

The climate benefit of a *greener* blue hydrogen

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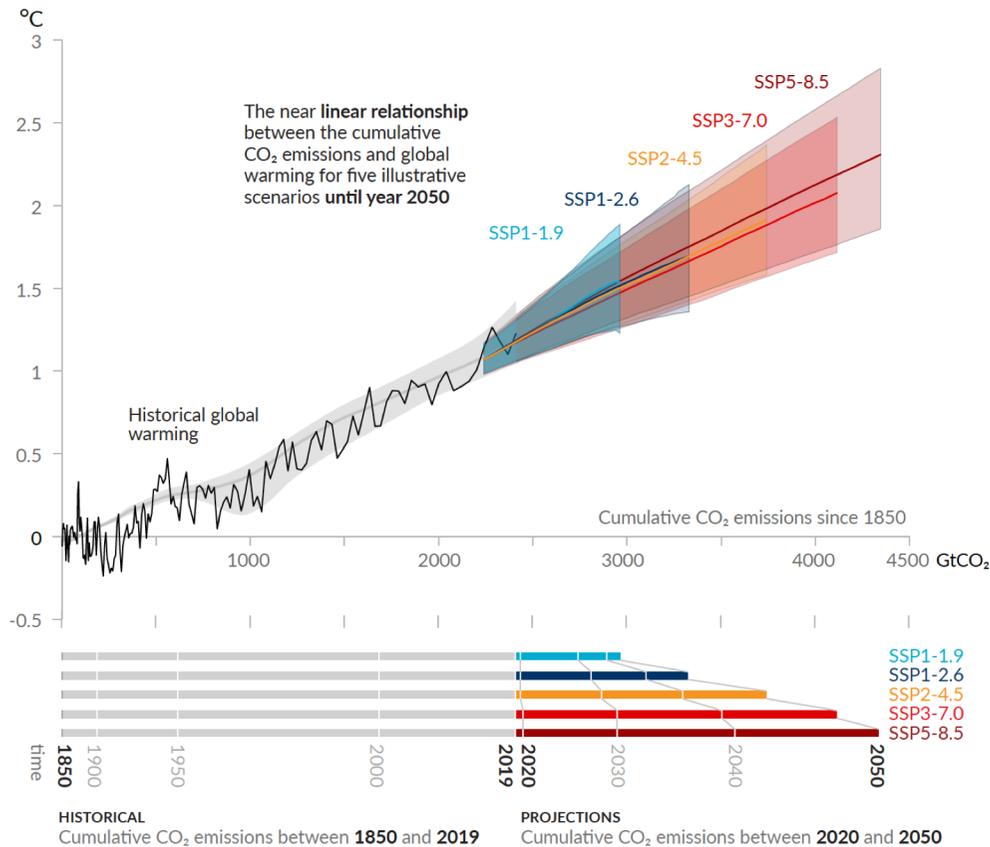
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Context : Cumulated carbon emissions and remaining carbon budget

2590 GtCO₂ have been emitted since 1850. The remaining carbon budget to limit global warming to 1.5°C, 1.7°C and 2°C is **275 GtCO₂**, **625 GtCO₂**, and **1150 GtCO₂** respectively, equivalent to 7, 15 and 28 years from 2024.

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)



Slope: Transient Climate Response to cumulative CO₂ Emissions (TCRE) of 0.45°C/1000 PgCO₂ (IPCC AR6).

Future cumulative CO₂ emissions differ across scenarios, and determine how much warming we will experience

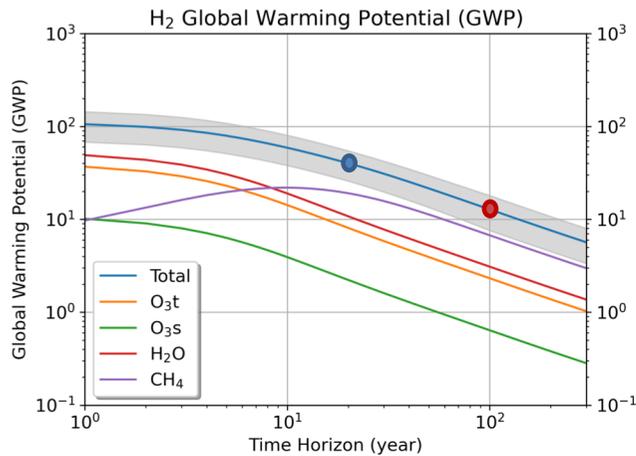
H₂ climate metrics used in this study

Global Warming Potential GWP

Integral of the H₂ total radiative forcing after a pulse emission of 1Tg relative to CO₂.

$$\text{GWP}_{100} = 12.8 \pm 5.2$$

$$\text{GWP}_{20} = 40.1 \pm 24.1$$

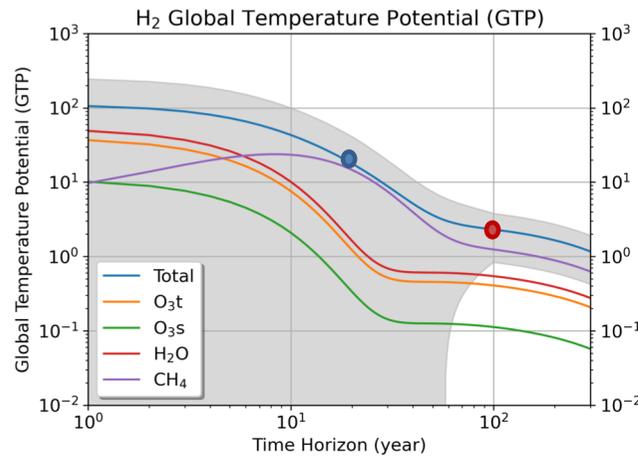


Global Temperature Potential GTP

Integral of the H₂ total radiative forcing X climate response after a pulse emission of 1Tg relative to CO₂.

$$\text{GTP}_{100} = 2.3 \pm 1.5$$

$$\text{GTP}_{20} = 17.8 \pm 23.3$$

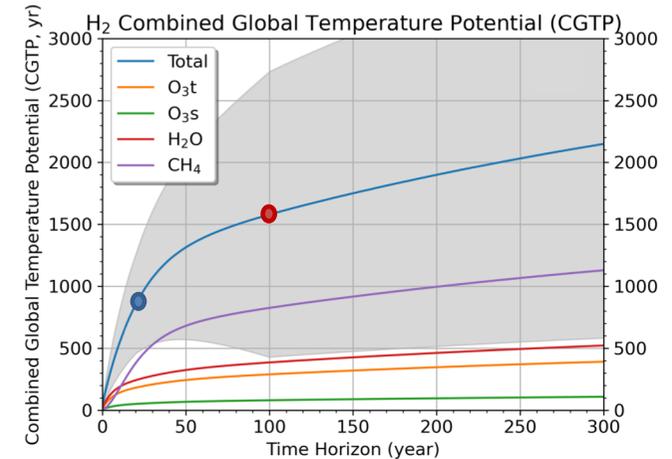


Combined GTP CGTP

Instead of a pulse emission, a sustained emission is used for H₂ relative to a pulse emission of CO₂.

$$\text{CGTP}_{100} = 1579 \pm 725$$

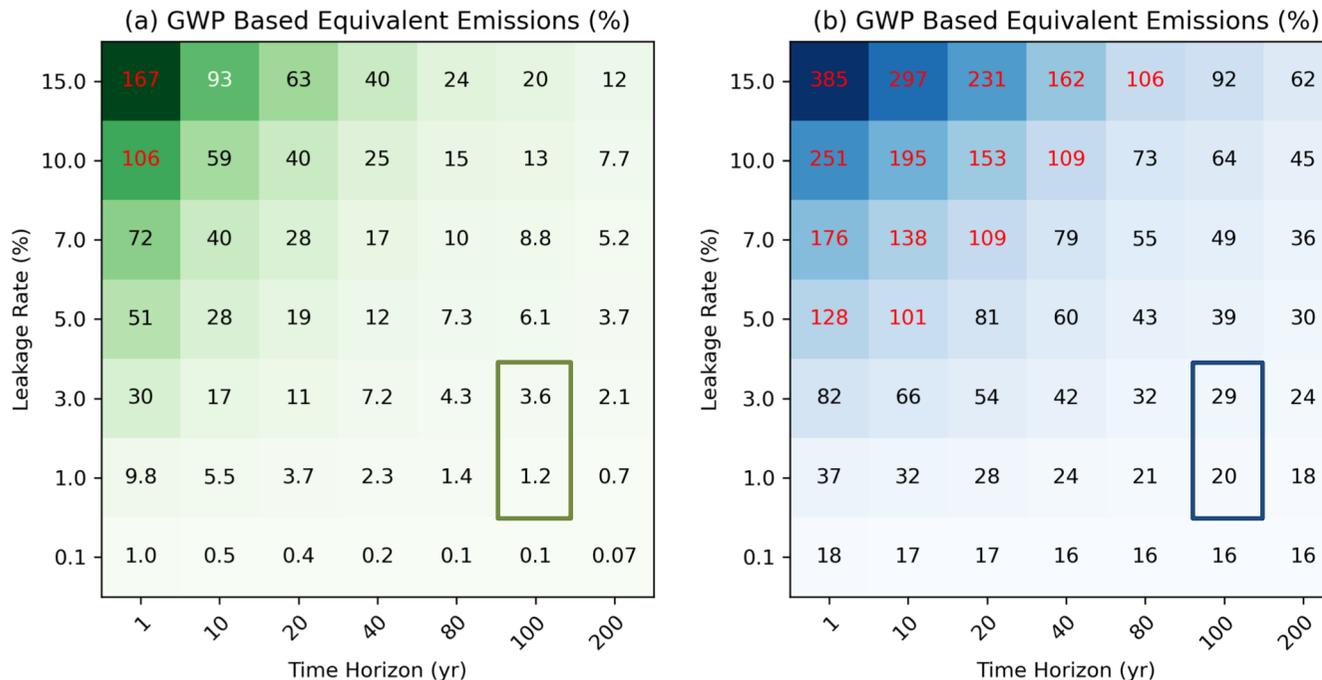
$$\text{GGTP}_{20} = 852 \pm 596$$



Climate benefit of a future hydrogen economy

« A clear benefit for climate arises from a transition to an hydrogen economy. For a leakage of 1-3%, in the case of green H₂ 1.2-3.6 % remaining CO₂e emissions (GWP100 based). Including 30% of blue hydrogen **20-29% remaining emissions** (GWP100 based). »

The blue hydrogen production assumptions we used based on Howarth and Jacobson (2021) were considered as rather pessimistic. We investigate the sensitivity to these assumptions.



Hauglustaine et al. (2022)

Hydrogen production pathways considered

“Using colours to refer to different production routes, or terms such as “sustainable”, “low-carbon” or “clean” hydrogen, obscures many different levels of potential emissions” (IEA,2023).

The European Commission requires that the production of low-carbon hydrogen results in “at least” 70 percent less greenhouse gas than the liquid fossil fuel benchmark, that means a maximum of 3.38 kg CO₂e per kg of hydrogen.

Today: production of about 100 Mt/year. 95% by Steam Methane Reforming.



Carbon intensity : about 10 kg CO₂ / kg H₂

Blue hydrogen : Steam Methane Reforming with carbon capture and storage.



Carbon intensity : about 3-5 kg CO₂ / kg H₂

Turquoise hydrogen : Methane pyrolysis (possibly with renewable electricity)



Carbon intensity : 1 kg CO₂ / kg H₂ (or less with biogas)

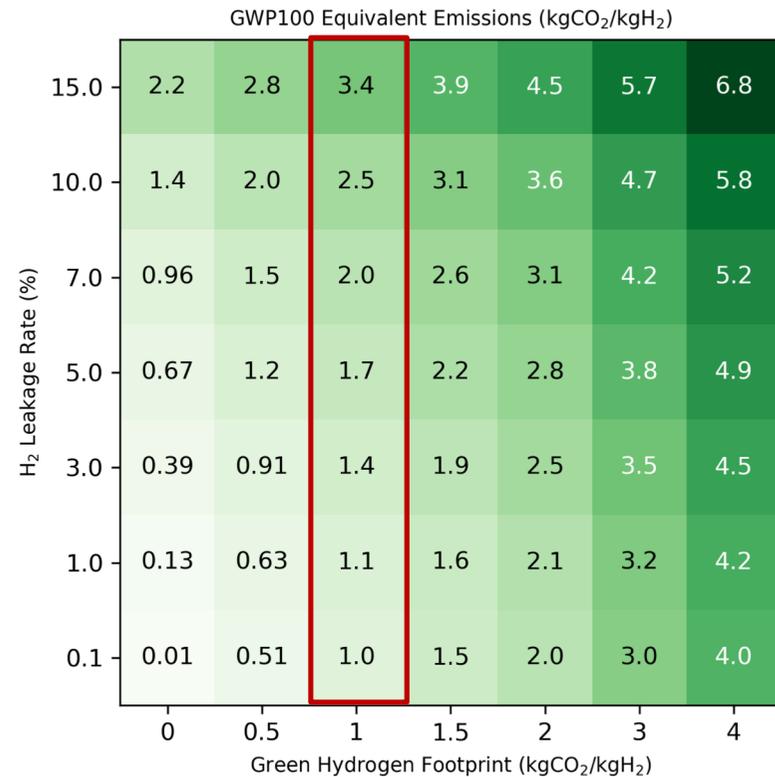
Green hydrogen : electrolysis with renewable electricity.



Carbon intensity : 1 kg CO₂ / kg H₂ or less depending on the renewal source and on the grid

Green hydrogen footprint

- While hydrogen production from renewable electricity via electrolysis is often assumed to lead to zero emissions, low emission intensity of hydrogen production still exists from renewables.
- Based on IEA (2023) : 12 gCO₂e/kWh for wind turbines and 27 gCO₂e/kWh for solar panels. Assuming 50% for both of these production pathways lead to a carbon intensity of about **1 kCO₂/kgH₂**.
- To this baseline carbon intensity for production we add the fugitive hydrogen equivalent emissions (GWP100 based on this figure).

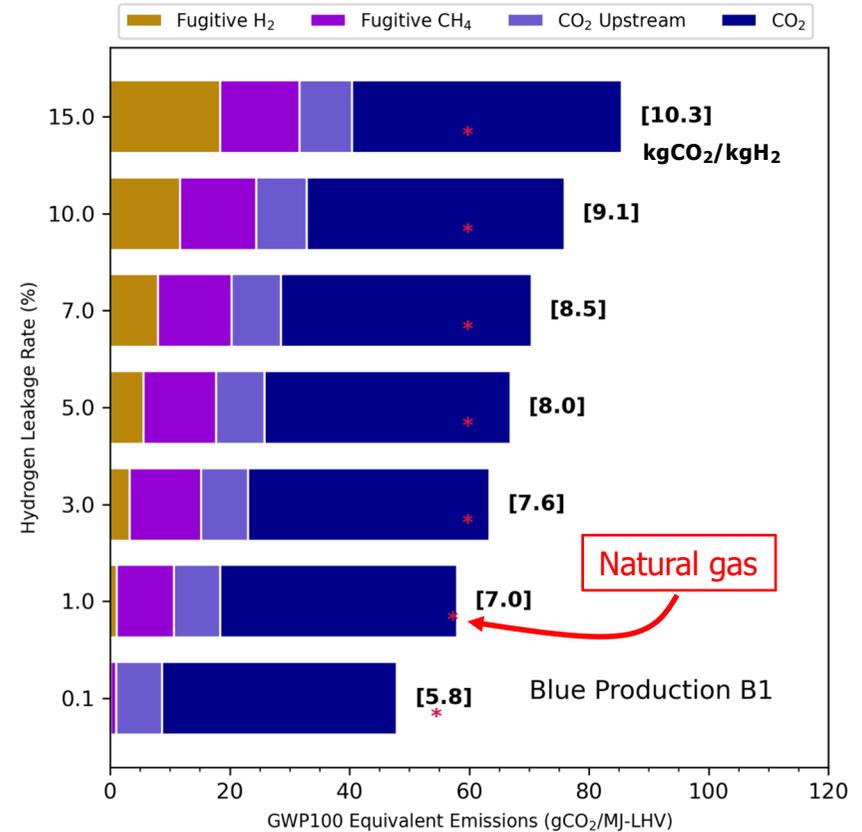


Blue hydrogen footprint for several production assumptions : B1

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Hydrogen production via the Steam Methane Reforming process :

- Sum of **CO₂ emissions during the SMR process** itself + during **heat and electricity generation needed to drive the SMR** + the **upstream emission from the energy used to produce, process, and transport natural gas**.
- Methane needed to produce hydrogen from the SMR + amount burned to generate the heat and pressure needed to drive SMR combined with maximum methane leakage rate (**baseline 1%**) and methane GWP (GWP100 = 30.9 ±12).
- CCS of CO₂ with 85% efficiency for SMR and 65% for driving SMR. Plus, energy required to drive the carbon sequestration.
- Scenario B1** : numbers based on Howarth and Jacobson (2021) considered pessimistic but based on an existing power plants from the Petra Nova / Gorgon projects.



GWP100 based
Methane leakage : 1%

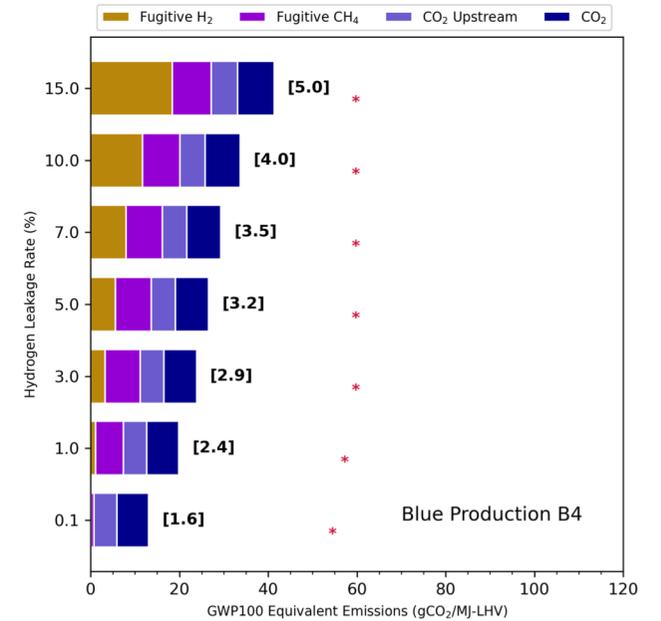
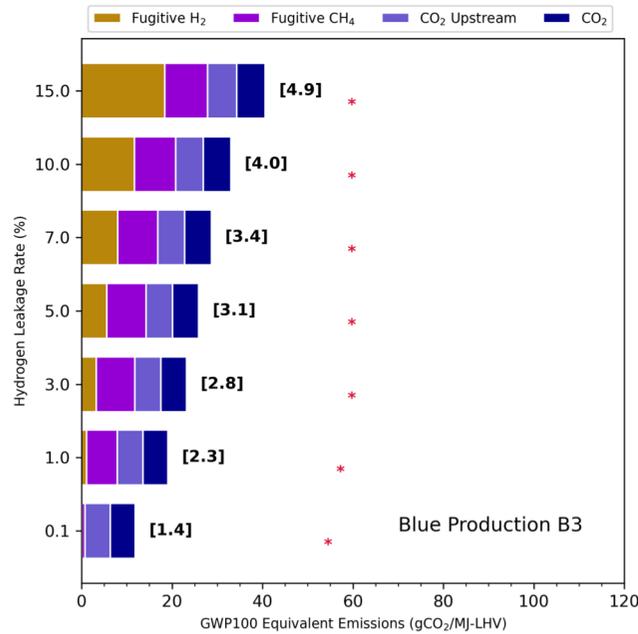
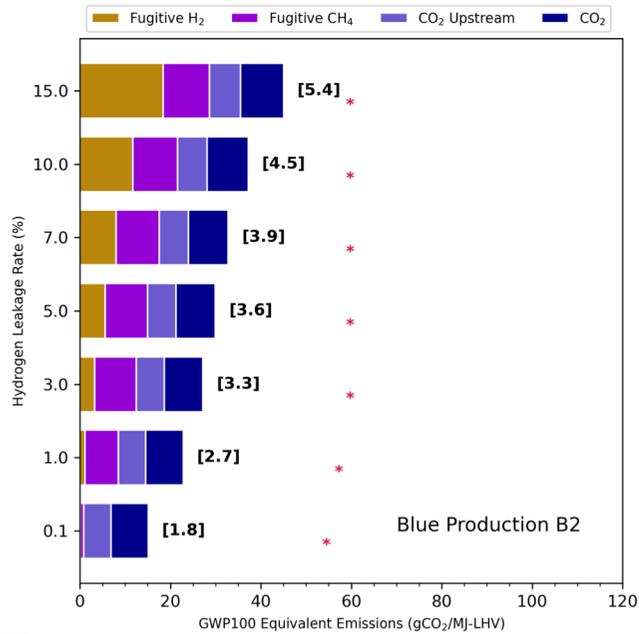
Blue hydrogen footprint for several production assumptions: B2, B3, B4

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Scenario B2. Theoretical conventional natural gas SMR modern blue hydrogen power plant (IEAGHG, 2017). With a CO₂ capture amine process designed to reach 90% efficiency. Feedstock consumption and emissions based on Romano et al. (2022).

Scenario B3. Theoretical natural gas SMR using an oxygen-blown autothermal reformer (ATR) combined with optimized mono-diethanol amine (MDEA) CO₂ CCS designed to reach 93% efficiency (Antonini et al., 2020; Romano et al., 2022).

Scenario B4.

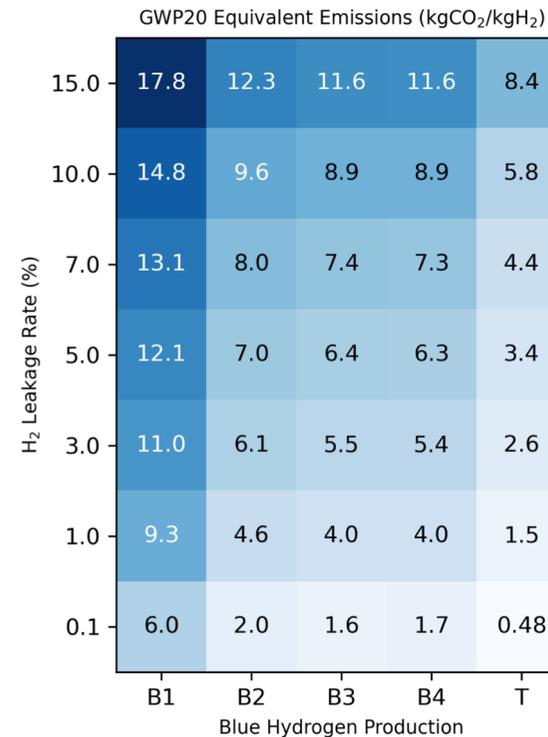
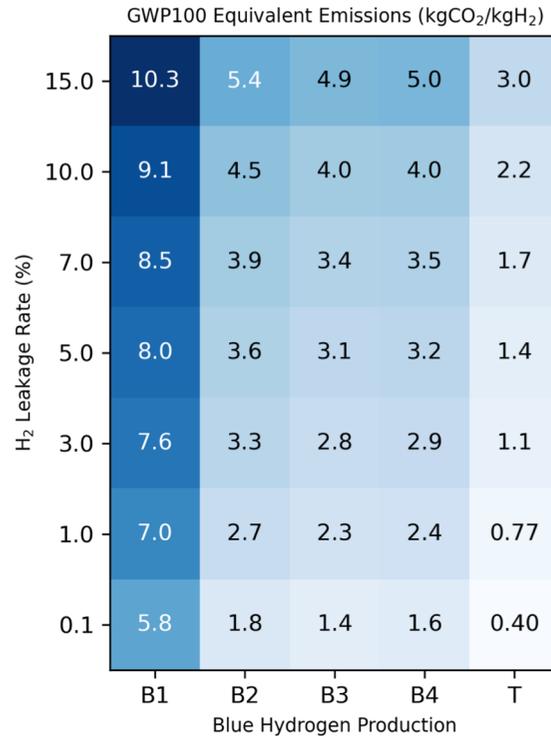


Blue hydrogen carbon footprint for several production assumptions

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Based on GWP100

Based on GWP20



Methane leakage rate : 1%

B1: Howarth & Jacobson; B2: Romano IEAGHG; B3: Antonini; B4: Pettersen; T: Monolith Diab

Climate benefit of an hydrogen transition

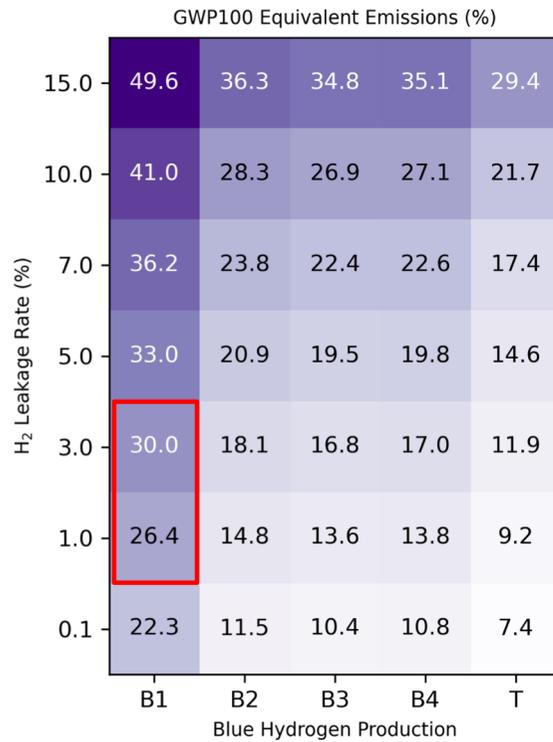
Climate benefit of an hydrogen transition in a given segment :

CO₂ equivalent emissions from hydrogen + methane fugitive emissions + CO₂ emissions from hydrogen production (kg CO₂e / year)

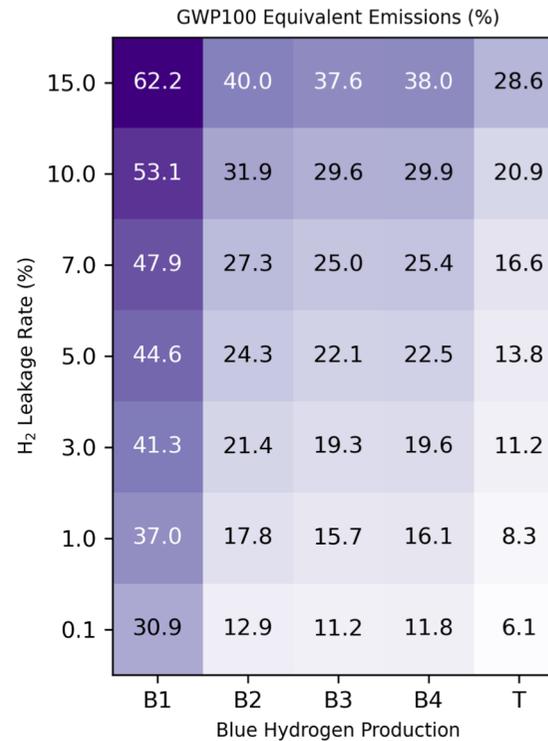
CO₂ emission abatement from hydrogen economy (kg CO₂ / year)

Climate benefit of an hydrogen transition

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Blue: 30%



Blue: 50%



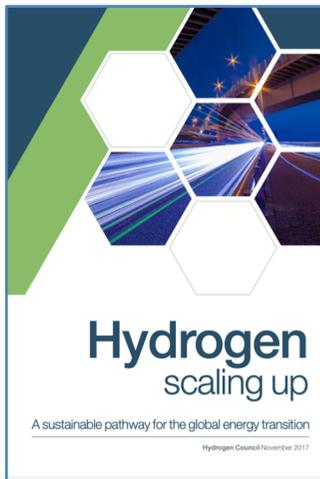
Blue: 70%

Scenarios for future hydrogen production (2030-2100)

Hydrogen Council 2017 (HC2017)

21,667 TWh (78 EJ) in 2050, a eight-fold increase over current hydrogen consumption. This implies a total supply of 549 Mt H₂ per year (70% green and 30% blue H₂). According to Hydrogen Council (2017), this represents an **abatement of 6 Gt CO₂ per year. Cumulative abatement 2030-2100: 331 GtCO₂.**

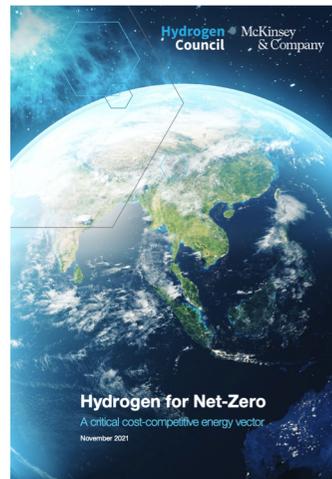
2030: 98 Mt/yr (33% blue H₂ and 33% grey H₂). 2040: 197 Mt/yr (50% blue H₂).



Hydrogen Council 2021 (HCMK2021)

26,111 TWh (94 EJ) in 2050. This implies a total supply of 660 Mt H₂ per year (100 % green H₂). According to Hydrogen Council (2021), this represents an **cumulative abatement 2030-2100: 417 GtCO₂.**

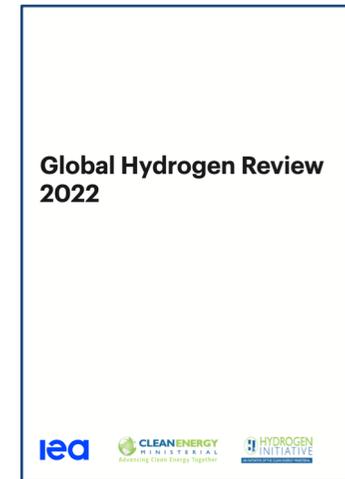
2030: 140 Mt/yr (30% blue H₂ and 50% grey H₂). 2040: 385 Mt/yr (40% blue H₂ and 5% grey).



IEA 2021

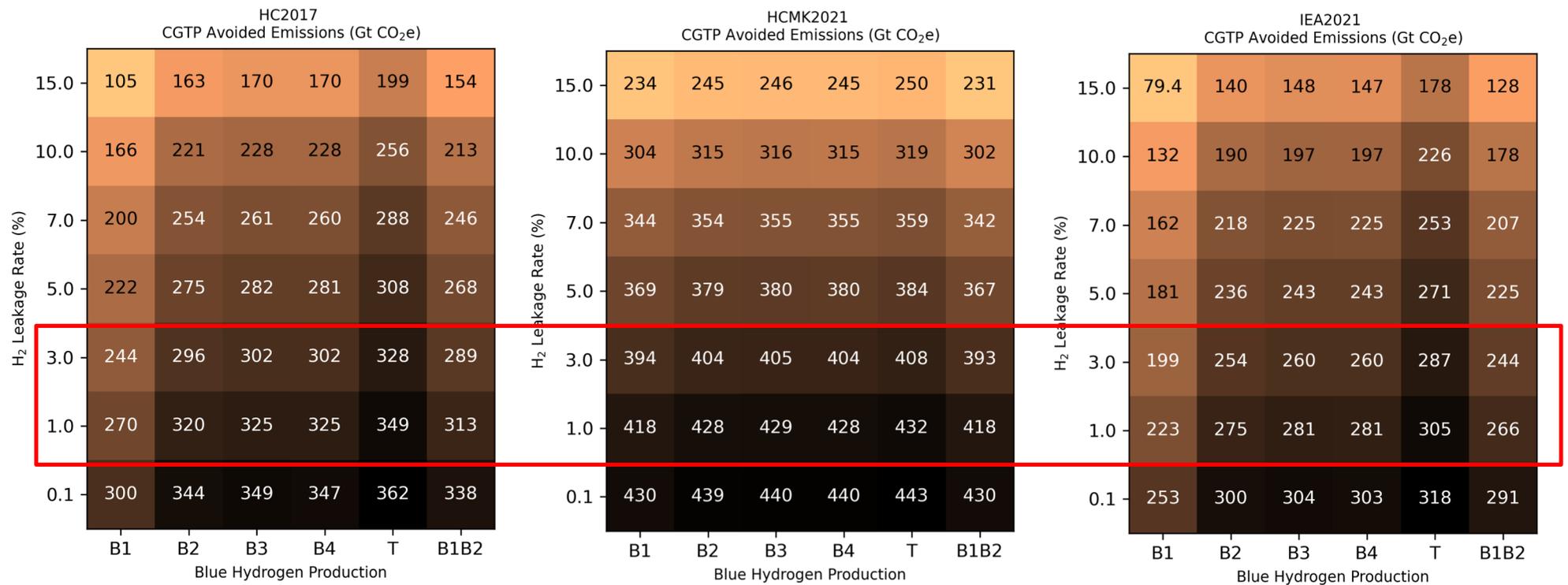
Total supply of 528 Mt H₂ per year in 2050 (62 % green H₂). This represents an **cumulative abatement 2030-2100: 353 GtCO₂.**

2030: 212 Mt/yr (32% blue H₂ and 30% grey H₂). 2040: 390 Mt/yr (38% blue H₂ and 9% grey).



Avoided cumulative CO₂ emissions (Gt CO₂e) over 2030-2100 based on the CGTP metric

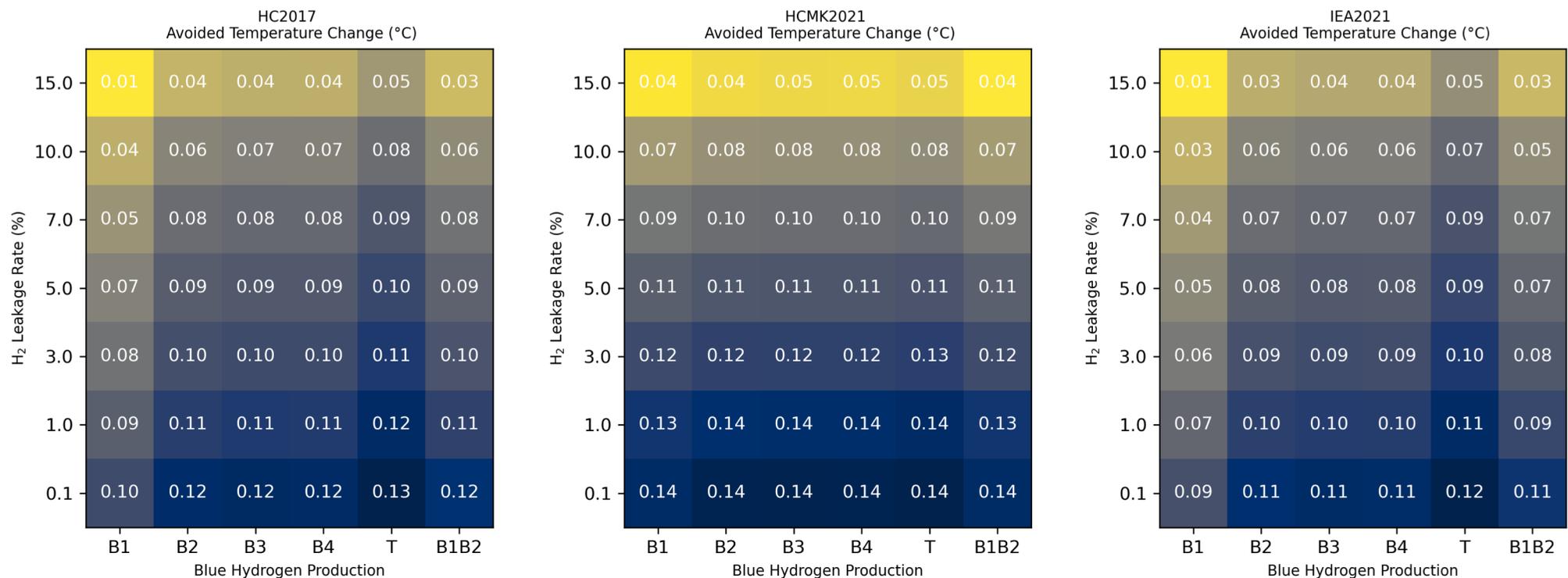
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Avoided Global Surface Air Temperature (GSAT) increase in 2100 based on the CGTP metric

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The avoided cumulative CO₂ emissions are converted to GSAT increase based on the Transient Climate Response to cumulative CO₂ Emissions (TCRE) of 0.45°C/1000 PgCO₂ (IPCC AR6).



Hauglustaine, in prep., 2024

Summary

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- ❑ In this study we derive a renewable hydrogen carbon footprint increasing by a factor 2-3 depending on the hydrogen leakage rate (**1 to 3.4 kg/kg** for a 1 kg/kg renewable electricity footprint; 2 to 4.5 kg/kg for a 2 kg/kg electricity footprint). For SMR + CCS, we derive a carbon footprint of **7-7.6 kg/kg** for current technologies and of **2.4-3.3 kg/kg** for theoretical new generation SMR power plants. Pyrolysis provide even lower carbon footprint of **0.8-1.1 kg/kg** under the assumption of renewable electricity use to drive the pyrolysis. Clearly, room for improvement in terms of carbon footprint of future hydrogen production from methane. Cost issues not considered in our study.
- ❑ Considering these new assumptions, a clear benefit for climate still arises from a transition to an hydrogen economy. For a H₂ leakage rate of 1-3%, **78%-82% of the CO₂ emissions avoided** (GWP100 based) for the most advanced SMR power plant facility (90-92% in the case of pyrolysis) even for a high blue hydrogen contribution of 70% (GWP100 based). The hydrogen production pathway and the H₂ (and CH₄) leakage rates still appear as key leverages to further mitigate the climate impact through an H₂ economy transition with significant room for improvement in the case of SMR/pyrolysis.
- ❑ Based on these different scenarios, a transition to an hydrogen economy could save up to **430 GtCO₂** over the 2030-2100 period (CGTP based) which can be translated into a global warming reduced by **0.14°C** at the end of the century.