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Estimation of the global average GHG emission intensity of hydrogen production

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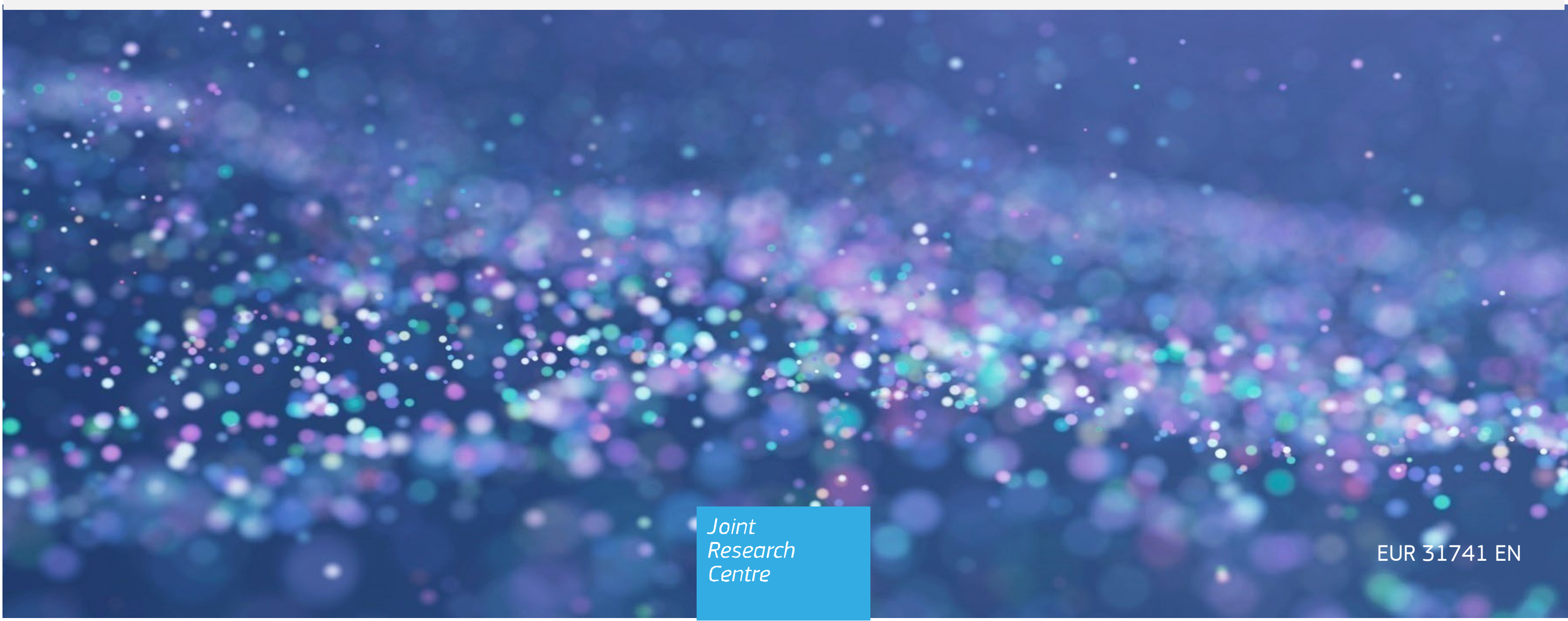

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Contents

Abstract

This document describes a simple methodology for estimating the global average greenhouse gas emissions intensity for hydrogen. The aim of this estimation is to provide scientific support to the implementation of the Carbon Border Adjustment Mechanism (CBAM).

1 Introduction

The Carbon Border Adjustment Mechanism (CBAM) forms part of the Fit-for-55 package and is designed to address the risk of carbon leakage. The CBAM will equalise the price of carbon between domestic products and imports and will ensure that the EU's climate objectives are not undermined by the relocation of production by industry to countries with less ambitious policies. It also aims to encourage industry at global level and the EU's international partners to take steps in the same (carbon-neutral) direction.

.This report is a contribution of the JRC in support to the CBAM implementation. Its purpose is to estimate the global average GHG emission intensity of hydrogen production. It complements other work of the JRC in estimating GHG emission intensity of other goods under the CBAM scope [Please add reference here to upcoming publication of the other JRC report].

For the purposes of this exercise the estimation of the average emission intensity for hydrogen was based on the most recent publicly available data on production routes currently used for hydrogen production [1-2]. A weighted average was then applied, with weights based on current production volumes.

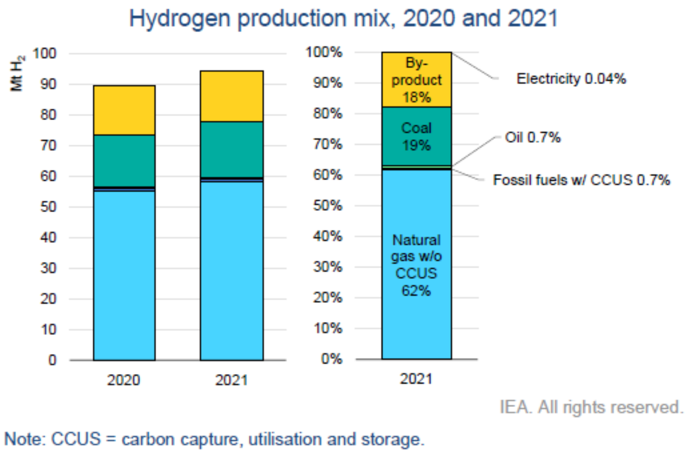
Since the CBAM does not include upstream emission linked for instance to mining and transportation of the fossil feedstock, these were excluded.

In the subsequent section the approach followed is described in more detail.

2 Analysis

Current global hydrogen production shares are based on a 2021 feedstock and process mix as presented in Figure 1 and Table 1 [1]. While more up-to-date data are not available, current shares should not vary significantly compared to those of 2021. An update by the IEA is expected in in Q3 2023.

Figure 1. Global hydrogen production from IEA data



Note: CCUS = carbon capture, utilisation and storage.

Source: IEA 2022 [1]

Table 1. Hydrogen production volumes assigned to each different feedstock and production process

Natural gas	58.28	MtH_2
Naphta (by-product)	16.92	MtH_2
Coal	17.86	MtH_2
Oil	0.66	MtH_2
Electricity (water electrolysis)	0.04	MtH_2
Natural gas (CCUS)	0.66	MtH_2
Electricity (by-product of chlor-alkali)	2.65	MtH_2

Source: IEA 2022 [1] and JRC analysis based on Statista [7]

In the latest publicly available IEA data, the total global hydrogen production is considered to be around 94 MtH_2/y. It includes both pure hydrogen (about 74 MtH_2/y) and hydrogen mixed together with other carbon-containing gases (about 20 MtH_2/y - used as feedstock in processes such as methanol production and direct iron reduction for steel manufacturing), but it excludes hydrogen contained in residual gases which are combusted for the production of heat or electricity (around 30 MtH_2/y). In our analysis, the by-product hydrogen fraction provided by the IEA source is assumed to be obtained fully from naphtha steam cracking. In addition to the 94 MtH_2/y figure mentioned above, it is assumed that the global chlor-alkali hydrogen production (hydrogen is a by-product of the process) is of the order of 2.6 MtH_2/y [7][1], bringing the actual total up to around 97 MtH_2/y.

The used GHG emission intensities associated with the different production routes are summarised in the **Table 2** below. For CCUS, a reasonable capture rate of 90%[2] of emission was applied with reference to steam methane reforming. The captured emissions are considered as avoided and not accounted for[3].

For hydrogen obtained as a by-product in chlor-alkali and naphtha steam cracking, the used values were obtained via substitution (system expansion)[4]. For hydrogen obtained from water electrolysis, the full electricity consumption is attributed to hydrogen and none to the oxygen by-product. Water electrolysis is considered as powered by electricity with the current global average emission factor for electricity generation [8][5].

When the retrieved literature values provide a range for GHG emission intensities, a value in the middle of the range was used.

Emissions are divided into direct emissions, and indirect emissions due to electricity as an input. Indirect emissions from electricity consumption are relevant only for water electrolysis and assumed as marginally present in naphtha cracking[6]. For chlor-alkali electrolysis, no indirect emissions are considered, as the aforementioned substitution approach was used (system expansion).

The small volumes of hydrogen produced in some processes such as CCUS and water electrolysis are diminishing any error stemming from miscalculations linked with wrong assumptions and are not expected to significantly affect results.

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[1] Considering a global production for 2021 of 93.2 Mt of chlorine and a stoichiometric production of 0.0285 kg of hydrogen for each kilogram of chlorine.

[2] https://climate.mit.edu/ask-mit/how-efficient-carbon-capture-and-storage#:~:text=CCS%20projects%20typically%20target%2090,will%20be%20captured%20and%20stored.

[3] This is a simplification. Most CCUS processes, according to the IEA classification should be falling under Enhanced Oil Recovery (EOR) and urea production activities. Carbon dioxide emission would not be fully captured in both processes and especially in the case of urea, they should not be considered as permanently stored. In order to have a more accurate approach detailing CCUS emissions, a more precise breakdown covering all processes labelled as such would be needed. Unfortunately, this information is not yet available. Nevertheless, due to the small volumes of hydrogen produced in this way, our approach is not going to introduce significant uncertainties.

[4] This LCA approach implies that co-products are considered as alternatives to available market products and can be assigned the same environmental burden linked to the use of those market products. In both cases it is assumed that the hydrogen GHG intensity corresponds to the GHG intensity of the fuel used to replace the hydrogen previously burned to cover the thermal requirements of the process and now considered to be sold. Natural gas is assumed to be used instead of hydrogen for providing heat. The GHG intensity is thus obtained by multiplying the lower heating value of hydrogen (0.11996 TJ/t H_2, https://en.wikipedia.org/wiki/Heat_of_combustion) with the emission factor of natural gas (56.1 t CO_2/TJ, Regulation (EU) 2018/2066, Annex VI) to give 6.7 t CO_2/t H_2.

[5] Using the 2021 average global CO_2 intensity of 462.02 g CO_2-eq/kWh (IEA data for 2021).

[6] As a first approximation, electricity consumption for steam methane reforming is not considered to be significant and its direct process emissions are dominating the overall GHG emission impact. A difficulty in assessing the actual electricity consumption process is that part of the electricity requirements (mainly used for running pumps and compressors) could be covered by steam produced as by-product in the process, or by gas turbines located onsite; this is however highly dependent on plant design.

3 Conclusions

Final values are 10.4 tCO_2/tH_2 for direct emissions, which include fuel-related emissions and process-intrinsic emissions and remains the same if also electricity use is included. Therefore the total emission value is 10.4 tCO_2/tH_2. These values are in line with data provided in a recent IEA report [3] [7].

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[7] IEA (2023) Towards hydrogen definitions based on their emissions intensities – "*Global hydrogen production is today almost completely based on the use of unabated fossil fuels, resulting in an emissions intensity of 12-13* $kgCO_2$*-eq/*kgH_2*.*". This value includes also upstream emissions.

Table 2. GHG emission intensities associated with the different hydrogen production routes

Feedstock type	***Total emissions/*** tCO_2/tH_2	***Comments***	***Source***
Natural Gas	9	-	*[3]*
Coal	19.2	-	*[3]*
Naphtha	7	This value considers the use of natural gas covering the heat requirements of the process and substituting for exported hydrogen.	*[4]*
Oil	12	-	*[5]*
Electrolysis (chlor-alkali)	7	This value considers the use of natural gas covering the heat requirements of the process and substituting for exported hydrogen.	*[6]*
Electrolysis (water), world average	23.1	Despite the significant amount of total emissions associated to this pathway, electrolysis has a negligible impact on the global average emission value because of its small global volumes.	*[3]*

Source: As specified in the Table

References

[1] IEA, Global Hydrogen Review, 2022

[2] IPHE, Methodology for Determining the Greenhouse Gas Emissions Associated With the Production of Hydrogen, 2022

[3] *IEA, Towards hydrogen definitions based on their emissions intensities, 2023*

[4] Dong-Yeon Lee and Amgad Elgowainy, *International Journal of Hydrogen Energy 43 (2018) 20143-20160*

[5] *IEA, The Future of Hydrogen, 2019*

[6] Dong-Yeon Lee, Amgad Elgowainy and Qiang Dai, *Applied Energy 217 (2018) 467-479*

[7] https://www.statista.com/statistics/1310477/chlorine-market-volume-worldwide/

[8] IEA, EMISSION FACTORS, 2021

List of abbreviations and definitions

CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture Utilisation and Storage
EU	European Union
GHG	Green House Gas
IEA	International Energy Agency
LCA	Life Cycle Assesment

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