Comparing hydrogen using emissions intensity rather than colours

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1. Summary

The use of colours to describe different forms of hydrogen production is common and easy to understand. The colours are, however, not designed as a tool to objectively compare the merits of the production routes they represent. There is potential for misleading assumptions, inconsistencies in use, and for the definitions of what the colours represent to vary and lack precision. Classification of hydrogen based on its carbon emissions intensity is an alternative, technology-neutral approach, seen in hydrogen policies and certification schemes that are emerging internationally. It has advantages over using colours – it is transparent, demonstrates low carbon credentials and if used internationally could limit market fragmentation and support trade in low carbon hydrogen. It would be an effective indicator for use in industry, government and international policy frameworks.,

2. Using colours to describe hydrogen

The colours[1]

Colours are used to distinguish the different ways hydrogen can be produced. For production routes that are being developed more widely, there are a few commonly used terms:

- **Green hydrogen** is made by using electricity from renewable energy sources to electrolyse water.
- **Blue hydrogen** is produced mainly from natural gas, using steam methane reformation, combined with carbon capture, utilisation and storage.
- **Grey hydrogen** is also created from natural gas using steam reformation, but without capturing greenhouse gases.

Other colours are used less frequently to describe other production methods:

- **Pink hydrogen** is generated through electrolysis, powered by nuclear energy
- **Yellow hydrogen** is hydrogen from electrolysis of water using solar power.
- **Black hydrogen** is when black coal is used, usually in a gasification process, to make hydrogen.
- **Brown hydrogen** is when lignite (brown coal) is used to make hydrogen, also usually in a gasification process.
- **White hydrogen** refers to naturally occurring hydrogen, found underground and exploited through fracking.
- **Turquoise hydrogen** is made using a process called methane pyrolysis to produce hydrogen and solid carbon.
- **Red or orange hydrogen** can refer to hydrogen made from biomass, usually via gasification.

Colours are easy to understand

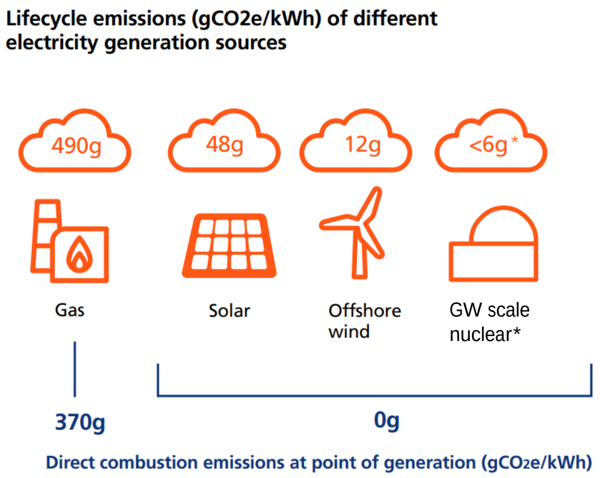
Colour is a concept that is familiar to everyone and distinguishing between different colours is something we do instinctively every day. It is no surprise that using colours to identify the different ways hydrogen is produced has caught on. A colour, or the word for the colour itself, stimulates a reference point in the mind that a description of a hydrogen production plant cannot compete with. The colour can be used as a shorthand to add brevity to a discussion and can widen interest in hydrogen by using more accessible language for technical concepts.

[1] The hydrogen colour spectrum - National Grid Group;
Types of hydrogen fuel - Energy Education;
Hydrogen colours codes - H2 Bulletin;
In a nutshell - Hydrogen Europe;
Hydrogen Color Theory - Graebener Maschinentechnik

But colour comparisons could lead to misleading assumptions

Although using colours to describe hydrogen is accessible, it could also give rise to misunderstandings or misappreciations of the differences between different production routes. The list of colours is an evolving characterisation of technologies, rather than being designed as an objective tool to compare their merits – on carbon emissions, production costs, technology readiness, etc. But there is a natural inclination to compare, particularly when coming across colour names for the first time. Added to that, we naturally attribute values to colours.[2] This could lead to assumptions being made, which miss some key points of comparison.

For example, one could understandably form a quick conclusion that electrolysis using nuclear energy is not a favourable method because it is not 'green', the colour naturally associated with nature, progress and sustainability. But lifecycle greenhouse gas emissions from nuclear power are among the lowest of any electricity source that could be used to produce hydrogen.[3]



*Based on expectations for new GW-scale nuclear in the UK. The global median for all nuclear is 12gCO2e/kWh

Source: EDF Energy UK sustainable business update; IPCC global median values

Another potential assumption when using colour labels could be to accept a general equivalence between colours that could be grouped together as 'clean' options (e.g. blue, green, pink, yellow) or 'dirty' options (e.g. grey, black, brown). For example, one may assume little difference between the merits of any electrolytic project or any steam reformation with CO2 capture project, without appreciating the wide variation in carbon emissions that could be involved, depending on capture rates or sources of electricity.

Colour definitions are not consistent

There is no universal agreement on colour designations, which causes variation and overlap in how the colours are used. For production pathways that are more frequently discussed, definitions are more established, particularly green and blue. Other definitions are less fixed.

The use of nuclear energy is a good example. In the sources used for the colour list in this document, pink, red and purple are at times used to refer to all electrolytic hydrogen production using nuclear energy, but equally they can also be used to differentiate between electrolysis using nuclear-generated electricity (pink), nuclear heat (red) or both (purple). Grey is another example where there is a degree of ambiguity. It can be used to denote all non-abated fossil-based production, both from steam reformation and gasification (in contrast to splitting these between grey, brown and black).

There are also gaps. The colours do not encompass all hydrogen production across their different definitions. Two plausible scenarios don't appear on the colour spectrum - electrolysis using electricity directly from a non-low-carbon source, or from a mixture of sources on the grid.

[2] Colour psychology - Wikipedia
[3] EDF Energy UK sustainable business update, 2022 New GW-scale nuclear in the UK refers to two 3.2GW plants, Hinkley Point C and Sizewell C. IPCC - ANNEX III Technology-specific Cost and Performance Parameters, 2014

Colour definitions are not precise enough for policy, regulatory or commercial uses

The IEA concluded in their recent report *'Towards hydrogen definitions based on their emissions intensity'* [4] that the existing colour definitions are generally considered insufficient to be used as a reference in regulations or supply contracts. The lack of consensus on definitions, potential gaps in the coverage of production methods and a lack of quantification of emissions all mean their use would be imprecise and not transparent.

3. Using emissions intensity to compare hydrogen

Emissions intensity

Measuring carbon emissions, or carbon equivalent greenhouse gas emissions, from the production of hydrogen provides a consistent comparator across production methods and indicates the true contribution of the hydrogen to decarbonising the energy system. It is used by some governments in regulation to support the development of the hydrogen sector. It does not exclude the ability of governments, or buyers of hydrogen, to explicitly favour one method of production over another. However, emissions intensity is inherently technology neutral.

Where emissions intensity is used

Emissions intensity is being used in some hydrogen certification schemes that are emerging internationally[5] to demonstrate the low-carbon credentials of hydrogen that reaches the market. As a means of transparency, the schemes require or encourage the declaration of the carbon content per unit of energy. The certification schemes can also use emissions intensity as a standard, which sets a threshold in emissions intensity to distinguish low-carbon and non-low carbon hydrogen (or multiple thresholds to define the degree of carbon intensity).

The UK is an example where emissions intensity is used to define a 'Low Carbon Hydrogen Standard'. It is set at 20gCO2e/MJ. If hydrogen is produced to this standard, regardless of the production pathway, it can be certified as 'low carbon'. Producing hydrogen to this standard is also a requirement for government funding for production projects, across different technologies.[6]

The EU has also introduced emissions intensity into the definitions it uses for hydrogen. 'Renewable hydrogen' and 'low carbon hydrogen' (a new definition currently being considered), must respect a 28.2gCO2e/MJ threshold, which corresponds to a 70% reduction in emissions intensity compared to a 94gCO2e/MJ fossil fuel equivalent. In addition, renewable hydrogen must comply with certain electricity sourcing rules (such as additionality and temporal correlation) to qualify the electricity as renewable and be counted as zero emission.[7] The EU experience shows that technology-neutral and technology-specific definitions are not mutually exclusive in a complex regulatory framework.

Possible international application

The IEA has made the case for an internationally agreed emissions accounting framework for hydrogen.[8] As well as the benefits of transparency and precision in regulations and contractual arrangements, the IEA also highlights the potential to facilitate greater interoperability internationally between regulations and certification schemes, with this greater alignment limiting market fragmentation and supporting investment and international supply chains.

Move away from colours

The use of colours has captured the imagination, despite the drawbacks. Abandoning them fully is perhaps unrealistic, however there is scope for them to be reserved for where they have most value, to engage non-expert audiences. Emissions intensity should be the key differentiator in all policy and regulatory frameworks at an industry, government and international level.

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[4] Towards hydrogen definitions based on their emissions intensity – International Energy Agency, 2023
[5] https://www.certifhy.eu/;
China Hydrogen Alliance Unveils the World's First 'Green Hydrogen' Standard (ceic.com);
UK Low Carbon Hydrogen Standard (www.gov.uk);
[6] Hydrogen production business model (www.gov.uk)
[7] C_2023_1087_1_EN_ACT_part1_v8.pdf (europa.eu)
[8] Towards hydrogen definitions based on their emissions intensity – International Energy Agency, 2023