Best Use of Renewable Hydrogen

Various Applications, Carbon Intensity of Hydrogen and Substitute Products

Prepared by Abhishek Kumar, Stefan Unnasch, Brian D. Healy, and Kathleen Dailey of Life Cycle Associates, LLC

23 February 2024

Green Hydrogen Options

Approximately 10 million tonnes of hydrogen are currently utilized in various industrial applications in the United States, which is mostly produced from natural gas (Shearman, 2021). The Inflation Reduction Act (IRA), specifically Section 45V, supports the expansion of green hydrogen applications through tax credits that increase based on reductions in carbon intensity (CI). Green hydrogen refers to the production of hydrogen via water electrolysis and low CI electric power. The goals of the IRA and the U.S. National Clean Hydrogen Strategy and Roadmap are to expand the use of green hydrogen to reduce GHG emissions and create new jobs in the sector (DOE, 2023). While these frameworks are sector and technology agnostic relative to green hydrogen applications, new technologies will contribute the most substantive GHG reductions. Considering the GHG reductions associated with green hydrogen adds an additional element of positive direct effects to the evaluation hydrogen options.

The impact of green hydrogen will depend on not only its carbon intensity but also how it is deployed. Figure 1 shows current global uses for hydrogen. Oil refining is the leading use and most of it is produced from natural gas.

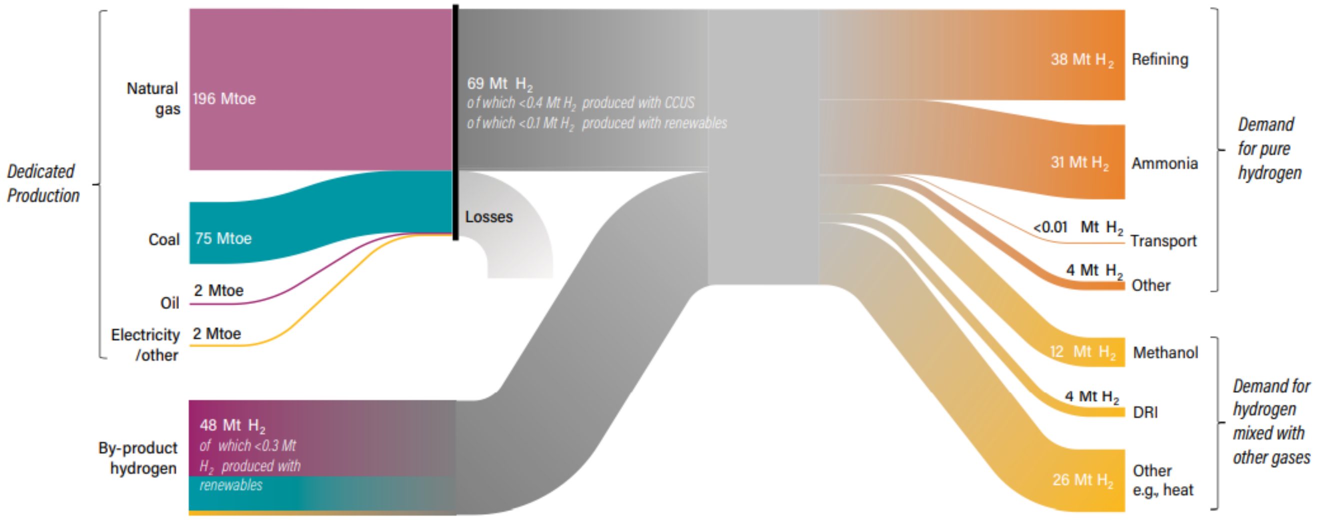

Figure 1. The global hydrogen value chain (2018) shows the dominant use of hydrogen is oil refining and ammonia production. Transportation is an emerging opportunity. Source: (John Feldmann, 2023), (IEA, 2019)

Existing uses of hydrogen include oil refining, steel manufacturing, chemical processing, oil and fats hydrotreating, and ammonia production. In these applications, green hydrogen would displace the fossil incumbent. Methanol production, currently reliant on natural gas reforming, involves hydrogen as an interim flow. The incorporation of green hydrogen, along with waste CO_2, introduces a novel low-carbon source for methanol or synthetic fuels

Copyright © 2024

through Fischer-Tropsch or methanol-to-olefin technologies. While green hydrogen has several applications, some will result in greater emission reductions which are on the scale of the indirect effects considered under the IRA.

These three pillars that form the framework for green hydrogen to qualify for IRA tax credits outlined in draft guidance for Section 45V are: the power generation would be time coincident, from new resources, and regionally connected (Federal Register, 2023). These requirements are intended to assure that low CI electric power is not diverted from existing customers to green hydrogen applications, yielding zero net environmental benefit. Achieving the lowest GHG score and maximum benefit under the IRA requires very low CI electric power. The power will need to have a CI below 8 g CO_2e/kWh[1] in order to achieve the IRA threshold of 0.45 kg CO_2e/kg H_2 which is feasible with renewable or nuclear power. In the case of fossil fuel generation, the CI is well above 400 g CO_2e/kWh; so even a small fraction of fossil power would exclude hydrogen from achieving the lowest IRA threshold value. The Internal Revenue Service (IRS) mandates that hydrogen eligible for 45V credits must not be used inefficiently while supporting emerging applications (IRS, 2023).

Emerging applications for green hydrogen include power-to-fuel, synthetic fuels, and hydrogen fuel cell vehicles (Chao, 2017). An additional benefit of the production of green hydrogen is the co-product oxygen. The oxygen co-product from electrolyzers or air separation units could be integrated with biomass gasification. This integration implies a potential synergy where the oxygen can be utilized to contribute to more sustainable industrial practices. Green hydrogen used as a boiler fuel could reduce the GHG footprint of industrial processes and even reduce the carbon intensity of natural-gas intensive fuels such as corn ethanol.

Figure 2 shows a range of potential green hydrogen applications and some of the displaced products. Several new applications have additional environmental benefits due to displacing more emissions or advancing technology in new sectors. For example, expanding renewable diesel facilities will rely on new sources of natural gas-based hydrogen or the use of renewable naphtha, which could otherwise be used as a chemical feedstock to produce low GHG materials. eFuels such as methanol to jet (MTJ) or Fischer Tropsch fuels derived from green hydrogen and waste CO_2 provide an opportunity to decarbonize the aviation sector. Ammonia is a key component to agriculture and it has a relatively high carbon intensity. The use of hydrogen in fuel cell vehicles will result in zero emission transportation and displace twice the amount of diesel energy in trucking applications.

The IRA guidance in Section 45V is sector and technology agnostic even though end use applications have different impacts on overall CI displacement. Natural gas-based pathways with CO_2 capture (blue hydrogen) could potentially qualify for credits under Section 45V. However, the three pillars will also apply to renewable power used to operate autothermal reformers. Proposed limitations on the IRA could also impact the incentive value for hydrogen projects at oil refineries (Martin, 2024). While reducing emissions from oil refineries will displace current hydrogen production emissions, continuing to refine crude oil is also an indirect impact of clean production.

---

[1] 8 g CO_2e/kWh × 55 kWh/kg H_2 = 0.44 kg CO_2e/kg H_2.

Copyright © 2024

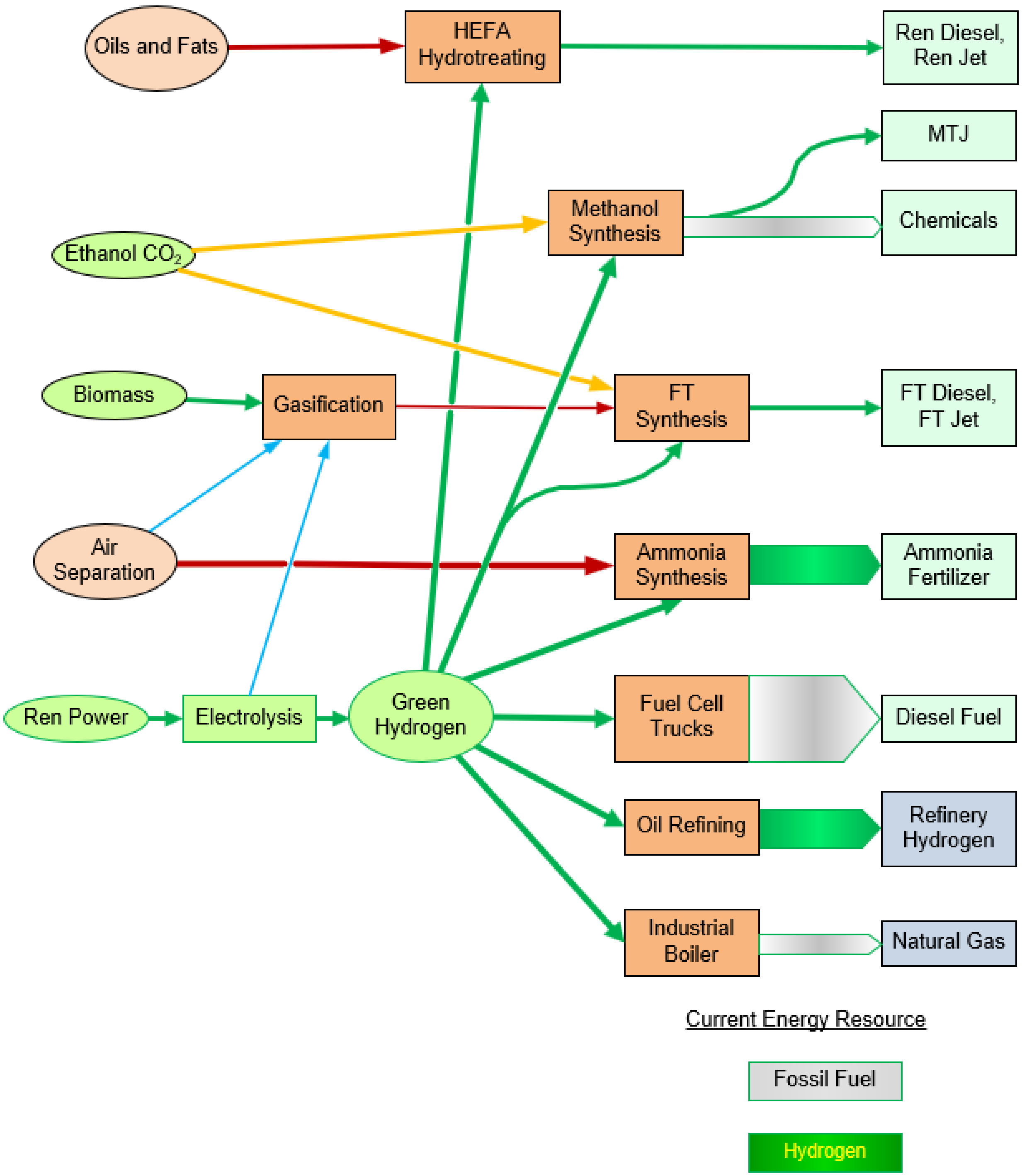

Figure 2. Green hydrogen has potential for use in many industrial applications.

Carbon Intensity of Hydrogen and Substitute Products

GHG reductions from green hydrogen depend on the displaced incumbent fossil fuel. In the case of refinery hydrogen and process heat, green hydrogen provides a 1:1 displacement of natural gas steam methane reforming (SMR) hydrogen on an energy basis. For ammonia, methanol, and on-road transportation fuels, the displacement ratio is pathway-dependent. In fuel cell vehicles, one kilogram (kg) of hydrogen displaces approximately double the energy content of petroleum diesel.

Copyright © 2024

Table 1 shows potential applications for green hydrogen and the displaced product. The carbon intensity (CI) of displaced products varies between 69.1 and 126.9 g/MJ of hydrogen. The hydrogen use rate per unit of product, along with CI, facilitates the calculation of GHG reductions per kilogram of green hydrogen. Considering this calculation, the GHG benefit per kilogram of green hydrogen used for ammonia, methanol, and trucking suggest they are the best sectors to achieve the GHG abatement goals of the IRA.

Displaced emissions from ammonia production are higher due to the complexities of the natural gas to ammonia process. Green ammonia, utilized in agriculture, promotes the advancement of low-carbon fuels and biomaterials, contributing to the reduction of GHG emissions in the agriculture sector as ammonia is a key component of fertilizer manufacturing (EIA, 2021). Nitrogen fertilizers, including urea and ammonium nitrate, constitute roughly 80% of the total ammonia market, with only 2% directly applied in pastures (Saygin, et al., 2023).

Grey methanol, an energy-intensive product, derives half of its global production from coal, potentially leading to an indirect displacement effect. Methanol's applications are widespread, ranging from chemicals and other industrial applications to transport fuel (EIA, 2019). The efficiency of fuel cell vehicles leads to green hydrogen displacing twice the energy in transportation fuel, resulting in a high GHG displacement rate for this application.

The effect of green hydrogen in industrial applications also depends on the displaced source of hydrogen. In oil refinery applications for example, hydrogen SMRs often provide waste heat for the refinery which lowers the overall CI of the grey hydrogen. Hydrogen liquefaction can add 8 kg CO_2e/kg of hydrogen; so, on-site green hydrogen production can displace more GHG intense sources of hydrogen. In heating applications, the use of hydrogen is less effective where it displaces relative low CI natural gas.

Table 1. Applications for Green Hydrogen and GHG Displacement of GHG emissions.

Application	Displaced Product	Hydrogen Use (M tonne/y)	Use Rate (kg H_2/kg Product)	Displaced Carbon Intensity (CO_2e)	
				g/MJ Product[a]	kg/kg H_2[b]
Ammonia	NG Ammonia	2.0	0.194	126.9	12.29
CO_2 to Methanol	NG, Coal Methanol	1.6	0.191	93.4 to 200	9.76 to 20
Fuel Cell Truck	Diesel	0.5	0.5	95.0	22.80
Oil Refinery Hydrogen	H_2 by NG SMR	6.8	1	78.7	9.44
HEFA	H_2 by NG SMR	0.336	1	80 to 90	9.5 to 10.8
LH2 Delivery	H_2 by NG SMR	0.04	1	150	18.0
Boiler Fuel	NG Boiler	2.4	1	69.1	8.29

[a] life cycle GHG emissions from GREET

[b] Displaced GHG emissions = CI (g/MJ) × LHV (MJ/kg)/Use Rate × 120 MJ/kg H_2/1000

$$= 126.9 \text{ g/MJ } NH_3 \times 18.8 \text{ MJ/kg } NH_3) \times 120/1000 = 12.29 \text{ kg } CO_2e/\text{kg } H_2$$

CI values from GREET (Wang, 2023) and GREET 45V calculator (ANL, 2023), and (Unnasch, 2018).

Best use of Green Hydrogen

Any use which displaces a fossil fuel will reduce GHG emissions; however, applications such as ammonia, fuel cell vehicles, and LH2 delivery provide the greatest emission reductions per kg. Figure 3 demonstrates the displaced GHG emissions from green hydrogen uptake, based on the end-use application. The largest diameter circle corresponds to greater emission reductions while the smaller blue circles represent established uses where green hydrogen will have less of an impact.

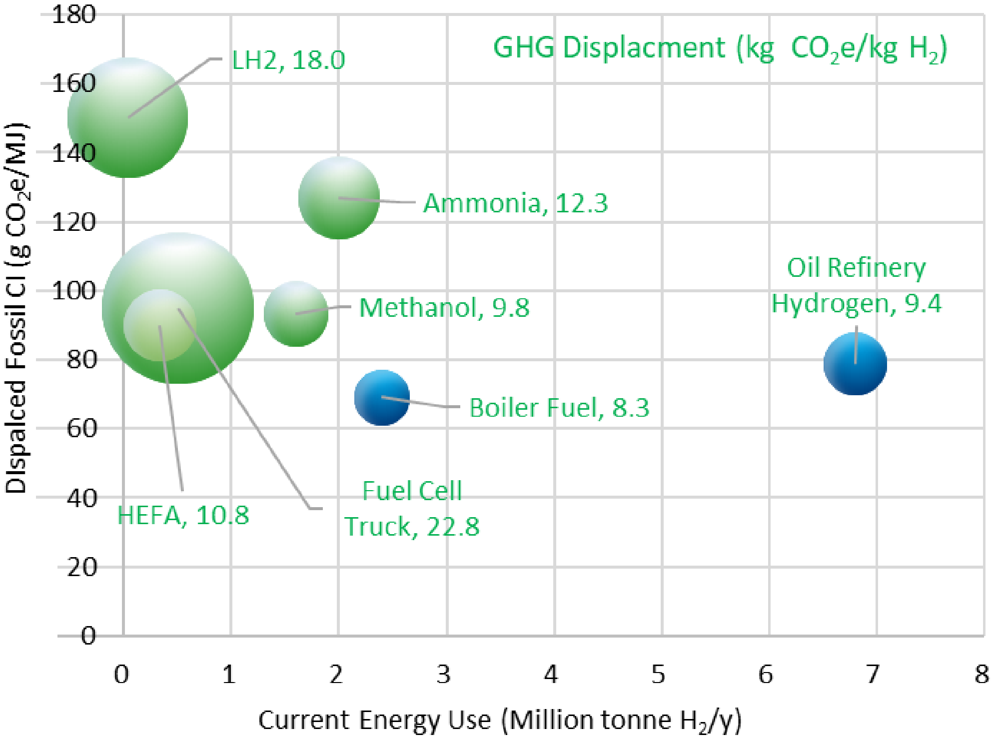

Figure 3. The displaced GHG emission from green hydrogen depends on the end-use application.

A few components from the preliminary guidance on the requirements for Section 45V of the IRA are worthy of comment to ensure the best uses of green hydrogen achieve even greater uptake. These include the requirements for the three pillars of renewable power, matching choices of feedstocks, and considerations for indirect effects.

Achieving time-of-use additionality and regional location requirements for renewable power is an ideal goal pursued by many developers. A current challenge however, is that such requirements are evolving and developers will have difficulty in procuring renewable power in the near term due to current capacity constraints. A transition period, similar to the one allowed under the European Union rules for renewable fuels of non-biological origin (RFNBOs) would be appropriate (EU Commission, 2023). The time horizon for EU producers is through 2045, creating an unlevel playing field for U.S. producers constrained to an immediate requirement.

Finally, many proposed hydrogen technologies provide significant environmental benefits above and beyond simply displacing fossil hydrogen from natural gas (EIA, 2023). For example, hydrogen powering fuel cell vehicles displaces double the volume of diesel on an energy basis, signifying a notable indirect effect in end-use applications. Prioritizing applications with the most substantial environmental would support the intended goals of the IRA and the strategic green hydrogen roadmap.

Copyright © 2024

References

ANL. (2023). *Guidelines to Determine Well-to-Gate Greenhouse Gas (GHG) Emissions of Hydrogen Production Pathways using 45VH2-GREET 2023.* Argonne National Laboratory (ANL). Retrieved from https://www.energy.gov/sites/default/files/2023-12/greet-manual_2023-12-20.pdf

Chao, J. (2017, October 6). *Berkeley Lab.* Retrieved from https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php

DOE. (2023). *U.S. National Clean Hydrogen Strategy and Roadmap.*

EIA. (2019, February 21). Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=38412

EIA. (2021, March 21). Retrieved from https://www.eia.gov/naturalgas/weekly/archivenew_ngwu/2021/04_01/

EIA. (2023, April 28). Retrieved from https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php

EU Commission. (2023, February 13). Retrieved from /Commission_sets_out_rules_for_renewable_hydrogen.pdf

Federal Register. (2023, December 26). Retrieved from https://www.federalregister.gov/documents/2023/12/26/2023-28359/section-45v-credit-for-production-of-clean-hydrogen-section-48a15-election-to-treat-clean-hydrogen

IEA. (2019). *The Future of Hydrogen: Seizing today's opportunities.* Paris: IEA (International Energy Agency). Retrieved from https://www.iea.org/reports/the-future-of-hydrogen

IRS. (2023, December 26). Retrieved from https://www.federalregister.gov/documents/2023/12/26/2023-28359/section-45v-credit-for-production-of-clean-hydrogen-section-48a15-election-to-treat-clean-hydrogen

John Feldmann, Z. B. (2023). Clean hydrogen: Outlook for freight transport in the United States. *Working Paper. Washington, DC: World Resources Institute*. Retrieved from https://www.wri.org/research/clean-hydrogen-outlook-freight-transport-united-states

Le PA, T. V. (2023 Sep 25). The current status of hydrogen energy: an overview. *RSC Adv*, 13(40):28262-28287.

Martin, P. (2024, February 23). *Hydrogen Insight.* Retrieved from https://www.hydrogeninsight.com/production/exxonmobil-threatens-to-scrap-worlds-largest-blue-hydrogen-project-over-us-emissions-criteria-for-tax-credits/2-1-1603061

Saygin, D., Blanco, H., Boshell, F., Cordonnier, J., Rouwenhorst, K., Lathwal, P., & Gielen, D. (2023). Ammonia Production from Clean Hydrogen and the Implications for Global Natural Gas Demand. *Sustainability*, 15, 1623. doi:https://doi.org/10.3390/su15021623

Shearman, S. (2021). *HYDROGEN'S PRESENT AND FUTURE IN THE US ENERGY SECTOR.* Sterling & Shearman . Retrieved from https://www.shearman.com/en/perspectives/2021/10/hydrogens-present-and-future-in-the-us-energy-sector

Stefano Sollai, A. P. (2023). Renewable methanol production from green hydrogen and captured CO2: A techno-economic assessment. *Journal of CO2 Utilization, 68*, 102345. doi:doi.org/10.1016/j.jcou.2022.102345

Unnasch, S. (2018). *GHG Analysis of Kalama Manufacturing and Marine Export Facility.* Life Cycle Associates Report LCA.6132.185.2018, prepared for Northwest Innovation Works.

Wakelin, S., & Beets, P. (2021). *Emission factors for managed and unmanaged Grassland with Woody Biomass.* Ministry for the Environment . Retrieved from https://environment.govt.nz/publications/emission-factors-for-managed-and-unmanaged-grassland-with-woody-biomass/

Wang, M. A.-A.-Y. (2023). Summary of Expansions and Updates in R&D GREET® 2023. *Systems Assessment Center, Energy Systems and Infrastructure Analysis Division, Argonne National Laboratory*.

Copyright © 2024