Originally published as Carbon Direct, which is now Relae. Learn more at relae.co



Journey to the Center of Hydrogen

Simplifying complexity with Carbon Direct's LCCA tool

February 18, 2025

Nicki Stuckert, Justine Davids, Julio Friedmann,
Thaddeus Woody, and Zhiyuan Fan

Contents

New opportunities for hydrogen 4
Scaling hydrogen effectively 4
Emissions abatement and displacement 5
The importance of geographic differentiation 5
Estimating the cost of abatement in tonnes and dollars 7
LCCA and the economics of decarbonization 8
Greater efficiency and inclusiveness with the LCCA tool 10
Acknowledgements 11

New opportunities for hydrogen

In January 2025, the United States (US) government released its guidance for 45V, the tax credit created under the Inflation Reduction Act for low-carbon hydrogen production. This comes during a moment of escalating electricity prices (including for various renewables), challenges in building out infrastructure, and growing electricity demand. At the same time, climate impacts continue to mount and there is renewed urgency around emissions abatement globally, including during the proceedings of COP29 and in anticipation of the Japanese Green Transformation Emissions Trading System (GX-ETS) rules and caps.

Against this backdrop, hydrogen is in the news and prompts two questions:

- Does using low-carbon hydrogen make sense?
- If so, in what context?

Let's start with the basics. Hydrogen is a useful molecule in that it stores chemical energy and can serve as an important clean energy option, providing a sustainable alternative to high-emissions fuels. It is an essential feedstock to fuel, fertilizer, and other chemicals that enable the modern world. Importantly, when used alone, it does not emit greenhouse gases.

Although useful and climate friendly, clean hydrogen projects are not being deployed fast enough to meet important climate goals—in terms of both financing and production. While many seek to produce or sell hydrogen into commercial markets as an energy source or feedstock, companies are often left with a core set of questions:

- What is the real climate benefit of different hydrogen supplies?
- Which are the most cost effective?
- Which hydrogen production methods are compatible with my location?
- What are the cost and climate impact tradeoffs?
- How do I create a reliable and accurate comparison between hydrogen and other alternatives?

The uncertainties behind these questions have hindered both investment in projects and commitments for commercial offtake, especially long-term offtake. Despite initial studies from many different technology vendors, success in reaching final investment decisions on projects has been minimal due to uncertainty surrounding this core set of questions.

To address these core questions and reduce uncertainty, Carbon Direct has created a levelized cost of carbon abatement (LCCA) tool, which quickly makes comparisons across technologies in specific markets and locations while estimating cost and climate benefits. This reveals how to achieve the most climate benefit for the lowest cost, and the trade-offs involved in any market or region.

Scaling hydrogen effectively

When implementing a new technology like hydrogen, it is important to start small before going big. Exploring the economic viability of a technology informs decisions about how it can be scaled and where it can be effectively deployed.

For each application and production method, small is defined differently—relative to the full scale or capacity required to address current and future needs. Importantly, moving from small to commercial scale is not achieved by simply applying a scaling multiplier. For instance, digging a mining pit instead of a hole requires more than just a bigger shovel. Successful scaling requires detailed analysis and is dependent not only on the readiness of the technology, but also on location-specific parameters (e.g., feedstocks, policies, co-benefits, energy supply, and costs).

Moving from an established technology to a new one also comes with risks. Often, the extra risk posed by commercial demonstration of emerging technology can be counterbalanced by policies and incentives that support development and deployment. Such market-aligning policies can give projects the boost they need to become feasible, both environmentally and commercially, making key problems solvable.

Emissions abatement and displacement

In isolation, many hydrogen projects are not feasible in terms of meeting a company's commercial, economic, or environmental goals. When reviewing available abatement technologies, companies must assess the various trade offs against their specific goals. In the energy sector, decarbonization plans must be considered holistically. Regarding climate benefits, these plans must consider the displacement of current fossil fuel sources, source climate-friendly alternatives, and plan for future increasing energy demand.

Many have attempted to create frameworks or guidelines to help drive the hydrogen market forward, but lack clear and easy tools to assess and recommend specific actions. It is challenging to find hydrogen solutions that both work and that are economically feasible relative to current technologies. With limited emissions abatement options available, many organizations find themselves struggling to appease investors or stakeholders (often at the expense of the climate).

The importance of geographic differentiation

The key to treasure hunting is knowing where to look. Although there are plenty of potential applications for clean hydrogen production, economically favorable options are scarce. Getting a toehold in the hydrogen market is dependent on investors having a defensible case as well as on high emitters having an incentive to decarbonize. Time dedicated to assessing tradeoffs or determining how to best take advantage of opportunities could delay needed implementation.

Location-specific considerations often drive the weighing of trade offs. In some cases, very little incentive is required for a project to be viable. For example, creating electrolyzer-based ammonia could make sense in areas with high-cost natural gas or oil, limited refining, and excess solar energy availability.[1] Hydrogen projects often need only minimal incentive to become feasible in locations where existing natural gas reforming or coal and oil pyrolysis suffers from high purification costs or supply-chain limitations. Location plays an important part in determining feasibility due to the specific energy constraints of each location and its grid.

[1] European Commission. 2024. European Hydrogen Bank auction provides €720 million. [accessed 2025 Jan 23]. https://ec.europa.eu/commission/presscorner/detail/en/ip_24_2333.

The geographic differentiation of clean hydrogen production, particularly hydrogen from electrolysis using zero-carbon electricity, is complex and subtle. For example, in the US, independent system operators (ISOs) vary by region in terms of price and carbon intensity. Once it is online for operation, each ISO has different market rules, pricing methods, and guidelines. ISOs are also regulated by the Federal Energy Regulatory Commission (FERC) which places price and operational limits on them. This means that price, carbon intensity, and access to electricity vary greatly by region. Similar issues complicate the European Union and other large power markets.

Regional complexity and hydrogen

Regional complexity can make it difficult to identify opportunities for hydrogen in the market, leaving unexplored options and confusion about which options are viable:

- Unexploited wind in close proximity to shipping warehouses could be used to enable hydrogen power for forklifts.
- In locations such as the Mojave desert, along the I-10 corridor, already built solar and wind systems in the interconnection queue could be used to supply hydrogen fueling stations.
- In locations like Wyoming, wind capacity could be harnessed next to a refinery that uses hydrogen for cracking.
- Houston, Texas has a constrained energy grid and efforts to apply electrolyzer hydrogen here may be wasted unless it functions as a "dispatchable" load.[2]
- The guidelines for the 45V tax credit are clear that using existing hydroelectric power in places like New York does not count as emissions-free electricity.[3]

The new 45V guidance provides some additional clarity and certainty. Under the new rules, existing nuclear energy facilities at risk of closure would be accepted as clean energy, as would newly built nuclear energy plants. The same is true for carbon capture and storage (CCS) retrofits to existing natural gas facilities. Additionally, a requirement to match electrolytic hydrogen production to clean electricity on an hourly basis has been delayed until 2030. Until then, projects may match on a yearly basis. The Department of Treasury also clarified the circumstances around which hydrogen produced from steam methane reforming would qualify for the credit. Namely, upstream methane leakage needs to be taken into account. Related Environmental Protection Agency regulations on methane emissions will also have an impact on this provision. However, identifying opportunities for receiving the 45V tax credit still carries some risk as the political landscape continues to evolve.

Natural gas that would have otherwise been flared, can also be used for hydrogen production. In certain production locations, such as the Marcellus or Permian Basins, many operators regularly flare gas. Some providers even offer natural gas for free if a partner can take it near a wellhead or transport it. A small collection (around 1%) of these sites are located near large industrial centers.

---

[2] Sofia S, Dvorkin Y. 2024. Carbon Impact of Intra-Regional Transmission Congestion. [accessed 2025 Jan 23]. doi:10.2139/ssrn.4972564.
[3] Federal Register. 2025 Jan 10. Credit for Production of Clean Hydrogen and Energy Credit. [accessed 2025 Jan 27]. https://www.federalregister.gov/d/2024-31513/p-374.

Natural gas flaring is the market equivalent of burning billions of dollars a year, so this 1% of sites alone represents a $100 million market opportunity. Leveraging this opportunity could be pivotal for powering a small town on hydrogen—in places such as southeastern New Mexico or western North Dakota (this is already being done in Fukushima, Japan[4] and in Lancaster, California).[5] However, receiving 45V tax credits for any natural-gas-based production methods would be dependent on the method used for accounting for upstream emissions leaks, which can be substantial.[6]

Estimating the cost of abatement in tonnes and dollars

Decarbonization technologies have different carbon reduction potentials and costs. Carbon Direct's LCCA tool has an easy-to-read model that combines cost and carbon intensity for a specific location and technology. With hydrogen specifically, there are many avenues for engagement, even when options are limited solely to those that make economic sense. To compare across multiple hydrogen uses and against other decarbonization options, Carbon Direct utilizes our LCCA tool to estimate the cost per tonne of carbon dioxide avoided for every hydrogen molecule used. This can be customized to compare across various technologies such as electrolyzers, CCS alongside existing hydrogen sources, and novel systems like methane pyrolysis or photocatalytic water cracking. Our scientific experts execute independent evaluations to recommend plausible strategies for each clients' individualized decarbonization goals and budgetary constraints. With these insights in hand, decision-makers can more easily evaluate trade offs and understand the impacts of their choices. **Figure 1** shows an example of the types of industries with varying potential to decarbonize using hydrogen.

[4] New Energy and Industrial Technology Development Organization [NEDO]. 2020 Mar 7. The world's largest-class hydrogen production, Fukushima Hydrogen Energy Research Field (FH2R) now is completed at Namie town in Fukushima. [accessed 2025 Jan 23]. https://www.nedo.go.jp/english/news/AA5en_100422.html.
[5] City of Lancaster. 2020 Nov 10. City News & Updates | City of Lancaster. [accessed 2025 Jan 23]. https://www.cityoflancasterca.org/Home/Components/News/News/9530/20.
[6] United States Environmental Protection Agency [US EPA]. 2018 Jan 30. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016. [accessed 2025 Jan 23]. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016.

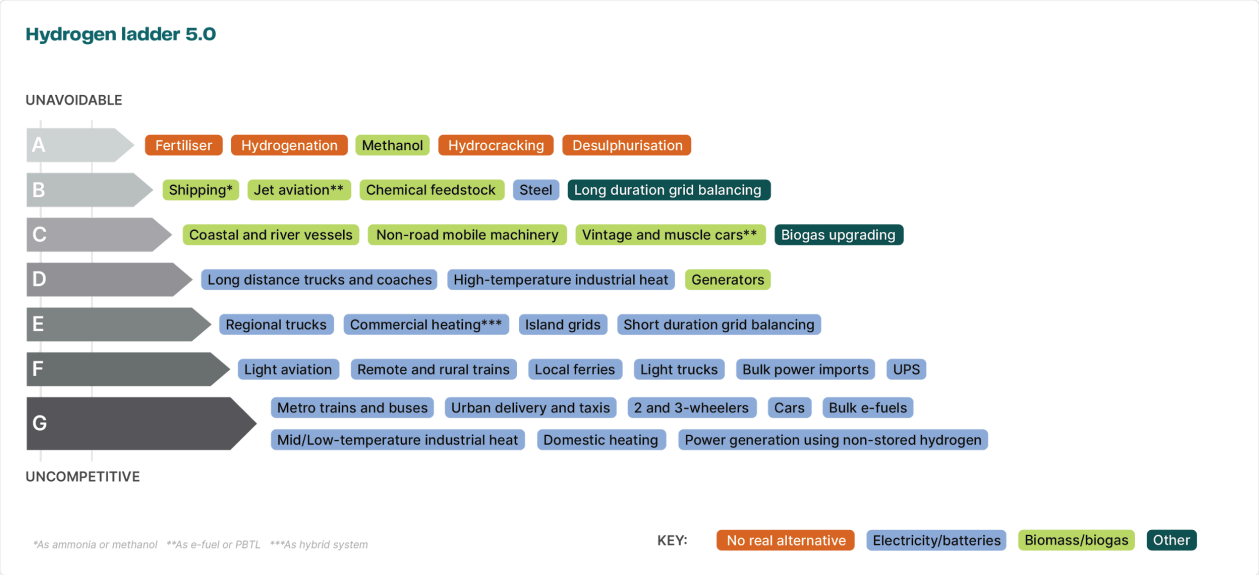


Figure 1. Hydrogen ladder showing industries with varied potentials to utilize hydrogen in decarbonization efforts. Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 5.0, 2023. Concept credit: Adrian Hiel, Energy Cities. As modified by Carbon Direct. CC-BY 4.0.

The LCCA is a key metric to consider when the goal is economical emissions reduction. When working with a fixed budget or a specific decarbonization target, such as 150,000 tonnes of carbon dioxide, our LCCA tool identifies an option's specific impact and cost. This allows clients to select the options that best suit their circumstance. The metric allows comparison across technologies and projects on a net-present-value basis against key scenarios. This can include comparing options like using sustainable aviation fuel, buying a large-scale renewable power purchase agreement, buying renewable energy credits, buying high-quality carbon dioxide removal, or switching the fuel for a warehouse's forklifts from natural gas to hydrogen. The LCCA tool also allows for comparisons across and between policies and mechanisms, such as carbon markets, incentives, and subsidies, which a company may still be considering or need guidance and direction on. Additionally, the LCCA tool can help with evaluating emissions reductions resulting from utilizing a clean energy source versus pairing existing systems with otherwise wasted energy sources, an avenue many investors and utility providers are exploring.

LCCA and the economics of decarbonization

By focusing on the LCCA when considering different decarbonization approaches, decision-makers can identify low-hanging fruit, allowing them to set investment priorities, set policy priorities, and allocate resources efficiently. For example, the LCCA can help in deciding which facilities should be retired or replaced first and what the best available options are for replacement.

More importantly, a minimum LCCA also directly indicates the most financially sustainable option. For instance, in certain hard-to-abate sectors, it is likely that a portion of greenhouse gas emissions are too expensive to directly mitigate. In these sectors, a suitable option would be to identify a cost-effective portion of emissions to abate and then purchase reliable carbon dioxide

removal for the unabated portion. The LCCA serves not only as a metric for making internal investment decisions within a company, but also as a metric for advising on alternative strategies, and for enabling stakeholders to minimize the need to purchase carbon credits and maximize the climate benefits of any potential investment. **Figure 2** shows an example of the LCCA tool being used to make a comparison of two electrolyzer suppliers of hydrogen.



Figure 2. The LCCA tool applied to a comparison of two electrolyzer suppliers of hydrogen for a unique client that uses periodic excess electricity. Hydrogen is being provided for a non-critical (~98% reliable) application. Figure shows cost, in US$, per tonne of abated emissions. **Supplier Y is the optimal choice due to fast ramp-up and ramp-down rates despite lower overall efficiency.** Note: CO_2 = carbon dioxide, H_2 = hydrogen, kg = kilograms. Source: Carbon Direct.

When hydrogen is part of a decarbonization strategy, the LCCA is determined by two factors: (1) the hydrogen cost, including capital expenditures, operating expenses, and net present value; and (2) the amount of greenhouse gas emissions that are abated or avoided compared to the alternative.

Evaluating options requires deep market intelligence, technical expertise across diverse technologies, knowledge of policies and subsidies, and the ability to navigate market and regulatory uncertainties. While many organizations have in-house teams with the expertise to assess these options, the assessment process can create a significant demand on resources and there is the risk of realizing minimal benefits due to the complexity of decarbonization landscapes.

A rigorous, “apples-to-apples” analysis can help decision-makers fully understand the trade offs among various decarbonization options and ensure that each dollar spent delivers the maximum emissions reduction. This kind of analysis can be utilized across different industries such as transportation, carbon dioxide storage, materials production, and hard-to-abate industries such as production of building and construction supplies like concrete and steel.

Greater efficiency and inclusiveness with the LCCA tool

By utilizing Carbon Direct’s LCCA tool, decision-makers can land on answers to core questions while avoiding the monotony and pitfalls of manual comparisons. With the LCCA tool, the complexities of utilizing hydrogen in decarbonization plans can be navigated more effectively. This enables organizations to focus on developing projects that are both economically feasible and the best fit for their specific climate goals. The Carbon Direct LCCA tool also allows for greater involvement across a larger swath of sectors. With greater involvement comes greater diversity of thought, which is key to pushing forward change. To solve the issue of climate change, we will need everyone.

To learn more about Carbon Direct's LCCA Tool, please reach out to us via our contact us form.

Acknowledgements

Authors and contributors

Nicki Stuckert, PhD, Senior Decarbonization Engineer
Justine Davids, Energy and Climate Strategist
Julio Friedmann, PhD, Chief Scientist
Thaddeus Woody, Policy Analyst
Zhiyuan Fan, Adjunct Engineer, Columbia University
Adrianna Sutton, Science Writer and Editor

About Carbon Direct

Carbon Direct Inc. helps organizations go from climate goal to climate action. We combine technology with deep expertise in climate science, policy, and carbon markets to deliver carbon emission footprints, actionable reduction strategies, and high-quality carbon dioxide removal. With Carbon Direct, clients can set and equitably deliver on their climate commitments, streamline compliance, and manage risk through transparency and scientific credibility. Our expertise is trusted by global climate leaders including Microsoft, American Express, and Alaska Airlines, as well as by the World Economic Forum, which selected Carbon Direct as an Implementation Partner for the First Movers Coalition. To learn more, visit www.carbon-direct.com.

Disclaimer

Carbon Direct does not provide tax, legal, accounting, or investment advice. This material has been prepared for informational purposes only, and distribution hereof does not constitute legal, tax, accounting, investment, or other professional advice. No warranty or representation, express or implied, is made by Carbon Direct, nor does Carbon Direct accept any liability with respect to the information and data set forth herein. The views expressed in this document are opinion only, and recipients should consult their professional advisors prior to acting on the information set forth herein.