Hydrogen decarbonization pathways

Introduction to the two reports: “Hydrogen Decarbonization Pathways: A Life-Cycle Assessment” and “Hydrogen Decarbonization Pathways: Potential Supply Scenarios”

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Hydrogen Council

Hydrogen momentum is accelerating further

In the studies “Hydrogen, Scaling Up” (2017) and “Path to Hydrogen Competitiveness: A Cost Perspective” (2020), the Hydrogen Council has laid out a cross-industry plan for a step-change in hydrogen deployment globally. They showed that hydrogen can play an important role in the decarbonized energy system, and that hydrogen can be a cost-competitive decarbonized solution in a large number of applications before 2030.

Since then, hydrogen has built unprecedented momentum. Large-scale projects have been announced, companies have undertaken strategic moves across the value chain, and there are increasing M&A and investment activities in the sector. In parallel, governments are committing to hydrogen as a part of their climate change strategies, with some deploying significant funds, policies, and regulatory support through newly launched hydrogen strategies and funding programs in the context of Covid-19 economic recovery packages.

Life-cycle emissions are coming into focus

Given that hydrogen is one of the keys to the energy transition, it is not only important to make it economically viable, but also to maximize the decarbonization impact and minimize its resource requirements. The European hydrogen strategy and the targets of many EU member states, among others, are geared to place most of their support on renewable hydrogen production. Countries such as China, Korea, Japan, as well as regions of the United States are increasingly introducing support for low-carbon hydrogen routes. Countries with abundant renewable and/or fossil and CCS potential are looking to optimize the value of these attributes in destination markets. In all cases, the decarbonization potential of hydrogen is critical. An evaluation of the carbon-saving potential of hydrogen over the life-cycle is therefore an important piece of the Hydrogen Council’s perspective.

Hydrogen supply pathways

In the study “Hydrogen Decarbonization Pathways – A Life-Cycle Assessment” different sustainability aspects have been assessed for hydrogen production and supply.

— As an energy source for hydrogen production, both **renewable power** for water electrolysis and **natural gas** with very high shares of CCS can achieve marginal to low greenhouse gas (GHG) emissions, respectively, when considered well to use, including end-of-life emissions. For fossil primary energies with CCS, a number of requirements must be met, namely sweet natural gas sources[1], highest capture rates[2], and best available technologies and operational practices.

— **Biogenic feedstock** for hydrogen production can result in a wide range of GHG emissions. While energy crops are between natural gas-based and renewable electricity-based pathways, GHG emissions from biogenic wastes can be as low as the best renewable power-to-hydrogen pathways (or even negative in case of bio + CCS) but with waste streams somewhat limited at global scale.

— In this study, **capex-related emissions** of energy production assets and a number of hydrogen applications have been calculated where data was available (generally weak) based on a global average electricity mix with a decreasing carbon intensity towards 2050.

1 Reserves providing a high-quality natural gas with low-carbon footprint for its production.

2 98% carbon capture assumed in this study.

    - Capex-related GHG emissions for the manufacturing of assets are low across the board for hydrogen supply options compared to the carbon intensity of incumbent fossil pathways, and have been calculated based on global average carbon intensities for energies used in plant and asset manufacturing. Some manufacturers already today excel with below-average emissions by using renewable and low-carbon energy sources.

    - GHG emissions of renewable power-to-hydrogen pathways are dominated by capex-related emissions, albeit at very low levels compared to fossil incumbents and alternatives.

- The impact of selected metal **recycling** on the GHG emissions balance well to use is somewhat limited. GHG reductions from recycling of selected metals is most pronounced with solar and wind power pathways, where recycling tends to yield GHG savings of about 30% for the manufacturing of photovoltaic plants and 40% for wind power plants in 2030 versus using virgin material). Recycling is of wider strategic relevance for deep decarbonization in the context of a circular economy.

- With a view to sustainability aspects other than GHG emissions, specific **gross water demand** has been assessed for hydrogen supply pathways.

    - Gross water demand is most pronounced in biomass cultivation and cooling of thermal power plants; hence, the focus should be on biogenic waste streams and dry-cooling systems in regions prone to water supply stress or already under supply risk.

    - Gross water demand for water electrolysis using PV and wind power is very low with 9 kg of water per kg of hydrogen; SMR/ATR are in the same order of magnitude. Plants at gigawatt-scale nevertheless can be a significant point-demand for water especially in arid regions. Site-specific water supply and demand assessments are regular tasks in environmental impact assessments prior to plant approvals. For large plants in dry regions, seawater desalination with adequate effluent management is an option. Water desalination for Power-to-X plants requires marginal additional energy.

Eight illustrative hydrogen value chains

The LCA analysis has not been limited to hydrogen supply routes alone, but addresses every aspect of the supply chain, from primary energy extraction to end use. For illustrative purposes, eight primary-energy-to-hydrogen value chains have been selected, and GHG emissions for 2030 and 2050 were calculated, including capex-related GHG emissions, where possible. Thereof, four pathways describe mobility and industry applications each. Half of the eight illustrative pathways comprise green value chains, and the other half represent blue hydrogen value chains. Across the hydrogen pathways and applications depicted, very high (around 90%+) to high (around 60%+) GHG emission reduction can be demonstrated using green (solar, wind) and blue (ATR + 98% CCS) hydrogen, respectively. Further GHG emission reductions observed from 2030 to 2050 are driven by a strongly improving global grid mix assumed for achieving Paris Agreement targets.

LCA results in context

In the LCA study, renewables + electrolysis shows strongest GHG reduction of the different hydrogen supply pathways assessed in this study, with a best-case blue hydrogen pathway also coming into the same order of magnitude. The blue options considered in this study show a noticeable but wide range of GHG reduction versus incumbent (grey) hydrogen production. Renewables + electrolysis and reforming + CCS pathways do come with different risks. Though they have not been analyzed in the study, we note that there are discussions related to long-term carbon storage and technology path dependencies, potentially impacting post-2050 emission-reduction trajectories, especially as energy infrastructure assets typically show investment cycles in the range of 30 to 40 years or even longer. Policymakers are thus encouraged to develop clear, long-term frameworks that enable and drive efficient investments to develop and deploy, in a quick and economically efficient manner, the most relevant deep-decarbonization options.

Hydrogen supply can and must be decarbonized

Currently, the vast majority of hydrogen is produced by fossil pathways. To take the role in the energy transition that the Hydrogen Council envisaged in its "Scaling Up" report, the existing use of hydrogen – and all its many potential new roles – need to be met by decarbonized sources. Based on the results of life-cycle emissions of various hydrogen production pathways, the Council therefore assessed what fully decarbonized hydrogen supply would entail.

The study "Hydrogen Decarbonization Pathways – Potential Supply Scenarios" lays out different supply scenarios that can achieve the ambitious ten-fold build-out of hydrogen supply by 2050 (outlined in the "Scaling Up" report) with decarbonized hydrogen sources – starting with an ambitious near-term phase-out of conventional "grey" hydrogen to already decarbonize more than half of the hydrogen supply by 2030.

We consider three hypothetical scenarios as thought experiments on ways to decarbonize the supply: a "green-only," renewables-based world, a "blue-only" world relying on carbon sequestration, and a combined scenario that uses a region-specific combination of green and blue hydrogen based on the expected regional cost development of each source.

The first finding is that a decarbonized hydrogen supply is possible regardless of the production pathway: while both the green and blue boundary scenario would be highly ambitious regarding the required speed of scale-up, they do not exceed the world's resources on either renewable energy or carbon sequestration capabilities. The renewable energy resources required to provide 78 EJ of green hydrogen would be equivalent to solar panels covering the area of Italy and wind turbines covering almost half of China's coastal waters – however, that is still less than 10% of the estimated accessible global renewables potential. In the "blue world", carbon sequestration capacities would need to be built out to 50 Gt by 2050 – a huge scale-up compared to today (and one that is not currently compatible with regulations in many regions), but less than 0.2% of estimated geological storage reserves. While both boundary scenarios would drastically reduce emissions compared to current "grey" hydrogen supply pathways, overall emissions would be even lower in the "green world" (approximately 10 Gt of CO_2 from 2020 to 2050, 8 Gt of which generated during the phase-out of grey hydrogen) than the "blue world" (20 to 25 Gt of CO_2 over the same time period)[3].

While both boundary scenarios are theoretically feasible, a combination of green and blue production pathways appears to result in the least-cost global supply over the entire period of scale-up. It does so by making best use of the near-term cost advantage of blue in some regions while simultaneously achieving a scale-up in electrolysis. This allows to achieve very low-cost green hydrogen in the

[3] The blue world assumes a region-specific natural gas and coal supply and a mix of SMR and ATR technologies with carbon capture rates between 90% and 98%. For comparison: Meeting the same hydrogen demand with grey hydrogen would generate approximately 65 Gt of emissions, compared to a remaining carbon budget of 235-985 Gt CO_2 until 2050 to stay within the 1.5°C-2°C global warming pathway.

medium and long term. A combined scenario also makes best use of complementary global resources: each region can follow a different build-out path and trade with other energy-rich regions, if advantageous. While the required build-out rates for electrolyzers and reformers (and hence the development of the required supply chains) still exceed 30% per year, this does not exceed the speed of build-out that has proven feasible in the solar and wind industry over the last decade. Cumulative CO_2 emissions from hydrogen would lie between the green- and blue-only boundary cases, making a major contribution to the decarbonization of the global energy system (but not fully maximizing the decarbonization promise of green hydrogen).

In reality, the decarbonized supply scenario will combine a range of different renewable and low-carbon hydrogen production pathways that are optimally suited to local conditions, political and societal preferences and regulations, as well as industrial and cost developments for different technologies. While a decarbonized hydrogen build-out is ambitious in any scenario, it is achievable both in the short and long term and is a prerequisite for growing hydrogen's role in the energy system.