled back the specific targets for refiners and fertiliser companies and instead created the Empowered Group (EG) to define new targets, to be notified in 2023-2024.

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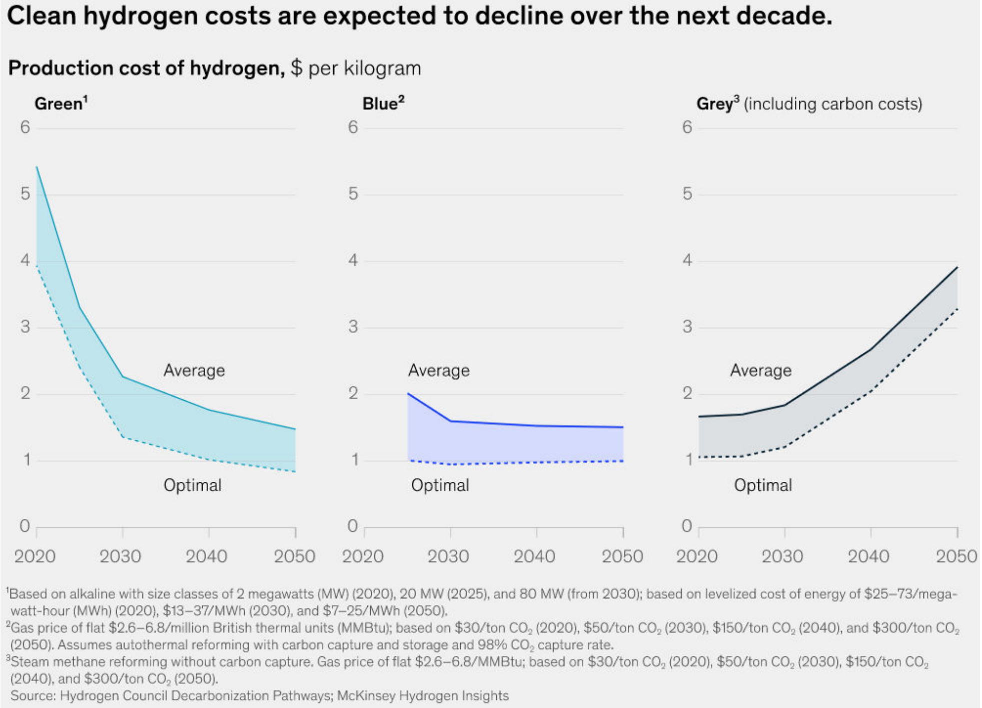
Commercial viability

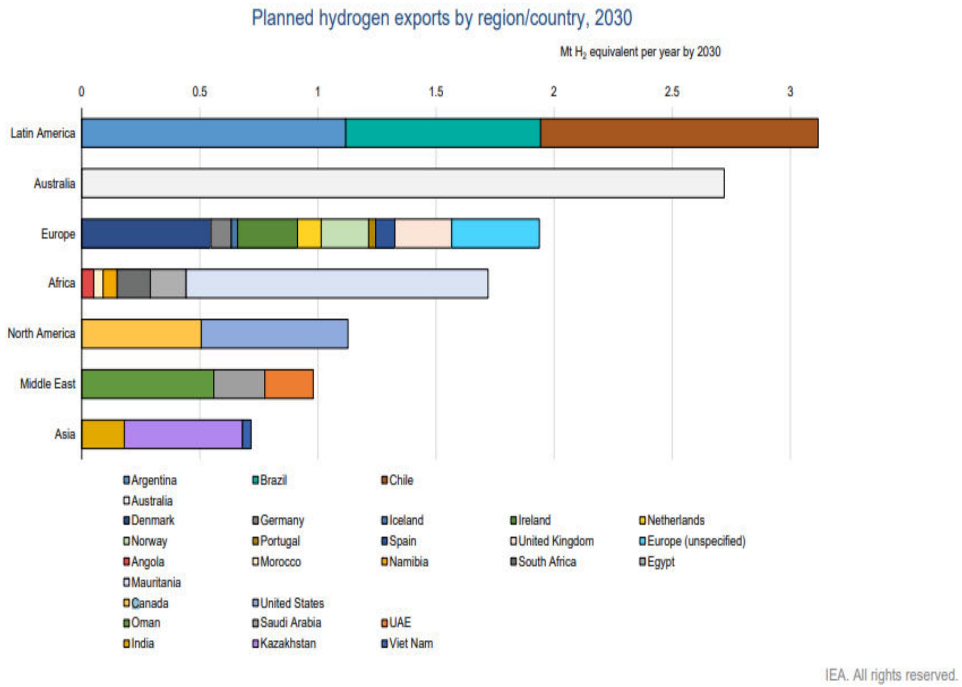
- The World Bank (Jun-22) said falling renewable energy prices - coupled with the dwindling cost of electrolysers and increased efficiency due to technology improvements - have increased the commercial viability of green hydrogen production.
- Citing Bloomberg, the World Bank article says if costs continue to fall, green hydrogen could be produced for US$0.70-US$1.60 per kg in most parts of the world by 2050, a price competitive with natural gas. NEL, the world's largest producer and manufacturer of electrolysers, believes green hydrogen production cost parity (or even superiority) with fossil fuels could be achieved as early as 2025.
- McKinsey (Oct-22) set out the following cost forecasts (see beow):



Source: McKinsey (Oct-22)

International trade

- According to IEA's 'Global Hydrogen Review 2022', the transition to a clean energy system will increase demand for low-emission hydrogen. Some countries may be able to cover low-emission hydrogen needs with domestic production, while others may import from countries with more favourable conditions to produce hydrogen from renewables or from fossil fuels in combination with carbon capture and storage (CCUS).
- International trade is generally expected to emerge as one component of the hydrogen supply chain. According to the IEA, 3% of global demand for hydrogen and hydrogen-derived fuels will be covered through international trade by 2030. By 2050, the share of traded hydrogen increases to 12%.
- Europe and some Asian countries, such as Japan and Korea, are likely importers of hydrogen, while other countries and regions, such as the Middle East, Australia, North Africa, North America, and Latin America become exporters.



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Cooperation agreements

- On top of trading hydrogen, countries are also announcing cooperation agreements to jointly explore the use of hydrogen.
- In April 2023, South Korea's Trade, Industry and Energy Minister Lee Chang-yang and the UK's Secretary of State for Energy Security and Net Zero Grant Shapps discussed cooperation in the area of clean energy. The joint declaration by the parties includes prospects of South Korea's participation in the UK's new nuclear power plant initiative, as well as exchange and cooperation between the countries on areas such as offshore wind power and hydrogen.
- In March 2023, the UK and Norway announced a cooperation on hydrogen after signing an expanded Memorandum of Understanding (MoU) on carbon capture and storage (CCS). The countries will regularly exchange knowledge and experience on technologies of hydrogen production as part of the expanded MoU. Norway and the UK have had an MoU on CCS since 2018.

CHALLENGES

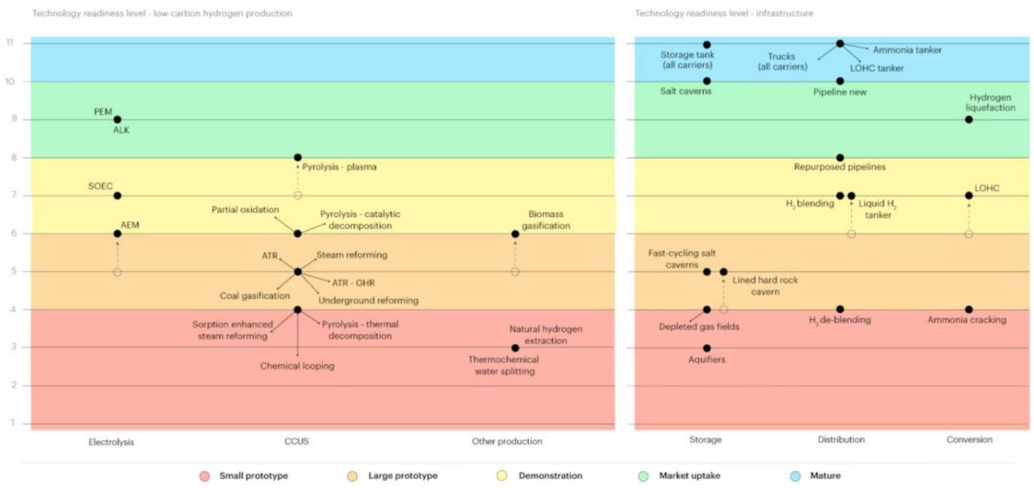
Failing to meet the net zero challenge

- The IEA (Sep-22) says hydrogen as a clean energy vector still has significant progress to make to get on track with the Net Zero Emissions by 2050 Scenario. In 2021, hydrogen demand was almost entirely met by unabated fossil fuel-based hydrogen. Getting on track with the Net Zero Scenario requires the production of low-emission hydrogen to be scaled up to reach total production of 95 Mt by 2030, as well as calling for the enabling infrastructure, including hydrogen-dedicated infrastructure, renewable generation capacity, and CO2 transport and storage infrastructure.
- Emissions of CO_2 associated with hydrogen production reached more than 900 Mt CO_2 in 2021, an increase of around +6% compared with 2020. This means the increase in hydrogen production and demand observed in 2021 were not beneficial to the fight against climate change. The positive trends observed in areas such as electrolyser deployment are still taking place at a very small scale.
- The increase in CO_2 emissions observed in 2021 resulted from the increase in hydrogen production since there has been practically no change in the fuel and technology mix used for production. The global average carbon intensity of hydrogen production remained the same as in 2020, at nearly 10g CO_2/g H_2. In the Net Zero Scenario, emissions related to the production of hydrogen decrease to around 800 Mt CO_2 by 2030, -13% lower than today. Taking into account the increase in hydrogen production, the global average carbon intensity of hydrogen production drops to slightly more than 4g CO_2/g H_2. This would require practically all new hydrogen production capacity coming online throughout the decade to be low-emission and the retrofit of carbon capture to some existing fossil-based production capacity.
- Practically all dedicated hydrogen production (more than 99%) is currently based on fossil fuels, mainly the steam reforming of natural gas and coal gasification. In 2021, around 70% of the energy requirement for dedicated hydrogen production was met with natural gas and around 30% with coal.

Technology challenge

- The IEA (Sep-22) says the technologies for the production of low-emission hydrogen are at different stages of development. For electrolysis technologies, alkaline and proton exchange membrane (PEM) electrolysers are commercially available, although they are still not competitive with conventional unabated fossil-based technologies. Solid oxide electrolyser cells (SOEC) are still under demonstration and anion exchange membrane (AEM) electrolysers are at prototype level. However, these technologies are observing rapid development.

Technology readiness levels of low emission hydrogen production and infrastructure



Source: IEA (Sep-22)

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- The IEA (Sep-22) goes on to say as regards fossil fuels with carbon capture and storage (CCUS), technologies with partial capture of CO2 (around 60%) are commercially available and well established for the co-production of ammonia and urea. However, the production of low-emission hydrogen requires much higher capture rates, which have not yet been demonstrated. These technologies are currently at pre-demonstration level and no projects are at the advanced stages of development or expecting to demonstrate them soon. In the case of biomass-based routes, although also less developed than other low-emission hydrogen production technologies, they have registered some progress this past year with full prototypes entering operation in Japan and France.
- Hydrogen infrastructure technologies are more developed than other areas of the hydrogen value chain. There are several fully commercial technologies, such as pipes for hydrogen transport, and pressurised tanks and salt caverns for bulk hydrogen storage. However, efforts are still required to bring certain critical technologies to commercialisation or to scale up commercial technologies, such as liquefaction.

Funding gap

- McKinsey (Oct-22) says despite hydrogen's momentum, a significant investment gap remains for it to fully contribute to decarbonisation. Achieving a pathway to net zero will require additional direct investments of US$460bn by 2030 (as of May 2022) - closing the gap between the US$240bn of announced projects (refer to 'Project pipeline' above under 'Market Size') and US$700bn in required investments.
  - *Production*. Clean-hydrogen production has the highest amount of announced investment. However, it is also the segment with the biggest investment requirements. The current investment gap is roughly US$150bn through 2030.
  - *Transmission, distribution, and storage*. Investments in this part of the value chain are critical to enabling access to cost-competitive hydrogen supplies, for example, connecting the regions with the lowest production costs to demand hubs, developing refuelling infrastructure for vehicles, or building pipelines to supply industrial plants. An investment gap of more than US$165bn remains.
  - *End-use applications*. Meeting projected demand in hydrogen's various end-use applications, including steel production and transportation, will require additional investments of US$145bn, with the largest absolute gap in mobility. New industry applications such as steel will require significant investments - about US$35bn - for outlays like new plants. However, steel is also one of the most advanced segments among announced investments, with about half of required investments announced.

Project financing

- Societe Generale (Sep-22) says that for the hydrogen economy to scale up equity will not be enough. In a similar way to how the Liquefied natural gas (LNG) or renewable energy sectors developed, equity must be paired with bank debt or project finance debt - only a mix of these two sources of capital can mobilise the quantity of funding that large-scale hydrogen projects require and the returns that investors expect. However, challenges still need to be addressed, including the long-term access of green electricity at competitive pricing, the level of government incentives and the offtake agreements[2]. Indeed, structuring and securing a long-term offtake with strong commercial conditions and creditworthy counterparties remains critical to the bankability of hydrogen projects. Today's energy crisis compounds the challenges, increasing the competition for renewable energy access and driving up power prices.
- Societe Generale says substantial expected growth in hydrogen demand is driving the need for electrolyser production and storage equipment. Consequently, technology manufacturers have embarked on the construction of giga electrolysis factories.
- BCG (Feb-23) surveyed over 100 experts and interviewed more than 35 executives from commercial banks, development banks, private equity firms, asset managers, and energy companies about why banks have not provided the debt financing necessary for hydrogen and carbon capture and storage (CCUS) to scale up. While commercial banks are keen to finance hydrogen and CCUS projects - both to support their clients and meet their own sustainability targets - they are holding back because of the perceived risks involved. And because most banks are not prepared to be more flexible with their project-finance risk criteria, many projects are simply not going ahead.

[2] An offtake contract is a contract under which a third party (the Offtaker) agrees to buy a certain amount of the product produced by a project at an agreed price.

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- BCG's research suggests that many commercial banks are waiting for these projects to meet the same standards and provide the same levels of risk as more developed green projects, such as solar photovoltaic (PV) parks and wind farms. Banks want the projects they finance to:
  - Have long-term offtake agreements with good quality counterparties (offtake risk);
  - Use mature technologies (technology risk);
  - Operate under clear regulations and industry standards (policy risk); and
  - Be able to sell into established markets (merchant risk).
- Hydrogen and CCUS project developers cannot currently provide the same degree of certainty in these areas.
- Policy changes and technology advances have revolutionised the renewables sector over the last two decades, bringing greater cost efficiency and production capacity and making projects more bankable. BCG expects many of the same forces to transform hydrogen and CCUS projects in the coming years. But these emerging technologies face different challenges than renewables, and they will need to evolve in different ways. For starters, renewable-energy project owners sell the power they generate into an existing electricity market. But because hydrogen and CCUS still lack an established marketplace - and because they involve molecules rather than electrons - offtake arrangements are less straightforward. For example, when it comes to using hydrogen to make green ammonia, production facilities for both hydrogen and ammonia typically need to be located next to each other due to transportation problems.
- There is also a chicken-and-egg situation between users and suppliers of hydrogen. Potential users (steel producers, for example) point to cost considerations, such as the premium they must pay for hydrogen, and inadequate supply volumes as reasons why they are reluctant to convert their operations to hydrogen use. On the flip side, hydrogen project developers cite such weak demand as the main reason for not being able to scale up production. Breaking the impasse will says BCG require more policy support, improved economics, and greater access to low-cost funding.
- Other specific risk factors for hydrogen and CCUS include the absence of international agreements on what constitutes green hydrogen and on permanent CO_2 storage, underdeveloped markets for trading hydrogen and carbon credits, a lack of clarity on liabilities and liability transfers relating to CO_2 storage, and significant variations in CCUS regulations by region. In the face of these challenges, banks need to have strong risk assessment and management capabilities to service emerging hydrogen and CCUS markets effectively.
- Policy measures, such as the Inflation Reduction Act in the US and the European Union's REPowerEU plan (reinforced in February 2023 with the EU Green Deal Industrial Plan), are set to improve the economics of hydrogen and CCUS projects and make them more bankable (refer to 'Government support and targets' under 'Trends' above).
- The incentives and regulatory approaches involved differ. The US' policy approach is based on tax incentives and less regulation, whereas the European approach is structured around regulated-asset-base models, contracts for difference, and carbon markets such as the Emissions Trading System. By removing elements of risk, both approaches are providing players with greater certainty through well-known and financeable business models. BCG expects these policy approaches to be replicated in other markets, creating new funding opportunities for banks.

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