Proposed definition of 'clean' hydrogen

Introduction

There are several methods for generating 'clean' (low carbon) hydrogen. This document concentrates on the two methods most likely to dominate future production, namely 'green' and 'blue':

- 'Green' hydrogen is made by electrolysis. Renewable electricity is passed through pure water (H_20), which splits the water into hydrogen gas (H_2) and oxygen gas (O_2). Provided the electricity is renewable with a low Carbon Factor (the amount of CO_2e1 emitted in its generation, less than about 20 gCO_2/kWh), then the resulting H_2 can be considered 'clean' (in accordance with our proposed definition) with low associated CO_2e emissions.

- Hydrogen can also be made from natural gas (methane = CH_4) by processing it with hot steam using 'Steam Methane Reforming' (SMR) or 'Autothermal Reforming' (ATR) processes. This mainly generates H_2 and CO_2 gas. If the resulting CO_2 gas is captured and stored permanently (possibly in 'geological' underground storage), then the resulting hydrogen is known as 'blue'.

Under some circumstances, manufacture of blue hydrogen can generate low CO_2e emissions, in which case the resulting hydrogen can be considered 'clean'. Under other circumstances, manufacture of blue hydrogen can generate high greenhouse gas emissions which are detrimental to the environment.

It is important to note that chemical plant of the type used to manufacture blue hydrogen, typically has an operational life of 30 years, because of the high cost of capital. Consequently, any new processing plant, built in the next decade will probably still operating into the 2060s. Blue hydrogen production cannot therefore be considered as a temporary or interim measure. Consequently, to be a sustainable solution, any new hydrogen manufacturing process must comply with rigorous 'Net Zero' emissions standards. (See here for discussion of this point.)

Performance requirements for green hydrogen have been specified by the GH2 organization [1] (more on this later). Consequently, the purpose of this document is to define the conditions under which blue hydrogen can be considered as 'clean', by building on the GH2 'standard'.

1 | CO_2e emissions are equivalent CO_2 emissions, accounting for the global warming potential (GWP) of all associated greenhouse gases released into the atmosphere.

Greenhouse gas emissions from production of blue hydrogen

There are several sources of greenhouse gas emissions in the blue hydrogen manufacturing process, as shown in Fig. 1. These include:

- **Upstream ('Fugitive') emissions** of methane CH_4 and other hydrocarbons released from the input gas supply chain. These emissions can come from the gas well (flaring, venting or leaking) and leaks in the supply chain infrastructure (e.g. pipes, pumps, valves, vessels, etc).
- **Energy source:** The process requires considerable energy input which has associated CO_2e emissions that must be considered. Energy is required to pump methane, provide the water, and particularly to heat the steam and run the process plant. A significant amount of energy is also needed to pump the output CO_2 into geological storage.
- **Production emissions:** The reforming process emits greenhouse gases (CH_4, CO_2, N_2O) as well as other gases with global warming potential (NO_x and H_2). The biggest issues are incomplete capture of CO_2 and methane as well as hydrogen leaks from equipment.

All these emissions must be measured and included when quantifying the equivalent CO_2 emissions associated with the manufacture of blue hydrogen.

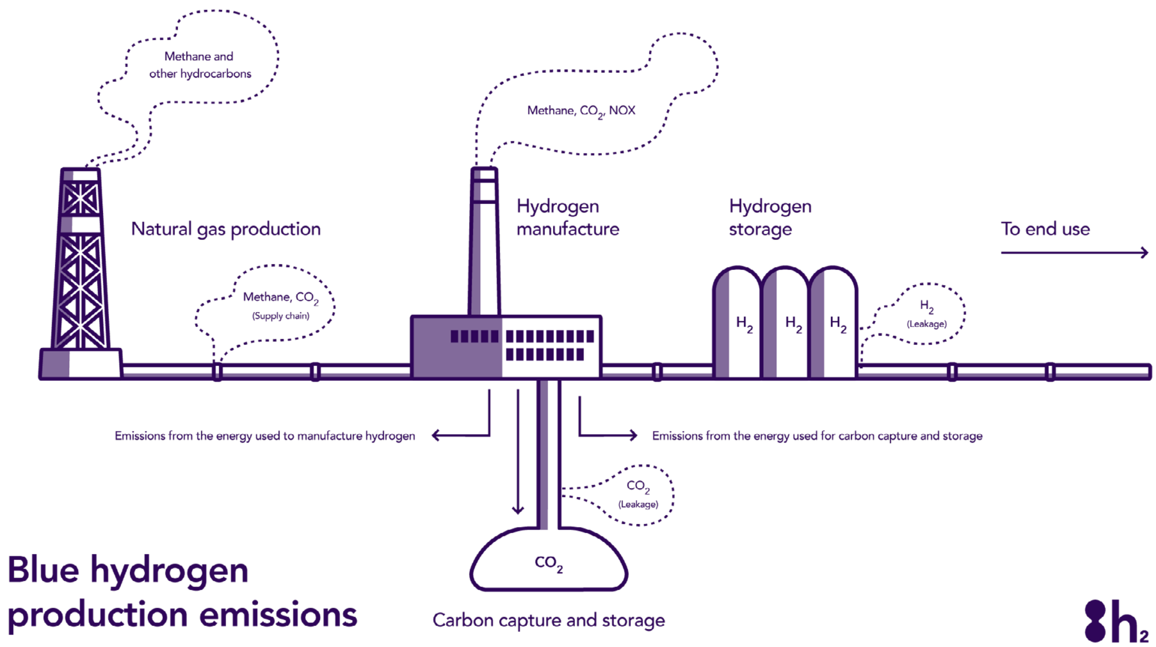

Figure 1. Gas emission in the process of generating blue hydrogen.

Definition concept

To be defined as 'clean', blue hydrogen must at least meet the same emissions levels as green hydrogen. Consequently, the lifecycle greenhouse gas emissions of blue hydrogen should be no greater than those of green hydrogen. This will ensure:

- A 'level playing field' in the hydrogen industry: all hydrogen should meet the same emissions standards and satisfy rigorous 'net zero' emissions standards into the future.
- When 'clean' hydrogen is used (e.g. for decarbonising industry, transport or heating) it will have equally low CO_2e emissions, whatever the source of the hydrogen.
- Anyone specifying systems that use clean hydrogen will be confident of the level of embodied carbon, without having to perform a detailed analysis of the pedigree of the hydrogen. This will simplify hydrogen trade by providing market alignment between countries.
- Best available technology will be used uniformly in hydrogen production.
- Subsidies for hydrogen production will not favour one sector of the industry over another.

The Definition

The starting point for the definition of clean hydrogen is the 'green hydrogen standard' proposed by the Green Hydrogen Organization (GH2) [1], as follows:

"Green hydrogen is hydrogen produced through the electrolysis of water with 100% or near 100% renewable energy with close to zero greenhouse gas emissions (≤ 1 kg CO_2e per kg H_2 taken as an average over a 12-month period)." [1]

The GH2 definition of green hydrogen includes 'scope 1' emissions from production, including water treatment and desalination and 'scope 2' emissions from on-site or purchased renewable electricity. It builds on the methodology proposed by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) [2]. According to GH2, this standard is "the only option [hydrogen definition] aligned with a 1.5 degree pathway"[2]. However, the GH2 standard omits two important criteria that are needed to ensure that hydrogen manufacture is not a major drain on existing renewables. New demand for electricity to manufacture green hydrogen must be matched by new extra renewable generation. Otherwise there is a distinct danger that total CO_2 emissions will increase as a result of the application of hydrogen. This matching requires the concepts of 'additionality' and 'temporal correlation' of supply and demand.

To guarantee that the greenhouse gas emissions of blue hydrogen are no greater than for green hydrogen, the Hydrogen Science Coalition's proposed definition has 4 components, as shown in Fig. 2.

2 | The GH2 criterion is easy to understand. It takes approximately 50 kWh of electricity to manufacture 1 kg of hydrogen by electrolysis. Consequently, the GH2 definition implies use of electricity with a low 'Carbon Factor' of 20 gCO_2e per kWh of electricity: 50 kWh/kgH_2 x 20 gCO_2e/kWh = 1000 $gCO_2e/kg\ H_2$ = 1 $kgCO_2e/kg\ H_2$.

1) Definition of clean	2) Clean energy input
CO_2e emissions from the entire supply chain consistent with the proposed Green Hydrogen Standard: 1 kg CO_2e per kg H_2 • Includes all ‘scope 1’ emissions from production, including methane reforming and CCS and ‘scope 2’ emissions from the methane supply chain and any on-site or purchased electricity. • GWP of all greenhouse gases, including CH_4, H_2, N_2O and NO_x calculated on a 100-year basis. https://gh2.org/our-initiatives/gh2-green-hydrogen-standard	(i) Certificates of origin for all energy (gas and electricity) used in hydrogen production and CO_2 sequestration. (ii) Guarantees of CH_4 emissions throughout the gas supply chain: • Production, gathering and boosting • Processing and liquefaction • Transmission: all pipes and vessels • Transport, loading, unloading and storage (iii) All renewable electricity must satisfy criteria for ‘additionality’ and ‘temporal correlation’. The guarantees must comply with the ‘Methane Emissions Certification Standard’ by MiQ, or equivalent: https://miq.org/
3) Low production emissions	**4) Independent process audit**
(i) Guarantees of CO_2e emissions through the Reforming process and downstream: • CO_2 and other GHGs released during Reforming and H_2 storage • CO_2e emissions from CCS process energy • CO_2 leakage from compression, transmission and sequestration (ii) Guarantees of long-term storage fidelity (99% over 1,000 years), with provision for long-term monitoring of storage permanence. Measurements, and calculations of CO_2 emissions according to ISO/TC 265 ’Carbon dioxide capture, transmission and geological storage’ https://www.iso.org/committee/648607.html	(i) Independent data-led verification by approved auditors, in accordance with the principles of ISO 14016:2020 ‘Environmental management — Guidelines on the assurance of environmental reports’ (ii) All emissions to be guaranteed during the design process; verified and certified for the end product. https://www.iso.org/obp/ui/#iso:std:iso:14016:ed-1:v1:en

Figure 2. Four components of the proposed definition of ‘clean’ hydrogen.

Definition of ‘clean’

The HSC’s proposed ‘clean hydrogen’ definition uses the same quantitative measure of GHG emissions as the Green Hydrogen Standard [1], but accounts for all GHG emissions in manufacture of blue hydrogen and its supply chain, as follows:

- The CO_2e emissions from the entire supply chain should be no more than 1.0 kg CO_2e per kg H_2 accounting for all ‘scope 1’ greenhouse gas emissions from hydrogen production, including methane CH_4 reforming and CCS and all ‘scope 2’ greenhouse gas emissions from the methane supply chain and any on-site or purchased electricity.
  To comply with the definition, the global warming potential (GWP) of all gases emitted in the blue hydrogen process (CO_2, CH_4, H_2, N_2O and NO_x) should be calculated on a 100-year basis. This metric is the most used in international agreements, including the GH2 standard [1]. It is important to note that the 100-year standard is increasingly viewed as an arbitrary choice that doesn’t align with global goals of the Paris Agreement. According to Abernethy and Jackson [3], the timeline of 100 years underestimates methane’s GWP by 63% relative to the 1.5°C target. They calculated that a 24-year time horizon, using 2045 as the endpoint time, with an associated $GWP_{1.5oC}$ of 75 is required to keep emissions in line with the target 1.5 °C maximum global temp rise.
  Given the large difference between the 20 and 100-year bases for calculating the equivalent CO_2 emissions, the HSC’s proposed ‘clean’ hydrogen definition recommends that businesses report their emissions on both 20 and 100-year time horizons.

Clean Energy Inputs

To guarantee that the CO_2e emissions of the input energy used in the blue hydrogen process:

- All input gas used in hydrogen production and all electricity used in hydrogen production and CO_2 sequestration must be supplied with certificates of origin.
- All CH_4 and other GHG emissions throughout the gas supply chain must be measured and guaranteed in accordance with the 'Methane Emissions Certification Standard' by MiQ, or equivalent [4]. This includes all emissions in:
  - Production, gathering and boosting
  - Processing and liquefaction
  - Transmission: all pipes and vessels
  - Transport, loading, unloading and storage
- All renewable electricity must satisfy criteria for 'additionality' and 'temporal correlation' (or '24/7 hourly matching') [6].

Low Production Emissions

The HSC's clean hydrogen definition requires that all gas emissions through the Reforming process[3] and downstream CO_2 and hydrogen processing and storage are certified. This includes:

- All process emissions must be certified:
  - CO_2e emissions from CCS process energy
  - Uncaptured CO_2 and other gases (CH_4, H_2, N_2O and NO_x) released during Reforming
  - CO_2 leakage during compression, transmission and sequestration
  - H_2 leakage from compression and storage
- CO_2 must be stored with a long-term storage fidelity of 99% over 1,000 years. This must be guaranteed and comprehensively risk-assessed and mitigated with provision for long term monitoring of the permanence of carbon storage.
- All measurements, calculations and process standards must comply with ISO/TC 265 [5]

Independent Process Audit

- The calculations performed to determine the CO_2e emissions of the clean hydrogen must be subject to independent data-led verification by approved auditors, in accordance with ISO 14016:2020 [7].
- All emissions to be guaranteed during process design; verified and certified for the end product.

3 | The most common process for reforming methane is called 'Steam Methane Reforming' (SMR). Recently an alternative process 'Autothermal Reforming' (ATR) has been tried for manufacture of hydrogen instead of SMR. A significant advantage of ATR is that it is easier to capture the CO_2 generated by the process than for SMR. Consequently, there is potential for less CO_2 to be released into the atmosphere using ATR.

References

- [1] Green Hydrogen Organisation (GH2) 'The Green Hydrogen Standard', May 2022, https://gh2.org/our-initiatives/gh2-green-hydrogen-standard
- [2] IPHE 'Methodology for Determining the Greenhouse Gas Emissions Associated With the Production of Hydrogen', Working Paper, v1, Oct 2021, https://www.iphe.net/_files/ugd/45185a_ef588ba32fc54e0eb57b0b7444cfa5f9.pdf
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