

Clean Hydrogen Definition

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':

(i) 'Green' hydrogen is made by electrolysis. Renewable electricity is passed through pure water (H₂O), which splits the water into hydrogen gas (H₂) and oxygen gas (O₂). Provided the electricity is renewable with a low Carbon Factor (the amount of CO₂e¹ emitted in its generation, units of kgCO₂/kWh), then the resulting H₂ can be considered 'clean' with low embodied CO₂e emissions.

(ii) Hydrogen can also be made from natural gas (methane = CH₄) by processing it with hot steam using 'Steam Methane Reforming' (SMR) or 'Autothermal Reforming' (ATR) processes. This mainly generates H₂ and CO₂ gas. If the resulting CO₂ 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 CO₂e 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 fossil 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. Fossil 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.)

The 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 | CO₂e emissions are equivalent CO₂ 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:

(i) 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 (eg pipes, pumps, valves, vessels, etc).

(ii) Energy source: The process requires considerable energy input which has associated CO_2 e emissions that must be considered. Energy is required to pump methane, provide the water, 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.

(iii) Production emissions: There are emissions of greenhouse gases (CH_4 , CO_2 , N_2O , NO_x and H_2) from the Reforming process, particularly due to incomplete capture of CO_2 and any methane or hydrogen leaks from equipment.

All these emissions must be measured and included when quantifying the greenhouse gas (GHG) emissions associated with the manufacture of Blue Hydrogen.

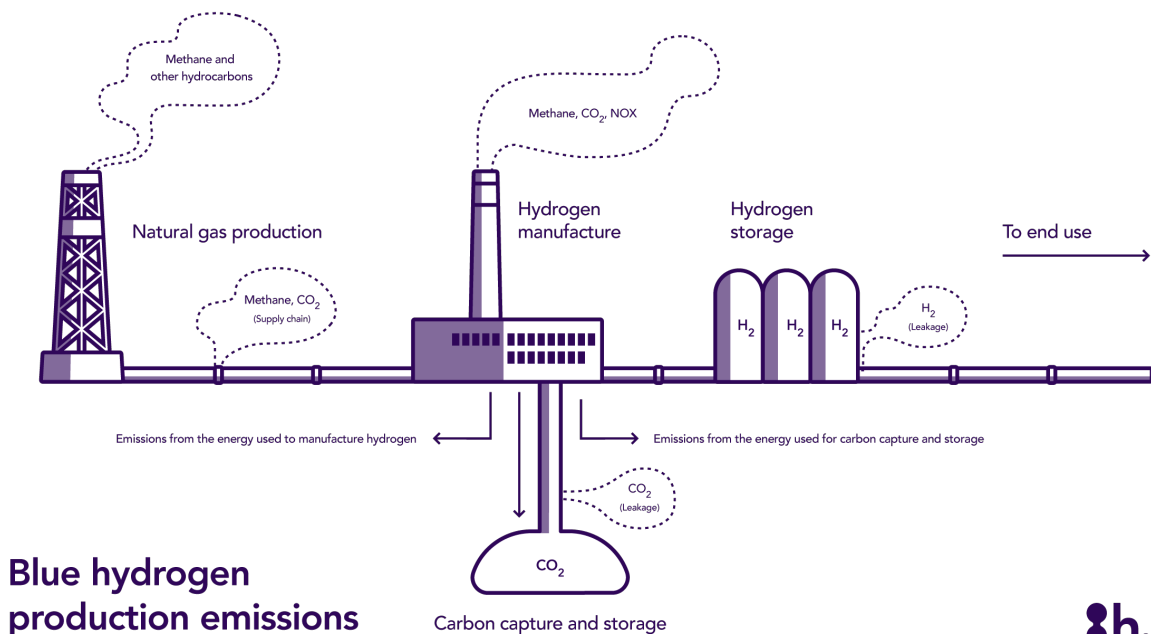


Figure 1. Greenhouse gas emission generated in the process of generating blue hydrogen.

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:

- (i) 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.
- (ii) When 'clean' hydrogen is used (e.g. for decarbonizing industry, transport or heating) it will have equally low CO₂e emissions, whatever the source of the hydrogen.
- (iii) 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.
- (iv) Best available technology will be used uniformly in hydrogen production.
- (v) Any government subsidies applied to clean hydrogen manufacture will be applied in the best interests of the environment, rather than in the interests of one sector of 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 CO₂e per kg H₂ 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.

To guarantee that the greenhouse gas emissions of clean fossil 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. Since it takes approximately 50 kWh of electricity to manufacture 1 kg of hydrogen by electrolysis, the GH2 definition implies use of electricity with a low 'Carbon Factor' of 20 gCO₂e per kWh of electricity: 50 kWh/kgH₂ x 20 gCO₂e/kWh = 1000 gCO₂e/kg H₂ = 1 kgCO₂e/kg H₂.

1) Definition of clean	2) Clean energy input
<p>CO₂e emissions from the entire supply chain consistent with the proposed Green Hydrogen Standard:</p> <p style="text-align: center;">1 kg CO₂e per kg H₂</p> <ul style="list-style-type: none"> 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 CH₄, H₂, N₂O and NO_x calculated on a 100-year basis. <p>https://gh2.org/our-initiatives/gh2-green-hydrogen-standard</p>	<p>(i) Certificates of origin for all energy (gas and electricity) used in hydrogen production and CO₂ sequestration.</p> <p>(ii) Guarantees of CH₄ emissions throughout the gas supply chain:</p> <ul style="list-style-type: none"> Production, gathering and boosting Processing and liquefaction Transmission: all pipes and vessels Transport, loading, unloading and storage <p>The guarantees must comply with the 'Methane Emissions Certification Standard' by MIQ, or equivalent: https://miq.org/</p>
3) Low production emissions	4) Independent process audit
<p>(i) Guarantees of CO₂e emissions through the Reforming process and downstream:</p> <ul style="list-style-type: none"> CO₂ and other GHGs released during Reforming and H₂ storage CO₂e emissions from CCS process energy CO₂ leakage from compression, transmission and sequestration <p>(ii) Guarantees of long-term storage fidelity (99% over 1,000 years), with provision for long-term monitoring of storage permanence.</p> <p>Measurements, and calculations of CO₂ emissions according to ISO/TC 265 'Carbon dioxide capture, transmission and geological storage' https://www.iso.org/committee/648607.html</p>	<p>(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'</p> <p>(ii) All emissions to be guaranteed during the design process; verified and certified for the end product.</p> <p>https://www.iso.org/obp/ui/#iso:std:iso:14016:ed-1:vi:en</p>

Figure 2. Four components of the proposed definition of 'clean' hydrogen.

1) Definition of 'Clean'

The Hydrogen Science Coalition'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 fossil Hydrogen and its supply chain, as follows:

(i) The CO₂e emissions from the entire supply chain should be no more than 1 kg CO₂e per kg H₂ accounting for all 'scope 1' greenhouse gas emissions from hydrogen production, including methane CH₄ 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 greenhouse gases (CH₄, H₂, N₂O and NO_x) emitted in the Blue Hydrogen process should be calculated on a 100-year basis. This metric is the most used in international agreements, including the GH2 standard [1]. However, it is important to note that the 100-year standard is increasingly viewed as an arbitrary choice, which 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. The authors calculated that a 24-year time horizon, using 2045 as the endpoint time, with its associated GWP_{1.5°C} = 75 is required to keep emissions in line with the target 1.5°C maximum global temperature rise. Given the large difference between the 20 and

100-year bases for calculating the equivalent CO₂ emissions, the Hydrogen Science Coalition's proposed 'clean' hydrogen definition recommends that businesses report their emissions on both 20 and 100-year time horizons.

2) Clean Energy Inputs

To guarantee that the CO₂e emissions of the input energy used in the Blue Hydrogen process, the Hydrogen Science Coalition's proposed definition requires that:

(i) All input gas used in hydrogen production and all electricity used in hydrogen production and CO₂ sequestration is supplied with certificates of origin.

(ii) All CH₄ and other GHG emissions throughout the gas supply chain are 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

3) Low Production Emissions

The Hydrogen Science Coalition's clean hydrogen definition requires that all Greenhouse gas (GHG) emissions through the Reforming process³ and downstream CO₂ and hydrogen processing and storage are certified. This includes:

(i) All process emissions must be certified:

- CO₂e emissions from CCS process energy
- Uncaptured CO₂ and other GHGs (CH₄, H₂, N₂O and NO_x) released during Reforming
- CO₂ leakage during compression, transmission and sequestration
- H₂ leakage from compression and storage

(ii) CO₂ 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.

(iii) All measurements, calculations and process standards must comply with ISO/TC 265 [5]

4) Independent Process Audit

(i) The calculations performed to determine the CO₂e emissions of the clean hydrogen must be subject to independent data-led verification by approved auditors, in accordance with ISO 14016:2020 [6].

(ii) All emissions must 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 CO₂ generated by the process than for SMR. Consequently, there is potential for less CO₂ to be released into the atmosphere using ATR.

References

- [1] Green Hydrogen Organisation (GH2) 'The Green Hydrogen Standard', May 2022
- [2] IPHE 'Methodology for Determining the Greenhouse Gas Emissions Associated With the Production of Hydrogen', Working Paper, v1, Oct 2021.
- [3] Abernethy, S. and Jackson, R.B. 'Global temperature goals should determine the time horizons for greenhouse gas emission metrics', Environmental Research Letters, Volume 17, Number 2, 024019.
- [4] MiQ 'Methane Emissions Certification Standard', 2022.
- [5] ISO/TC 265 'Carbon dioxide capture, transmission and geological storage'
- [6] ISO 14016:2020 'Environmental management — Guidelines on the assurance of environmental reports'

 @h2coalition

 /hydrogen-science-coalition

www.h2sciencecoalition.com

media@h2sciencecoalition.com

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