GREEN VS. BLUE HYDROGEN

A perspective on scaling low-carbon hydrogen production

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Producing low-carbon hydrogen at competitive costs is one of the key factors in getting to net-zero emissions. Not only could it be used as a replacement for fossil fuels in hard-to-decarbonize industries such as steel production, but it may also eventually be used as fuel for space heating, large trucks, or even to create synthetic fuels for aviation.

However, today the most common form of hydrogen produced is gray hydrogen — with some 90 million metric tons[1] created for the production of commodities such as ammonia, generating around one billion metric tons of carbon dioxide (CO2), or about 2% of global CO2 equivalent emissions.

While industries and governments are exploring lower-carbon solutions such as blue and green hydrogen as long-term tools that can improve security of energy supply and reduce reliance on Russian gas, there is considerable debate as to the most cost effective and environmentally attractive production route. For example, should low-carbon hydrogen be made using electricity, generated by renewable energy, producing so-called green hydrogen? Or, should it be made from natural gas, relying on carbon capture and storage (CCS) technology to capture the carbon, producing blue hydrogen?

Blue hydrogen is not zero carbon, because not all carbon is captured and any methane leakages during gas production can be sizable contributors to global warming. Therefore, from a sustainability perspective, one might reckon that green hydrogen has to be more environmentally advantageous than blue — and in an ideal world, that would be the case. But this paper will show that in certain circumstances green hydrogen emissions can be twice those of gray hydrogen. Thus, if the goal is decarbonization, industries and governments need to be thoughtful as to when and where green hydrogen projects are deployed, if they are to successfully lower emissions and increase security of supply.

Green hydrogen is the clear environmental choice in instances when it is produced using excess renewable energy that cannot be accommodated on the grid or from a renewable project that is not able to connect to the grid. However, at the other end of the spectrum, if renewable electricity is diverted from the grid to produce green hydrogen and this electricity is then replaced with fossil fuel-generated electricity, then this is clearly not green electricity.

In this analysis, we will assess the hydrogen alternatives and their implications for policy and industry. We'll start with the cost and full-system carbon footprint of green hydrogen today under different circumstances and follow with a discussion of how these impacts might change through time.

1 Source: IEA, Global Hydrogen review 2021

GREEN HYDROGEN
THE FULL-SYSTEM CARBON FOOTPRINT AND ECONOMICS

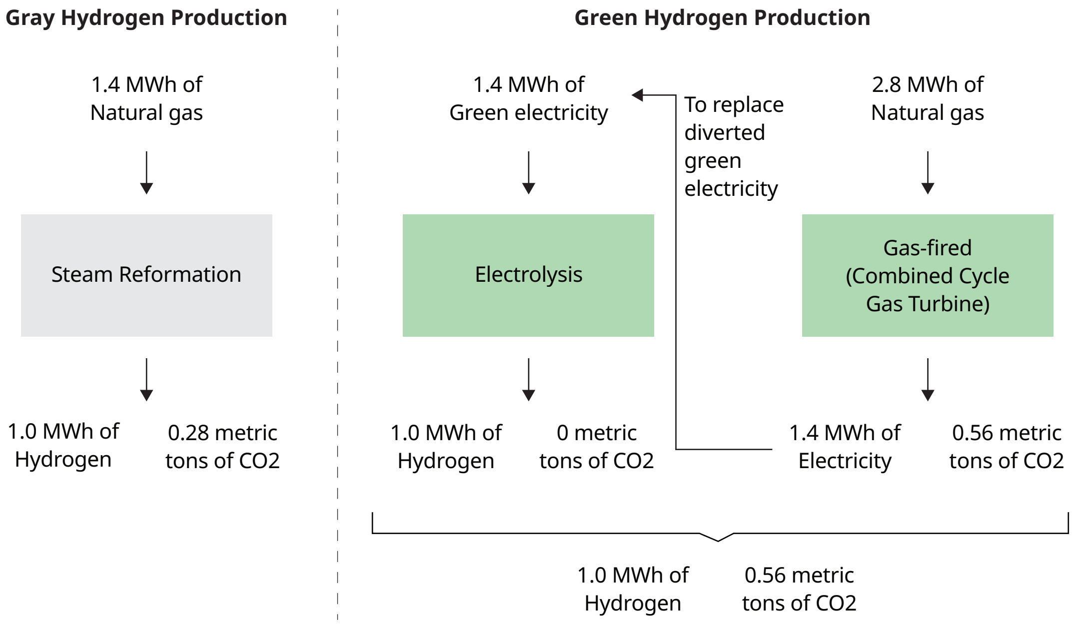
Green hydrogen is produced by electrolyzing water using low-carbon electricity generated by renewables or, more controversially, nuclear energy. Besides producing molecules of hydrogen, the principal byproduct in the making of green hydrogen is oxygen. While today green hydrogen is expensive to produce, the falling cost of renewable energy and improved electrolyzers are expected over time to make it cost-competitive with other fuels. For those reasons, long term, it is the most environmentally friendly approach to producing low-carbon hydrogen.

But that's not necessarily the case over the medium term. As previously mentioned, if green electricity is diverted from the grid for hydrogen production, then this has its own environmental implications. In cases where baseload electricity is taken from the electricity grid and used to produce hydrogen, this electricity will need to be replaced by incremental power generation. Given that existing renewables are already running at full power, the incremental power typically needs to be produced from either natural gas-powered generation or — in many markets including advanced economies like Germany and China — coal, the most carbon-intensive of all the fossil fuels.

Exhibit 1 examines the relative environmental impacts of gray hydrogen and green hydrogen, for the case where the electricity is diverted from the grid and needs replacing with natural gas-fired power generation. Only 1.4 megawatt-hours (MWh) of gas is required to produce 1 MWh of gray hydrogen, with an associated 0.28 metric ton of CO2 emissions. To produce the same amount of green hydrogen, 2.8 MWh of natural gas is burned in a gas-fired power plant (combined cycle gas turbine) to generate the electricity to replace the diverted green electricity, with a consequent overall 100% increase in carbon emissions to 0.56 metric ton. If the electricity is generated from coal, then the total emissions would be over 1 metric ton.

On a full-power-system basis, both paths start with gas. However, by going through two process steps, the green hydrogen is inherently less efficient, with typical conversion losses for a gas-fired power stations of 50% followed by a further 30% loss at the electrolyzer, giving a cumulative 65% loss, whereas steam reformation losses are of the order of 30%.

Exhibit 1: Schematic — why green hydrogen can be more carbon intensive than gray

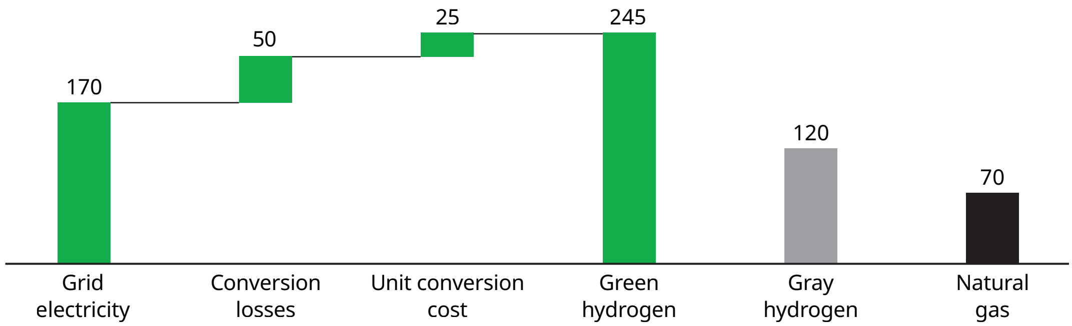


Source: Oliver Wyman Analysis

Green hydrogen appears to be economically inefficient, since its production requires electricity, a high-value product, to make a generally lower-value product, hydrogen. For example, markets currently indicate prices of around $170 per MWh for electricity and $70 per MWh for natural gas in Europe in 2025. Once the cost of the electrolyzer conversion is factored in, converting grid electricity to green hydrogen results in a hydrogen cost of around $245 per MWh (Exhibit 2), compared to gray hydrogen at around $120 per MWh. Using green hydrogen at $245 per MWh to replace natural gas (at $70 per MWh) is even less efficient. This is also the case when looking at prices that prevailed before the current energy crisis.

A standalone green hydrogen plant taking electricity from an offshore wind farm can produce green hydrogen for a total cost of around $130 per MWh, considerably cheaper than green hydrogen from the grid. However, this effectively relies on the windfarm selling the electricity to the electrolyzer at around $60 per MWh, which is not a logical choice when the alternative is to sell the electricity to the grid at $170 per MWh.

Exhibit 2: Green hydrogen — projected production costs vs. gray hydrogen and natural gas in 2025 [$ per MWh]



Source: Hydrogen Council, BEIS, Oliver Wyman Analysis

If hydrogen is produced from excess green electricity that has no other use, or from a standalone renewable project that cannot be connected to the local grid because of transmission constraints, then this is clearly a green product. In many markets today, however, increasing electricity demand to produce green hydrogen will result in an overall increase in gas demand or coal demand and carbon emissions, as a gas-fired or coal-fired generation plant is required to supply the increased electricity demand.

With strong renewable growth predicted across the world, periods of excess low-carbon electricity will increase. The United Kingdom's department for Business, Energy, and Industrial Strategy (BEIS) estimates that in a market with excess electricity for 25% of the year, truly green hydrogen can be produced for a cost of $80 per MWh by only running the electrolyzer during periods of excess electricity when electricity prices will be close to zero. However while the supply of renewable energy is growing, so too is the demand for it. A number of other market developments are likely to limit the growth of periods of excess low-carbon electricity:

Increase in demand for power. The growth in the number of electric vehicles (EVs) and heat pumps will increase overall demand.

Changing customer demand patterns. Energy suppliers are starting to encourage demand to shift to periods of high renewables production through lower electricity rates during these periods. This is an attractive prospect in particular for EV customers.

Increased interconnection between national power grids. This interconnection is creating diversification of the renewable supply, reducing the likelihood that any one particular market will have excess electricity. Connecting the United Kingdom market with Norway, for instance, makes it possible for the United Kingdom to effectively use Norway's large hydro capacity as long-term storage, importing power when the wind is not blowing and exporting excess renewables during high wind allowing Norway to conserve hydro resources for the future.

More battery storage. The growth in lithium-ion batteries offers a far more economical solution for any renewable oversupply than green hydrogen production for short-periods of oversupply, with only about a 15% efficiency loss and a lower capital cost per megawatt than an electrolyzer. With battery costs falling rapidly, their deployment is expected to scale rapidly, allowing their economic use case to extend into longer periods of oversupply.

Battery research and development. Alternative battery technology is receiving significant research and development investment, encouraging the development of longer-duration batteries, such as flow batteries, and creating competition with green hydrogen for excess renewable electricity.

Taken together, these trends suggest that the potential of truly green hydrogen over the next two decades may be lower than believed. Given these challenges, we need to look more seriously at blue hydrogen to fill the gap in the meantime.

BLUE HYDROGEN
THE FULL-SYSTEM CARBON FOOTPRINT AND ECONOMICS

Blue hydrogen is produced by reformation of natural gas. This is accomplished by heating natural gas to high temperatures using steam methane reformation or auto thermal reformation to convert it into hydrogen and carbon dioxide. The concentrated CO2 is then captured and stored. Typically, the heat to drive the process is also produced using natural gas, creating a secondary, more dilute CO2 stream. A capture efficiency for both streams of about 90% is achievable.

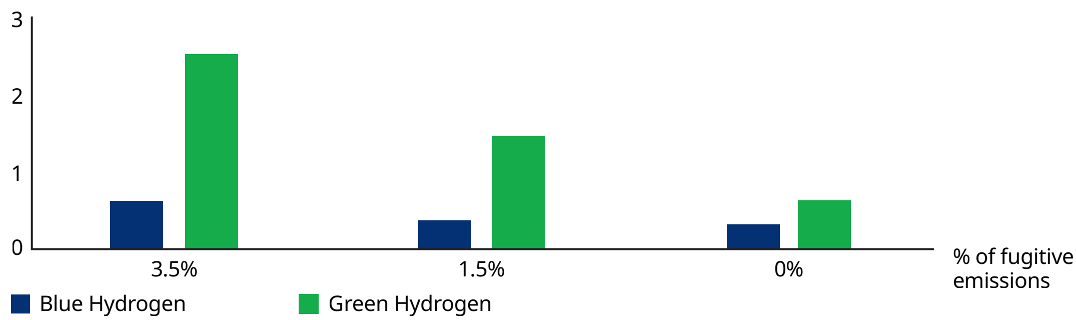
Blue hydrogen today is expected to have a lower cost to produce than green hydrogen. The key concern many have with blue hydrogen is the reliance on fossil fuel production and the consequent environmental risks through methane emissions associated with the gas production and the less than 100% capture of the CO2.

Methane has a much higher greenhouse gas impact than CO2 — about 86 times more when measured over a 20-year period. That means only small levels of leakage of the natural gas (methane) used to produce the blue hydrogen can increase the carbon footprint significantly. In a 2021 paper, professors Robert Howarth of Cornell and Mark Jacobson of Stanford[2] estimated the level of fugitive emissions at 3.4% (based on measurements in the United States) and calculated that at this level of emissions blue hydrogen has a similar carbon footprint as gray. They concluded that the world should focus on green hydrogen. However, by applying the whole-system concept we developed in the previous section to green hydrogen, it is clear that green hydrogen is often effectively being generated from gas-fired power, so fugitive emissions can be as much a challenge for green hydrogen as they are for blue.

2 How Green Is Blue Hydrogen, Howarth and Jacobson July 2021

Exhibit 3 shows the relative greenhouse gas emissions levels of green vs. blue hydrogen at differing fugitive emission level assumptions. The 3.4% appears a rather high estimate as to the long-term level of fugitive emissions from gas production. For example, the Oil and Gas Climate Initiative, a CEO-led council of 12 leading oil and gas producers that support the 2015 Paris Agreement targets, reported 0.2% of fugitive emissions in 2020[3]. As demonstrated in Exhibit 3, the carbon footprints of both green and blue hydrogen are highly sensitive to these assumptions. However, in all cases, blue hydrogen's footprint is significantly smaller than green hydrogen, where that green hydrogen is produced from baseload power taken from the grid.

Exhibit 3: Blue vs. green hydrogen — greenhouse gas emissions with differing fugitive methane assumptions [metric tons CO2 per MWh]



Notes: Blue hydrogen as per Howarth and Jacabson, Green hydrogen assuming gas-fired generation required to replace diverted renewable generation

Source: Oliver Wyman Analysis

This analysis reinforces the importance of tight control of fugitive emissions for gas, whether this is for production of gray hydrogen, blue hydrogen, or for use in power generation. However, it should not be used as an argument against blue hydrogen.

THE KEY CHALLENGE FOR BLUE HYDROGEN — PUBLIC ACCEPTANCE

While commercial-scale carbon capture plants have been envisaged for more than 15 years, few currently exist outside the oil and gas industry. Today there is some 40 million metric tons of worldwide carbon capture and storage capacity per year. That represents about 0.1% of worldwide carbon emissions, of which 80% is to support enhanced oil recovery rather than primarily for carbon abatement[4]. This is despite the fact that all of the key technology elements are in place, and cost estimates for this kind of carbon abatement are similar to other well-supported low-carbon technologies (for example, the support for offshore wind in the North Sea 10 years ago).

3 OGCI performance data 2019

4 Global Status of CCS 2021, CCS Institute

Blue hydrogen and carbon capture have faced considerable political challenges, with some arguing this is merely a smokescreen to enable the continued production of fossil fuels. As a consequence, governments have been slow to put in place the financial and legal support frameworks investors need to make substantial investments in blue hydrogen and the associated carbon capture and storage. Prices in existing carbon markets, such as Europe, have been insufficient to incentivize carbon capture and storage on their own.

Today support for blue hydrogen is growing, with a number of countries now planning blue hydrogen development projects, many situated close to the North Sea with access to natural gas and offshore storage locations — for example, the United Kingdom, Norway, and the Netherlands. However, many countries are also prioritizing strong green hydrogen. For example, the European Union's hydrogen strategy envisages strong growth in green hydrogen to deliver decarbonization and increase energy security.

SUMMARY AND IMPLICATIONS

The view that green hydrogen is lower carbon than blue hydrogen is an oversimplification. Longer term, once electricity is predominately produced from renewable electricity and there are significant periods of excess renewables with no market on the power grid, then this will be the case. But in the short and medium term, policymakers and hydrogen generators need to understand the nuances of when green hydrogen is truly green and to also not discount blue hydrogen prematurely before its economics and environmental performance have been fully tested.

Done incorrectly, large-scale deployment of green hydrogen production will result in increasing emissions and gas consumption vs. continuing to use gray hydrogen. This will cease to be the case only when there is significant excess renewable electricity produced that can be dedicated to the production of green hydrogen.

Renewable generation capacity is ramping up rapidly worldwide, yet there are limitations across the supply chain as to how quickly capacity can increase. Consequently, renewable power should initially be deployed where it delivers the most effective carbon abatement, for example decarbonizing existing grids, supplying additional power required for EVs and heat pumps, and supplying growing electricity demand in developing economies — before seeking to convert it to green hydrogen.

Given the challenges facing green hydrogen, the need to scale blue hydrogen cannot afford to be overlooked. Commercial-scale blue hydrogen development needs to be given financial backing and the opportunity to demonstrate whether it can economically and environmentally produce low-carbon hydrogen, while recognizing and aggressively addressing fugitive emissions.

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