Hydrogen Criteria Background Paper

Development of Eligibility Criteria under the Climate Bonds Standard & Certification Scheme

Published for certification

NOTE: These Criteria can be used to certify Use-of-Proceeds Instruments, Sustainability-Linked Debt Instruments, Assets and Entities per the Climate Bonds Standard v4.0

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The Industry Working Group provided critical and useability focused consultation and feedback on the Criteria, but this does not automatically reflect endorsement of the criteria by all members.

Definitions

Additionality principle: Ensuring that electrolytic hydrogen is produced from additional renewable electricity.

Applicant: The term or name for any potential bond issuer, or non-financial corporate entity that might seek certification under the Steel Criteria.

Carbon Capture and Storage (CCS): describes a suite of technologies that capture waste CO2, usually from large point sources, transport it to a storage site, and deposit it where it will not enter the atmosphere. Stored CO2 is injected into an underground geological formation; this could be a depleted oil and gas reservoir or other suitable geological formation.

Carbon Capture, Utilisation and storage (CCUS): describes a suite of technologies that capture waste CO2, usually from large point sources, to then use it in other processes, or to make products.

Climate Bonds Initiative (Climate Bonds): An investor focused not-for-profit organisation, promoting large-scale investments that will deliver a global low carbon and climate resilient economy. Climate Bonds seeks to develop mechanisms to better align the interests of investors, industry, and government to catalyse investments at a speed and scale sufficient to avoid dangerous climate change.

Climate Bonds Standard (CBS): A screening tool for investors and governments that allows them to identify green bonds the proceeds of which are being used to deliver climate change solutions. This may be through climate mitigation impact and/or climate adaptation or resilience. The CBS is made up of two parts: the parent standard (CBS v4.0) and a suite of sector specific eligibility Criteria. The parent standard covers the certification process and pre- and post-issuance requirements for all certified bonds, regardless of the nature of the capital projects. The Sector Criteria detail specific requirements for assets identified as falling under that specific sector. The latest version of the CBS is published on the Climate Bonds website.

Climate Bonds Standard Board (CBSB): A board of independent members that collectively represents $34 trillion of assets under management. The CBSB is responsible for approving (i) Revisions to the CBS, including the adoption of additional sector Criteria, (ii) Approved verifiers, and (iii) Applications for Certification of a bond under the CBS. The CBSB is constituted, appointed, and supported in line with the governance arrangements and processes as published on the Climate Bonds website.

Climate Bond Certification: allows the issuer to use the Climate Bond Certification Mark in relation to that bond. Climate Bond Certification is provided once the independent CBSB is satisfied the bond conforms with the CBS.

Critical interdependencies: The asset or activity's boundaries and interdependencies with surrounding infrastructure systems. Interdependencies are specific to local context but are often connected to wider systems through complex relationships that depend on factors 'outside the asset fence' that could cause cascading failures or contribute to collateral system benefits.

Geographic correlation: Renewable electricity generation must be geographically correlated to the hydrogen production site, which means to be located in the same electricity market price area.

Green Bond: A green bond is a bond of which the proceeds are allocated to environmental projects or expenditures. The term generally refers to bonds that have been marketed as green. In theory, green bonds proceeds could be used for a wide variety of environmental projects or expenditures, but in practice they have mostly been earmarked for climate change projects.

Hydrogen production assets and projects: Assets and projects relating to the acquisition, installation, management and/or operation of infrastructure for hydrogen production and delivery.

Hydrogen Delivery projects: All the operations and activities after hydrogen production and before end-use. It includes conditioning, transportation, conversion, reconversion, and storage.

Industry Working Group (IWG): A group of key organisations that are potential issuers, verifiers and investors convened by Climate Bonds IWG provides feedback on the draft sector Criteria developed by the TWG before they are released for public consultation.

Investment Period: The interval between the bond's issuance and its maturity date. Otherwise known as the bond tenor.

Technical Working Group (TWG): A group of key experts from academia, international agencies, industry and NGOs convened by Climate Bonds. The TWG develops the Sector Criteria - detailed technical criteria for the eligibility of projects and assets as well as guidance on the tracking of eligibility status during the term of the bond. Their draft recommendations are refined through engagement with finance industry experts in convened Industry Working Groups (see below) and through public consultation. Final approval of Sector Criteria is given by the CBSB.

Temporal correlation: Ensuring that renewable energy generation and hydrogen production coincide temporally.

List of acronyms

A&R	Adaptation and Resilience
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CO2eq	CO2 equivalents
EGS	Environmental, Social, and Governance
GHG	Greenhouse Gas
GWP	Global Warming Potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IWG	Industrial Working Group
NGO	Non-governmental organisations
SBTi	Science-Based Targets initiative
TWG	Technical Working Group

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1 Introduction

1.1 Overview

This document serves as a reference document to the Criteria Document for Hydrogen Production. The purpose of this document is to provide an overview of the key considerations and issues that were raised during the development of the Hydrogen Criteria and provide the rationale for why requirements were chosen and set.

The Criteria were developed through a consultative process with TWG and IWG, and through public consultation. The TWGs comprised academic and research institutions, civil society organisations, multilateral banks and specialist consultancies whereas IWGs are represented by industry experts including potential bond issuers and investors. A 52-day period of public consultation offers the opportunity to any member of the public to comment on the Criteria. This document aims to capture these various dialogues and inputs and substantiate the reasoning behind the Hydrogen Criteria.

Supplementary information will be made available in addition to this document, including:

- Information to support issuers and verifiers is available at the Hydrogen Criteria.
- Hydrogen Frequently Asked Questions
- Hydrogen public consultation feedback and responses summary
- Climate Bonds Standard: contains the requirements of the overarching CBS
- The Climate Bonds Standard & Certification Scheme Brochure: provides an overview of the Climate Bonds Standard & Certification Scheme, of which these Criteria are a part

For more information on Climate Bonds and the Climate Bonds Standard and Certification Scheme, see www.climatebonds.net.

1.2 Funding the goals of the Paris Agreement

The current trajectory of climate change, expected to lead to a global warming of 2.7-3.1°C by 2100[1], poses an enormous threat to the future of the world's nations and economies. The aim of the Paris Agreement is to limit warming to a global average of no more than 2°C higher than pre-industrial levels by the end of the century, and ideally no more than 1.5°C. The effects of climate change and the risks associated even with a 2°C rise is significant: rising sea levels, increased frequency and severity of hurricanes, droughts, wildfires and typhoons, and changes in agricultural patterns and yields. Meeting the 2°C goal requires a dramatic reduction in global greenhouse gas (GHG) emissions.

At the same time, the world is entering an age of unprecedented urbanisation and related infrastructure development. Global infrastructure investment is expected to amount to USD 90 trillion by 2030, more than the entire current infrastructure stock[2].

To ensure sustainable development and avoid dangerous climate change, this infrastructure needs to be low-carbon and resilient to physical climate impacts, without compromising the economic growth needed to improve the livelihoods and wellbeing of the world's poorer citizens. Ensuring that the infrastructure built is low-carbon raises the annual investment needs by 3-4%. Climate adaptation needs to add another significant amount of investment, estimated at USD 280-500 billion per annum by 2050 for a 2°C scenario.

1.3 The role of bonds

Traditional sources of capital for infrastructure investment (governments and commercial banks) are insufficient to meet these capital needs; institutional investors, particularly pension and sovereign wealth funds, are increasingly looked to as viable actors to fill these financing gaps.

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[1] According to Climate Tracker, under current policies we could expect 2.7 - 3.1°C: http://climateactiontracker.org/global.html

[2] The Global Commission on the Economy and Climate (2018), 'Unlocking the Inclusive Growth Story of the 21st Century: Accelerating Climate Action in Urgent Times': https://newclimateeconomy.report/2018

Capital markets enable issuers to tap into large pools of private capital from institutional investors. Bonds are appropriate investment vehicles for these investors as they are low-risk investments with long-term maturities, making them a good fit with institutional investors' liabilities (e.g., pensions to be paid out in several decades).

Bond financing works well for low-carbon and climate-resilient infrastructure projects post-construction, as bonds are often used as refinancing instruments. Labelled Green Bonds are bonds with proceeds used for green projects, mostly climate change mitigation and/or adaptation projects, and labelled accordingly. The rapid growth of the labelled green bond market has shown in practice that the bond markets can provide a promising channel to finance climate investments.

The Green Bond market can reward bond issuers and investors for sustainable investments that accelerate progress toward a low-carbon and climate-resilient economy. Commonly used as long-term debt instruments, Green Bonds are issued by governments, companies, municipalities, and commercial and development banks to finance or re-finance assets or activities with environmental benefits. Green Bonds are regular bonds with one distinguishing feature: proceeds are earmarked for projects with environmental benefits. Green Bonds are in high demand and can help issuers attract new types of investors.

A green label is a discovery mechanism for investors. It enables the identification of climate-aligned investments even with limited resources for due diligence. By doing so, a green bond label reduces friction in the markets and facilitates growth in climate-aligned investments.

Currently Green Bonds only account for less than 0.2% of a global bond market of USD128 trillion[3]. The potential for scaling up is tremendous. The market now needs to grow much bigger, and quickly.

1.4 Introduction to the CBS

Activating the mainstream debt capital markets to finance and refinance climate friendly projects and assets is critical to achieving international climate goals, and robust labelling of green bonds is a key requirement for that mainstream participation. Confidence in the climate objectives and the use of funds intended to address climate change is fundamental to the credibility of the role that green bonds play in a low carbon and climate resilient economy. Trust in the green label and transparency to the underlying assets are essential for this market to reach scale but investor capacity to assess green credentials is limited. Therefore, Climate Bonds created the Climate Bonds Standard & Certification Scheme, which aims to provide the green bond market with the trust and assurance to achieve the required scale.

The Climate Bonds Standard & Certification Scheme is an easy-to-use tool for investors and issuers to assist them in prioritising investments that truly contribute to addressing climate change, both from a resilience and a mitigation point of view. It is made up of the overarching CBS detailing management and reporting processes, and a set of Sector Criteria detailing the requirements assets must meet to be eligible for certification. The Sector Criteria covers a range of sectors including solar energy, wind energy, marine renewable energy, geothermal power, low carbon buildings, low carbon transport, and water. The Certification Scheme requires issuers to obtain independent verification, pre- and post-issuance, to ensure the bond meets the requirements of the CBS.

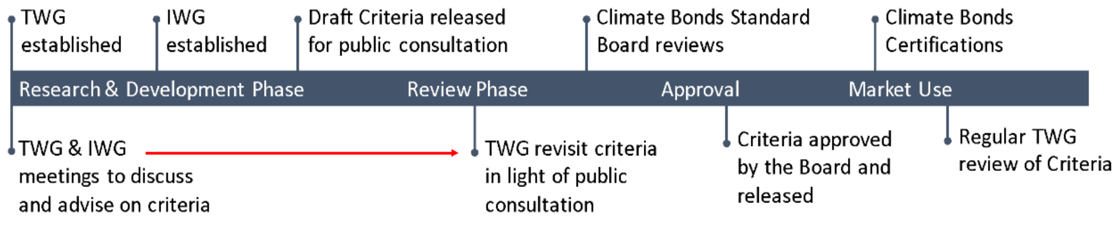
Existing Sector Criteria cover solar energy, wind energy, marine renewable energy, geothermal power, buildings, transport (land and sea), bioenergy, forestry, agriculture, waste management and water infrastructure, hydropower, electricity grids and storage. In addition to Hydrogen, additional Sector Criteria currently under development include Cement and Steel.

1.5 Process for Sector Criteria Development

The CBS has been developed based on public consultation, road testing, and review by the Assurance Roundtable (a group of verifiers) and expert support from experienced green bond market participants.

[3] www.icmagroup.org/regulatory-policy-and-market-practice/secondary-markets/bond-market-size

Figure 1: Criteria development process



The Standard is revisited and amended on an annual basis in response to the growing climate aligned finance market. Sector specific Criteria are developed by TWG made up of scientists, engineers, and technical specialists. Draft Criteria are presented to IWG before being released for public comment. Finally, Criteria are presented to the CBSB for approval (see diagram below).

Sector Criteria for many sectors are available and include wind, solar, geothermal, marine renewables, hydropower, road transport, marine transport, electrical grids, water management and buildings. Criteria are available at www.climatebonds.net/standard/available.

1.6 Structure of this document

This document supports the Hydrogen Criteria. It captures the issues raised and discussed by the TWG, as well as the arguments and evidence in support of the Criteria. It is structured as follows:

Section 2 provides a brief overview of the sector: its status, trends and role in mitigating and adapting to climate change.
Section 3 outlines the objectives, principles, boundaries and overarching considerations for setting the criteria and provides an overview of the criteria.
Section 4 describes the rationale behind the mitigation requirements.
Section 4.6 describes the rationale behind the adaptation and resilience requirements.

2 Sector Overview

2.1 What is hydrogen?

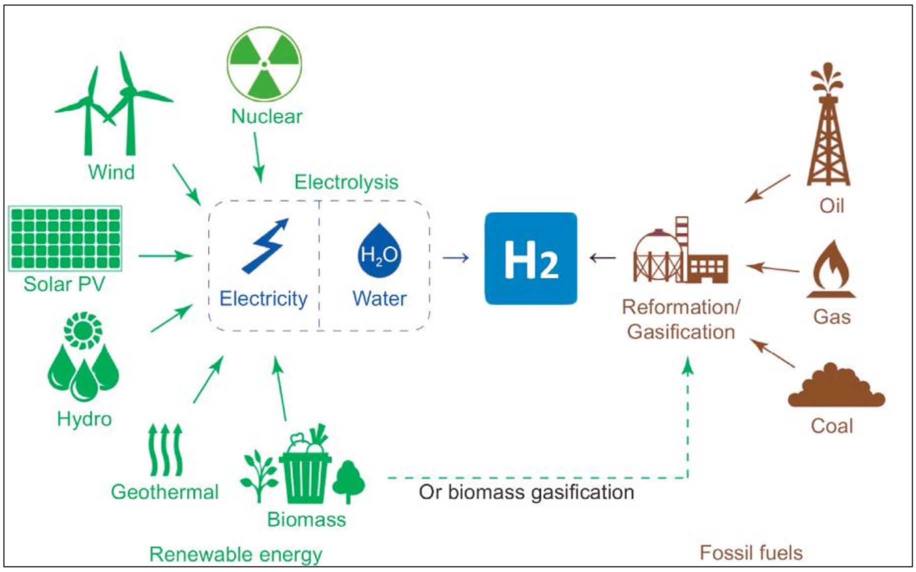
Hydrogen is a basic chemical that has been used for years mainly as a feedstock for refineries and chemical processes, such as ammonia and methanol production. However, hydrogen is experiencing an unprecedented momentum today as a sustainable fuel and feedstock beyond its traditional applications. It offers a huge opportunity to replace fossil fuels and contribute to the decarbonisation of the economy.

Hydrogen is not a primary energy source but an energy carrier whose production requires high amounts of energy. It can be produced from different energy sources, such as fossil fuels, biomass, renewables, nuclear, and via diverse conversion technologies. Nevertheless, most of its production today is based on fossil fuel-based alternatives: steam methane reforming (SMR) of natural gas and coal gasification; these production pathways have high carbon footprints; hence, making hydrogen production less emission intensive is essential to contribute to decarbonisation of the economy. Today hydrogen production accounts for 6% of fossil gas and 2% of coal consumption globally[4].

The following diagram illustrates the main technologies and energy sources to produce hydrogen.

[4] IEA, 2021. The future of hydrogen. https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

Figure 2: Hydrogen Production routes[5]



According to the International Energy Agency (IEA), the total demand for hydrogen in 2020 was around 90 million tonnes. Around 45% was used in oil refining, and 50% in chemicals production, mainly ammonia, and the remaining 5% was used for steel production through the Direct Reduced Iron (DRI) process.[6]

The criteria development process included considerations about acceptable energy sources, lock-in risks for fossil-based production, end-use targeting, and ambitious thresholds for emissions reduction among other key elements.

2.2 Future of Hydrogen

Estimating hydrogen future demand depends on different scenario assumptions involving policy frameworks, diverse technology deployment, and market dynamics. Although it is expected that most of the global demand will be for low-carbon (ideally zero-carbon) hydrogen in the future, it is not possible to accurately predict the hydrogen demand by 2050. The estimations vary considerably, including 149 Mt/year, according to Shell´s 2018 Sky Scenario[7]; 300 Mt/year under the "Energy of the future" scenario, developed by Deloitte[8]; and 546 Mt/year in the Hydrogen Council 2019 forecast [9]. Most of these projections foresee a slight and stable growth by 2030. Then, after 2035, steeper growth is expected, influenced by capacity increase and the development of the essential infrastructure. Usually, the time needed to implement hydrogen infrastructure projects, such as pipelines and terminals, is around 10 to 12 years.[9]

Despite a wide range of demand estimations per sector, heavy industry, long-distance transport, and other energy sectors seem to dominate the future demand.

2.2.1 Key players

The hydrogen generation industry is a global and competitive market. Traditionally, it was led by key multinational corporations, such as Air Liquide (France), Air Products and Chemicals (U.S.), Linde Group (Germany), and Messer Group (Germany), which produce mainly industrial gases. Also, Cummins (U.S.), a power technology company that recently acquired Hydrogenics, an

[5] Zhang *et al*, 2021. https://reader.elsevier.com/reader/sd/pii/S1674862X2100001X?token=45189D47108BFB3EB9E1276C36F19EAFD40D16A4103A51D1C5BAC21CD67B106AE1A4FFE0931EC3241B57FED439E50027&originRegion=eu-west-1&originCreation=20221114115024

[6] IEA, 2021. Global Hydrogen Review. https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf

[7] World Energy Council, 2021. Working Paper | Hydrogen demand and cost dynamics. www.worldenergy.org/assets/downloads/Working_Paper_-_Hydrogen_Demand_And_Cost_Dynamics_-_September_2021.pdf

[8] Deloitte, 2021. Scenario Analysis COAG Energy Council - National Hydrogen Strategy Taskforce www2.deloitte.com/content/dam/Deloitte/au/Documents/future-of-cities/deloitte-au-australian-global-hydrogen-demand-growth-scenario-analysis-091219.pdf

[9] World Energy Council, 2021

industrial gas technology manufacturer. Many acquisitions, joint ventures, and alliances are increasing capabilities and competitiveness in a growing and challenging market. Some players are developing new technologies to meet the demand of emerging markets, such as fuel cell vehicles. The deployment of new applications and the shift of hydrogen use toward other industries will drastically modify the dynamics of this market, including new players and stakeholders[10].

Large energy companies are announcing low-carbon hydrogen development projects. Most of the hydrogen scaling up project announcements have been from the oil and gas sector. These projects mainly focus on meeting actual demand from industrial clusters and their internal demand using the existing gas infrastructure. BP in Australia, Shell in the Netherlands, Equinor in the UK, Sasol in South Africa, and Sinopec in China announced large green hydrogen projects. Repsol, in Spain, announced a quarter of its capital expenditure on low carbon projects, including hydrogen, through 2025[11]. Large utility companies started to react by announcing electrolysis infrastructure projects for hydrogen production to complement their renewable assets[12]. ACWA Power in Saudi Arabia is involved in a $6.5 billion green hydrogen project. NextEra in the US is working on a green hydrogen pilot using solar energy to meet the demand of its plant in Florida, which today operates with natural gas. San Diego Gas & Electric announced two green hydrogen storage projects, and Ohio's Long Ridge Energy Terminal confirmed its plans to convert a gas power plant to 100% green hydrogen[13]. In Europe, the German utility Uniper developed a decarbonisation strategy to transform its gas power production to hydrogen through an alliance with GE, a gas turbine manufacturer and Siemens. Iberdrola, in Spain, will work on an innovation project to build an electrolyser powered by solar energy, which will supply hydrogen demand of an ammonia plant [14].

Other critical stakeholders across the value chain are renewable energy companies, technology providers, electrolyser and fuel cell manufacturers, pipeline and infrastructure companies, refueling station operators, storage operators, fossil gas industry, and potential off-takers in the industrial sector, such as steel, and chemicals, heavy transport sector, including vehicle manufacturers & OEMs on the road transport, shipping sector to use or transport hydrogen [12]. However, it is not clear who the off-takers of hydrogen will be. Although some refinery and petrochemical assets have been listed as end-users, there is still a lack of visibility and definitions of business models.

2.3 Climate change and main decarbonisation challenges

2.3.1 Hydrogen Production

Different hydrogen production technologies can be classified depending on the energy source and the production unit size and location. It can be decentralised (distributed), which implies small production plants located near the point of use, and centralised, in large plants to transport and distribute the hydrogen through pipeline or lorry [7]. The infrastructure required for each varies and will have its own challenges.

There is a vast opportunity to decarbonise hydrogen production, which will accelerate its adoption as an alternative feedstock and fuel. Hydrogen demand is mainly fulfilled by the processes based on fossil fuels, with 68% of the share from natural gas, 16% from oil, and 11% from coal. Production processes include steam methane reforming (SMR), autothermal reforming (ATR), partial oxidation (POX), and coal gasification. Today around 95% of total hydrogen is produced from fossil resources [7]. The remaining amount is produced by electrolysis, which needs to use low-carbon electricity to be considered low-carbon hydrogen.

Every region has a different perspective on hydrogen production pathways. Some countries prioritise renewable-based production, and others include fossil-based production with carbon capture, utilization and storage (CCUS) in the medium term to decarbonise existing assets. Nuclear electricity source is taking more relevance, especially in regions such as China and Russia[14].

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[10] Schlund and Schulte, 2021. The who's who of a hydrogen market ramp-up: A stakeholder analysis for Germany www.researchgate.net/publication/350107324_The_who's_who_of_a_hydrogen_market_ramp-up_A_stakeholder_analysis_for_Germany

[11] Petroni and Holger, 2020. Betting on hydrogen. Journal report. https://powertapfuels.com/pdf/WSJ_Hydrogen_Overview_Oct_2020.pdf

[12] Parnell, 2020. Who Will Own the Hydrogen Future: Oil Companies or Utilities? www.greentechmedia.com/articles/read/utilities-on-both-sides-of-atlantic-follow-oil-majors-hydrogen-lead

[13] Pearl, 2021. NextEra sees hydrogen as key to deep decarbonization, takes small steps for now www.utilitydive.com/news/nextera-sees-hydrogen-as-key-to-deep-decarbonization-takes-small-steps-for/598855/

[14] Noussan *et al*., 2020. The Role of Green and Blue Hydrogen in the Energy Transition - A Technological and Geopolitical Perspective www.researchgate.net/publication/348116004_The_Role_of_Green_and_Blue_Hydrogen_in_the_Energy_Transition_-_A_Technological_and_Geopolitical_Perspective

Alternative pathways exist, such as biomass gasification and pyrolysis, thermochemical water splitting, photocatalysis, and supercritical water gasification of biomass; however, their maturity levels are still low[15].

The next table contains the technology readiness level (TRL) of the main production technologies.

Table 1: Technology Readiness Level of Hydrogen Production Options16

Technology name	Short name	TRL
1. Steam methane reforming	SMR	9
2. Steam methane reforming with CCS	SMR+CCS	7-8
3. Coal gasification	CG	9
4. Coal gasification with CCS	CG+CCS	6-7
5. Methane pyrolysis	CH4 pyrolysis	3-5
6. Biomass gasification	BG	5-6
7. Biomass gasification with CCS	BG+CCS	3-5

- **Electrolytic Hydrogen**

  Electrolytic hydrogen, also referred as green hydrogen when electrolyser is powered by renewable electricity, is produced via decomposition of water into oxygen and hydrogen gas. Different electrolysis technologies exist to produce hydrogen, Alkaline technology being the most mature and widely used, even for existing processes such as chlorine production. Proton exchange membrane (PEM), which is already commercially available, offers more flexibility, with a wider operating range, shorter response time, and lower footprint. Solid oxide electrolysers (SOEC), which has better energy efficiency if thermally integrated and works at higher temperatures, are still under development [7].

  The main barrier to electrolytic hydrogen is the cost. However new developments, membrane materials and stack options can reduce it.

- **Fossil-based Hydrogen with CCS**

  The commonly named blue hydrogen uses traditional fossil fuel-based processes with carbon capture and storage (CCS) to reduce carbon emissions. Although it is possible to retrofit existing fossil-based hydrogen assets with CCS, additional transport and storage infrastructure may be required. The capture rate can vary depending on the plant design and whether carbon capture is implemented to all CO_2 sources in the plant. The effective capture rate can be 60-95%. [17]However, according to the Energy Transition Commission, it should be at least 90% to qualify as low-carbon hydrogen.

  Another critical issue is the upstream methane leakages, including fossil fuel extraction, transport, and use. It must be accounted for to accurately quantify the total GHG emissions from hydrogen production.[18]

- **Methane/biomethane Pyrolysis**

  Methane pyrolysis is the thermal decomposition of methane into hydrogen and carbon. There are no CO2 emissions from this process. The only by product is solid carbon. However, because this process relies on fossil resources, except for biomethane pyrolysis, it is not a long-term solution.[19] It should be seen as a transition alternative to enhance the development of the hydrogen market, which should move towards renewable-based options, to avoid carbon lock-in risks.

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[15] IRENA, 2018 Hydrogen from renewable power: Technology outlook for the energy transition. www.irena.org/publications/2018/sep/hydrogen-from-renewable-power

[16] Al-Quahtani *et al*., 2021. Uncovering the true cost of hydrogen production routes using life cycle monetisation www.sciencedirect.com/science/article/pii/S0306261920314136

[17]National Energy Technology Laboratory, 2022. Technical Report. https://netl.doe.gov/energy-analysis/details?id=ed4825aa-8f04-4df7-abef-60e564f636c9Cite

[18] Bauer *et al*, 2022. https://pubs.rsc.org/en/content/articlehtml/2022/se/d1se01508g

[19] Sánchez-Bastardo *et al*., 2021. Methane Pyrolysis for Zero-Emission Hydrogen Production: A Potential Bridge Technology from Fossil Fuels to a Renewable and Sustainable Hydrogen Economy. https://pubs.acs.org/doi/10.1021/acs.iecr.1c01679

2.3.2 Hydrogen Delivery

Technologies and infrastructure to deliver hydrogen from production assets to end-users are critical parts of the value chain. Because of the low volumetric energy density of hydrogen at ambient temperature and pressure, transporting and storing it requires high amounts of energy. The emissions reduction potential of hydrogen as an alternative fuel to decarbonise some sectors of the economy can be eclipsed when delivered using energy intense alternatives. Therefore, ensuring a clean delivery pathway is required to keep consistency with a low-carbon production process. Overlooking delivery technologies can become a barrier to deploy the hydrogen market and decarbonise some sectors of the economy.

2.3.2.1 Hydrogen Delivery pathways

From a process point of view, hydrogen delivery includes three main steps:

a) Conversion/ packing: Physical or chemical conditioning of hydrogen to have it ready for transport.
b) Transport and storage: Storing and transporting hydrogen to the end user.
c) Reconversion/unpacking: Separation and conditioning operations to have the hydrogen gas ready to use.

Further, there are two main ways of delivering hydrogen: Distribution, and transmission or transport. Distribution of hydrogen is from a single production point to a distribution network. Transmission of hydrogen is from a single production plant to a single end-use point.[20] Additional details can be found in the following sections.

2.3.2.1.1 Distribution

Exist different alternatives to supply end users, which includes transport through pipelines or trucks. The most suitable option depends on the end-use application. In the future, pipelines will be the most cost-efficient distribution alternative; in the short and medium term, hydrogen production near demand centers using trucks, trains, and refueling stations will be the best alternative[21]. Ensuring cost-effective transmission and distribution of hydrogen will be essential to unlocking hydrogen applications.

2.3.2.1.2 Transmission and Transport

Long-distance transmission and global trade will be part of the hydrogen value chain, especially for regions with significant hydrogen demand but limited land area to generate power from renewable sources. Hydrogen's global value chain will have long-distance pipelines, and shipping routes[22].

Hydrogen transportation is a critical part of the value chain sustainability analysis. High amounts of energy are required to compress or liquify gas hydrogen or convert it to another energy carrier, such as ammonia. Currently, the main transportation alternatives for hydrogen are compressed gaseous or liquid hydrogen by truck and compressed gaseous by pipeline. Another option is hydrogen blends using existing fossil gas infrastructure. Although blends have been promoted in some countries, the emissions saving potential is lower than expected. Because blends are typically expressed in volumetric percentages, and the volumetric energy density of hydrogen is lower than the one of methane, in consequence, the energy share of hydrogen is lower in gas blends.[23] The Following graph illustrates the emissions reduction potential of different blends of hydrogen and natural gas. Considering its low mitigation potential, blends are excluded from the Climate Bonds criteria.

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[20] Yang and Ogden, 2007. https://www.sciencedirect.com/science/article/abs/pii/S0360319906001765

[21] Hydrogen Council, 2021. https://hydrogencouncil.com/en/hydrogen-insights-2021/

[22] Hydrogen Council, 2021. https://hydrogencouncil.com/en/hydrogen-insights-2021/

[23] Noussan *et al.*, 2020 www.researchgate.net/publication/348116004_The_Role_of_Green_and_Blue_Hydrogen_in_the_Energy_Transition_-_A_Technological_and_Geopolitical_Perspective

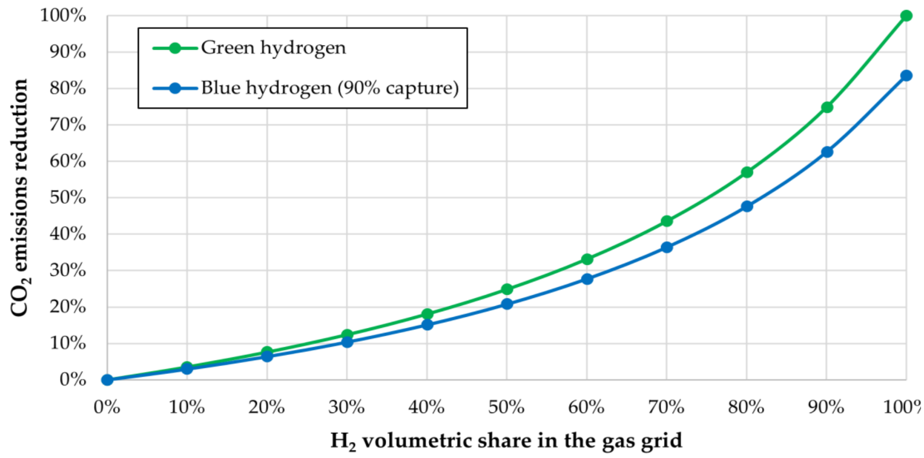

Figure 3: Carbon dioxide emissions reduction vs. hydrogen volumetric blending [23]

For hydrogen medium-distance transport the lower-cost alternative is through pipelines. This option would have the potential advantage of using existing infrastructure, assuming it is possible. For long distances, ship transport is the best alternative. It is due to the lower costs and better flexibility to supply to different countries from a single exporter.[23] However, an energy carrier such as ammonia can also be an alternative because of the energy required to liquefy hydrogen and keep it at low temperatures. The diagram below shows the main routes for hydrogen transport.

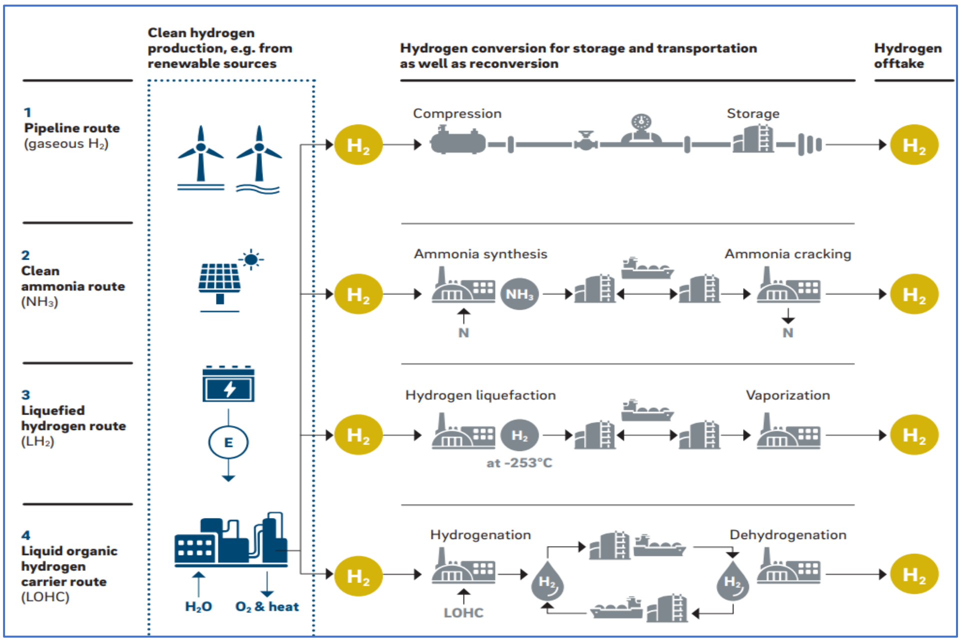

Figure 4: The most common routes for large-scale hydrogen transportation

Table 2 summarizes the main transport alternatives, including a brief description of the technologies, the main energy requirements, and the advantages and disadvantages. Information was taken from the technical report "Assessment of Hydrogen Delivery Options" by the Joint Research Centre (JRC)[24] recently published and the report "Hydrogen transportation / The key to unlocking the clean hydrogen economy" by Roland Berger. The energy requirements are based on estimations and modeling from Roland Berger.[25]

[24] Ortiz *et al.*, 2022. https://publications.jrc.ec.europa.eu/repository/handle/JRC130442

[25] Roland Berger, 2021. https://www.rolandberger.com/publications/publication_pdf/roland_berger_hydrogen_transport.pdf

Table 2: Main hydrogen carriers and delivery options comparison

Alternative	Description	Advantages	Disadvantages	Conversion energy req. [MWh/t H2]	Reconversion energy req. [MWh/t H2]
Compressed	Hydrogen is compressed to the pipeline pressure. It might require recompression at different distances across the pipeline. Existing fossil gas pipelines can be retrofitted and adapted to transport hydrogen.	• Low operational costs • Long lifetimes • Mature technology and successful experiences. • Pipelines can be used as a storage option.	• High initial capital costs • Long construction times (more than 10 years) • Complex permitting and authorization processes • Cross-border pipelines are more complex and require cooperation • Material and network components incompatibility of existing pipelines for repurposing. • Blending has a very low emissions reduction potential	Different assumptions need to be made to estimate energy requirements of compressed hydrogen. Network configuration, pressure, and hydrogen flow influence the energy requirements.	
Liquefied	Liquefying hydrogen requires a cooling step, up to -253°C. After that, hydrogen is stored in insulated tanks. After transporting the liquified hydrogen, it is vaporised to have it back as a gas.	• Mature technology at small-scale (in the aerospace industry and refueling stations).	• Liquefaction requires high amounts of energy. Because of the specific refrigeration needs, storing, handling, and transporting it is more challenging. • Boil-off losses • Transporting liquified hydrogen at large scales, using vessels, is at early stages of development	12.0	0.6
LOHC (Liquid organic hydrogen carriers)	LOHC are chemical compounds that have hydrogen chemically bind (hydrogenation). LOHC can be transported at atmospheric pressure. After transporting it, the LOHC is dehydrogenated using heat, to remove the hydrogen. Some LOHC are toluene, dibenzyltoluene and benzyltoluene.	• LOHC can be stored, transported, and handled without complexity and safety issues, even under ambient temperatures. • Existing infrastructure can be used. • No hydrogen losses • Good storage alternative to manage renewable intermittencies.	• Dehydrogenation is an energy intensive process • Producing the organic carrier has an additional carbon footprint.	0.5	15.0
Ammonia	Ammonia is a basic chemical used mainly to produce fertilisers. Most of its production is based on fossil resources. Ammonia today is a storage alternative for hydrogen. Liquid ammonia is transported in refrigerated tanks, and then its components are split through a cracking process.	• Ammonia production, transport and storage are mature processes, that already have infrastructure and standards. • Ammonia can store larger volumes of hydrogen compared to other carriers.	• Safety concerns related to toxicity and pollution. • Ammonia production is high energy intensive. • The process of cracking ammonia to obtain hydrogen has a low technical readiness level. It has high energy requirements.	5.72	11.2

As it is illustrated in the Table 2, conversion contributes the most to the energy consumption of liquified hydrogen. Conversely, the most significant step for LOHC is the reconversion process. For ammonia, both conversion and reconversion contribute to energy requirements. However, the cracking process is more energy intensive. In the case of compressed hydrogen, although it is not included in Table 2, transport energy requirements are the most critical part beyond the compression process. According to the JRC report, more than 70% of the energy consumption to deliver compressed hydrogen by ship is related to transport.

Some aspects need to be considered to define the criteria for hydrogen infrastructure projects and investment. The energy consumption, carbon footprint, and safety considerations are critical when defining low-carbon and certifiable projects. Setting emissions intensity benchmarks should also be part of the criteria to certify hydrogen delivery and infrastructure projects to avoid affecting the low-carbon definition of hydrogen production. The Climate Bonds hydrogen production criteria include transport emissions as part of GHG accounting systems boundaries. However, there is still a lack of guidance on methodologies to quantify these emissions.

2.3.3 Hydrogen Storage

The energy content of an energy carrier influences the storage method. Hydrogen density must be increased to be stored due to its low volumetric energy density.

It is necessary to differentiate between hydrogen storage to operate its supply chain and large seasonal hydrogen storage to deal with renewables intermittencies. Storage at terminals, refueling stations, and vehicles, such as ships and trucks, are part of the supply chain storage activities. The hydrogen carriers described above are also part of the storage alternatives. Regarding large seasonal storage, options include salt caverns, aquifers, or exhausted oil and gas reservoirs[26].

Gaseous hydrogen storage requires vessels using materials like steel, glass fiber, carbon fiber, and different polymeric materials.

Underground hydrogen storage implies the use of cushion-gas to keep the pressure of the reservoir and facilitate a good hydrogen injection and removal rates. The amount of cushion gas can vary from 25% to 80% of the total volume, depending on the type of storage and its specific needs. Some cushion gas alternatives are methane, CO_2, and nitrogen. Because of the leakage risk and given the warming potential of CO_2 and methane, these are excluded from these criteria for hydrogen storage projects to be certified.

2.4 Investment need

Today, the costs of production of low-carbon hydrogen are higher than other low-carbon energy sources. In addition, because of the uncertainties around the future hydrogen demand, revenues, and risk allocation, financial support will be necessary in the short and medium term. A greater certainty will attract investors and reduce risk, which is essential to develop a healthy hydrogen market.

Financial institutions will be vital in mitigating the financial risk of early projects. During the past ten years, the European Investment Bank (EIB) financed R&D hydrogen projects and now is offering technical advice and funding for large-scale hydrogen projects. In 2020, the Clean Energy Finance Corporation dedicated AUD 300 million to the Advancing Hydrogen Fund[27].

According to the Hydrogen Council insights report, there are 228 hydrogen projects announced mainly in Europe, Asia, and Australia. It would represent above the USD 300 billion by 2030 in total investments across the value chain, with only USD 70 billion from Governments.

2.5 Deals already seen in the sector

Many deals are taking place to accelerate the development of hydrogen projects. Hydrogen features in a small share of green bonds so far (approximately 122 green bonds so far, worth about USD83.6 billion). The three largest deals were sovereign deals,

[26]Noussan *et al*.,2020. https://www.researchgate.net/publication/348116004_The_Role_of_Green_and_Blue_Hydrogen_in_the_Energy_Transition_-_A_Technological_and_Geopolitical_Perspective/link/5fef3daf92851c13fedb8fb9/download

[27] IEA, 2021. Global Hydrogen Review. https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf

notably those from the UK, Canada, Sweden, and Saudi Arabia. Other notable issuers include Munich Re, Daimler, and Fortescue. The following table includes some examples of announced projects[28]:

Table 3: Deals already seen in the hydrogen market

Production	Infrastructure/Transportation	End-uses
• UK Government Green Gilt, blue hydrogen production with CC(U)S. • Air liquid issued a 500-million-euro green bond to finance the development of sustainable projects, including hydrogen.	• Fuel cells: Faurecia, France, development, and production of hydrogen fuel cell systems (stacks) for light vehicles, commercial and utility vehicles, and other applications. • Vehicles: Hyundai Capital, South Korea. • Refuelling stations: Iwatani Corp, Japan.	• Fuel cells: Faurecia, France, development, and production of hydrogen fuel cell systems (stacks) for light vehicles, commercial and utility vehicles, and other applications. • Vehicles: Hyundai Capital, South Korea. • Refuelling stations: Iwatani Corp, Japan.

3 Principles and Boundaries of the Criteria

3.1 Guiding Principles

The objective of Climate Bonds has been to develop Hydrogen Criteria that can maximise viable bond issuances with verifiable environmental and social outcomes. This means the Criteria need to balance the following objectives:

- They form a set of scientifically robust, verifiable targets and metrics; and
- They are usable by the market, which means they must be understandable for non-scientific audiences, implementable at scale, and affordable in terms of assessment burden.

The Criteria should:

- Enable the identification of eligible assets and projects (or use of proceeds) related to Hydrogen investments that can potentially be included in a Certified Climate Bond;
- Deploy appropriate eligibility Criteria under which the assets and projects can be assessed for their suitability for inclusion in a Certified Climate Bond; and
- Identify associated metrics, methodologies, and tools to enable the effective measurement and monitoring of compliance with the eligibility Criteria.

The Hydrogen Criteria are split into two distinct subsets, depending on the financial instrument being certified:

a) Use-of-Proceeds bonds (for example, green bonds)
b) General Corporate Purpose bonds (for example, Sustainability-Linked Bonds)
c) Each subset of criteria may share common requirements, pathways or metrics but require different demonstrations of compliance. In general, the Criteria are made up of four components which need to be satisfied for assets to be eligible for inclusion in a Certified Climate Bond.

[28] Climate Bonds Market Intelligence

3.1.1 Guiding principles - Use-of-Proceeds bonds

The guiding principles for the design of the Hydrogen Criteria, which is a standard approach for all Climate Bonds criteria are summarised in Table 3.

The Hydrogen Criteria are made up of two components, both of which need to be satisfied for assets to be eligible for inclusion in a Certified Climate Bond. These are as follows:

1) Climate Change Mitigation Component - addressing whether the asset or project is sufficiently 'low GHG' to be compliant with rapid decarbonisation needs across the sector - see ***Sections 3*** and ***Sections 4*** of the criteria document for details
2) Climate Change Adaptation and Resilience Component - addressing whether the facility is itself resilient to climate change and furthermore not adversely impacting the resilience of the surrounding system. This encompasses a broad set of environmental and social topics - see ***Section 4.4*** of the criteria document for details.

Table 4: **Key principles for the design of Climate Bond Standard Sector Criteria**

Principle	Requirement for the Criteria
Ambitious	Compatible with meeting the objective of limiting global average warming to a 1.5°C temperature rise above pre-industrial levels set by the Paris Agreement.
Material	Criteria should address all material sources of emissions over the lifecycle. Scope 1 & 2 emissions should be addressed directly and scope 3 considered.
No offsets	Offsets should not be counted towards emissions reduction performance.
Resilient	To ensure that the activities being financed are adapted to physical climate change and do not harm the resilience of the system them are in.
Scientifically Robust	Based on science not industry objectives.
Granular	Criteria should be sufficiently granular for the assessment of a specific project, asset or activity. Every asset or project to be financed must comply.
Globally consistent	Criteria should be globally applicable. National legislation or NDC's are not sufficient.
Aligned	Leverage existing robust tools, methodologies, standards.
Technology neutral	Criteria should describe the result to be achieved.
Avoid lock-in	Avoid supporting development that may result in long term commitments to high emission activities.

3.1.2 Guiding principles - General Corporate Purpose bonds

Climate Bonds' focus to date has been UoP bonds but it is our intention to certify instruments beyond UoP, including corporate SLBs and similar (e.g. Sustainability Linked Loans - SLLs). This will allow us to provide guidance to issuers and assurance to investors around the credibility of those instruments, which can at present prove difficult to evaluate due to lack of consistency in approaches and metrics used by each issuer. This will require assessment of both the company's transition KPIs, and their ability to deliver on their targets. Such certification would follow the requirements set for UoP bonds, namely a standardised, common rule set, binary assessment, simplicity, transparency, and science-based criteria.

Nonetheless, the two subsets of criteria share many of the same guiding principles. The Climate Bonds Initiative sets out the following as key principles for setting entity level criteria:

- Science based.
- Testable.
- Relatively simple.
- Not reinvent the wheel.
- Consistent over time and companies.

Rather than the two components for green (mitigation and adaptation & resilience), the Climate Bonds Initiative has proposed five hallmarks for transition that are relevant to entities, these are summarized in Error! Reference source not found..

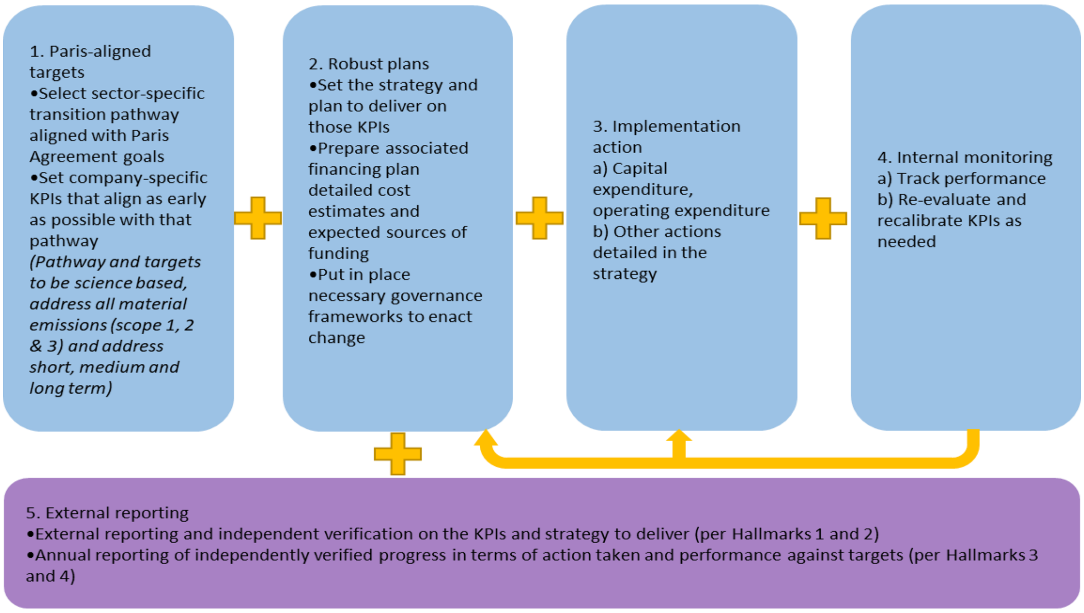

Figure 5: The Hallmarks of a credibly transitioning company

3.2 Assets and Activities Covered by these Criteria

The Climate Bonds hydrogen criteria cover activities and projects across the hydrogen value chain, including production, conditioning, conversion, transportation, and storage activities. Some requirements for certification are included beyond the emissions intensity. A compatible production and transport emissions benchmark using an LCA approach should be used. It will incentivize collaboration and data exchange across different players in the hydrogen value chain, and the most important aspect, it will ensure that hydrogen has a substantial emissions reduction potential.

Exist some initiatives, such as the "Modular certification" approach, which focus on each part of the value chain individually to set benchmarks. This approach could facilitate custody transfer, given the different stakeholders involved in each part of the value chain. [29] A modular approach proposes certifying a single step instead of the entire value chain. This approach was discussed with the TWG; however, setting emissions intensity benchmarks per module can be challenging and out of the scope of these criteria, given the lack of hydrogen delivery emissions data. There are multiple combinations of production and delivery alternatives, which makes the benchmark setting a difficult task. Nevertheless, once the market is developed and there is more available data, a modular approach should be used.

The following diagram illustrates a simplified version of the hydrogen value chain and the activities in scope of the Climate Bonds criteria.

[29] White *et al.*, 2021. https://www.sciencedirect.com/science/article/abs/pii/S0360544220322465

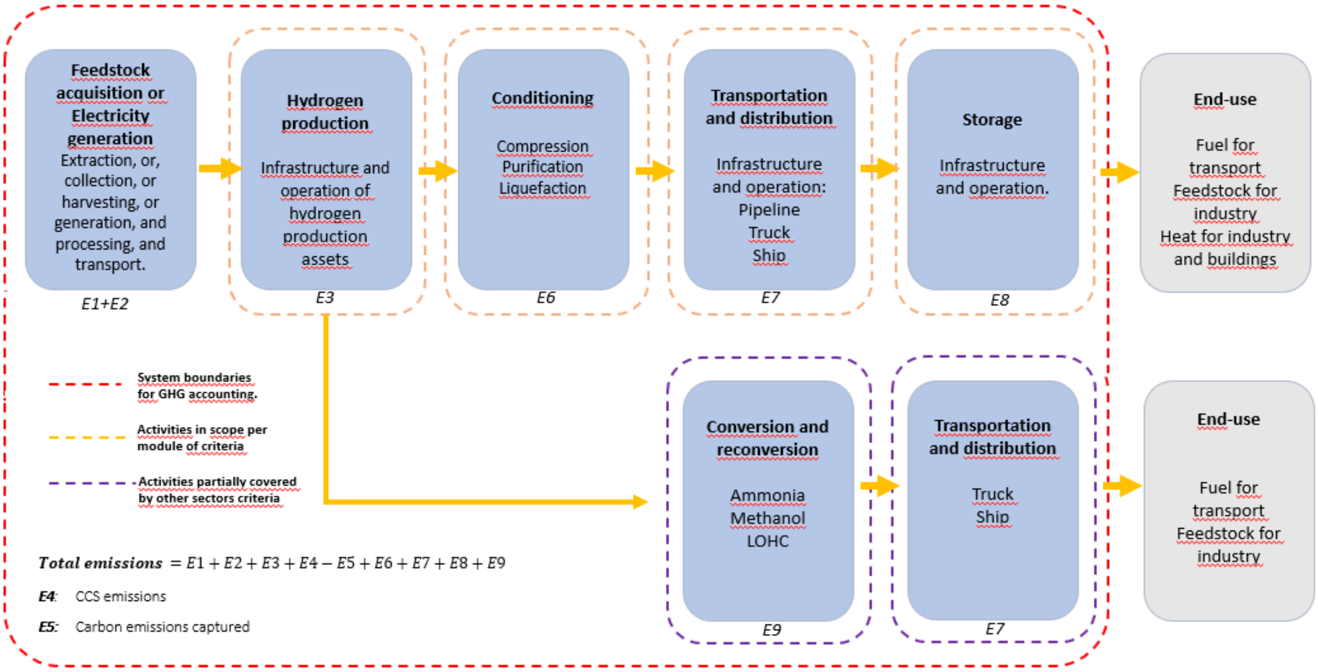

Figure 6: Simplified Representation of Hydrogen Value Chain

Although most of the investment has been in production and final application projects, industry, governments, and key players are bringing the attention to the necessity to fill the gap on delivery infrastructure projects. Because of logistic issues and high costs, most of the hydrogen production today is on site. However, promoting hydrogen as an alternative fuel would require transport and distribution infrastructure development, especially to deliver hydrogen towards regions with limited renewable energy sources or CCS infrastructure.

3.3 Overarching considerations

In setting the criteria, the emissions to be included were discussed, along with the scope of emissions and what criteria would test that the sector is decarbonising and give assurance to investors that financial instruments issued by companies are of satisfactory quality. The key considerations are summarised in this section.

3.3.1 GHG emissions that are included

Although the major GHG emitted from hydrogen generation is CO_2, there are other GHG such as methane (CH_4) and, nitrous oxide (N_2O), which can have significant contributions for some hydrogen production pathways. CH_4 has a global warming potential (GWP) of 83 times of CO_2's global warming potential over 20 years and, 30 times over 100 years, thus, underestimating methane emissions from the hydrogen value chain could lead to an inaccurate GHG accounting and favour some pathways that emit high amounts of that potent GHGs.

Discussions concluded that all relevant GHG based on the most up to date IPCC Assessment Report (AR6) and not just CO_2 should be included in the assessment of emissions. Further, the most up-to-date IPCC 100-year global warming potential factors should be adopted, and the energy values must use the lower heating value (LHV).

Although hydrogen is an indirect GHG, it is still uncertain its global warming potential. Thus, for the purpose of these criteria hydrogen emissions will not be part of the GHG accounting yet. The criteria will be revised periodically, and once research developed further and there is more available data on hydrogen emissions and GWP, the criteria will be updated, and hydrogen will be included in the GHG accounting. Hydrogen leaks will be addressed from a detection, monitoring, and mitigation perspective.

3.3.2 System boundaries and Scope 1, 2 and 3 emissions

The system boundaries and scope of emissions are important aspects to define as part of the criteria development process. It influences the focus of the analysis and sets the boundaries for the calculation of emissions intensity. Scope 1 emissions are direct process emissions, scope 2 are indirect emissions from purchased electricity, heat, and power; and scope 3 emissions are indirect emissions from extraction and manufacture of raw materials and fuels that are not included in scope 2 (all these also known as scope 3 upstream emission) and include waste disposal and product end use (these also known as scope 3 downstream emissions) and many others.

By conducting a cradle-to-site life cycle assessment, which is cradle to gate plus transportation emissions, the scope 1, 2, and partially scope 3 emissions are covered. For the aim of the Climate Bonds Criteria, only scope 3 emissions from purchased goods, plus transportation emissions to the site where the product is used, must be considered. Transportation emissions contribute to the total GHG emissions of hydrogen. For example, local hydrogen production in an exporter country can be low carbon. Still, once it is transported long distances, the total emission could be higher and not classified as a low-carbon alternative to decarbonising other sectors. Transport emissions should be included in the carbon intensity benchmark, as part of the system boundary. The proposal is to use a compatible production and transport emissions benchmark using an LCA approach, regardless of the production and delivery pathway combination.

The following figure illustrates how the scope of emissions at the corporate level relates to life cycle stages at the product level. The dotted line shows the system boundary for the LCA, and the scope of emissions covered. Because there are no CO_2 emissions from hydrogen combustion, excluding end-use emissions does not affect the GHG accounting.

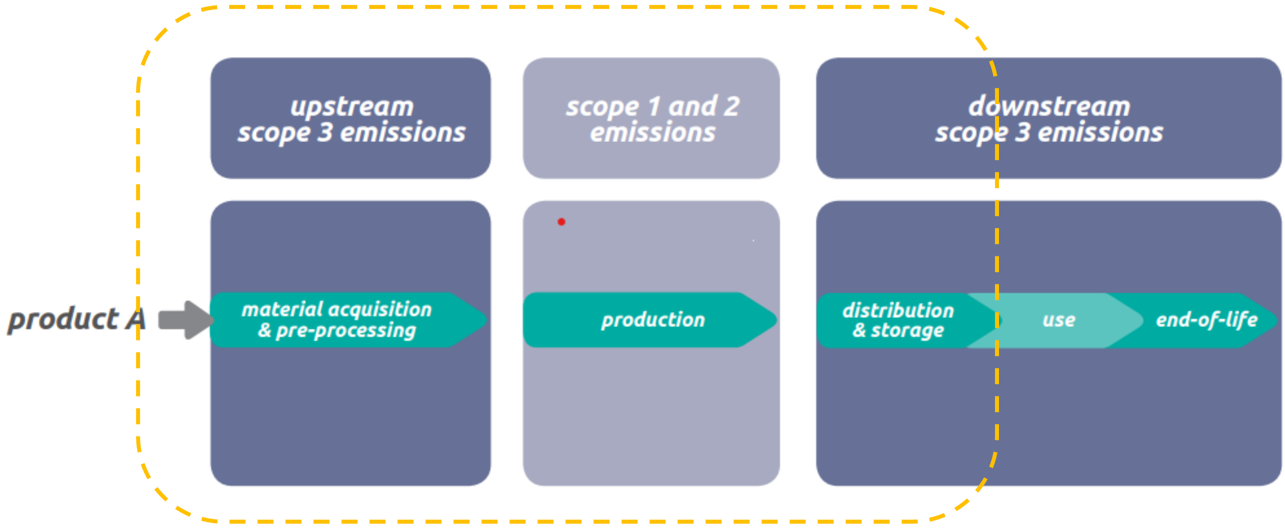

Figure 7: The relationship between the Corporate, Scope 3, and Product Standards for a company manufacturing product A[30]

3.3.3 Colour spectrum classification and carbon intensity benchmarks

- **Colour spectrum**

  Technologies to generate hydrogen can be classified using a colour spectrum. Terms such as low carbon and clean hydrogen are also being adopted. However, there is no common consent for their use.[8] Next figure illustrates the main colours used to classify different hydrogen production pathways.

[30] Product life cycle accounting reporting standard. GHG protocol. https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

Colour	Fuel	Process	Products
Brown/Black	Coal	Steam reforming or gasification	$H_2 + CO_2$ (released)
White	N/A	Naturally occurring	H_2
Grey	Natural Gas	Steam reforming	$H_2 + CO_2$ (released)
Blue	Natural Gas	Steam reforming	$H_2 + CO_2$ (% captured and stored)
Turquoise	Natural Gas	Pyrolysis	$H_2 + C$ (solid)
Red	Nuclear Power	Catalytic splitting	$H_2 + O_2$
Purple/Pink	Nuclear Power	Electrolysis	$H_2 + O_2$
Yellow	Solar Power	Electrolysis	$H_2 + O_2$
Green	Renewable Electricity	Electrolysis	$H_2 + O_2$

Figure 8: Hydrogen Colour Spectrum[31]

The Climate Bonds criteria do not use a colour spectrum classification, but a low-carbon concept and a benchmark approach, which is explained in the following section.

- **Carbon Intensity Benchmarks**

  Carbon intensity benchmarks ($kgCO_2eq/kgH_2$) are also applied as an indicator to compare hydrogen production processes. This perspective focuses on meeting the carbon footprint requirement regardless of the technology. Canada has taken this approach.[32] Likewise, the EU taxonomy sets benchmarks without specifying the technology to produce hydrogen.[33]

  Carbon intensity varies depending on the production pathway. Electrolysis pathways are affected by the carbon content of the electricity used, and fossil-based production combined with CCUS is impacted by the capture rate and fugitive methane and CO_2 emissions.

  The Climate Bonds criteria include a carbon intensity benchmark of below 3 $kgCO_{2eq}/kgH_2$ as a starting point for low-carbon production, which represents an emissions reduction of 73% of traditional fossil-based production processes. In order to avoid carbon lock-in risk, for fossil-based production facilities the benchmark must reduce overtime to reach net zero by 2050. Additional information is given in ***Section 4.3.1.*** The benchmark was set regardless of the production pathway. Nevertheless, additional restrictions and requirements were included to reduce potential carbon lock-in risks, and other sustainability impacts associated with some production routes. More details can be found in ***Section 4.2.***

3.4 GHG accounting methodology

During the discussion sessions, the adoption of the international partnership for hydrogen and fuel cells in the economy (IPHE) methodology was considered[34]. The IPHE developed a methodology for determining the GHG emissions of hydrogen production using a "cradle to gate" system boundary, which includes conditioning of hydrogen. They will expand its system boundary incorporating transport emissions. The IPHE methodology has been adopted by some initiatives, including the Australian and the Green Hydrogen Standard. Although there are some criticisms from other authors, the IPHE methodology is a good initiative to promote harmonisation in GHG accounting for the global hydrogen market. Nevertheless, the TWG highlighted the ISO standards as a well-known and straightforward methodology that avoids overspecification.

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[31] https://rail.ricardo.com/news/opinion-decoding-the-hydrogen-t-rainbow

[32] Hydrogen strategy for Canada. www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

[33] https://ec.europa.eu/sustainable-finance-taxonomy/activities/activity/15/view

[34] The IPHE is an intergovernmental initiative with the participation of 21 countries and the European commission.

The life cycle assessment includes a cradle-to-site system boundary, excluding CAPEX emissions. Even though some authors have demonstrated that emissions from hydrogen infrastructure, and renewable energy production can be material[35], according to the Hydrogen Council, they represent a low percentage of the total emissions for different production pathways[36]. It is important to highlight that no existing criteria or standards for hydrogen production include CAPEX emissions[37].

3.4.1 Hydrogen Production GHG Accounting Methodology

The Climate Bonds criteria include a life-cycle approach using the ISO 14040, ISO 14044 for life-cycle assessment, and ISO 14067 for product carbon footprint calculations. The ISO 14040 and 14044 are complementary standards. The ISO 14040 contains the principles and framework, and the ISO 14044 set the requirements to measure the impacts of hydrogen on the environment. The ISO 14067 is focused on its climate impacts.

3.4.2 Hydrogen Transportation GHG Accounting Methodology

Hydrogen transportation emissions to the site where hydrogen will be used must be covered. It includes energy and electricity related emissions. The life cycle assessment for hydrogen transportation and storage should follow the ISO 14083:2023 "Quantification and reporting of greenhouse gas emissions arising from transport chain operations". This standard was developed to address GHG emissions from supply chains, which means addressing scope 3 emissions. It is based on the GLEC framework, which is aligned with the GHG Protocol and the Carbon Disclosure Project. [38]

3.5 Considering regional differences

Even tough addressing regional differences is out of the scope of the Climate Bonds criteria development process, discussing these potential differences and understanding their implications is crucial for setting criteria. Regional differences have implications to produce hydrogen. The carbon intensity of hydrogen production change depending on aspects such as energy mixes and production efficiency. Countries with available renewable energy sources, space for solar and wind farms, and good access to water sources will be producers of renewable based hydrogen. Countries with low gas prices will favour fossil-based production. The following graph shows the per capita electricity mix of different countries.

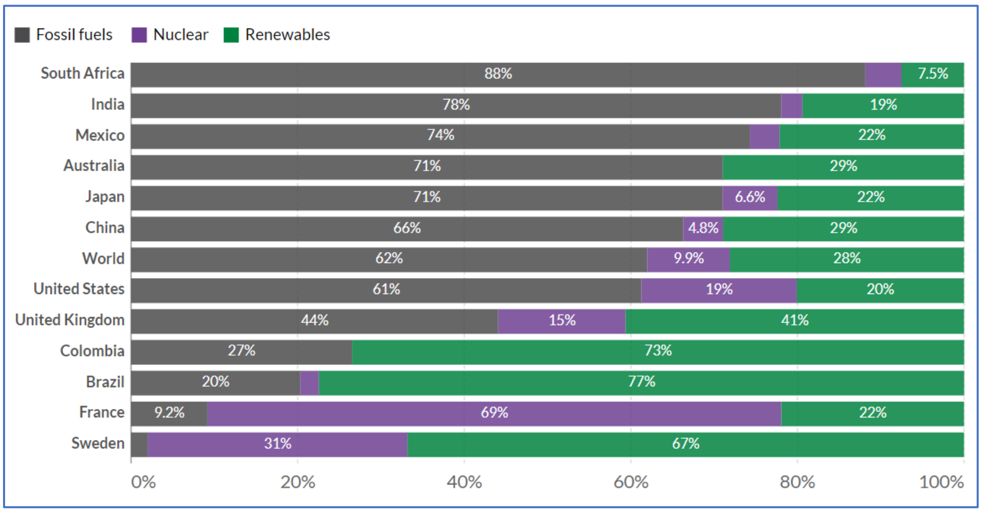

Figure 9: **Electricity mix 2021**[39]

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[35] Majer, S., Oehmichen, K., Moosmann, D., Schindler, H., Sailer, K., Matosic, M., & Reinholz *et al*., T. (2021). REGATRACE D5.1. Assessment of integrated concepts and identification of key factors and drivers. www.regatrace.eu/wp-content/uploads/2021/04/REGATRACE-D5.1.pdf

[36] German Energy Agency/World Energy Council - Germany (publisher) (dena/World Energy Council - Germany, 2022), Global Harmonisation of Hydrogen Certification, Berlin 2022. Retrieved from www.weltenergierat.de/wp-content/uploads/2022/01/dena_WEC_Harmonisation-of-Hydrogen-Certification_digital_final.pdf

[37] German Energy Agency/World Energy Council - Germany (publisher) (dena/World Energy Council - Germany, 2022), Global Harmonisation of Hydrogen Certification, Berlin 2022. Retrieved from www.weltenergierat.de/wp-content/uploads/2022/01/dena_WEC_Harmonisation-of-Hydrogen-Certification_digital_final.pdf

[38] https://www.ideagen.com/thought-leadership/blog/iso-140832023-greenhouse-gas-emissions-in-your-supply-chain

[39] Hydrogen Council, 2021. https://hydrogencouncil.com/wp-content/uploads/2021/01/Hydrogen-Council-Report_Decarbonization-Pathways_Part-1-Lifecycle-Assessment.pdf

In addition, local regulatory frameworks for energy generation, national hydrogen strategies, and different GHG emissions monitoring and reporting mechanism available in different jurisdictions might directly affect the adoption of the hydrogen criteria at a global level. However, Climate Bonds aims to promote criteria that are ambitious enough and that can be implemented globally.

3.5.1 Additional requirements and qualitative criteria

Beyond setting a carbon intensity benchmark, it is crucial to consider important aspects that could affect the performance of a project to be certified as low-carbon under Climate Bonds criteria.

Depending on the production process, feedstock used, decarbonisation measure, and the delivery alternative, specific criteria and qualitative requirements might be necessary. It includes compliance with existing criteria for other sectors for which Climate Bonds developed criteria for. It also includes methane and hydrogen leaks monitoring, detection, and mitigation strategies, and compliance with existing regulations or ISO standards relevant for a specific activity.

3.5.2 Other environmental impacts

The comparative analysis of the different hydrogen production pathways has focused mainly on carbon intensity, efficiency, and costs, nevertheless, some studies have pointed out the relevance of including other environmental impacts, using methodologies such as sustainability assessments, and integrated assessments over the entire value chain.[40] Including these methodologies can be essential for decision-making and prioritising alternatives with lower impacts beyond climate change.

Although Climate Bonds' primary focus is on climate, criteria were set to prevent undesirable side effects on other environmental objectives. The analysis for the criteria setting included existing criteria and standards for hydrogen production addressing them.

- **DNSH Principle:** The EU taxonomy establishes six environmental objectives and considers other impacts by setting qualitative criteria. Activities should comply with the "Do No Significant Harm" (DNSH) principle. Economic activities making a substantial contribution to the first two objectives (mitigation or adaptation) must be assessed to ensure they do not cause significant harm to all remaining environmental objectives (sustainable use and protection of water and marine resources, transition to a circular economy, protections and restoration of biodiversity and ecosystems; and pollution prevention and control).

- **Land Use:** Land use change criteria are implemented in the Renewable Energy Directive II (RED II) for biofuels, not for power fuels. H2Global, ISCC PLUS, and LCFS address land use criteria for power fuels. There are some recommendations on including emissions related to ILUC into hydrogen standards.[41] However, to keep consistency with other industry sector´s criteria developed by Climate Bonds, and avoiding overspecification, the only requirement included in these criteria to address land use is meeting the requirements of the bioenergy criteria on ILUC risks.

- **Water:** Water consumption usually is 10-15 ℓ/kgH_2, which can be supplied with fresh water, desalinated seawater, and wastewater recovery. Nevertheless, electrolytic hydrogen deployment can be affected by water scarcity, which can be critical in specific regions. Fossil-based hydrogen production with CCS also has a considerable water consumption. Al-Qahtani *et al.*, 2021 estimate that its production requires 24 ℓ/kgH_2 using natural gas and 38 ℓ/kgH_2 using coal, which is higher than the amount required for electrolytic hydrogen.[42]

  The RED II and H2Global address excess of water use, and ISCC considers it within its GHG accounting methodology.

  The TWG concluded that water consumption should also be addressed from a sustainability perspective, mainly focused on avoiding excessive water consumption, and not as part of the GHG accounting. Addressing water consumption is critical particularly in regions with water stress or scarcity, thus avoiding water use competition with other essential uses such as human consumption, and agriculture.

  Although it was discussed whether excluding water scarce regions from the criteria, it was decided not excluding specific regions. The proposal is to request a water management plan and a local water availability assessment to demonstrate a

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[40] www.weltenergierat.de/wp-content/uploads/2022/01/dena_WEC_Harmonisation-of-Hydrogen-Certification_digital_final.pdf

[41] World Energy Council, 2022. Report Global Harmonisation of Hydrogen Certification Overview of global regulations and standards for renewable hydrogen www.weltenergierat.de/wp-content/uploads/2022/01/dena_WEC_Harmonisation-of-Hydrogen-Certification_digital_final.pdf

[42] Al-Qahtani *et al.*, 2021 Uncovering the true cost of hydrogen production routes using life cycle monetisation. www.sciencedirect.com/science/article/pii/S0306261920314136

responsible water sourcing and management. Some regions could become water stressed at any point, so it would be uncertain which regions to exclude given the changing dynamics of potential climate impacts. Furthermore, there are some desertic regions, like the Atacama Desert in Chile, with low water availability but with a high potential for hydrogen production implementing seawater desalination technologies, which should be included.

- **Sustainability and social aspects for raw materials sourcing:** Sustainability and social issues related to raw materials sourcing for hydrogen production, including critical minerals, polymers, among others, were highlighted as critical aspects for the sustainable production of hydrogen, however they are out of the scope of these criteria.

  The final criteria proposal to address other environmental impacts included a thorough environmental impact assessment as a component for issuers, to identify and report any potential risks, and relevant plans or measures to address them. This suggestion was thus adopted as it is a reasonable requirement, and many facilities will already have to comply with similar local regulations which enables straightforward reporting.

- **Pollution prevention:** Pollution prevention requirements for hydrogen fossil-based production were included. These requirements imply compliance with best available techniques emissions levels of pollutants, for the specific industrial process.[43]

  In addition, brine management is critical for projects using desalination technologies, aiming to address the potential negative impacts on ecosystems and soil. Compliance with Climate Bonds criteria for desalination plants in the Climate Bonds water sector criteria was included as part of the criteria[44].

4 Criteria Overview

4.1 Eligible assets and projects

The hydrogen production criteria cover:

- Manufacturing or acquisition of electrolysers and membranes for low-carbon hydrogen production.
- Decarbonisation measures or retrofitting activities within facilities producing hydrogen. These criteria apply to specific projects that require investment for the implementation of a specific decarbonisation measure in a facility.
- Facilities producing hydrogen. These criteria apply to the certification of the whole facility for production of low-carbon hydrogen and includes carbon or energy intensity thresholds and additional criteria depending on age of facilities, feedstock and electricity source.
- Criteria for entities producing hydrogen. These criteria cover entities or business segments of a company dedicated to low-carbon hydrogen production.

The hydrogen delivery criteria cover:

- Hydrogen conditioning, including compression and liquefaction.
- Hydrogen transportation, including pipelines (transmission and distribution networks), LOHC (Liquid organic hydrogen carriers), truck and shipping.
- Hydrogen storage.

[43] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0738&from=EN

[44] Climate Bonds Water Criteria. 4.2.2. Desalination projects and assets; and Appendix 1, Section 5. Desalination Plants www.climatebonds.net/files/files/Water%20Criteria%20Document%20Final_100822.pdf

4.2 Mitigation criteria for decarbonisation measures, and specific projects within facilities producing hydrogen

Decarbonisation measures are categorised as follows:

Table 5: Mitigation measures categories

Category	Mitigation measures
Relating to feedstock use	• Using biogas
Relating to electricity source	• Using renewables: Wind, solar, hydropower, geothermal
Various	• Manufacture of electrolysers and membranes • Electrification of processes • Carbon Capture and Storage, Carbon Capture and Utilisation

For each mitigation measure, specific constraints, and requirements to provide consistency and coherence with the decarbonisation goals were set. These requirements for decarbonisation measures are provided in ***Section 3.1*** of the criteria document.

Following section provides further definitions and explanation of these measures as considered in these criteria.

4.2.1 Relating to feedstock use:

- **Biogas from biomass:**

  Eligibility for biomass as a feedstock is restricted to secondary organic streams, (i.e., materials usually discarded or classified as wastes from another primary use, e.g., residues from agriculture, organic matter from agro-industrial processing). The use of primary biomass may lead to increased demand for wood and dedicated energy crops. This can lead to unintended consequences such as an increase in emissions due to increased deforestation, direct and indirect land use change.[45]

  Climate Bonds developed criteria for sustainable biomass sourcing, as part of the bioenergy criteria, thus biomass-based production needs to meet these Climate Bonds criteria.

- **Biogas from landfill sites, wastewater sludge and manure:**

  Anaerobic digestion of manure and sewage wastewater sludge, and landfill gas produce biogas, which is then converted to bio-methane. Biomethane can be used to produce hydrogen throughout the conventional SMR process. Although these hydrogen production pathways can reduce GHG emissions compared to fossil-based production, upstream methane leakages can increase considerably the carbon intensity of hydrogen production.[46] Methane leakage monitoring, reporting, and verification is part of the requirements when using these alternative feedstocks.

4.2.2 Relating to electricity source

- **Renewables energy: Wind, solar, geothermal, hydropower**

  Electrolytic hydrogen using carbon intensive grid electricity might have higher GHG emissions than using conventional processes such as fossil based production without CCS. Thus, the share of renewable energy content in the grid should be enough for electrolysis-based production using electricity from the grid. The criteria do not include a minimum share of renewables, given that a high carbon content of electricity will not allow a project to meet the carbon intensity benchmark.

  Additionality, temporal and geographic correlation: In order to avoid the risk of increasing the fossil-based electricity production by using existing renewable energy generation for hydrogen production, additionality criteria were included. Additionality aims to ensure that renewable electricity used for hydrogen production is additional to the renewable

[45] Jan P.M. Ros, Jelle G. van Minnen, Eric J.M.M. Arets (2013). Climate effects of wood used for bioenergy. PBL Netherlands Environmental Assessment Agency. PBL publication number: 1182 www.pbl.nl/sites/default/files/downloads/PBL-2013-climate-effects-of-wood-used-for-bioenergy-1182_0.pdf

[46] Life-cycle greenhouse gas emissions of biomethane and hydrogen pathways in the European Union .ICCT, 2021. https://theicct.org/wp-content/uploads/2021/10/LCA-gas-EU-white-paper-A4-v5.pdf

generation used to decarbonise the grid electricity for other purposes. Although it could imply administrative burden for issuers, it was included to avoid a negative impact in the whole energy system decarbonisation.

Additionality can be ensured using any of the following approaches[47]:

- Physical link: New renewable electricity generation capacity physically linked to the electrolyser.
- Commercial link: Using a PPA (power purchase agreement) to demonstrate new renewable electricity capacity link to the electrolyser.
- System-wide/ Marginal technology approach: Electricity for hydrogen production would be considered renewable during the time when the renewable energy sources are the marginal technology in the market merit order.

Temporal and geographic correlation between the power generation plant and the hydrogen production facility must be demonstrated, to ensure the renewable character of the electricity used and the use of additional energy. Temporal correlation is a good approach to ensure that renewable electricity to produce hydrogen is additional all time. Nevertheless, it is important to define the frequency of the correlation´s evaluation. On the one hand, a simultaneous approach, hourly evaluation, would ensure compliance of the additionality requirement; however, it could be too strict and set a barrier, especially in some regions, to accelerate the deployment of hydrogen projects. On the other hand, a yearly assessment would facilitate the electrolyser operation at its optimal utilisation rate; however, it could increase the carbon intensity of electricity generation by using different energy mixes.[47]

These criteria propose a time span of one month to evaluate temporal correlation, to facilitate the electrolysers to operate at a better capacity rate and reducing costs. It would promote the deployment of the hydrogen market at early stages by reducing the strict hourly burden. However, this monthly time span will be evaluated on each criteria update and modified accordingly to making it stricter and promoting the decarbonisation of hydrogen production.

Geographic correlation is particularly important when using a commercial link approach. It aims to ensure that there is no congestion impeding that the electricity goes to the electrolyser. It must be ensured that both, electricity generation and electrolysers, are in the same network.

- **Nuclear energy**

Although Climate Bonds have not yet developed criteria for nuclear energy generation, the TWG acknowledges the role that nuclear energy can play in producing low-carbon hydrogen. From a mitigation perspective, it is an important alternative; nevertheless, it is critical to consider potential risks associated with safety and nuclear waste management, which will be addressed from the Adaptation and Resilience Risk criteria.

4.2.3 Various

- **Manufacturing and acquisition of electrolysers and membranes**

Because of the critical roles of electrolysers in developing the industry, manufacturing and acquisition of these are automatically eligible under the mitigation criteria. However, the adaptation and resilience requirements need to be met to be certified.

- **Electrification of processes**

This measure implies a shift from providing process heat by fossil fuel combustion and using electrified equipment instead. Examples include innovations in steam boilers, using an AC current and direct electrical resistance to heat the reactors. Renewable electricity should be used to reduce emissions. Implementing this technology could reduce around 1% of global CO_2 emissions[48].

[47] Pototschnig, 2021. https://cadmus.eui.eu/bitstream/handle/1814/72459/PB_2021_36_FSR.pdf?sequence=1&isAllowed=y

[48] Sebastian T. Wismann, Jakob S. Engbæk, Søren B. Vendelbo, Flemming B. Bendixen, Winnie L. Eriksen, Kim Aasberg-Petersen, Cathrine Frandsen, Ib Chorkendorff, Peter M. Mortensen (2019) "Electrified methane reforming: A compact approach to greener industrial hydrogen production" *Science* Vol. 364, Issue 6442, pp. 756-759 doi: 10.1126/science.aaw8775

A rather more advanced and accessible technology applicable in low to medium temperature processes is the use of electric heat pumps to recover and provide process heat. With this measure, up to 67% reduction in process emissions can be achieved and the use of fossil fuels is avoided[49]. This reduction can be increased when renewable power is used to run the heat pump.

- **Carbon Capture and Storage**

This is the process of capturing (separating from dilute sources), transporting and storing CO_2 in order to prevent its release into the atmosphere. Carbon dioxide storage can be in open, closed or cycling systems[50]. Open systems include natural systems such as in biomass growth and soil. Closed systems include the geological storage in lithosphere or deep oceans and mineral formations. Cyclic systems include the conversion of CO_2 into fuels or chemicals, this form is also known as carbon capture and utilisation (CCU). For the purposes of this criteria document, CCS refers specifically to closed systems as in geological storage since this is the one with the largest storage life span[51]. Biomass and CCU are defined and addressed separately under the measures of using biomass or biomass derived feedstock and using CO_2 as feedstock, respectively. Emissions from carbon capture must be included in the emissions from the conversion plant.

Hydrogen produced from natural gas resources can have high methane emissions due to methane leakages. Methane leakages may occur during the reforming process. Also, upstream methane leakages can be in the order of 20%, based on observed measurements during fossil gas extraction and distribution[52]. Thus, projects using fossil gas combined with CCS should demonstrate MRV (monitoring, reporting and verification), and mitigation measures for methane leaks[53]. Upstream methane emissions must be of maximum 0.2%[54]. Shell set a methane emissions target of 0.2% by 2050. Likewise, country members of the global methane alliance have an intensity target of 0.25% or below.

- **Carbon Capture and Utilisation**

Carbon capture and utilisation (CCU) includes the use of captured CO_2 as a raw material. The major sources of CO_2 considered in this measure include flue gases, industrial off-gases, which requires concentration and purification of CO_2 using carbon capture processes. CO_2 can then be converted into hydrogen through electrochemical or catalytic synthesis. Care should be taken regarding the end use of the product generated from CO_2. This is mainly because if the CO_2 is immediately released into the atmosphere during end product use, the mitigation is ephemeral. This means, additional restrictions are included for the end product, which should be a long-lasting or recyclable product so as to keep CO_2 in a loop.

- **Research & Development Projects**

The Climate Bonds Standard includes certification of R&D projects. To be eligible, relevant research and development expenditure at advanced stages must have clear and measurable climate-related goals, such as emissions or energy reduction potential. Early-stage projects must present a detailed climate benefits plan and be assessed periodically.

The low-carbon hydrogen industry is nascent and relies on new technologies and innovation projects, which are still under development and need to be financed. Thus, promoting finance for R&D projects is critical to enhance the sector's development.

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[49] De Boer, R., Marina, A., B. (2020) Zühlsdorf Strengthening Industrial Heat Pump Innovation. Decarbonizing Industrial Heat. www.sintef.no/globalassets/sintef-energi/industrial-heat-pump-whitepaper/2020-07-10-whitepaper-ihp-a4.pdf

[50] Hepburn, C, Adlen, E, Beddington, J *et al*. (2019) The technological and economic prospects for CO_2 utilisation and removal. Nature, 575 (7781). pp. 87-97. ISSN 0028-0836

[51] According to the IPCC, well-selected, well-designed and well-managed geological storage sites can maintain CO2 trapped for millions of years, retaining over 99 per cent of the injected CO_2 over 1000 years. IPCC Special Report on Carbon Dioxide Capture and Storage, www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf

[52] ICCT, 2021. https://theicct.org/wp-content/uploads/2021/10/LCA-gas-EU-white-paper-A4-v5.pdf

[53] Additional guidance can be found in the report Best Practice Guidance for Effective Methane Management in the Oil and Gas Sector. Monitoring, Reporting and Verification (MRV) and Mitigation. United Nations Economic Commission for Europe. 2019 https://unece.org/fileadmin/DAM/energy/images/CMM/CMM_CE/Best_Practice_Guidance_for_Effective_Methane_Management_in_the_Oil_and_Gas_Sector__Monitoring__Reporting_and_Verification__MRV__and_Mitigation-_FINAL__with_covers_.pdf

[54] The Global Methane Alliance country members committed to reduce emissions from the oil and gas sector in 0,2% in their NDC. Also, Shell, set a methane target of 0,2% by 2025 from its oil and gas assets. www.ccacoalition.org/en/activity/global-methane-alliance; https://safety4sea.com/why-shell-has-set-a-methane-emissions-target-of-below-0-2-by-2025/

4.3 Mitigation criteria for assets or facilities producing hydrogen

The following sections elaborate on the elements of the mitigation criteria for production facilities.

4.3.1 Carbon intensity benchmark

To be eligible for certification, facilities producing hydrogen must meet specific emissions intensity thresholds provided in the Hydrogen Criteria document. During the TWG meetings, some of the existing standards and carbon intensity benchmarks for hydrogen production were discussed. The CertifHy guarantee of origin scheme set a $4kgCO_{2e}/kgH_2$ carbon intensity limit. The US benchmark for low-carbon hydrogen is also $4kgCO_2e/kgH_2$. The EU taxonomy set a $3kgCO_{2e}/kgH_2$ carbon intensity benchmark, and the Green Hydrogen Standard a $1kgCO_2e/kgH_2$. The

Table 6 below shows some of the main existing standards and their system boundaries.

Table 6: Main existing standards for hydrogen production

	CertifHy	The US standard	Green Hydrogen Standard	EU Taxonomy	UK Low carbon Standard	TÜV SÜD CMS70	Climate Bonds
Description	Guarantee of origin scheme	National Standard	Global standard	Classification system	National Standard	Industry standard	Sustainable finance standard
Geographic level	EU Level	US National level	Global	EU Level	UK National level	EU	Global
Criteria approach	• Green hydrogen criteria. • Low carbon criteria. • Same GHG threshold.	• Clean hydrogen criteria. • GHG threshold regardless of the technology.	• Green hydrogen criteria. • Other renewable non-fossil sources on a case-by-case basis.	• Low-carbon criteria. • GHG threshold regardless of the technology	• Low-carbon criteria. • GHG threshold regardless of the technology	• Green hydrogen criteria • GHG thresholds regardless of the technology.	• Low-carbon criteria. • GHG thresholds regardless of the technology. • Specific climate mitigation requirements.
System boundary	Cradle-to-gate.	Cradle-to- gate.	Cradle-to- gate.	Life cycle emissions.	Cradle-to- gate.	Cradle to site (cradle to gate plus transportation emissions).	Cradle to site (cradle to gate plus transportation emissions).
GHG Emissions criteria	< 4,3 kg CO2e/kg H2	4.0 kg CO2e/kg H2	1.0 kg CO2e/kg H2	< 3.0 kg CO2e/kg H2	2,4 kg CO2e/kg H2 (20 gCO2/MJLHV)	3,5 kg CO2e/kg H2 (from the REDII in the EU)	3,0 kg CO2e/kg H2 (Sliding scale target)
GHG Calculation methodology	• ISO 14044 • ISO 14067	• ISO 14044 and • aligned with the IPHE methodology	• IPHE Methodology with some modifications	• EU Directive or • ISO 14067: 2018(119) or • ISO 14064-1: 2018(120).	• ISO 14040 • ISO 14044 • ISO 140672 • GHG Protocol	• EU Directive • ISO 14040 • ISO 14044 • ISO 140672	• EU Directive • ISO 14040 • ISO 14044 • ISO 140672

The TWG concluded that $4kgCO_2e/kgH_2$ is not ambitious enough for projects to be aligned with the Paris agreement. In order to be ambitious but not so restrictive to limit the deployment of the hydrogen market at early stages, the TWG defined adopting a below $3kgCO_2e/kgH_2/kgH_2$ emissions limit as a point for projects today, using a cradle-to-site plus delivery emissions system boundaries. It is an ambitious, technologically feasible, and compatible target that allows different production and delivery pathways combinations to meet the total emissions intensity required. A detailed analysis of the life cycle emissions of several fossil gas-based hydrogen with carbon capture configurations has been studied by Bauer, et.al 2022. See figure below.[55] According to it, the target can be achieved for fossil-based production combined with CCUS with a minimum capture rate of 93% and a maximum methane

[55] Bauer *et al*, 2022. https://pubs.rsc.org/en/content/articlehtml/2022/se/d1se01508g

leakage rate of 0.2%. Because the numbers in the graph do not include emissions from hydrogen transportation, it can be assumed that local demand or short-distance transportation alternatives using renewables are a good option, mainly to decarbonise existing demand.

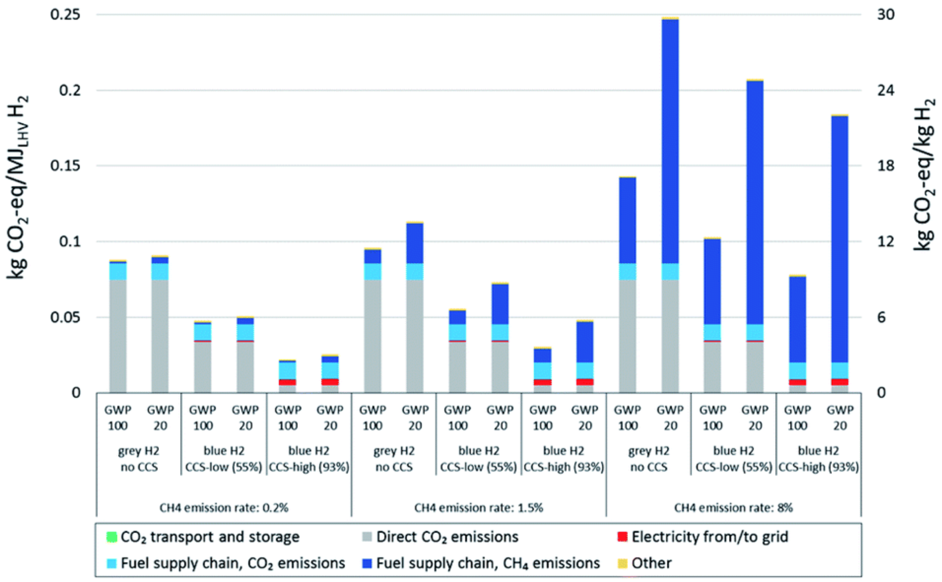

Figure 10: Impacts on climate change associated with the production of NG-based hydrogen with methane emission rates of 0.2%, 1.5%, and 8%, and two plant configurations with high and low CO2 removal rates, applying both GWP100 and GWP20.55

For renewable based projects, production emissions can be lower than 1.0 $kgCO_2e/kgH_2$, so there is more room for conditioning, conversion, and transportation emissions.[56]

According to Ortiz Cebolla *et al*.[57], depending on the inlet pressure, the energy requirements for compressing can vary from 3 to 30 MJ/kg H_2, which means 0.4-3.6 $kgCO_2e/kgH_2$. For liquefaction, an ideal operation has an energy consumption of 14.4 MJ/kgH_2, which is approx. 1.7 $kgCO_2$ e/kgH_2. Scaling up liquefaction plants will reduce emissions to 2.2-2.6 $kgCO_2$ e/kgH_2.

The emissions of an average transport cycle (i.e., a combination of diesel and electric compressors) for a hydrogen transport distance of 1200 km are in the order of 0.58 $kgCO_2e/kgH_2$. For 402 km, it is 0.19 $kgCO_2e/kgH_2$.[58] It can be significant, depending on the production pathway selected. If renewable power is used for hydrogen delivery activities, the operating emissions can be eliminated.

4.3.2 Emissions reduction trajectory

According to the IEA, Irena, and High-Level Champions hydrogen production emissions must trend towards near zero by 2050. Climate transition action plans are essential to guide investors in defining whether plans are credible and compliant with reduction targets. When selecting a pathway, it must be compatible with the 1.5°C global warming relative to the pre-industrial level target over time. Mitigation pathways are a guide to estimate the rate of emissions and carbon intensity reductions needed to achieve a specific target global average temperature rise by a certain year. Thus, the projection of decreasing threshold values was performed to ensure that assets and activities included in the use of proceeds contribute to the 1.5°C target. Numerous end-to-end hydrogen production pathways depend on the selected energy source, conversion technology, and transport method. The adopted benchmark sets a sliding scale target, which reduces over time. Because the goal is to reduce emissions towards near zero, lower thresholds were proposed by 2030, 2040, and 2050 to guide investors and industry. The criteria include the emissions reduction trajectory for fossil-based production assets for facilities certification. It is recommended to follow the trajectory for facilities using other production pathways, such as renewable-based production, which already have a low-emissions intensity.

[56] Emissions intensity does not include emissions from the manufacture of turbines, solar panels, or materials for the production of renewable energy, neither for the production of tanks, pipelines, trucks and ships.

[57] Ortiz Cebolla, R., Dolci, F. and Weidner, E., Assessment of Hydrogen Delivery Options, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/869085, JRC130442. https://publications.jrc.ec.europa.eu/repository/handle/JRC130442

[58] MIT Energy Initiative's SESAME platform

Still, it is not a requirement for these facilities to avoid over-specification. For entities, the trajectory should apply regardless of the production pathway, given that having a decarbonisation pathway towards 2050 is a common practice for companies today, and Climate Bonds want to incentivise it.

Table 7: Hydrogen carbon intensity thresholds

Asset Type	Criteria			
	2023[59]	2030	2040	2050
Production and delivery of hydrogen	3,0 $kgCO_2e/kgH_2$	1.5 $kgCO_2e/kgH_2$	0.7 $kgCO_2e/kgH_2$	0 $kgCO_2e/kgH_2$

The benchmarks in Table 7 take into consideration an analysis of the technologies that should be disincentivised in a near-zero trajectory. The estimations made and illustrated in the graph below, by the Hydrogen Council, can be used as a reference. CAPEX emissions should not be included to be able to compare with the targets in the graph. As mentioned above, the hydrogen production emissions benchmarks can be met by different energy sources and technology options. The 3$kgCO_2e/kgH_2$ carbon intensity limit can be achieved via natural gas reforming with CCS, mainly for on-site demand or local consumption without transportation emissions. Also via electrolytic hydrogen production including transportation emissions. For the natural gas with CCS path, at 90% carbon capture rate, the upstream methane leakage should be below 0.45%. At 95% carbon capture rate, up to 0.75% upstream methane leakage rate will be tolerable.[60] For electrolytic pathway the carbon intensity of the electricity supply should be below 62 gCO_2e/kWh, which is equivalent of having a power system with at least 90% generation from zero carbon options such as solar, wind, hydro and nuclear and the remaining 10% is an average fossil gas combined cycle plant. 1.5 $kgCO_2e/kgH_2$ can be met by 2030 with either electrolytic hydrogen powered by an electricity supply of 31 gCO_2e/kWh carbon intensity or with fossil gas pyrolysis with 0.7% upstream leakage rate. It implies having strict methane leakages mitigation and monitoring mechanism. By 2040, fossil-based production should be disincentivised and renewable based production should be the focus of hydrogen production. To meet 0.7 $kgCO_2e/kgH_2$ and 0 $kgCO_2e$/kgH2, electricity supply should be 98% zero carbon by 2040, and 100% zero carbon, by 2050 respectively. These pathway carbon intensity values are estimated by MIT Energy Initiative's SESAME platform[61] to provide examples. An analysis of various pathway options can be found in the recent NETL report[62] and Hydrogen Council's report.[63] If renewable energy sources are used to supply the energy required for conditioning, conversion operations, road and maritime transportation, emissions targets should be achieved.

[60] Gencer *et al*, 2020. https://www.sciencedirect.com/science/article/pii/S030626192031062X

[61] https://sesame.mit.edu

[62] National Energy Technology Laboratory, 2022. https://netl.doe.gov/projects/files/ComparisonofCommercialStateofArtFossilBasedHydrogenProductionTechnologies_041222.pdf

[63] Hydrogen Council, 2021. https://hydrogencouncil.com/wp-content/uploads/2021/01/Hydrogen-Council-Report_Decarbonization-Pathways_Part-1-Lifecycle-Assessment.pdf

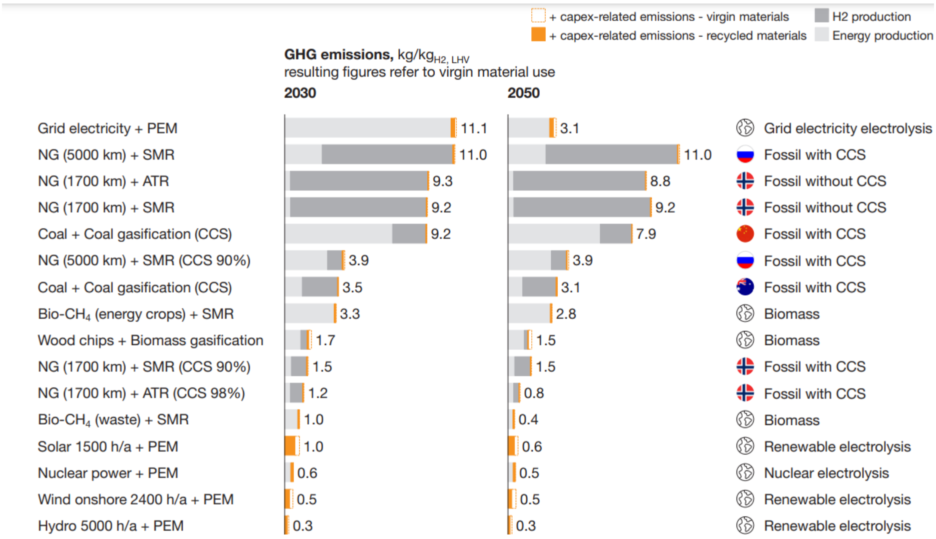

Figure 11: Carbon-equivalent emissions by hydrogen production pathways, 2030 and 2050[63]

The figure below shows some potential production pathways and delivery alternatives that meet the proposed carbon intensity benchmarks overtime, according to the explanation above.

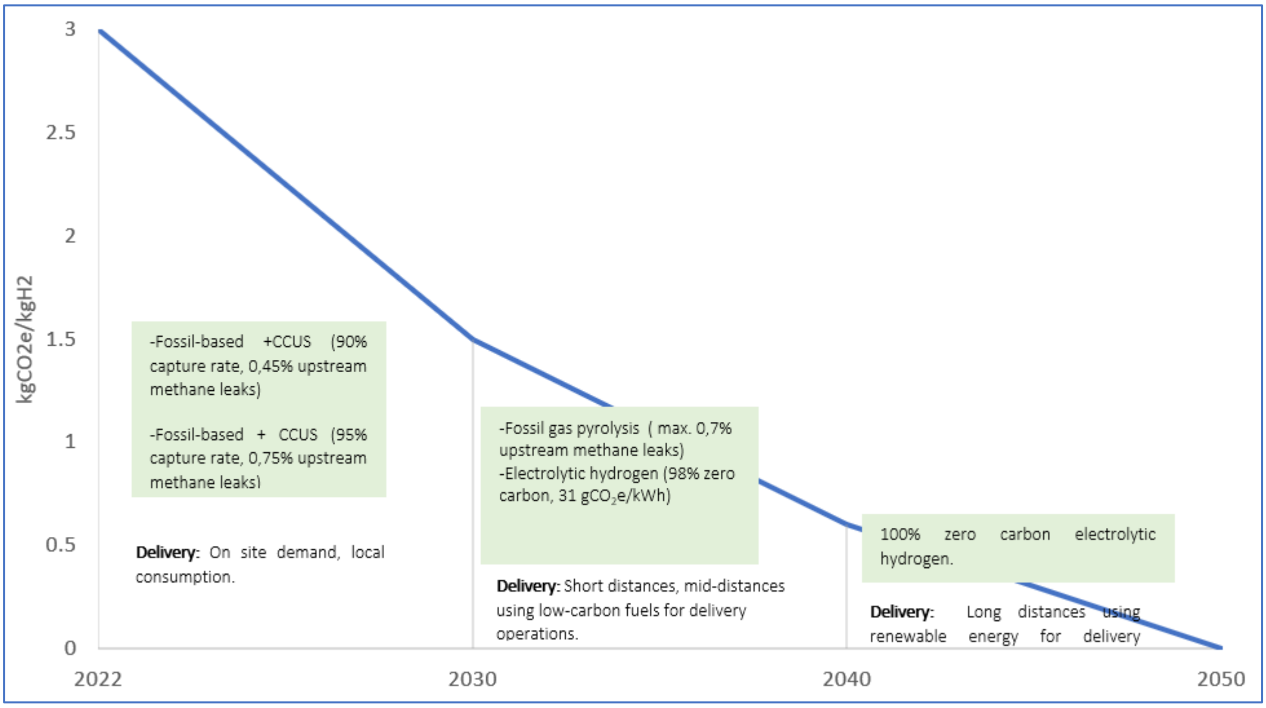

Figure 12: Example of technologies to reduce emissions from hydrogen production towards net zero by 2050.

4.3.3 Cross cutting criteria for decarbonisation measures and retrofitting activities

- **Additional criteria depending on the age of the facility**

  In setting the criteria, it was important to differentiate between existing operating assets which are transitioning towards low-carbon production processes, and those financed as brand-new assets. Brand-new assets may be standalone facilities and outside boundary limits of existing facilities, or they can be new production trains integrated into existing facilities (thus, not necessarily green field developments).

  Although criteria apply to both types of facilities, there are additional requirements set depending on the age of the facility, as shown in the criteria document. There are two main reasons for this: to prevent carbon lock in and ensure emissions reduction over time and prevent stranded assets. In order to reduce potential lock-in risks related to the use of fossil resources for the production of hydrogen, new facilities can use fossil resources only if combined with CCS or CCU technologies until 2035.

- **Additional criteria depending on the feedstock used**

  These additional criteria refer to criteria set for the capital investments used for implementing decarbonisation measures including the use of hydrogen, biomass, and energy from alternative sources, and to the Climate Bonds most up to date criteria for each source of energy. Coal based production is excluded to avoid potential carbon locking risks, and other environmental impacts related to coal. Nuclear based production is excluded because of the lack of criteria for nuclear energy generation.

- **End-uses exclusions**

  Regarding end-uses, which sector should be prioritized and how to define it is still under discussion. Allocating resources to projects with an ambitious mitigation potential should be part of the role of sustainable finance and the green bonds market. There are two main perspectives. On the one hand, the lack of hydrogen end-uses restrictions could promote the use of hydrogen in sectors that have more efficient decarbonization pathways. In that sense, end-uses such as urban heating, light mobility and electricity storage are part of the criteria exclusions. On the other hand, end-uses can be defined by the market further development. Also, for some sectors, such as steel, basic chemicals and shipping there are already criteria for alternative fuel and feedstocks, which includes hydrogen. Thus, the use of hydrogen for these sectors should be defined for each specific sector criteria.

4.4 Mitigation Criteria for Hydrogen Delivery Projects

Multiple combinations of production, delivery pathways operations, technologies, and delivery ways make the hydrogen value chain complex. There is no specific delivery alternative that best fits all hydrogen projects. Each project has its own particularities; thus, setting criteria is challenging. Some carriers can be the preferred option depending on the distance, the hydrogen flow, the infrastructure and resources for reconversion at the end-use point.

Some aspects need to be considered to define the criteria for hydrogen delivery projects and investment. The energy consumption, carbon footprint, and safety considerations are critical when defining low-carbon and certifiable projects. Setting emissions intensity benchmarks should also be part of the criteria to certify hydrogen delivery and infrastructure projects to avoid affecting the low-carbon definition of hydrogen production. The Climate Bonds hydrogen production criteria include transport emissions as part of the GHG accounting system boundary. However, there is still a lack of guidance on methodologies to quantify these emissions and set a benchmark for each delivery pathway. The IPHE methodology is expanding its work to cover transportation emissions. The GH2 alliance is also developing a methodology to account for transportation emissions. However, due to the lack of a specific methodology today, the Climate bonds criteria adopted the ISO standards, and set as a main requirement demonstrating that delivery projects will be used only for low-carbon hydrogen purposes. Thus, a transporter needs to involve the hydrogen producer to present its hydrogen production emissions intensity or a low-carbon hydrogen certificate.

If a chemical carrier is used, its emissions intensity needs to be included in the GHG accounting as well.

Further, potential leaks across the value chain should not be overlooked. Leak monitoring and mitigation should not be only for methane. A recent study from a group of researchers at the University of Cambridge highlights the warming effect impacts of hydrogen emissions and some air quality implications.[64] However, specific methods and technologies for monitoring these emissions need to be defined. There is a company working on hydrogen detection sensors, which would be critical for accurate GHG accounting and avoiding economic losses. Potential certification of the manufacture of this kind of equipment should be discussed.

Transport distance is another influential factor. It affects the hydrogen pressure, temperature, and fuel requirements. Although long transport distances should not be encouraged, it is necessary to evaluate to which extent these aspects can be part of criteria, standards, and certification schemes or if it is more convenient to address them from a policy point of view. In the meantime, the Climate Bonds criteria will not set a distance limit. Instead, the compatible emissions intensity must be met. In addition, for road and maritime hydrogen transportation, the existing low-carbon transport and shipping criteria developed by Climate Bonds can be adopted.

For addressing safety, the Climate Bonds criteria adopted the ISO/TR 15916:2016, "Basic considerations for the safety of hydrogen systems".

[64] Warwick *et al.*, 2023. https://acp.copernicus.org/preprints/acp-2023-29/

4.5 Mitigation Criteria for entities and Sustainability Linked Debt (SLD)

The criteria for entities and SLDs are based on the [Climate Bonds Standard v4.0](). However, entities working on hydrogen production and delivery are diverse. These can be oil and gas companies, renewable energy companies, electricity utilities, infrastructure companies, gas network operators, transport companies, and storage facilities operators. The main requirement for them is demonstrating that their operations are focused on low-carbon hydrogen that meets the emissions intensity benchmark at the time of certification and in the future.

Hydrogen production companies must commit to an emissions reduction trajectory towards close to net zero by 2050. For entities focused only on hydrogen delivery projects, it is more challenging to reduce emissions aligned with a specific trajectory; it will depend to some extent on their hydrogen supplier. Because of that, the principal certification requirement is ensuring that their operations will be dedicated only to low-carbon hydrogen. Fossil gas delivery must not be part of their operations.

4.6 Criteria for adaptation & resilience

4.6.1 An overview of the criteria for adaptation & resilience

Potential risks associated with climate change include negative impacts on capital assets, transport and raw materials availability difficulties, productivity, and safety problems[65]. Potential risks include negative impacts to capital assets, transport and raw materials availability difficulties, productivity and safety problems. This section describes the Adaptation & Resilience (A&R) Component of the eligibility Criteria for assets and projects under the Climate Bonds Standard. This component of the Criteria views the potential climate adaptation and resilience impacts/benefits of the Hydrogen sector as inextricably linked to a broad range of environmental and social issues and proposes to assess these in the round.

Section 4.6.2 below describes the scope of this component in terms of the key factors that need to be assessed to ensure that Certified Climate Bonds are delivering on key climate outcomes in line with the overall objectives of the Standard. ***Section 4.6.3*** describes practical aspects of this component, to ensure that any transaction burden for issuers is minimised, while maintaining rigour and robustness in assessment. ***Section 4.7*** describes existing tools. The Adaptation and Resilience Component of the Hydrogen Criteria balances the needs for assessments while leveraging existing tools where appropriate.

4.6.2 Key aspects to be assessed

Climate adaptation and resilience mitigation criteria are designed to ensure that a project itself is resilient to climate change and that it does not affect the resilience of other sectors. The development of the requirements for the A&R component was based on Climate Bonds "Climate resilience principles" document[66]. Figure 6 gives an overview of the six principles for resilience.

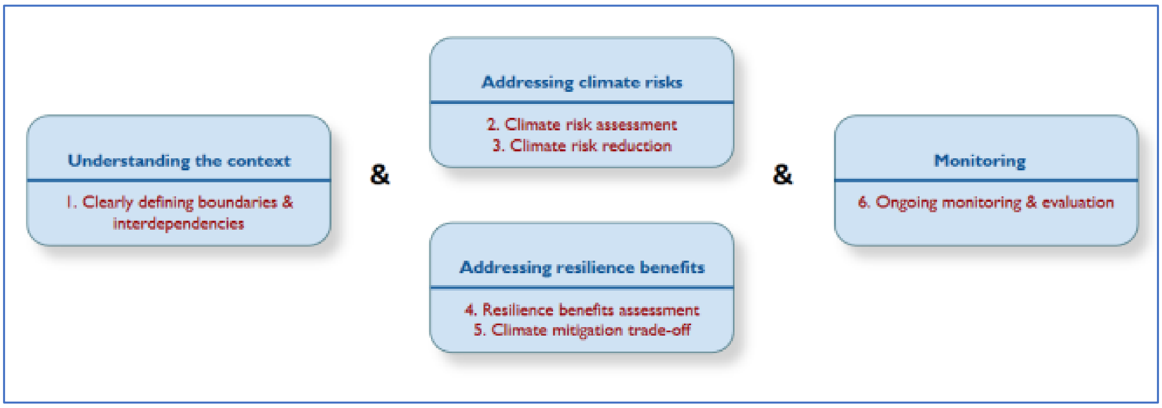

Table 8: The Climate Bonds principles for Resilience

[65] Lux Research (2020). In the Path of Destruction: Preparing for Global Climate Change in the Chemical Industry. https://members.luxresearchinc.com/research/report/36147

[66] Climate Bonds Initiative (2019). Climate Resilience Principles. A framework for assessing climate resilience investments. www.climatebonds.net/climate-resilience-principles

Although the principles provide a framework and serve as guidance for general aspects to consider, it is also recognised the challenges and limitations to assess the adaptation and resilience aspects in general. Such limitations include the lack of awareness of climate resilience benefits and a common language, robust data on climate risks and common methodologies for climate risk assessment, lack of capacity and interdependencies with other assets or actors in the supply chains. It is also acknowledged that A&R has inherent complexities which makes it harder to quantify and it can be very context specific, depending not only on location but also on the type of asset, the type of risk looked at, the level of severity and frequency of the risk, and so on. The frequency and magnitude of the impacts are commonly underestimated by companies.

Because hydrogen is a basic chemical, the adaptation and resilience developed by the basic chemicals working group apply for hydrogen production projects and assets.

- **Location**: Appropriate geographic or other spatial boundaries for climate risk and benefits assessments for assets and activities in the sector was discussed as well as consideration of the broader system affected by those assets and activities. There are expected internal and external interdependencies between assets or activities in a given sector and between sectors (which become evident when a climate event results in a potential failure of value chains) but there can also be opportunities to maximise resilience benefit.

Key infrastructure dependencies were identified with special relevance for the chemicals sectors including water (which is as process raw material, cooling agent and in cleaning), gas, energy, and other key utilities necessary to run the processes and keep the adaptation and resilience equipment and infrastructure operating during any outage arising from climate change events. All these infrastructure dependencies are to be included in the production element.

- **Timeframes**: Appropriate time horizons for climate resilience assessments need to be set for the assets and activities in scope. The criteria to base the time horizon for the assessments are set based on the typical lifetimes of assets in the chemicals sectors which is 30 years on average (though it is recognised that some may last for 50 years or more).
- **Hazardous substances**: Criteria include a classification of geographies according to the level of risk. This can be determinant to certify a project or not. Risk assessments are routinely conducted by insurance companies. They include type of risk, the probability and the magnitude of the impact. In addition, a timeline of when risks could occur is required (identify zones prone to floods, storms, etc). The assessment should be preferably based on local models and data, but it can also be more regional or global. Again, the level of detail may depend on the types of risks.
- **Disclosure**: As part of the monitoring and evaluation principle, there are requirements for reporting and disclosing risks assessments. Currently there are a number of issued seen:
    - a lack of alignment or harmonisation as reporting is often undertaken on a voluntary basis
    - the level of completeness can be low which leads to accusations of greenwashing
    - the frequency for reporting and updating the assessment varies (recognising that the time horizons for revisiting the assessments will likely depend on the level of risk of a facility: low risk facilities can have long time horizons, and high-risk facilities short time horizons). Depending on the severity of the risk the time horizon can be set.

  Other aspects to consider when setting the A&R requirements are listed as follows:
- **Identification of the key climate risks** - including hazards, exposures, and vulnerabilities - likely to be experienced by assets and activities in that sector The U.S. Chemical Safety and Hazard Investigation Board document is an example of guidance to reference when assessing risks. Some insurance companies, such as FM global, can also be a useful source of data for risk assessments.
- **Models, methodologies and data sets** that would be most appropriate for determining likely physical climate risks to be faced in context for activities and assets in that sector
- **Climate change risk measures and metrics** for assets and activities in that sector - e.g. how should assets and activities deal with these risks? How this could be evaluated?

  Based on the discussions presented above, the assessment methodology includes a verification list that the verifier should complete when assessing an asset or project. It is recognised that this may not be complete, but is presented as the most robust available, given the complexities and several angles of the topic, and the lack of robust and more quantitative methodologies and tools. In setting such verification lists, documentation from Lux Research and guidelines from the UK Chemical Industry Association[67], and Dale (2021)[68] were taken as key references.

- **Wider environmental and social risks** are complex and interconnected and should be assessed under these Criteria, however the following points are noted:

  The Climate Bonds Standard is focused on climate impacts - including low GHG-compatibility (mitigation) and also climate adaptation and resilience. Defining resilience can be challenging. However, it is clear that many topics which have been a part of environmental and social assessments for a number of years overlap significantly with the resilience of affected populations and ecosystems and their ability to adapt to climate change.

  The most obvious example is the potential impact of climate change on hydrological conditions, and consequently water supply and local livelihoods. Another is climate change exacerbating ecological problems such as impaired species migration and algal blooms. Environmental and social impacts such as these, already complex and interconnected, become more so when climate change impacts and risks are taken into account, and there is a logic to addressing all key environmental factors, rather than trying to separate them out.

  The Climate Bonds Standard does not usually address primarily social impact issues, these were discussed but not considered within scope.

4.6.3 Practical requirements for this Component

- **Leverage existing tools**

  The knowledge and literature on adaptation and resilience impacts of the hydrogen facilities, and the chemicals sector in general, is limited as this area is in its infancy. The A&R Component will require consideration of a highly complex and varied set of issues across the environmental and social spectrum for which data, methodologies and metrics may not be available. Qualitative methods based on verification lists or questionnaires have been proposed which can however be leveraged. It is not appropriate for Climate Bonds to commit resources to address these issues, and the guiding principle of simplicity shall be applied at this time. More robust criteria can be developed over time as more information is generated and integrated in the subsequent revisions of the Criteria.

  However, it should be noted that existing methods do not always fully or explicitly cover the additional, often interrelated impacts connected to climate adaptation and resilience. Many of the risk assessments and management processes specified by existing ES guidelines will be a prerequisite for identifying A&R risks, but more may be needed to fully address them given that this is an emerging topic.

- **Minimise the assessment burden**

  In addition, there needs to be a balance between rigour and practicality. Any Criteria with a prohibitively expensive assessment burden will discourage certification. Any methodology adopted therefore need to avoid this.

- **A binary 'pass'/'fail' outcome rather than scores or grades**

  Certification decisions under the Climate Bonds Standard are binary - applicants are either certified or not. Therefore, the A&R Component needs to be framed in terms of pass/fail thresholds. Where an assessment tool provides scores or grades for a facility, consideration has been given to what threshold 'score' or result should represent a pass for the purposes of Climate Bonds Certification.

- **Retrospective application**

  Finance raised in this sector may be for new, greenfield facilities, for retrofits or upgrades to existing facilities, or they may be a straight refinancing of an existing facility. Therefore, any proposal and associated approved assessment tool under this Component needs to be usable for both new and existing facilities.

  This is not a straightforward issue; as in the case of refinancing, the facility may have been operating for a number of years. It may have been compliant with best practices in place at the time of its implementation but may not meet current best

[67] Chemical Industries Association (2015). Safeguarding chemical businesses in a changing climate. How to prepare a. Climate Change Adaptation Plan. www.cia.org.uk/LinkClick.aspx?fileticket=KW8WF8CBZG0%3D&portalid=0

[68] Dale, S.(2021). Disaster Planning: Improve Your Plant's Resilience. Become more proactive in dealing with acute and chronic natural disasters. ChemicalProcessing.com. www.chemicalprocessing.com/articles/2021/disaster-planning-improve-your-plants-resilience/

practice requirements. The selected methodology and tool will therefore need to be able to address and resolve any 'legacy issues' that may be identified.

4.7 Existing tools and guidelines considered

A range of existing tools and guidelines with the most potential to be leveraged for the Hydrogen Criteria are listed below, with a brief indication of whether they were taken forward for further consideration or not.

Risk Assessment and Climate Scenarios

- The ISO 14091:2021 Adaptation to climate change - Guidelines on vulnerability, impacts and risk assessment standard offers guidelines for assessing the risks related to the potential impacts of climate change.69
- Risks can be characterised by the associated annual probability of failure or annual costs of loss or damage
- For risk assessment, the TCFD The Use of Scenario Analysis in Disclosure of Climate Related Risks and Opportunities is recommended.
- A broad range of models can be used to generate climate scenarios. Users should apply climate scenarios based on representative concentration pathway (RCP) 4.5 and 8.5 or similar / equivalent to ensure consideration for the worst case scenario. (The IPCC 'Shared Socioeconomic Pathways' to develop potential temperature scenarios. SSP5-8.5 is the highest warming pathway, SSP3-7.0 the second highest and so on).
- The IPCC Sixth Assessment report also provides an indication as to how different temperatures impact the likelihood and severity of different climate impacts
- A framework for risk management for climate security. www.c2es.org/document/degrees-of-risk-defining-a-risk-management-framework-for-climate-security/
- Climate Change Risk Assessment Guidelines. www.ctc-n.org/system/files/dossier/3b/D4.2%20Climate%20change%20risk%20assessment%20guidelines.pdf

[69] www.iso.org/standard/68508.html

Appendix A: TWG and IWG members

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Gabriela Nascimento da Silva Hydrogen consultant	KfW (the development bank of Germany)	**Marta Lovisolo** Advisor on Renewable Energy Systems	Bellona Europa
Giuseppe Bianchi Senior Professional in Innovation and Decarbonisation	Independent. Former IEA analyst	**Patrick Molloy** Manager Breakthrough Technologie	Rocky Mountain Institute (RMI)
Gniewomir Flis Associate, Senior Advisor Hydrogen	Energy Revolution Ventures	**Rachel Fakhry** Green Hydrogen Sector Lead	Climate Champions. Race to zero UNFCCC
Joe Powell Director Energy Transition Institute	University of Houston	**Zainab Datti** Technical Advisor	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Zaffar Hussain Project Lead PtX Africa	Agora Energiewende		
Additional experts consulted:			
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Sarah Torkamani Environmental and energy policy expert	Independent		
Graeme Sweeney Chair of the Advisory Council	European Technology Platform of Zero Emission		

IWG Members	
CWP Global	Institutional Investors Group on Climate Change (IIGCC)
Bureau Veritas	JCRA (Japan Credit Rating Agency)
Carbon Trust	Kawasaki Heavy Industries
China Hydrogen Alliance	Mizuho International
Eletrobras	NSW | Point Advisory an ERM Group Company
Hydrogen Brazil	Rubicola Consulting
Hydrogen Europe	Snam
IFA (International Fertilisers Association)	Socalgas
IHI Corporation	Sustainalytics