Title
Hydrogen Can Have a Much Lower Carbon Intensity than Fossil Fuels But This Largely Depends on How It Is Produced and Distributed

Authors
Lipman, Timothy, PhD
Horvath, Arpad, PhD
Collins, Stephanie
et al.

Publication Date
2022-09-01

DOI
10.7922/G21834TX

Institute of Transportation Studies | UNIVERSITY OF CALIFORNIA

Hydrogen Can Have a Much Lower Carbon Intensity than Fossil Fuels But This Largely Depends on How It Is Produced and Distributed

Timothy Lipman, PhD; Arpad Horvath, PhD; and Stephanie Collins - UC Berkeley
Allisa Kendall, PhD; Lewis Fulton, PhD; and Pablo Busch - UC Davis

September 2022

Issue

As interest in hydrogen as an energy carrier has increased, the various ways that hydrogen is made are being categorized as "green," "blue," "gray," and other colors in relation to their environmental impact. While these categorizations are somewhat useful to indicate the environmental and climate change impacts of different production pathways, they are not especially useful for policy making or industry decision-making purposes because they are subjective. For example, most definitions of green pathways for hydrogen production only include electrolysis from renewable electricity sources; however, Figure 1 indicates additional production pathways with some of these having near-zero or even negative greenhouse gas (GHG) emissions as well as low or no other emissions of concern. To help clarify the role of hydrogen in decarbonizing California, this brief summarizes the latest scientific findings from recent and in-progress research across the University of California Institute of Transportation Studies (UC ITS) concerning the relative carbon intensity (CI) of hydrogen production pathways. It also briefly covers the availability of biomass and biogas in California that could be applied to the production of low-CI hydrogen.

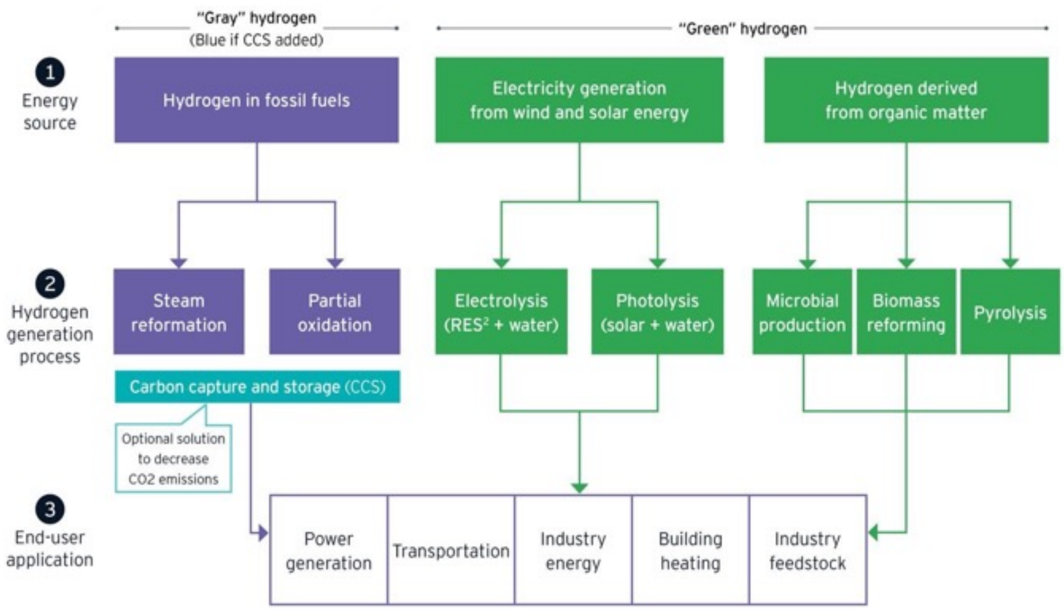

Figure 1: Example Schematic of Hydrogen Production Pathway Classificatio

Source: EY - Global ns

California Resilient and Innovative Mobility Initiative

Primary Research Findings

Hydrogen is not an inherently low-carbon fuel as this largely depends on how it is produced and distributed. There are many ways to produce hydrogen, including by electrolysis, biomass, waste stream conversion, and more advanced pathways (e.g., pyrolysis, solar thermochemical, nuclear cycle related). As shown in Figure 2, hydrogen pathways have varying CI scores, ranging from somewhat lower than the California gasoline (CARBOB) baseline to even less than zero. The CI scores reflect the greenhouse gas emissions (GHG) from the overall process used to produce hydrogen as well as from other details, including the feedstock used (e.g., natural gas, biogas, biomass, or electricity and water); how the feedstock is pre-processed (if needed); process efficiency that can be dependent on scale and technology type; distance of transport from where hydrogen is produced to where it is used; and other factors such as the CI of any electricity used for hydrogen production and compression.

How is carbon intensity calculated?

California's Low Carbon Fuel Standard (LCFS) takes a lifecycle approach when calculating the CI of transportation fuels. In the LCFS, CI is in "grams of carbon-dioxide equivalents" per megajoule (an energy unit) and indicates the GHG emissions from the production, transportation, and use of a fuel. An "energy economy ratio" (EER) adjustment is applied to account for the efficiency of a vehicle's drivetrain. For example, hydrogen fuel cell vehicles can go more than twice as far on a unit of energy as their gasoline and diesel fuel counterparts. Carbon-dioxide equivalents (CO2e) combine various GHG emissions (e.g., methane and nitrous oxide in addition to CO2) into a single measure by multiplying the impact of each gas by its estimated global warming potential compared to CO2 over a given time horizon (e.g., 100 years).

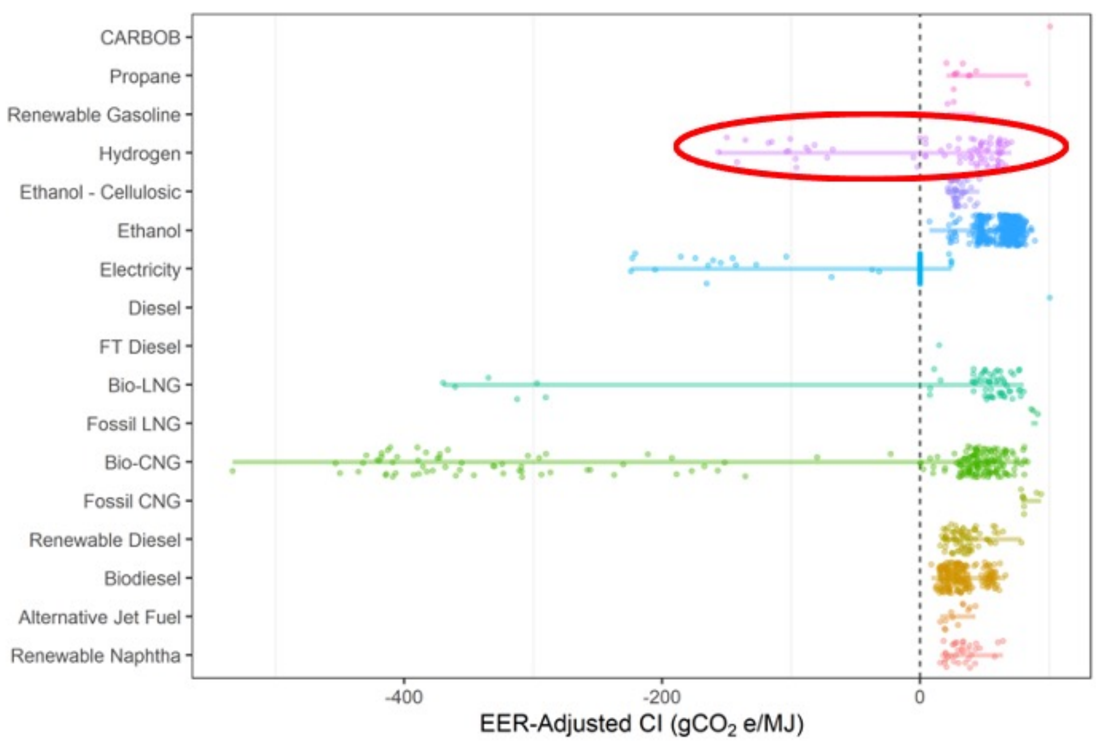

Figure 2: CI of Different Transportation Fuel Pathways as Defined in California's LCFS Program. Source: California Air Resources Board. Note: California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB) is the gasoline used in California; CNG is compressed natural gas; FT is Fischer-Tropsch process; LNG is liquified natural gas.

Some hydrogen production pathways have the lowest CI scores available, making them among the lowest emissions options. Figure 3 shows a more nuanced view of CI scores for the main hydrogen production pathways, which vary between and within production types. Pathways for producing hydrogen based on water electrolysis can have near zero CI scores; however, water availability may be a concern in dry desert areas. Also noteworthy is the projected reduction in CI for grid electrolysis from 2020 through 2040 based on California's commitments to a clean power grid. Some biogas pathways can have negative CI scores—at least in the near term—because they receive carbon credits for preventing methane (a potent GHG emission) from otherwise being released directly into the atmosphere, and are limited by feedstock availability. Other hydrogen production pathways deliver only modest GHG reduction benefits. For example, pathways based on conventional steam methane reforming (SMR) without CO2 sequestration can reduce CI scores less than 50% relative to gasoline, especially when hydrogen is compressed and transported as a liquid.

There is a potentially large supply of bio-feedstocks for low CI hydrogen production in California. An estimated 56 million dry tons of waste biomass could be available by 2045 in California and could potentially produce up to 5 million tons of hydrogen per year. A recent estimate of the state's available biomass resources for biogas and/or hydrogen production (Figure 4) identifies feedstock source availability by region. Southern California production resources are dominated by municipal waste and other gaseous waste sources. Central California has a mix of those sources as well as agricultural residues and forest waste. Northern California sources come mostly from wood waste, forest management, and sawmill residues.

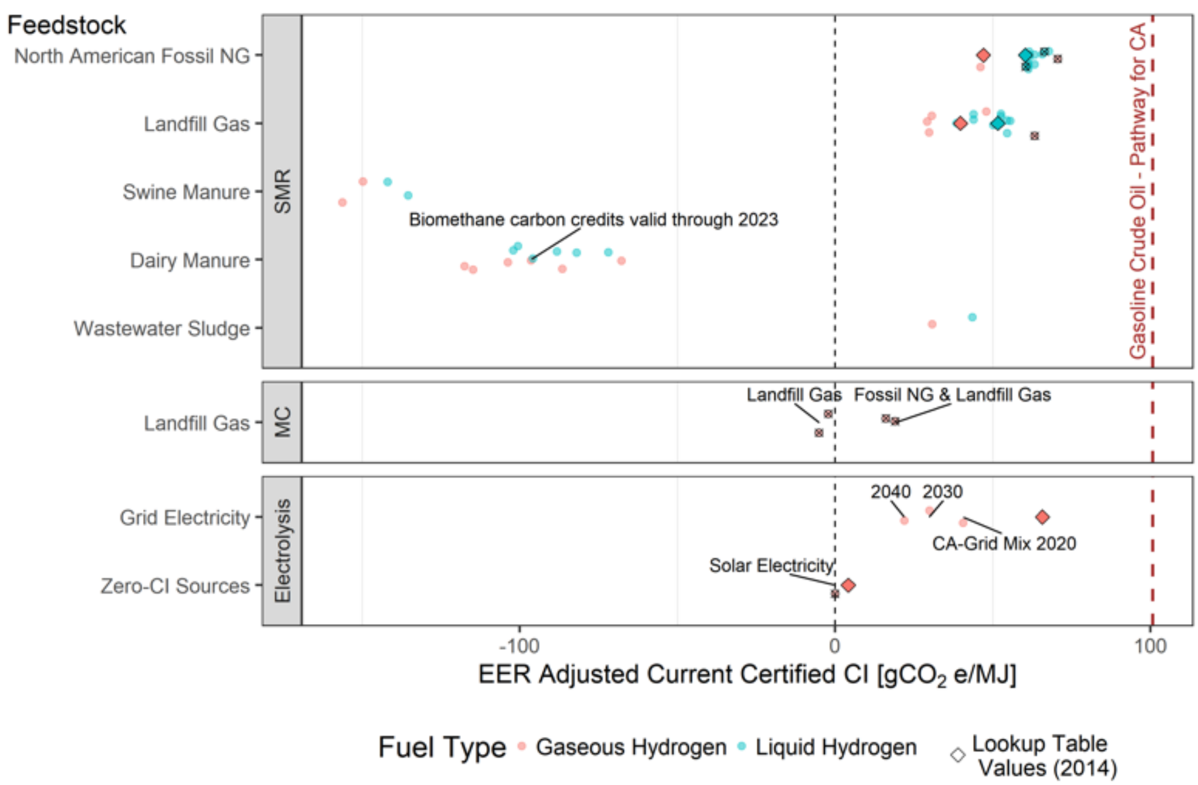

Figure 3: CI Scores of Main Hydrogen Production Pathways as Used in Transportation Applications. Source: Compiled by UC ITS from California Air Resources Board June 2022 data. Notes: MC is methane cracking; NG is natural gas. Carbon intensity values are from: ww2.arb.ca.gov/es/resources/documents/lcfs-pathway-certified-carbon-intensities.

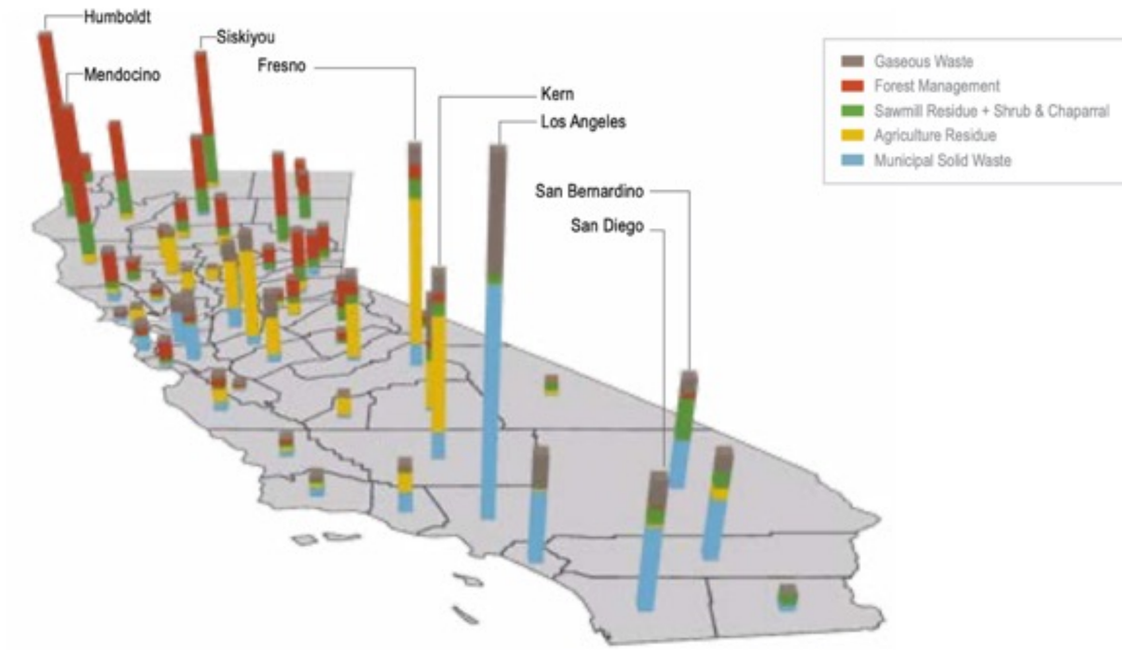

Figure 4: Biomass and Waste Feedstock Availability Estimate for California. Source: Lawrence Livermore National Laboratory

More Information

This brief is one in a series highlighting the latest research findings and insights related to the role, production, and use of hydrogen in achieving a zero-emission energy future for California. To learn more about this series, visit www.ucits.org/research-project/rimi-3n. For more information about the findings presented in this brief, contact Tim Lipman at telipman@berkeley.edu.

Further Reading

Brown, A. L; Sperling, D.; Austin, B.; DeShazo, JR; Fulton, L.; Lipman, T., et al. (2021). Driving California's Transportation Emissions to Zero. UC Office of the President: University of California Institute of Transportation Studies. http://dx.doi.org/10.7922/G2MC8X9X Retrieved from https://escholarship.org/uc/item/3np3p2t0.

Baker, S. E., J. K. Stolaroff, G. Peridas, S. H. Pang, H. M. Goldstein, et al. (2020), Getting to Neutral: Options for Negative Carbon Emissions in California, January, Lawrence Livermore National Laboratory, LLNL-TR-796100.

Romano et al. (2022) "Comment on How green is blue hydrogen?", Energy Science and Engineering, DOI: 10.1002/ese3.1126.

Lipman, Timothy E. and Adam Z. Weber (2018), "Fuel Cells and Hydrogen Production," A Volume in the Encyclopedia of Sustainability Science and Technology Series, Second Edition, Springer, New York, NY, ISBN: 978-1-4939-7789-5.

Research presented in this policy brief was made possible through the Resilient and Innovative Mobility Initiative (RIMI) led by the UC Institute of Transportation Studies (UC ITS). RIMI is supported by the State of California through a one-time allocation in the 2021 State Budget Act. The UC ITS created RIMI as a living laboratory – bringing together university experts, policymakers, public agencies, industry stakeholders, and community leaders – to inform the state transportation system's immediate COVID-19 response and recovery needs, while establishing a long-term vision and pathway for directing innovative mobility to develop sustainable and resilient transportation in California. Established by the California Legislature in 1947, the UC ITS has branches at UC Berkeley, UC Davis, UC Irvine, and UCLA.

Project ID RIMI-3N, RIMI-3P | DOI: 10.7922/G21834TX

California Resilient and Innovative Mobility Initiative