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Russia Sanctions and Gas Price Crisis Reveal Danger of Investing in "Blue" Hydrogen

Gas-derived Hydrogen Increases Imports and Prices, Adding More Risk to Europe's Security of Supply

Key Findings

- Elevated gas prices and a future tight market means blue hydrogen is no longer a low-cost solution; **IEEFA estimates that blue hydrogen costs published by the UK government last year are now 36% higher**, calling into question continued policy support for development of the technology.

- Blue hydrogen is an **extension of the gas value chain** and does not make sense as an investment during a gas price crisis.

- The UK will need to import **10% more natural gas to produce blue hydrogen than if the gas was used directly for heat**. This would raise demand for gas at a time when Europe is seeking to reduce its dependence on the fossil fuel.

- If blue hydrogen were used to heat a building, you would need to use **at least one third more natural gas** than if it was used directly for heat.

- Reducing the demand for gas needed for grey hydrogen production could help ease issues with gas price, security of supply and energy transition. According to BNEF,[1] just replacing current grey hydrogen demand with green hydrogen for oil refining and fertilizer production could reduce the European Union's gas demand by 12%.

- Blue hydrogen projects are high risk and likely to become stranded assets.

- Twenty-six green hydrogen projects are expected to start construction around the world this year; no blue hydrogen projects are slated, demonstrating that its financial risks are already playing out in the global market.

[1] Bloomberg. Russia's Invasion Supercharges Push to Make a New Green Fuel. 10 April 2022.

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Introduction

Hydrogen is expected to be a key instrument in meeting European objectives of climate-neutrality by 2050, since it does not emit carbon dioxide (CO_2) when burnt and can be produced from renewable electricity and water (known as green or renewable hydrogen).

Following the European Green Deal announcements in December 2019,[2] the EU announced its hydrogen strategy in 2021,[3] targeting 40 gigawatts (GW) of electrolysers and 10 million tonnes (mt) of domestic renewable hydrogen production by 2030.

In response to the Russian invasion of Ukraine, REPowerEU announced in March 2022 plans to further replace demand for Russian gas with an additional 15mt of renewable hydrogen (10mt imports and 5mt additional domestic production).[4] Notably, hydrogen produced by other means is not considered part of the solution.

Meanwhile the UK's British Energy Security Strategy,[5] published in April 2022, describes hydrogen as a "low carbon super fuel of the future" and aims to produce as much as 10GW of low carbon hydrogen by 2030, with at least half produced from water electrolysis (using renewable or nuclear electricity) and the rest produced from natural gas with emissions reduced by carbon capture and storage (blue hydrogen).

Gas-derived blue hydrogen has long been proposed by the oil and gas industry as an energy carrier that can help reduce global warming, although this has been contested by climate and energy experts:

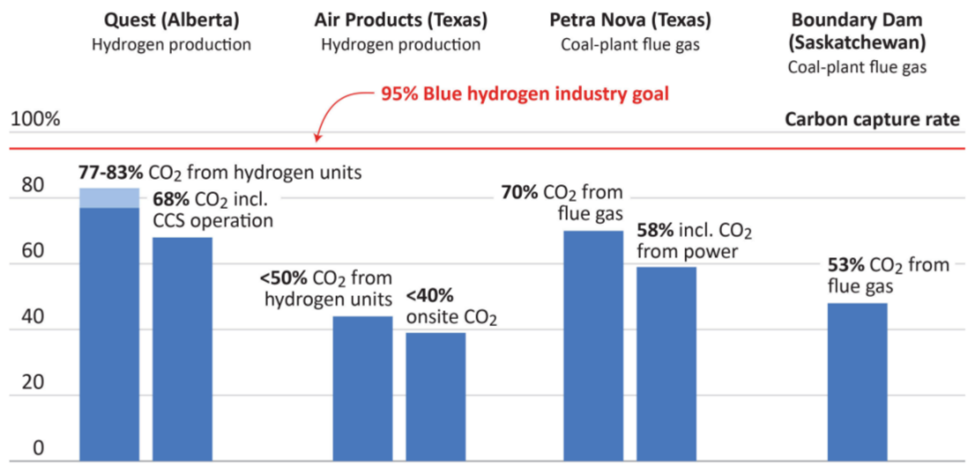
- The International Council on Clean Transportation recommended that policymakers should not support fossil-based hydrogen in climate and gas policies,[6] saying that only hydrogen produced from renewable electricity or forest residue biomass can have low greenhouse gas (GHG) emissions after accounting for uncertainties in parameters, especially methane leakage and carbon capture rates.

- Cornell and Stanford University researchers concluded that blue hydrogen may harm the climate more than directly burning gas or even coal for heat,[7] due to methane emissions from its supply chain and uncertainty over the performance of carbon capture and storage (CCS) technology.

[2] European Commission. A European Green Deal. Last accessed 4 May 2022.
[3] European Commission. Hydrogen Factsheet. 14 July 2021.
[4] European Commission. Factsheet - REpowerEU. 8 March 2022.
[5] UK Government. Press Release: Major Acceleration of Homegrown Power in Britain's Plan for Greater Energy Independence. 6 April 2022.
[6] International Council on Clean Transportation. Life-Cycle Greenhouse Gas Emissions of Biomethane and Hydrogen Pathways in the European Union. 10 October 2021.
[7] Energy Science and Engineering. How Green is Blue Hydrogen? 12 August 2021.

- A recent analysis by IEEFA in the U.S. has highlighted how large commercial CCS projects have not achieved the industry target rate over time,[8] despite years of investment and projects.

Reality Check: Real-World CO_2 Capture Far Below Promised Rate



Source: IEEFA US.

More broadly speaking, other studies have been published questioning the Global Warming Potential (GWP) of hydrogen. A recent study released by the UK government's own Department of Business, Energy and Industrial Strategy (BEIS) found that hydrogen is twice as powerful a greenhouse gas as previously thought.[9] Global warming potential (GWP) is a measure used to compare the warming effect of different gases with that of CO_2. By definition CO_2 has a GWP of 1. BEIS estimated that hydrogen has a GWP of six to 16 over a 100-year time horizon, and 20 to 44 over a 20-year horizon. This compares with a GWP of 84 to 87 for methane, the main component of natural gas. But hydrogen is the lightest element and leaks more easily than methane, so any future hydrogen systems will need to have strong leakage protection and monitoring to be considered climate neutral.

[8] Institute for Energy Economics and Financial Analysis (IEEFA). Hydrogen. Technology Challenges, Weak Commercial Prospects, and Not Green. February 2022.
[9] University of Cambridge and NCAS, and University of Reading. Atmospheric Implications of Increased Hydrogen Use. April 2022.

How Hydrogen Is Made

To produce hydrogen, it must be separated from the other elements in the molecules where it occurs. The two most common methods for producing hydrogen are:

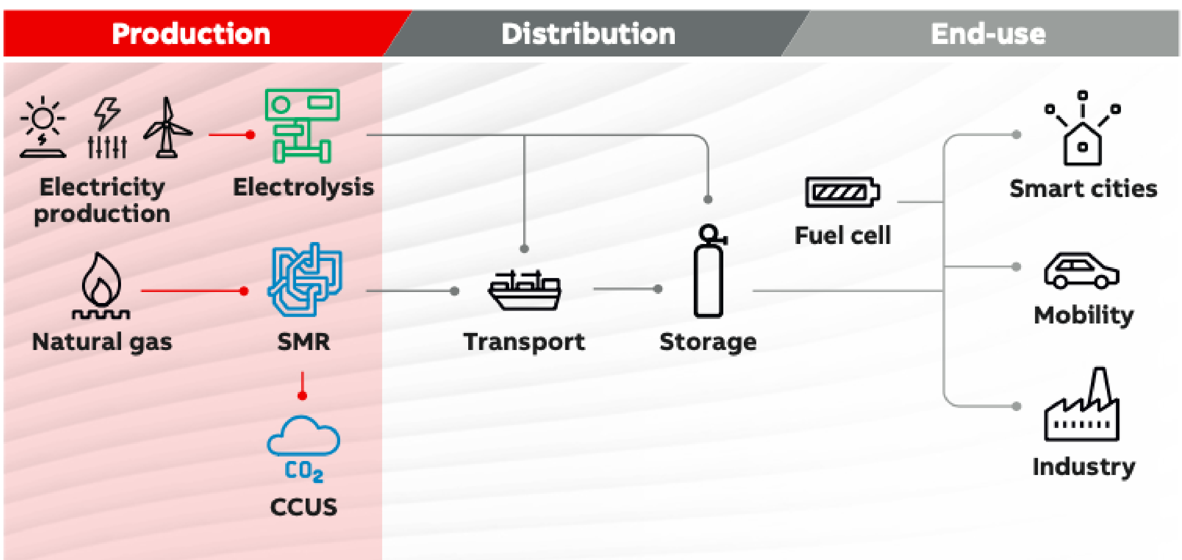
1. **Steam-Methane Reforming (SMR)**

   - Commercial hydrogen producers and petroleum refineries use steam-methane reforming to separate hydrogen atoms from carbon atoms in methane (CH_4).

2. **Electrolysis**

   - Electrolysis is a process that splits hydrogen from water using an electric current. The electricity for electrolysis can come from renewable sources such as hydro, solar, or wind energy, or from other sources such as nuclear power.

Figure 1: Overview of the Hydrogen Value Chain



Source: ABB, Partnering for our energy future — strengthening the hydrogen value chain, 2020.

The oil and gas industry describes hydrogen mainly as grey, blue, or green,[10] depending on how it is made; grey from fossil fuel with CO_2 emissions, blue from fossil fuel with CO_2 captured, and green from renewable electricity and water with no CO_2 emissions. There are in total nine colour codes to identify hydrogen that form what is sometimes described as the "hydrogen rainbow."[11] For example, pink hydrogen could be produced from electrolysis using nuclear power, while black/brown hydrogen uses the gasification of coal and has high emissions. Others

[10] Seeking Alpha Hydrogen Vs. Natural Gas for Electric Power Generation. 2 December 2020.
[11] H2 Bulletin, Hydrogen colour codes. Last accessed 4 May 2022.

are turquoise, purple and red hydrogen, while white refers to naturally occurring hydrogen. In this report, we have focused mainly on blue and green.

Green hydrogen is produced from the electrolysis of water using electricity from renewable sources like solar and wind energy.[12] It has been identified as an important clean energy carrier that could help bring the world to net-zero emissions, though it will require significant build-out of renewable power generation.

Blue hydrogen is produced by splitting natural gas, which is predominantly methane (CH_4), into hydrogen and CO_2 but the CO2 is captured and then stored.[13] The "capturing" is done using CCS, and the carbon is stored or marketed. The goal is to capture 90 percent to 95 percent of the carbon, but typically only the hydrogen process emissions are targeted, not the equipment power source or the carbon compression and transport power source.

SMR is the most widely used process for the generation of hydrogen.[14] SMR mixes natural gas with very hot steam,[15] in the presence of a catalyst, where a chemical reaction creates hydrogen, carbon dioxide and carbon monoxide. Most SMR facilities in current operation produce hydrogen for use as a feedstock to other processes such as oil refining,[16] fertilizer, or chemical production.

Blue hydrogen can also be produced by Autothermal Reforming (ATR) or other emerging technologies. ATR combines the steam reforming reaction and fuel oxidation into a single unit. ATR is a commercial technology commonly used in the production of ammonia and methanol, but it is not currently used for hydrogen production at scale because the Carbon Monoxide (CO) content of the produced syngas is too high.[17]

Compared to SMR, ATR has a simpler production stream, with a high concentration of carbon dioxide. This makes it easier to capture a greater percentage of carbon emissions in the conversion process. But an ATR plant with carbon capture typically requires more electricity than an SMR plant.[18]

A UK government report on hydrogen production assumes that any excess steam in the SMR production process can be used to generate power,[19] which is sufficient to

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[12] ABC. What is green hydrogen, how is it made and will it be the fuel of the future? 22 January 2021.
[13] Petrofact. The Difference Between Green Hydrogen and Blue Hydrogen. Last accessed 4 May 2022.
[14] Student Energy. Steam Methane Reforming. Last accessed 4 May 2022.
[15] Hydrogen Europe. In a Nutshell - Myths. Last accessed 4 May 2022.
[16] Pembina Institute. Carbon Intensity of Blue Hydrogen Production. Accounting for Technology and Upstream Emissions. August 2021, p. 1
[17] *Ibid*.
[18] *Ibid*.
[19] UK Department for Business, Energy, and Industrial Strategy. Hydrogen Production Costs 2021. August 2021.

meet the power demand of the overall plant. This report assumes that SMR plants achieve a conversion efficiency of 74% (HHV).[20]

Grey hydrogen is created from natural gas,[21] or methane, using steam methane reformation but without capturing the greenhouse gases made in the process.

Currently, approximately 98% of the ~120Mt of hydrogen produced annually is "grey hydrogen",[22] via SMR or the gasification of coal or similar materials of fossil-fuel origin. Only about 1% of hydrogen production from fossil fuels currently uses CCS.

The process of making blue hydrogen requires a lot of energy. For every unit of heat potential in the natural gas at the start of the process, only 70% to 75% of that energy remains in the hydrogen product.[23] That means that if the hydrogen is used to heat a building, you would need to use about one-third more natural gas to make blue hydrogen than if it was used directly for heat.

On average over the last decade, 36% of the UK's annual gas demand has been used for domestic consumption. If we assume that 80% of this gas is used for space heating[24], if household boilers were converted to burn blue hydrogen instead of gas **the UK's gas demand would actually increase by 10%**. Several countries in Europe use gas extensively for heating,[25] especially the Netherlands (83% heat market share), the UK (77%), Italy (72%), and Hungary (69%). Substituting blue hydrogen for gas in these nations would increase their national gas imports and reduce their energy security.

CCS involves the capture of CO_2 from large point sources, including power generation or industrial facilities that use either fossil fuels or biomass for fuel.[26] The CO_2 can also be captured directly from the atmosphere. If not used on-site, the captured CO_2 can be compressed and transported by pipeline, ship, rail or truck to be used in a range of applications, or injected into deep geological formations (including depleted oil and gas reservoirs or saline formations) that trap the CO_2 for permanent storage. To date, carbon capture technology has mainly been used for enhanced oil recovery (EOR), where CO_2 is pumped with water into oil reservoirs to flush out more oil, increasing production and extending the life of the asset. Research by IEEFA has shown that CCS projects have failed to reach their 90-95%

[20] HHV, Higher Heating Value, refers to the total amount of heat liberated during the combustion of a unit of fuel, including the latent heat stored in the vaporised water.
[21] National Grid. The Hydrogen Colour Spectrum. Last accessed 4 May 2022.
[22] The Global CCS Institute. Blue Hydrogen. April 2021.
[23] Hydrogen Science Coalition. Blue hydrogen - what it is, and should it replace natural gas? 20 November 2021.
[24] BEIS. Energy Trends: UK gas. Updated 28 April 2022.
[25] Heat Roadmap Europe. Quantifying the Heating and Cooling Demand in Europe. 2015.
[26] International Energy Agency. About CCUS. April 2021.

carbon capture rates over time, with measured 5-year performance being around half of the target capture rates.[27,28]

Figure 2: Hydrogen "Colours"

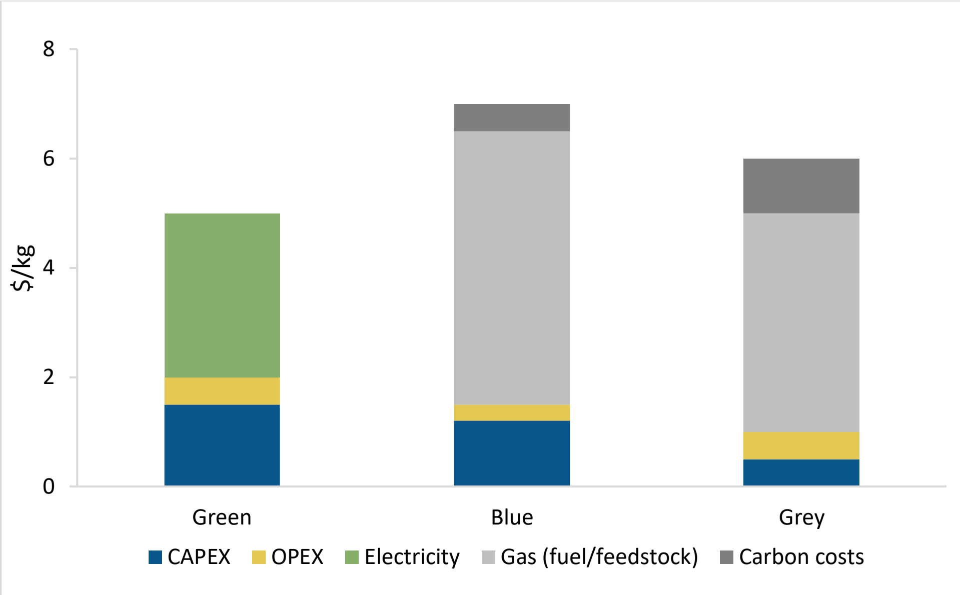
GREEN HYDROGEN	BLUE HYDROGEN	GREY HYDROGEN
Made by using electricity from renewable energy technologies to electrolyse water (H_2O), separating the hydrogen atoms within it from the oxygen. No CO_2 by-product.	Produced using natural gas but with a percentage of carbon emissions that can be captured and stored, or reused. Negligible amounts in production due to a lack of successful CCS. Projects may end up stranded. GHG emissions from upstream methane and uncaptured CO_2	The most common form (>95%) of hydrogen production today. Produced from natural gas via SMR and without any emissions capture. High carbon footprint; global annual emissions of 900mt CO_2 are equivalent to the combined emissions of the UK and Indonesia.

The Economics of Hydrogen Production

Hydrogen production requires various fixed and variable costs. Levelized cost of hydrogen (LCOH) is a calculated metric that enables different production methods to be compared on a similar basis. It estimates all the capital and operating costs of producing hydrogen over the lifetime of a project and discounts future costs to the present. As with all such measures, it is completely dependent on the assumptions used and subject to uncertainty. However, it does reveal the major cost components of each production route and when considered within the context of energy market trends, can indicate relative risks as well as likely potential for future cost reduction.

[27] Institute for Energy Economics and Financial Analysis (IEEFA). Blue Hydrogen. Technology Challenges, Weak Commercial Prospects, and Not Green. February 2022.
[28] Institute for Energy Economics and Financial Analysis (IEEFA). Shute Creek – world's largest carbon capture facility sells CO2 for oil production, but vents unsold. 1 March 2022.

Figure 3: Illustrative LCOH Cost Components for Hydrogen Production



Source: Rethink Energy Research October 2021, IEEFA edit.

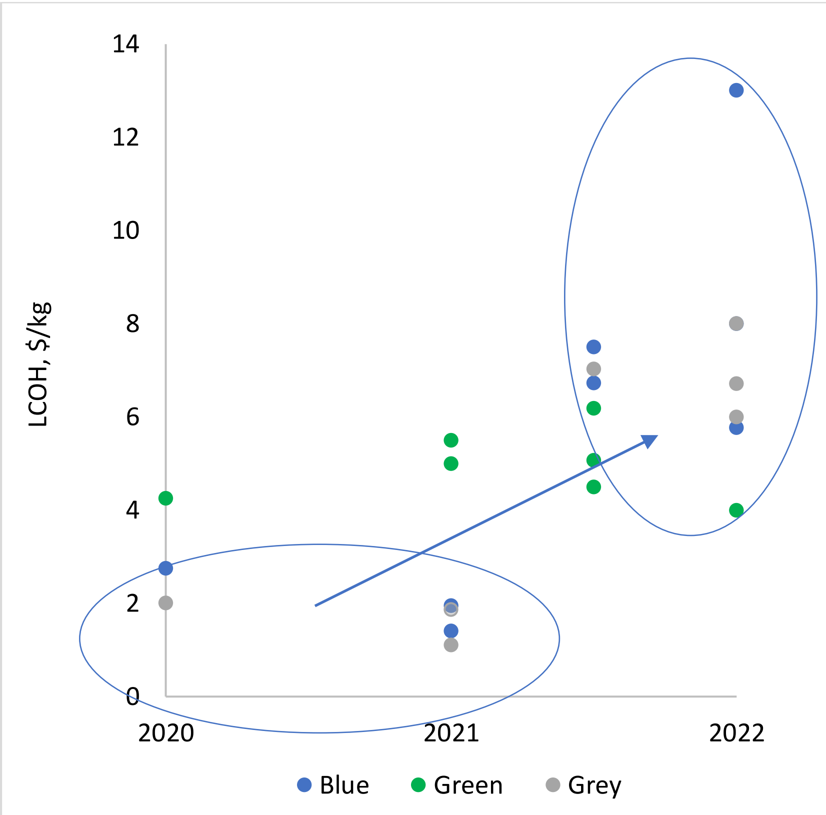
The largest cost component for blue and grey forms of hydrogen is the cost of gas used as feedstock and fuel for the SMR or ATR process. The cost of production is highly sensitive to assumptions about the current and future price of gas, with longer-term pricing carrying less weight due to discounting. As well as the price of gas, blue hydrogen is sensitive to factors such as the project capital expense (capex), efficiency and timeline for the plant, the price of carbon and proximity of the CCS storage site.[29] For green hydrogen, the largest components are the cost of power needed to run the electrolysis process and the plant capex, which is primarily the cost of electrolysers. Green hydrogen is also sensitive to electrolyser utilisation (or load factor) and efficiency assumptions.

The global gas price crisis over the last two years and the Russian invasion of Ukraine have highlighted the danger of relying on globally priced fossil fuels. Record high gas prices and expectations of sustained tightness in global gas markets have all but destroyed the business case for blue (and grey) hydrogen in Europe. As gas prices skyrocketed last year, several research institutions published information on how this could affect production costs, claiming that gas-derived hydrogen had become more expensive to produce than renewable hydrogen, or that it would become more expensive years earlier than previously expected.

The figure below shows the impact of the gas price increase over the past year. Compared to 2021, blue hydrogen is more expensive than green hydrogen, assuming recent price levels.

[29] Government of Alberta. Ministry of Energy. Alberta Hydrogen Roadmap. November 2021.

Figure 4: Gas-based Hydrogen Is No Longer Economical in Europe: Levelised Cost of Hydrogen Estimates, 2020-2022



Source: IEEFA based on estimates published by BNEF, Energy Flux, ICIS, IEA, GCCSI, KPMG, Lazard, Rethink Energy and Rystad.
Note: Where ranges were given mid-points have been shown for illustration.

UK Hydrogen Production Cost Estimates

In August 2021, the UK government department for business, energy and industrial strategy (BEIS) published its perspective on hydrogen production costs.[30] We note the overarching conclusion of the study:

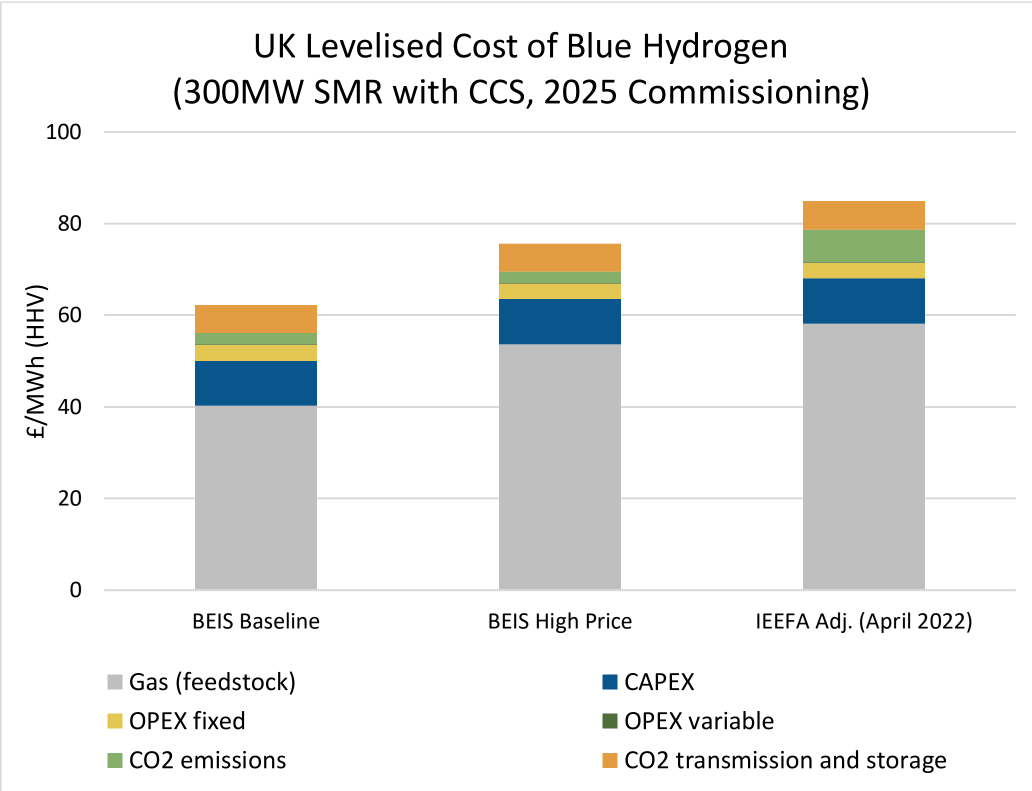
> *"The use of different sensitivities has shown that LCOH estimates are subject to large uncertainties and has highlighted the importance of considering the individual circumstances of technologies and scenarios. Certain technologies may be heavily impacted by a scenario change, whereas others may not."*

Since the first quarter of 2021, industrial gas prices in the UK have been higher than the BEIS sensitivity upper limit for blue hydrogen costs. We have therefore adjusted for this and other prices and trends to show how the BEIS outlook is outdated and presents an overly optimistic view on blue hydrogen. The IEEFA analysis indicates

[30] UK Department of Business, Energy, and Industrial Strategy. Hydrogen Production Costs 2021. 17 August 2021.

that since BEIS published the document last year, its blue hydrogen production costs (shown as LCOH) have risen by 36%.

Figure 5: IEEFA: The UK's Expected Cost of Blue Hydrogen Has Risen by 36% Compared to Baseline Estimates Published Less Than a Year Ago



Source: IEEFA, BEIS.

Two assumptions have been updated to arrive at this figure:

1. Gas (feedstock): In the fourth quarter of 2021, UK industrial gas prices reached 4 pence per kilowatt-hour (p/kWh), which is higher than all BEIS baseline (2.2 rising to 2.9 in 2035) and BEIS high price (3.1 rising to 3.9 in 2035) scenarios. Assuming a flat 4p/kWh instead implies a 45% increase to the BEIS baseline levelized cost of gas.

2. CO_2 emissions:

   a) The price of UK emissions allowances has risen to approximately £80/tonne (t), compared to BEIS baseline expectations of £25.74/t rising to £43.49/t in 2030 and rising linearly thereafter to £378 in 2050. Assuming an £80/t price rising to £98/t in 2030 and £378 in 2050 implies a 44% increase to the levelized cost of CO_2 emissions.

b) IEEFA research has found real-world carbon capture rates for CCS projects have consistently been consistently below industry targets. Adjusting BEIS assumed capture rate from 90% to 80% implies a doubling of the levelized CO_2 emissions cost.

Our revised LCOH of £85/MWh for blue hydrogen in 2025 is much higher than BEIS estimates for green hydrogen produced in 2025 from curtailed renewable electricity (£58/MWh) and similar to green hydrogen produced in 2030 from dedicated offshore generation (£88/MWh). This raises the question: Why does the UK government continue to provide public funding and policy support to blue hydrogen projects with multi-decade operating lifetimes, if they will be uncompetitive with green hydrogen in just a few years—and more importantly, well before the end of their operating lifetime?

Table 1: UK LCOH for Green and Blue Hydrogen (£/MWh)

Commissioning Year	Source	Blue Hydrogen *300MW SMR + CCS*	Green Hydrogen *Dedicated Offshore, PEM*	Green Hydrogen *Curtailed Electricity, PEM*
2025	BEIS reference	62	112	58
	IEEFA Adj.	84	-	-
2030	BEIS reference	64	88	48
	IEEFA Adj.	85	-	-

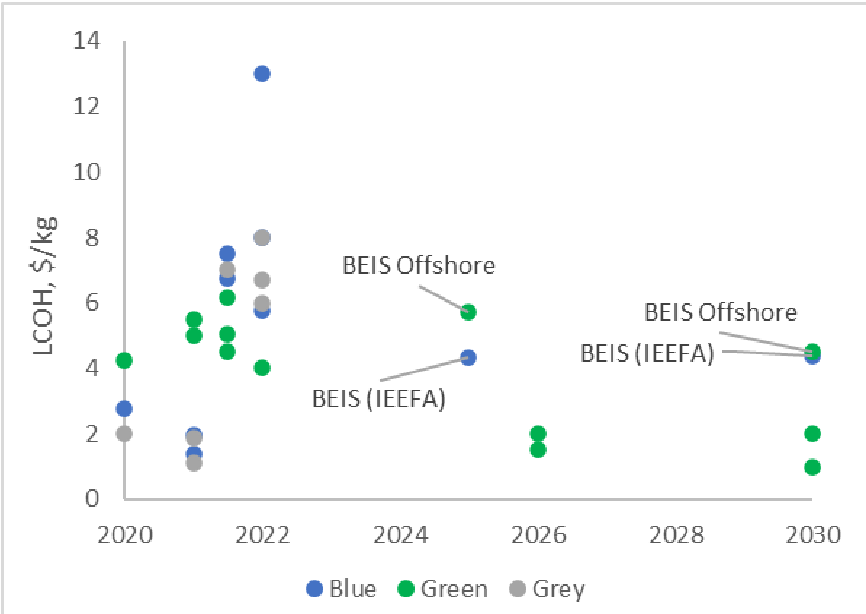
Source: BEIS, IEEFA.

Global Longer Term LCOH Trajectories

Blue hydrogen was previously advertised as cheaper to produce than its green equivalent because the underlying coal or gas technology is commercially mature, even though CCS is not.[31] It is hard to see a dramatic technology breakthrough that could reduce key costs for blue hydrogen, especially since CCS has already suffered decades of failed investments.[32] Meanwhile, assuming there will be sufficient demand for hydrogen globally, the long-term price forecasts for green hydrogen are getting cheaper. In particular, the cost of electrolysers is expected to reduce rapidly in coming years as companies and governments around the world invest in projects, production capacity, and technology research & development.[33] As a result, global green hydrogen costs are expected to plummet in the coming decade.

[31] Bloomberg. Blue Hydrogen Could Become the White Elephant on Your Balance Sheet. 16 December 2021.
[32] Institute for Energy Economics and Financial Analysis (IEEFA). Federal Blue Hydrogen Incentives: No Reliable Past, Present or Future. 8 February 2022.
[33] Institute for New Economic Thinking. A New Perspective on Decarbonising the Global Energy System. 20 April 2021.

Figure 6: Longer Term LCOH Estimates $/kg



Source: IEEFA based on estimates published by BEIS, BNEF, Energy Flux, ICIS, IEA, GCCSI, UN/RMI's Green Hydrogen Catapult, KPMG, Lazard, Rethink Energy Research, Rystad and the US Department of Energy Hydrogen Shot.
Note: Where ranges were given, mid-points have been shown for illustration.

A Side Note on LCOH Assumptions

LCOH requires pricing assumptions throughout the lifetime of the project (20 to 40 years. Even if gas prices are high today, there will be a lower LCOH for blue and grey hydrogen if they are assumed to drop significantly in coming years and stay low. Similarly, if the cost of electricity is expected to rise, the LCOH for green hydrogen will rise, too. So with certain assumptions, one could also arrive at the opposite conclusion, i.e. that blue (and grey) will be cheaper than green hydrogen. This is exactly what one researcher at the University of Groningen Centre for Energy Economics Research concluded in a working paper published 14 April 2022.34 However, there are a few important points opposing this view:

1. Green hydrogen projects are likely to be protected from merchant power price risk by long-term power purchase agreements (PPAs). So even if power prices rise— which they have, significantly—the cost of power to the green hydrogen project will not necessarily rise with it. Renewable power can be contracted because there is no exposure to fuel (gas) costs set by volatile and unpredictable global markets.

2. The Russian invasion of Ukraine has led to a renewed political will and urgency in Europe to shift from cheap Russian gas, which will require a greater dependence on relatively expensive imports, such as LNG or piped

[34] Centre for Energy Economics Research. Levelised Cost of Low Carbon Hydrogen Technologies Production: An analysis of the competitive position of bio-hydrogen. April 2022.

gas from alternative suppliers. This makes it more likely that gas prices will remain elevated for years.

3. There is no guarantee that the current European electricity pricing mechanism remains unchanged in the coming decades. Countries including Spain have already been calling for a change to the current "pay-as-clear" system, which pins the electricity price to the marginal (usually fossil-fuel dependent) producer.[35] A reform of the system could lead to decoupling of gas and electricity prices, and, for example, a scenario where gas remains expensive but electricity becomes cheap.

The Global CCS Institute reported last year that the cost of producing clean hydrogen from gas with CCS could vary significantly from place to place due to differences in fuel costs.[36] In locations with cheap gas ($3/MMBtu), capex is the largest cost component, and the overall hydrogen cost was predicted at $1.50/kg. In locations with very expensive gas, gas is the largest cost component. Assuming a very high gas price ($11/ MMBtu), the organisation estimated the cost of blue hydrogen at $2.40/kg.

IRENA expects green hydrogen to undercut blue hydrogen on costs by 2030.[37] It may do so even sooner in some countries, such as China, thanks to its cheap electrolysers, and Brazil and India, thanks to their inexpensive renewables and relatively high gas prices.

Bloomberg New Energy Finance (BNEF) predicts the cost of producing hydrogen from renewable electricity should fall by up to 85% from today to 2050,[38] leading to costs below $1/kg ($7.4/MMBtu) by 2050 in most international markets. As the price of electrolysers rapidly declines, BNEF predicts that green hydrogen will be cheaper to make than blue hydrogen by 2030. Notably, BNEF's most recent forecasts for 2030 and 2050 were 13% lower and 17% lower than its previous ones. Blue hydrogen project developers will increasingly need subsidies to stay viable.

Prior to the gas price crisis, KPMG estimated that the scale-up of green hydrogen projects and innovations would make green hydrogen cost-competitive with blue by 2050.[39] By their estimates, water electrolysers account for about 45% to 75% of green hydrogen production costs.

Blue hydrogen project investors should be concerned about green hydrogen technology becoming cheaper, faster, and making their projects uncompetitive, leading to stranded assets in the future.

Rystad Energy reported that the production costs of the green gas hovered around $4/kg (particularly in the Iberian Peninsula), compared with $14/kg for blue

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[35] Euronews. EU Leaders rebuff Spain's pleas for market reform to curb electricity prices. 25 March 2022.
[36] Global CCS Institute. Blue Hydrogen. April 2021.
[37] International Renewable Energy Agency. Geopolitics of the Energy Transformation: The Hydrogen Factor. January 2022.
[38] BloombergNEF. Hydrogen: 10 Predictions for 2022. 21 January 2022.
[39] KPMG. The Hydrogen Trajectory. November 2020.

hydrogen and $12/kg for grey hydrogen.[40] Costs of blue and grey hydrogen had jumped about 70% since the Russian invasion began, with the price of conventional energy surging due to concerns about the future of Russian supply, typically a significant percentage of Europe's coal and gas.

This latest calculation shows the fragility of the gas market and its influence in the cost of producing blue hydrogen. Blue hydrogen costs of $14/kg in March 2022 is almost six times more expensive than the cost of $2.40/kg predicted by the Global CCS institute when assuming a high cost of gas.

Table 2: Various Predictions of Cost of Producing Blue and Green Hydrogen

Predictions	Cost of Producing Blue Hydrogen	Cost of Producing Green Hydrogen
Global CCS Institute (April 2021)	Assuming low-cost gas: $1.50/kg H_2 Assuming high-cost gas: $2.40/kg H_2	-
IRENA	Expects green hydrogen to undercut blue hydrogen on costs by 2030	
BNEF	Expects green hydrogen from onshore wind or solar PV to undercut blue hydrogen by 2030	In 2030: Below $2/kg H_2 In 2050: Below $1/kg H_2
Rystad Energy (March 2022)	**$14/ kg H_2**	**$4/kg H_2**

A study conducted by Tyndal Centre for Climate Change Research concluded that "there are at present disparities in the extent to which CCS is featured in the future hydrogen pathways, relative to electrolysis based hydrogen and electrification alternatives. The European Commission assumes a limited if any role for CCS in hydrogen production, while in the UK its application varies across scenarios considerably. SMR and ATR processes of transforming natural gas feedstock into hydrogen entails greenhouse gas emissions in production and across the supply chain. Producing fossil fuel-based hydrogen with CCS is estimated to produce 50gCO2/kWh to 188 gCO2/kWh (process and supply emissions)."[41] This raises the question: Is fossil fuel-based hydrogen sufficiently low-carbon to be considered a decarbonisation solution?

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[40] Rystad Energy. Cheap, Secure, and Renewable: Europe bets on green hydrogen to fix energy woes. 21 March 2022.
[41] Tyndall Centre. A Review of the Role of Fossil Fuel-Based Carbon Capture and Storage in the Energy System. 24 April 2022.

Hydrogen Projects

CCS Underperformance

Only two currently operational facilities in the world attempt production at a commercial scale: Quest in Alberta, Canada and Air Products in Port Arthur, Texas.[42] Unsuccessful carbon capture, however, means they are not truly "blue." According to research on blue hydrogen,[43] the effective onsite CO_2 capture rate at the Air Products facility is less than 40%. For the Quest project, the annual average CO_2 capture rate on hydrogen units ranges from 77% to 83%, but the five-year average is just 68% when including uncaptured CO_2 from CCS operation, transport and storage.

Research conducted by Global Witness shows that Shell's Quest blue hydrogen plant in Alberta emits more carbon than it captures.[44] Despite having captured 5 million tonnes of carbon across a five-year period, it has emitted 7.5 million tonnes of polluting gases during the same time.

This mirrors broader difficulties with CCS technology. An IEEFA report recently highlighted how the world's largest CCS project at Gorgon LNG in Western Australia—backed by Chevron, ExxonMobil and Shell— failed to meet its target by 50% over the first five years of operation.[45]

According to Bloomberg New Energy Finance,[46] "with blue Hydrogen, it is go big or go home. A typical project costs $500 million to build, and there is not much scope to go smaller because the technology only works at large scale. That's an awful lot of risk to bear on a single project."

Planned Projects: Green Outnumber Blue

A number of blue and green hydrogen projects are being planned in the coming years.

According to the Hydrogen Council's update in July 2021, 131 large-scale hydrogen projects around the globe were announced between February 2021 and its publication, taking the total to 359 projects. "The total investment into projects and along the whole value chain amounts to an estimated $500 billion through 2030. Of the total investment, $150 billion, or 30%, can be considered "mature"— meaning that the investment is either in a planning stage, has passed a final investment decision (FID), or is associated with a project that is already under construction, commissioned, or currently operational. With these total investments, hydrogen production capacity will exceed 10 million tons p.a. by 2030. Seventy percent of the

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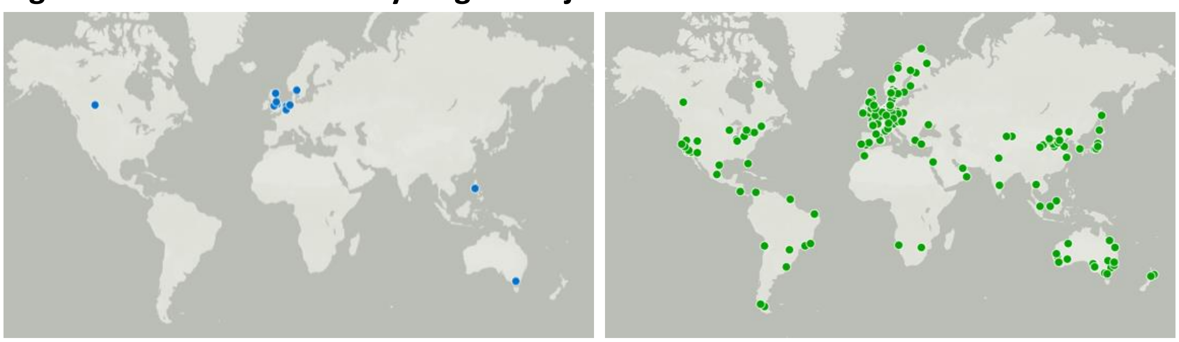
[42] Energy Science and Engineering. How Green is Blue Hydrogen? 12 August 2021.
[43] Institute for Energy Economics and Financial Analysis (IEEFA). Blue Hydrogen. Technology Challenges, Weak Commercial Prospects, and Not Green. February 2022.
[44] Global Witness. Hydrogen's Hidden Emissions. 20 January 2022.
[45] Institute for Energy Economics and Financial Analysis (IEEFA). Gorgon Carbon Capture and Storage-The Sting in the Tail. 26 April 2022.
[46] BloombergNEF. What is Blue Hydrogen? It Could be a White Elephant on Your Balance Sheet. 16 December 2021.

production capacity will come from renewable energy sources, while the other 30% is low-carbon hydrogen generated by fossil fuels and carbon capture and storage (CCS)," the council noted in its update.[47]

According to the IEA's hydrogen projects database,[48] last updated in October 2021, there are 29 blue hydrogen projects at feasibility stage, with only one at final investment decision (FID) and one under construction. This compares with 161 green hydrogen projects (using dedicated renewables) at feasibility stage, 11 at FID and two under construction – i.e., almost six times more green hydrogen projects.

The Hydrogen Map records and plots a regularly updated compendium of global low-carbon hydrogen projects and their status.[49] As can be seen in the following maps, proposed green hydrogen projects greatly outnumber blue hydrogen projects.

Figure 7: Blue and Green Hydrogen Projects



Source: The Hydrogen Map.

In 2021, 26 green hydrogen projects were expected to start construction, while only one blue hydrogen project was expected to start. In 2022, 27 green hydrogen projects are expected to start construction; no blue hydrogen projects were expected.

The EU, through the European Clean Hydrogen Alliance, has planned a variety of projects covering hydrogen production and its use in industries such as chemicals, refining, steel, or transport, particularly heavy-duty road transport and maritime transport.[50] The projects are located across Europe, with many set to enter into operation by the end of 2025.

Life cycle emissions from low-carbon hydrogen production are coming under scrutiny as policymakers set out long-term decarbonization pathways.[51] As

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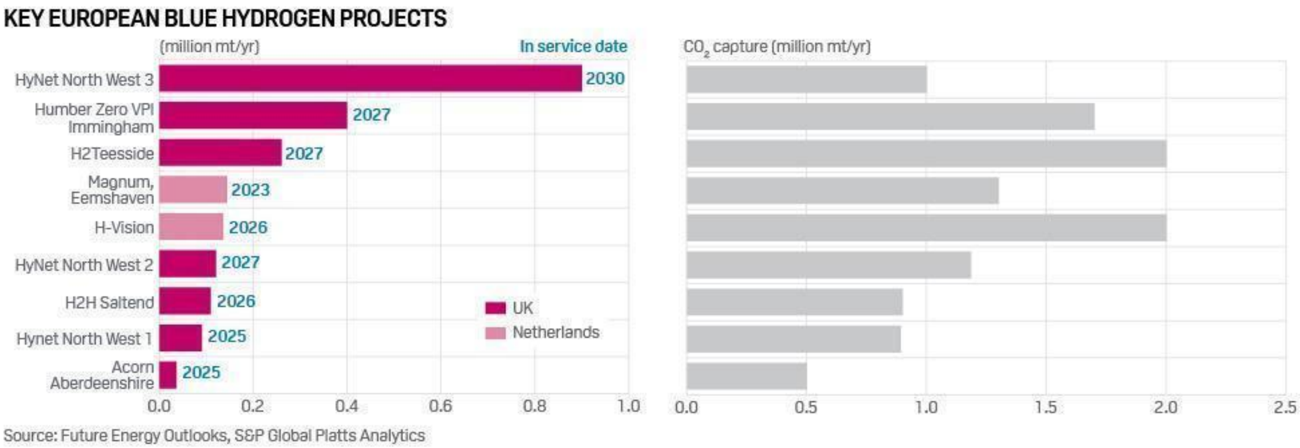
[47] Hydrogen Council. Hydrogen Investment Pipeline Grows to $500 Billion in Response to Government Commitments to Deep Decarbonisation. 15 July 2021.
[48] International Energy Agency. Hydrogen Projects Database. Last updated October 2021.
[49] Pillsbury Law. Hydrogen Energy Map Tracker. Last accessed 4 May 2022.
[50] European Commission. Project Pipeline of the European Clean Hydrogen Alliance. Last accessed 4 May 2022.
[51] S&P Global. Blue Hydrogen Lifespan Raises Questions Over Carbon Offsets. 8 October 2021.

explained by BNEF,[52] the typical lifetime of blue hydrogen facilities would be at least 30 years (UK BEIS assumes a 40-year lifetime in its costs analysis). Many facilities proposed in the EU would be commissioned in the second half of the 2020s, raising questions over the need for significant carbon offsetting after 2050.

But some European nations are still planning to invest in blue hydrogen projects,[53] as shown in Figure 8 below.

Figure 8: Key European Blue Hydrogen Projects



Green hydrogen projects are also ramping up in Europe:

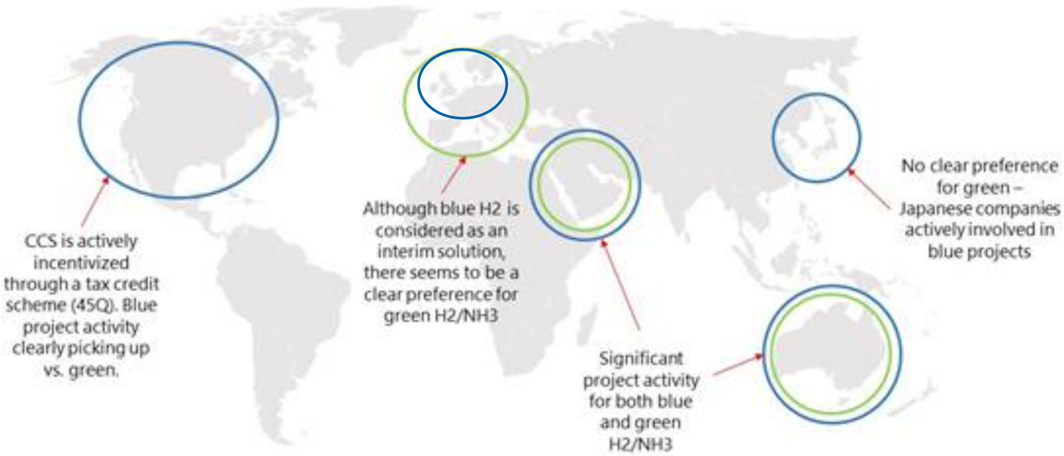
- In Leuna,[54] Germany, a joint venture between Linde and ITM Power plans the world's largest electrolyser plant based on proton-exchange membranes.

- The Hydrogen Stream is Europe's largest green hydrogen project.[55] HyDeal Spain will be the first industrial implementation of the HyDeal Ambition platform announced in 2021, supplying renewable hydrogen for the production of green steel, green ammonia, and green fertilizers.

There are signs of a market split between countries that are clearly incentivising blue hydrogen production,[56] and also actively investing in projects, and other locations in which regulators and consumers are taking a more cautious approach.

[52] BNEF. Blue Hydrogen Could Become the White Elephant of Your Balance Sheet. 15 December 2021.
[53] S&P Global. Norway's Equinor Sees Role for Blue Hydrogen Beyond 2050 in Net-Zero CO2 World. 12 June 2021
[54] Chemical & Engineering News. Green Hydrogen Ramp Up in Europe. 21 January 2021.
[55] PV Magazine. The Hydrogen Stream. Europe's Largest Green Hydrogen Project Takes Shape. 18 February 2022.
[56] Argus Media. CCS and Blue Hydrogen - How Are Regulators and Markets Positioning Themselves? 6 December 2021.

Figure 9: Market Divides for Blue and Green Hydrogen



Source: Argus Media, IEEFA edit.

Subsidies

The European Climate Law cements Europe's goal to become climate-neutral by 2050,[57] in line with the objectives of the Paris agreement. G7 leaders pledged to phase out new direct investment support for international carbon-intensive fossil fuel energy as soon as possible, and reaffirmed existing commitments to eliminating inefficient fossil fuel subsidies.

In December 2021, the European Commission released its "Hydrogen and Gas Market Decarbonisation package" ("gas package").[58] The package aims to facilitate the integration of renewable and low-carbon gases, including hydrogen into the existing gas network.

The European Commission has approved a €900 million German scheme to support investments in the production of renewable hydrogen in non-EU countries, which will be then imported and sold in the EU. The scheme, called "H2Global,"[59] aims to meet the EU demand for renewable hydrogen that is expected to significantly increase in the coming years by supporting the development of the unexploited renewable resource potential outside the EU.

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[57] European Commission. Annex to the Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - 2021 report on the State of the Energy Union - Contribution to the European Green Deal and the Union's recovery. 26 October 2021.
[58] European Commission. Hydrogen and Decarbonisation Gas Market Package. Last accessed 4 May 2022.
[59] European Commission. State Aid: Commission Approves €900 Million German Scheme to Support Investment in Production of Renewable Hydrogen. 20 December 2021.

The UK says it will finalise a plan to subsidise the production of low-carbon hydrogen by the end of this year,[60] with the first support contracts for projects scheduled in 2023. The government's Contracts for Difference (CfD) plan — being billed as a "variable premium price support model" — would offer a subsidy representing "the difference between a 'strike price' reflecting the cost of producing hydrogen and a 'reference price' reflecting the market value of hydrogen."

There's broad interest from governments in subsidising green hydrogen[61] to help reduce production costs more quickly, in a similar way to historical subsidies for wind and solar energy. Government support will accelerate the ramp up of green hydrogen production.

There's a risk in subsidising all types of hydrogen.[62] Based on published estimates and IEEFA analysis, blue hydrogen projects could become stranded this decade. From a decarbonisation perspective, blue hydrogen may reduce emissions at the point of capture, but methane and CO_2 emissions that escape capture may well undermine these saved emissions.

Gas Price, Security of Supply and Energy Transition

Europe is facing difficulties trying to balance between three priorities: Reducing the gas price, offering a secured supply of energy and continuing with energy transition objectives. **The only clear way to achieve all of this at once is by reducing gas demand**.

Reducing gas demand will also help reduce European dependency on Russian gas. According to BNEF,[63] just replacing current hydrogen demand with green hydrogen in industries like oil refining and fertilizer production **could reduce the European Union's gas demand by 12%**.

It is important to understand that **blue hydrogen production is an extension of the natural gas value chain**, affected by the same uncertainties of the gas industry. As a consequence, Europe will need to import more gas for blue hydrogen. This will increase prices, increase energy security risks and cause more greenhouse gas emissions.

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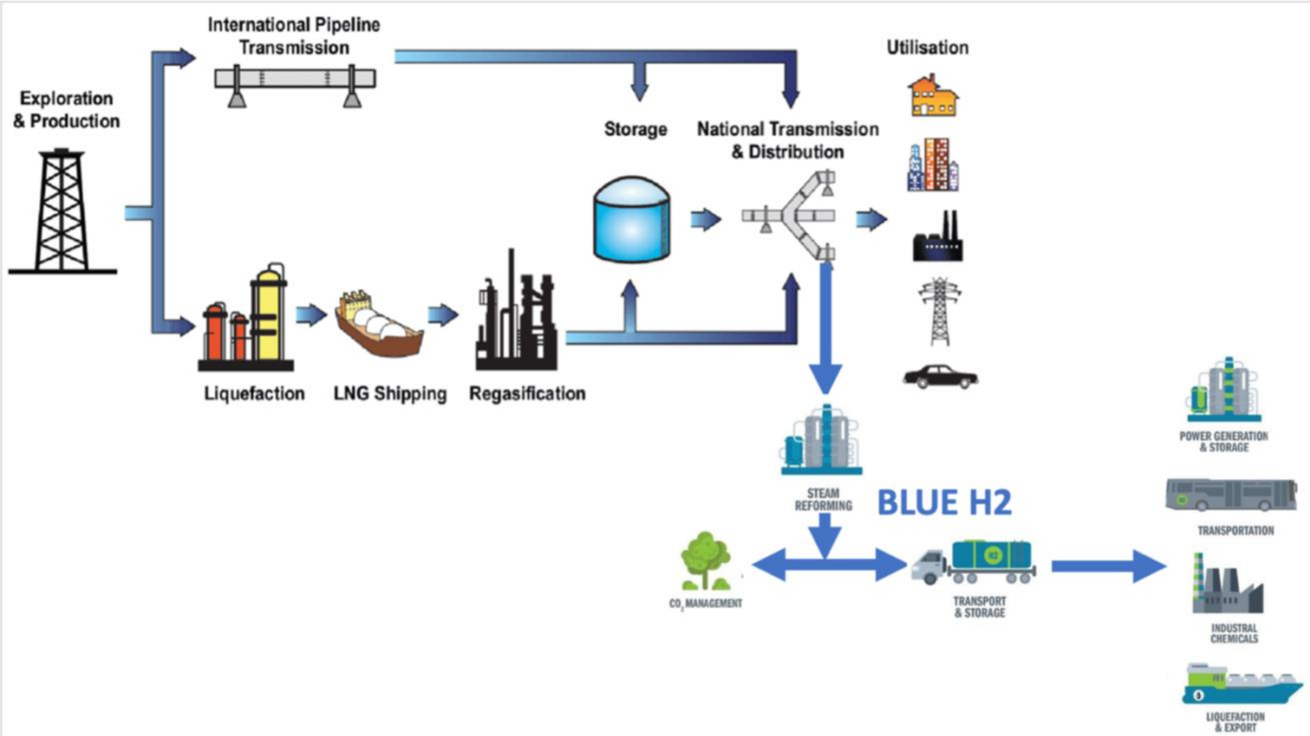
[60] REcharge News. UK to Finalise World's National Subsidy for Clean Hydrogen Production By End of Year. 11 April 2022.
[61] REcharge News. How to Make Expensive Green Hydrogen Commercially Viable Today - Without Subsidies. 11 January 2022.
[62] International Institute for Sustainable Development. Should Governments Subsidize Hydrogen? 19 January 2021.
[63] BloombergNEF. Russia's Invasion Supercharges Push to Make a New Green Fuel. 10 April 2022.

Figure 10: Natural Gas and Hydrogen Value Chain



Source: Researchgate. Blue and Green Hydrogen Production.

Conclusion

Looking to the future, the EU and UK urgently need to reduce their gas dependency. This can only be done by redefining energy security as being based on a diversity of energy sources, not as a diversity of gas supply routes and infrastructure.

Hydrogen is expected to play an important role in this transition, whether for sectors that are hard to electrify, or to address seasonal energy storages. If blue hydrogen projects are supported by governments and come into operation, there will be a need to increase gas imports significantly, probably at high prices, which will only lead to higher energy costs for the wider population.

The gas market is global and very volatile. Prices can easily fluctuate due to geopolitical issues, weather disruptions, variations in supply and/or demand, etc. Blue hydrogen project economics are tied to this volatility. Expected production costs published only a year ago are significantly higher today, raising questions about continued policy support for the technology.

Unlike gas, renewables can be more regionally or locally located and are free from annual fuel cost dependency. Green hydrogen projects can capitalise on this advantage and offer an alternative route to hydrogen production that generates near-zero emissions, at a cost that is expected to become cheaper than blue no later than 2030. Although we would like to note that where possible, renewables should be used directly instead of for producing green hydrogen.

Europe needs to plan for a robust and resilient energy market that will be able to cope with any crisis. This can be achieved by having a diverse energy mix, reducing gas dependency, and increasing energy efficiency and renewable power generation. By doing this, our energy system will be reliable and able to offer a real security of supply.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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