05.03.24

50 shades of blue and grey: How dirty is hydrogen from fossil gas?

Academia, industry, and policy makers often disagree on what can be considered clean hydrogen. Strict criteria for production of hydrogen are necessary for hydrogen to play a credible role in a low carbon society. Here are the things to consider, and what loopholes to look out for.

The industry and transport sector can reduce emissions significantly by switching from carbon containing fuels that emit carbon dioxide to hydrogen that only "emits" water when burned. However, significant emissions can be related to its production, therefore low emission production of hydrogen is crucial to keep life cycle emissions of hydrogen value chains as low as possible.

The two main production pathways for low carbon hydrogen are electrolysis of water using renewable electricity, also known as **green hydrogen,** and reforming of fossil gas with carbon capture and storage, also known as **blue hydrogen**.

Though the final molecule of blue and green hydrogen is identical, the upstream emissions of greenhouse gases are determined by different factors. In this article we build on an academic debate on blue hydrogen and draw conclusions on how to assess if hydrogen is low-emission or not.

In 2021, Robert W. Howarth and Mark Z. Jacobson conducted a life cycle analysis of greenhouse gas emissions linked to blue hydrogen production (Howarth & Jacobsen, 2021). They focused on hydrogen production using Steam Methane Reforming (SMR) with carbon capture and storage. Their conclusion questioned the viability of blue hydrogen on climate grounds due to significant life cycle emissions. In 2022, Romano, et al. critiqued Howarth and Jacobson's analysis, primarily challenging their assumptions:

1. High methane intensity in fossil gas production (3.5 %), which can be argued is unrepresentative of the industry.

Mats Rongved, Advisor CCS – mats@bellona.no

Bellona
Rådhusgata 28, 0151 Oslo
23 23 46 00
post@bellona.no

2. Low carbon capture rates of 85% for syngas and 65% for flue gas, stating that current technology allows for higher capture rates.
3. Simplistic energy balance estimation in blue hydrogen production, which can lead to overestimations of CO2 emissions and fossil gas consumption.

Romano et al. (2022) proposed an alternative life cycle analysis based on detailed process simulations from IEAGHG, concluding that blue hydrogen can have significantly lower emissions than Howarth and Jacobsen argued (IEAGHG, 2017).

Later in 2022, Howarth and Jacobson responded to Romano et al.'s critique, rejecting all criticisms (Howarth & Jacobson, 2022). They argued that Romano's process simulations were untested in commercial operations, methane intensity factors were incompatible with peer-reviewed data, and carbon capture rates lacked proof in commercial projects.

In essence, both groups debate the assumptions underpinning blue hydrogen life cycle analysis. Depending on variables like fossil gas production emissions, process facility improvements, and capture technology, blue hydrogen could be either an important part of the transition into a low-carbon future or impede it. This underscores the importance of stringent regulations of blue hydrogen and its life cycle emissions.

It should be noted that the results and possibly the conclusions from the analysis are also dependent on the Global Warming Potential (GWP) which is assumed for the leaked methane, normally either 20 years or 100 years. Further, the EU recommends that hydrogen is produced with emissions lower than $3\ kg_{CO_2eq}\ /kg_{H_2}$ using GWP_{100}, to be categorized as a "substantial contribution to climate change mitigation" (EU Taxonomy Regulation 2020/852).

The important questions can therefore be summarized to:

1. What is the expected future methane intensity of fossil gas?
2. How high carbon capture rates can be sustained on a commercial scale?
3. How efficient will future blue hydrogen plants be?

How green is blue hydrogen in the EU?

It appears likely that blue hydrogen production can achieve life cycle emissions well below EU taxonomy limits. This assertion is supported by the following arguments:

1. Several European gas companies are already committed to significant reductions in methane intensity, targeting levels between 0.03% and 0.2% by 2025 (UN, 2021), but regulations are also needed to ensure industry initiatives are followed through.
2. Both literature and policy often advocate for 90-95% carbon capture rates. The enforcement of minimum mean capture rates is, however, crucial to meet climate standards in the long term.

Mats Rongved, Advisor CCS – mats@bellona.no

Bellona
Rådhusgata 28, 0151 Oslo
23 23 46 00
post@bellona.no

3. The IEAGHG's process simulations are substantial and hold some credibility, although real-world viability requires confirmation.

The figure below illustrates the CO2 intensity of blue- and grey hydrogen (in $kgCO_2/kgH_2$) for various methane intensities of fossil gas.

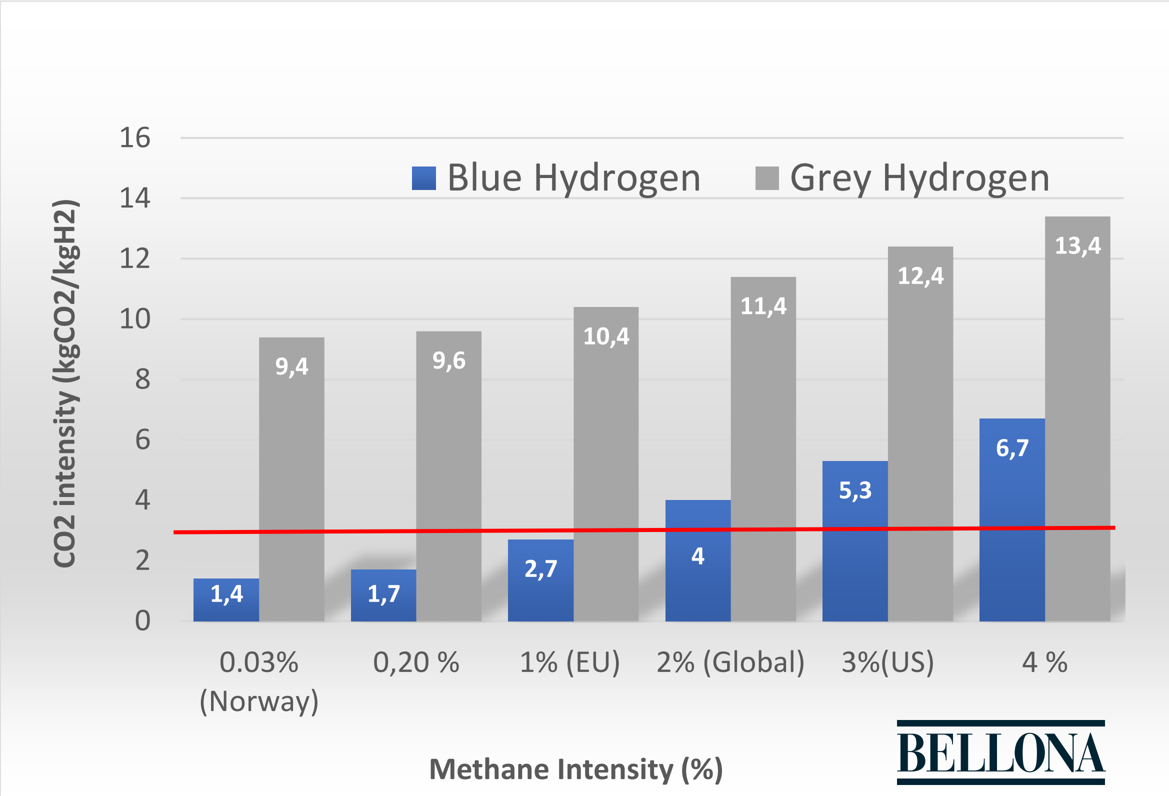

Figure 1: The figure shows the CO2 intensity ($kgCO_2/kgH_2$) for blue- and grey hydrogen production based on various methane intensities of the fossil gas. The red line indicates the 3 $kgCO_2/kgH_2$ threshold for low carbon hydrogen, as set by the EU taxonomy. The location associated with the methane intensities are approximate values from literature, but contain some uncertainty (Shirizadeh, Villavicencio, Douguet, & others, 2023; Cooper, Balcombe, & Hawkes, 2021). The process is based on IEAGHG simulations including a 90% capture rate (IEAGHG, 2017). In addition, the calculations assume a CO2 intensity of 2 $gCO_2\ /MJCH_4$ from the up- and midstream of the fossil gas. A GWP_{100} for the methane is used for the calculations.

As can be seen from the chart, blue hydrogen can meet the EU threshold of 3 $kgCO_2/kgH_2$. However, its performance is closely linked to methane intensity and therefore the fossil gas's origin and transportation method. Current methane emissions in large parts of the world, including Russia and the US, results in very high emission hydrogen (Cooper, Balcombe, & Hawkes, 2021). In addition, transportation of fossil gas as LNG typically entails large emissions, not compatible with low-emission hydrogen production. This underscores the need for regulation of

Mats Rongved, Advisor CCS – mats@bellona.no

Bellona
Rådhusgata 28, 0151 Oslo
23 23 46 00
post@bellona.no

blue hydrogen which includes emissions related to the production and transportation of the fossil gas.

Green Hydrogen

Figure 2 displays the CO_2 intensity of hydrogen produced by electrolysis (in $kgCO_2/kgH_2$) for various CO_2 intensities of the electricity used.

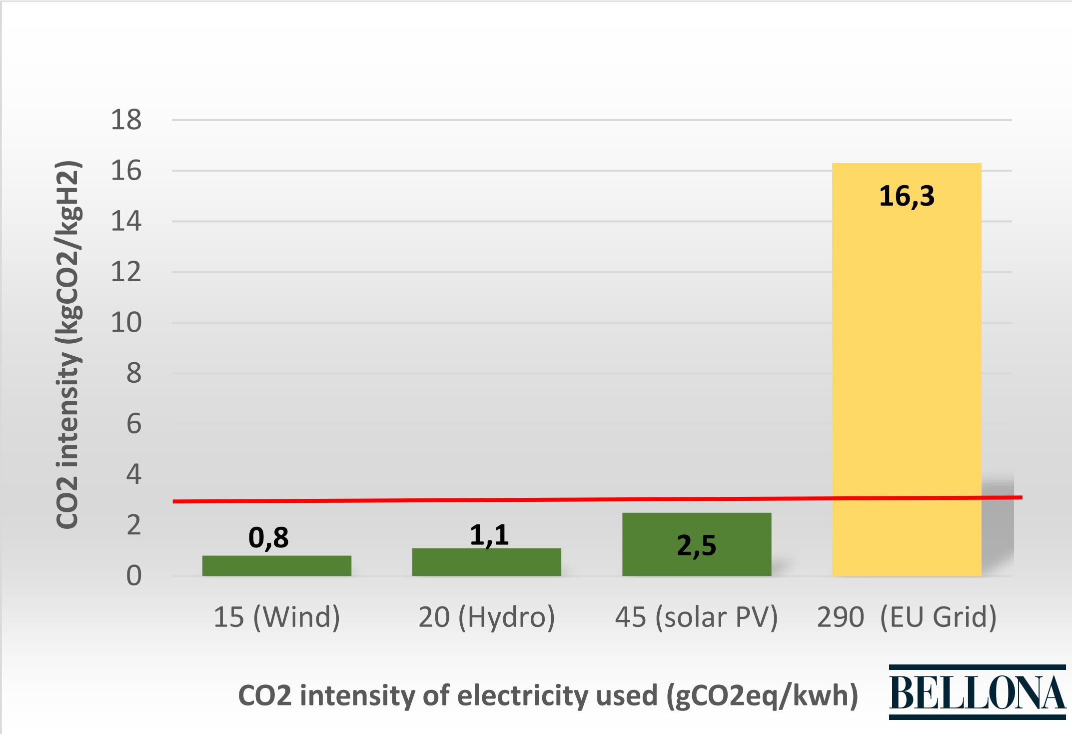

Figure 2: The figure shows the CO_2 intensity ($kgCO_2/kgH_2$) for green and grid-based hydrogen production based on various electric CO2 intensities with representative sources. The red line indicates the 3 $kgCO_2/kgH_2$ threshold for low carbon hydrogen, as set by the EU taxonomy. A 70% efficiency of the electrolysis (including grid loss) is assumed for the calculations. Life cycle emissions from the different sources and the EU grid (2019) are based on Scarlat et al. (2022) and the IPCC AR5.

As shown in figure 2, green hydrogen demonstrates the potential to produce very low emission hydrogen and comply with the EU's 3 kgCO2/kgH2 threshold. Nevertheless, solar energy is close to the limit, necessitating a concerted effort to reduce Life Cycle Emissions (LCE) associated with solar power. It is imperative that electrolysis-based hydrogen production avoids any reliance on power sourced from the EU grid, as this could rapidly yield emissions-intensive hydrogen (as shown in the yellow collum in figure 2). To produce low emission grid-powered hydrogen

Mats Rongved, Advisor CCS – mats@bellona.no

Bellona
Rådhusgata 28, 0151 Oslo
23 23 46 00
post@bellona.no

production, a CO2 intensity of 53 gCO2/kWh is needed, constituting approximately one-sixth of the current grid intensity of 290 gCO2/kWh. This underscores the significance of maintaining stringent regulations governing green hydrogen production and highlights the premature nature of encouraging or subsidizing grid-powered hydrogen until grid emissions closely approach 50 gCO2/kWh.

Regulations ensuring that green hydrogen production exclusively relies on renewable include the Additionality Delegated Act, which involve Power Purchase Agreements (PPAs) with both geographical and temporal correlations. These PPAs mandate that green hydrogen producers source power from newly developed renewable energy sources within the same bidding zone and synchronize hydrogen production with renewable power generation. The geographic and temporal correlation aim to ensure that the hydrogen is indeed produced on renewable power, and the PPAs are to provide an extra incentive for renewable energy development and avoid cannibalizing existing renewables whose role is to decarbonize the grid. As a result, green hydrogen production at scale is dependent on large scale deployment of new renewable energy.

Concluding remarks

In conclusion, the debate surrounding low-emission hydrogen production, specifically blue and green hydrogen, hinges on several crucial factors. The viability of blue hydrogen is contested due to varying factors concerning emissions and carbon capture rates. While it has the potential to meet EU taxonomy thresholds, real-world feasibility must be confirmed, and stringent regulation is necessary. On the other hand, green hydrogen can produce very low-emission hydrogen, but it is dependent on large amounts of new renewable energy deployment. A central question is whether there is sufficient new renewable power to produce green hydrogen at the quantities needed while decarbonizing the rest of the economy...

Mats Rongved, Advisor CCS – mats@bellona.no

Bellona
Rådhusgata 28, 0151 Oslo
23 23 46 00
post@bellona.no

Bibliography

Cooper, J., Balcombe, P., & Hawkes, A. (2021). The quantification of methane emissions and assessment of emission data for the world's largest gas supply chains. *Journal of Cleaner Production*.

Howarth, R. W., & Jacobsen, M. Z. (2021). How green is blue hydrogen. *Energy Science and Engineering* .

Howarth, R. W., & Jacobson, M. Z. (2022). Reply to comment on "How green is blue hydrogen?". *Energy Science & Engineering*.

IEAGHG. (2017). *Techno - Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS.* IEA.

Romano, M. C., Antonini, C., Bardow, A., Bertsch, V., Brandon, N., Brouwer, J., . . . Dodds, P. (2022). Comment on "How green is blue hydrogen?". *Energy Science & Engineering*.

Scarlat, N., Prussi, M., & Padella, M. (2022). Quantification of the carbon intensity of electricity produced and used. *Applied Energy*.

Shirizadeh, B., Villavicencio, M., Douguet, S., & others, a. (2023). The impact of methane leakage on the role of fossil gas in the European energy transition. *Nature Communications*.

UN. (2021). *An Eye on Methane: International Methane Emissions Observatory.* UN.

Mats Rongved, Advisor CCS – mats@bellona.no

Bellona
Rådhusgata 28, 0151 Oslo
23 23 46 00
post@bellona.no