INTERNATIONAL PARTNERSHIP FOR
HYDROGEN AND FUEL CELLS IN THE ECONOMY

IPHE Position Paper
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Impact of Atmospheric Hydrogen on Climate Change

Hydrogen (H_2) has an important role to play in the transition to a clean energy economy, particularly in reducing greenhouse gas (GHG) emissions, in achieving global climate objectives and the transition to a net zero economy, as well as supporting energy security and resilience and providing economic benefits.

However, when present in the atmosphere, hydrogen reacts with other gases and prolongs the lifetime of GHGs like methane (CH_4). Therefore, additional anthropogenic releases of hydrogen into the atmosphere can have indirect global warming impacts.

In order to maximize hydrogen's positive potential, it is crucial to manage H_2 emissions, which can dampen the climate change mitigation potential of using clean hydrogen in its main applications.

By learning historical lessons from methane (CH4) emissions and being proactive and transparent in addressing the issue early, the benefits of hydrogen can be maximized while minimizing the economic and environmental drawbacks associated with emissions. This position paper examines the topic and discusses potential measures to minimize climate impacts.

Measures to be taken to maximize the Climate Benefits

As mentioned at COP 28, transitioning away from fossil fuels in general and reducing hydrogen emissions along the whole value chain are key priorities to maximize the climate benefits of H2. Appropriate management is therefore essential.

By adopting proactive measures, the global community can maximize the benefits of hydrogen while minimizing the economic and environmental drawbacks associated with emissions. The International Partnership for Hydrogen and fuel cells in the Economy (IPHE) therefore recommends a holistic and collaborative approach to tackling the challenge of H_2 emissions, involving industry, governments, academia and broader society to ensure a sustainable and climate-friendly energy transition based on:

1. **Reduce current major sources of H2 in the atmosphere—**in particular, reduce emissions of methane (CH_4)from all sources, Methane is not only a potent GHG in itself, but is also the single largest source of hydrogen in the atmosphere**;**
2. **Improve performance of containment technologies**: Develop and implement more efficient H_2 production, storage and transport technologies to work towards eliminating releases (such as boil-off, venting and purging) and unintentional emissions (such as leakage);
3. **Develop and improve monitoring, measurement, and detection techniques and guidance**: Establish standard hydrogen loss detection and monitoring systems to identify and quantify sources of releases to promote equipment design improvements to minimize losses;

4. **Increase training and awareness**: Educate industry and workers on the importance of H_2 detection and emission mitigation strategies and incentivize the use of best practices that mitigate hydrogen losses at commercial deployments;
5. **Promote energy efficiency**: Encourage energy efficiency at all stages of the H_2 supply chain to minimize losses;
6. **Increase understanding of hydrogen mechanisms**: Support research for improved atmospheric and soil models based on a reliable H_2 observational network, including more robust measurements of H_2 key climate metrics;
7. **Develop and promulgate standards and regulations**: Develop and implement standards and regulations for the management and reduction of H_2 emissions, while promoting transparency and accountability

About IPHE

The IPHE is a government-to-government working level partnership to advance hydrogen and fuel cell technologies across applications and sectors. Today, IPHE is composed of 24 partners from all the continents. This publication was developed under the framework of IPHE but does not necessarily reflect the views of individual IPHE member countries. The IPHE makes no representation or warranty, express or implied, with respect to the publication's contents (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the publication.

Rationale

Scientific knowledge regarding the understanding and quantification of atmospheric hydrogen sources and sinks is continually advancing, but significant uncertainties still persist. The following points provide an overview of current knowledge. A working group within the IPHE is actively engaged in addressing this important topic and will release more information as it becomes available.

The importance of hydrogen in addressing climate change

Hydrogen is an important energy carrier, feedstock, and chemical reactant that can be produced from renewable resources, such as solar, wind or hydro power, as well as nuclear power, or fossil fuels along with Carbon Capture and Sequestration (CCS). It offers the promise of significantly reducing GHGs by replacing fossil fuels in a variety of sectors, including transport, industry, and power generation and thus limiting global warming, and enabling climate neutrality to help meet the climate goals of the Paris Agreement.

Where is the hydrogen present in the atmosphere coming from?

The presence of molecular H_2 in the atmosphere is not new with recent estimates of ≈530 parts per billion (ppb; nmol H_2 mol^{-1} air), and an atmospheric lifetime of about 2 years[1]. While there is considerable uncertainty regarding the quantity and sources of anthropogenic hydrogen in the atmosphere, recent measurements indicate that atmospheric H_2 has increased over the 20th century in the high southern latitudes. The increase in atmospheric H_2 is primarily attributed to increasing anthropogenic emissions and increasing atmospheric concentrations of CH_4 over the last century[1].
The H_2 budget, including both natural and anthropogenic terms consists of sources (emission and production in the atmosphere) of 70-80 Tg/year (1 Tg = 1 Million Metric tonnes) and a comparable sink[2,3]. The largest source of atmospheric H_2 is the photolysis of formaldehyde, formed by the atmospheric oxidation of CH_4 and Non-Methane HydroCarbons (NMHCs). Other major sources include direct emissions from fossil fuel combustion and biomass burning. Nitrogen (N_2) fixation both on land and in the ocean is an additional source.

[1] John D. Patterson et al. *PNAS* 2021 Vol. 118 No. 36 https://doi.org/10.1073/pnas.2103335118
[2] Chris Greening, *Trends in Microbiology*, April 2022, Vol. 30, No. 4 https://doi.org/10.1016/j.tim.2021.08.004
[3] Arrigoni, A. and Bravo Diaz, L., Hydrogen emissions from a hydrogen economy and their potential global warming impact, EUR 31188 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-55848-4, doi:10.2760/065589, JRC130362,

The impact of atmospheric hydrogen on climate change

The concentration of atmospheric molecular H_2 increases the lifetime of CH_4, as well as increasing the concentrations of tropospheric ozone (O_3) and stratospheric water vapor, and thus impacts Earth's radiative budget and air quality. By reacting with OH radicals ($OH^{\cdot}$), H_2 can increase the atmospheric lifetime of GHGs like CH_4 and assists in the catalytic production of O_3 in the troposphere (0-10 km altitude)[4]. Higher stratospheric concentrations of water vapor also have direct radiative effects[5]. The oxidation of H_2 by $OH^{\cdot}$ in the stratosphere (10 -30 km) also increases hydroperoxyl (HO_2) and water vapor concentrations which induce indirect radiative effects due to losses of O_3 through changes to catalytic cycles and alterations to the distribution of polar stratospheric clouds.

The impact of developing a hydrogen economy

Hydrogen is a carbon-free molecule and hence can offer climate benefits that are not currently available using fuels that contain carbon. While it is not a GHG, it has indirect warming impacts that can be mitigated by managing hydrogen emissions.[6] With the development of a future large-scale hydrogen economy, it is important to take into consideration these potential additional hydrogen emissions into the atmosphere when assessing the GHG reduction potential from hydrogen systems and undertake efforts to minimize them.

In general, a clear climate benefit arises from a transition to a renewable and fossil-free low-carbon hydrogen economy[7]. For low H_2 emission rates along the whole value chain, the use of renewable or low carbon H_2 makes it possible to avoid significant climate impacts with respect to unabated fossil fuel based hydrogen production[8]. In assessing the value of hydrogen to society, a life cycle analysis of the implications of productions routes against appropriate counterfactuals should be undertaken to understand how the benefits can be maximized.

It should be noted that in addition to the beneficial impact on climate change, lowering H_2 emissions will also improve energy efficiency and safety management.

[4] P. C. Novelli et al, *J. Geophys. Res.* 104, 30427–30444 (1999).
[5] T. K. Tromp et al., *Science* 300, 1740–1742 (2003)
[6] The UK, for example, as part of its Low Carbon Hydrogen Standard (LCHS), requires hydrogen production facilities to submit information of fugitive hydrogen emissions, and includes clear guidance on monitoring and reducing hydrogen emissions. This is within Chapter 10 of the main LHCS guidance (template here).
[7] D. Hauglustaine et al., *Communications Earth & Environment* (2022) 3:295 | https://doi.org/10.1038/s43247-022-00626-z
[8] Assuming a baseline of hydrogen produced from natural gas without carbon capture and sequestration (CCS), and an emissions intensity of 10 $kgCO_2e/kgH2$. Also assumes use of GWP-100 metrics, and that the indirect global warming potential of hydrogen is 11.6 +/- 2.8 standard deviation. (Sand et. al., 2023)