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Controlling Emissions in a European Hydrogen Economy

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Controlling Emissions in a European Hydrogen Economy

Greenhouse gas (GHG) emissions from a future hydrogen economy could be substantial if not adequately managed.

by **Kathleen A. Mar** and
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Hydrogen – as an indirect GHG – could have a significant impact on warming if emissions are not controlled along the value chain. When also considering methane and CO_2 emissions from the production of blue hydrogen, the climate impact would be even more significant, requiring stringent measures to ensure their effective management in producing countries.

Key takeaways

- Hydrogen (H_2) emissions have a significant impact on climate warming and require regulatory interventions to contain them. Blue hydrogen also produces significant emissions of methane and CO_2, even under the assumption that it meets the standard for low-carbon hydrogen.
- According to current scientific literature, H_2 emissions primarily occur at the point of production, where they can be controlled by operational measures that eliminate intentional venting of H_2 emissions.
- The European Union should acknowledge the role of hydrogen as an indirect GHG by incorporating hydrogen emissions in the methodologies for calculating GHG savings from low-carbon hydrogen and renewable fuels of non-biological origin (RFNBOs).
- The EU should strengthen its regulatory framework to limit all climate-warming emissions from blue hydrogen production — both in the EU and abroad.
- Expanding the EU's Methane Regulation to include methane emissions from imported hydrogen and its derivatives offers an important first step towards a more robust regulatory framework.

Warming impacts of a future hydrogen economy

Increasingly, hydrogen is being seen as an important energy carrier that can help the world reach a net-zero future, based on the fact that its combustion does not produce CO_2. It has become an integral part of many countries' strategies to reach net zero. Germany has positioned itself as a major global frontrunner in this regard, aiming to utilize hydrogen to decarbonize hard-to-abate sectors like steel and chemicals in the country.

However, hydrogen (H_2) itself is an indirect GHG, and hydrogen emissions have the potential to lead to significant warming if not controlled. In a recent RIFS study [**1**], we evaluated the warming potential of H_2 emissions for a German hydrogen economy in 2045. To do this, we developed scenarios based on official targets and estimates for domestic hydrogen supply and use, as well as hydrogen imports [**2-3**]. Using a range of plausible emission rates — based on current knowledge in the field and assumptions regarding technology and policy development — we estimate the amount of potential H_2 emissions resulting along the domestic and international hydrogen value chain serving Germany's hydrogen economy in 2045. We assume that all domestic production of hydrogen in Germany will be green (i.e., using electrolysis powered by renewable energy) and consider cases with different shares of imported 'blue' hydrogen, i.e., production using Steam Methane Reforming (SMR) combined with Carbon Capture and Storage (CCS). Figure 1 illustrates the steps along the hydrogen value chain and their emissions that we considered in our study along with the relevant emissions sources.

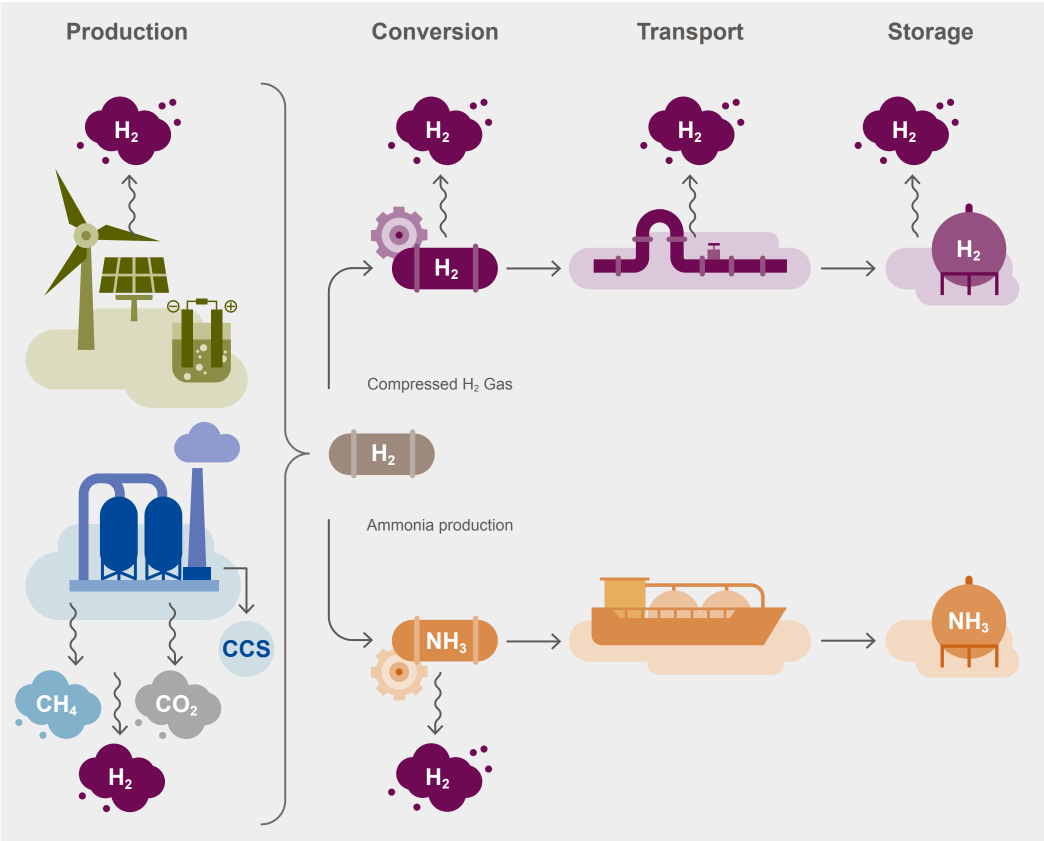


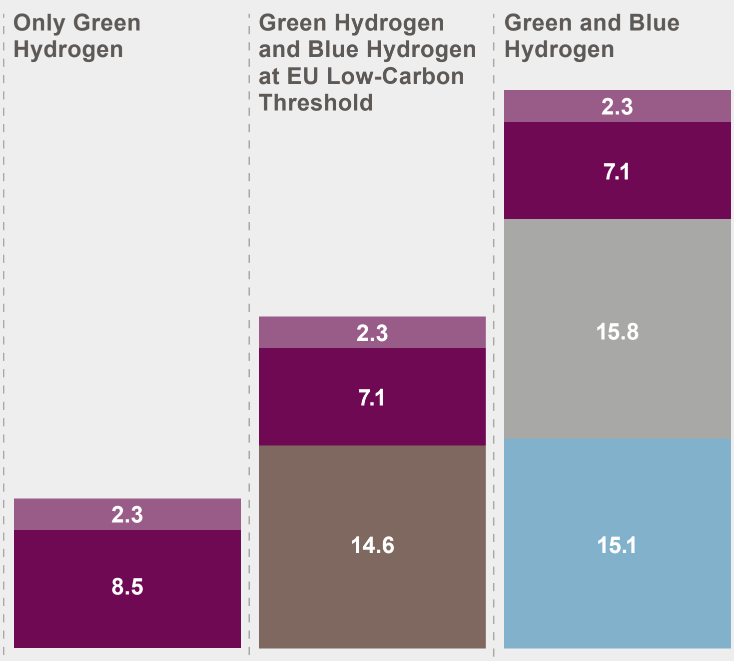
Figure 1. Schematic diagram showing steps along the hydrogen value chain and their emissions considered in RIFS study [**1**].

The warming impact of hydrogen (H_2) emissions cannot be ignored.

Hydrogen is an indirect greenhouse gas that is more than 11 times more potent than CO_2 over a 100-year timescale, with a GWP100 of 11.6 [**4**]. If uncontrolled, H_2 emissions along the value chain can have a potentially significant warming impact, reducing hydrogen's overall climate benefit. Assuming high demand for hydrogen and high emission rates, we calculate that H_2 emissions resulting from an all-green German hydrogen economy in 2045 amount to 10.8 Mt CO_2e in emissions (Figure 2). For comparison, this is equivalent to 17% of Germany's projected residual emissions in their 2045 net-zero scenarios.[1] Notably, H_2 emissions are not considered within Germany's residual emissions and are likewise neglected in nearly all forms of climate accounting worldwide (e.g. benefit calculations, Life Cycle Assessments).

Production is the most important source of H_2 emissions.

When considering scenarios with only green hydrogen, production is responsible for more than 75% of H_2 emissions along the value chain (Figure 2), based on calculations using emission rates from current scientific literature. Notably, these high production emissions are driven by current operational practices in which gases are intentionally released, due to venting from electrodes and during purification. These emissions can be reduced significantly by capturing the vented hydrogen and recombining it with oxygen to produce water. If these practices are applied, production emissions can be nearly eliminated (reduced from 8.5 Mt CO_2e to 0.2 Mt CO_2e in our scenarios [1]).



	Only Green Hydrogen	Green Hydrogen and Blue Hydrogen at EU Low-Carbon Threshold	Green and Blue Hydrogen
Total [Mt CO_2e]	10.8	22.7	40.2
is equivalent to			
of residual GHG emissions in Germany's net-zero scenario	17%	37%	64%
of Germany's total GHG emissions in 2023	1.6%	3.5%	6%

- H_2 emissions from H_2 production [Mt CO_2e]
- H_2 emissions from conversion, transport and storage [Mt CO_2e]
- Methane (CH_4) emissions [Mt CO_2e]
- Uncaptured CO_2 emissions from Steam Methane Reforming (SMR) [Mt CO_2e]
- GHG emissions from blue hydrogen based on EU standard for low-carbon hydrogen, includes CO_2 and CH_4 emissions from production [Mt CO_2e]

Figure 2. Overview of results from RIFS study [1]. Scenarios presented assume 188 TWh of production of domestic (German) green hydrogen and an additional 418 TWh of imported hydrogen. For the right two columns, it is assumed that 1/3 of Germany's hydrogen imports are of blue hydrogen. The EU low-carbon threshold (middle column) requires a maximum emissions intensity of 3.38 kg CO_2e per kg hydrogen produced.

I The 10.8 Mt CO_2 in emissions includes both domestic emissions and 'imported' emissions; only domestic emissions would need to be included on Germany's own net-zero balance sheet.

Including blue hydrogen in the mix significantly increases climate-warming emissions, even assuming that it would meet the EU standard for low-carbon hydrogen.

Methane and CO_2 emissions from blue hydrogen production increase the warming impact of using hydrogen significantly. In a scenario where blue hydrogen makes up one third of Germany's hydrogen imports, total emissions jump to 40.2 Mt CO_2e. More than 75% of these emissions are due to the CO_2 and CH_4 emissions from production of blue hydrogen (Figure 2, right column). This calculation assumes high emission rates of both CH_4 and CO_2, driven by upstream emissions from natural gas production as well as low CO_2 capture rates for CCS, consistent with current practices. We alternately assume that imported blue hydrogen would meet the EU definition for low-carbon hydrogen. While this reduces total emissions to 22.7 Mt CO_2e (Figure 2, middle column), the impact is still significant — and twice as large as when all demand is met by green hydrogen.

Recommendations for EU policy makers

Given the significant warming potential of hydrogen as an energy carrier — in particular when considering emissions from production of blue hydrogen — regulatory action will be needed to control these emissions in a future hydrogen economy.

Control hydrogen emissions along the value chain

The most effective way to minimize emissions related to the hydrogen value chain is the reduction of hydrogen use by prioritizing direct electrification of end-uses wherever possible. Aside from this, the most important lever for managing H_2 emissions along the value chain is at the point of production. The most immediate entry-point for regulating this is national pollution control legislation, such as the German Federal Immission Control Act (BImSchG). In this vein, EU Member States should define maximum emission rates for electrolysers and prescribe the implementation of best available techniques (BAT) for emission reduction. An important point of reference for this is the guidance for hydrogen production by electrolysis recently published by the UK government, which includes specific provisions for the minimization of H_2 emissions [**5**]. National legislation should provide the basis for subsequent strengthening of the EU Industrial Emissions Directive. To underpin effective implementation, the EU should also mandate comprehensive monitoring of H_2 emissions by the European Environmental Agency.

A second major avenue for controlling hydrogen emissions is the methodologies for calculating GHG savings from low-carbon hydrogen (see Directive (EU) 2024/1788) and so-called renewable fuels of non-biological hydrogen (RFNBOs), which includes green hydrogen and its derivatives. To be recognized as low-carbon or an RFNBO, emissions cannot exceed 3.38 kg CO_2e per kg of hydrogen. However, neither the methodology for RFNBOs nor the draft methodology for low-carbon hydrogen (published on 27 September 2024) consider H_2 emissions. This gap should be closed by revising the draft low-carbon methodology and by updating the RFNBO methodology. Indeed, the Hydrogen and Decarbonized Gas Market Package (Directive (EU) 2024/1788) already alludes to the role of H_2 emissions when referring to the development of the methodology.

Key recommendations

- Define maximum emission rates for electrolysers and prescribe the implementation of BAT for emission reduction in national pollution control legislation and update the EU Industrial Emissions Directive accordingly
- Mandate the European Environment Agency to comprehensively monitor H_2 emissions along the value chain
- Include hydrogen emissions in the methodologies for calculating GHG savings from low-carbon hydrogen and RFNBOs

Ensure strict standards for controlling GHG emissions from blue hydrogen — for domestic production and imports into Europe

The potential impact of GHG emissions from blue hydrogen production significantly exceeds that of H_2 emissions and requires strict standards to contain them. The GHG emissions saving threshold of 70% for low-carbon hydrogen provides an important starting point for this. To be effective, it is essential to develop and maintain high levels of transparency and ensure robust certification schemes to verify compliance both in the EU and in countries exporting to the EU. Moreover, over time, this threshold value should be increased to ensure the lowest possible level of GHG emissions. Such an increase should be considered in the next review of Directive (EU) 2024/1788, to be conducted by December 31, 2030. The EU Methane Regulation (Directive (EU) 2024/1787) offers a further entry point for controlling GHG emissions from blue hydrogen. Currently, this applies only to imported gas, oil and coal but not hydrogen or its derivatives. Adding hydrogen and its derivatives (e.g., ammonia, methanol) to the list of regulated goods would help minimize methane emissions for all fossil-based hydrogen entering the EU, whether in compliance with the standard for low-carbon hydrogen or not. The planned review of the Methane Regulation in 2028 offers a suitable opportunity for implementing this amendment.

Key recommendations

- Ensure high levels of transparency and robust certification schemes to verify compliance with the GHG savings threshold for low-carbon hydrogen
- Increase the stringency of the GHG savings threshold over time
- Include hydrogen and its derivatives in the list of regulated imported goods in the next review of the EU Methane Regulation

Promote greater recognition of hydrogen as an indirect GHG

Internationally, the EU should promote increased awareness of hydrogen as an indirect GHG and support updating its GWP100 in the next IPCC report to reflect the latest science. The latter would establish a clear point of reference that researchers and policy-makers could draw on to quantify the climate impact of H_2 in future research and regulatory standards. Indeed, in its draft methodology for the calculation of GHG savings for low-carbon hydrogen, the European Commission cites the lack of a precise scientific basis as justification for omitting H_2 emissions from the proposed approach, despite the availability of several recent, high-quality scientific publications on the GWP for H_2 [**4, 6–7**]. Here, inclusion of an updated GWP for H_2 within the IPCC would provide recognition and credibility.

Key recommendations

- Launch a targeted communication effort to raise awareness of hydrogen's role as an indirect GHG, without discrediting its important contribution to decarbonizing hard-to-abate sectors
- Support an update of the GWP100 for hydrogen in the next IPCC Assessment to reflect the latest science

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