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RENEWABLE THERMAL COLLABORATIVE

Assessment of green hydrogen for industrial heat - A Summary

April 2023

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Background

The industrial sector is the third largest source of greenhouse gas (GHG) emissions in the United States after electricity and transportation, accounting for approximately 24% of the total US emissions.[1] Over half of the industrial sector's emissions come from fossil fuel combustion to generate process heat. Decarbonizing industrial process heat, and overcoming the many technological, market, and policy barriers that prevent companies from using renewably powered heat, is essential for a meeting a 1.5°C climate ambition.

More and more governments and companies are committing to climate action across the global economy. They are examining and implementing various decarbonization tools with governments offering new policy incentives, and investment in research, development and demonstration (RD&D) and renewable energy generation accelerating across renewable thermal energy solutions.

Among these solutions, green hydrogen, produced by electrolysis using renewable electricity, may have a critical role to play in decarbonizing industrial process heat. The industrial sector often needs high heat for production, and green hydrogen may be a strong candidate to decarbonize high-heat industrial processes, such as manufacturing steel, chemicals, and cement. Beyond industrial process heat, green hydrogen has the potential to cost-effectively store energy to balance intermittent and variable electricity production from wind and solar. Hydrogen fuel cells are already used to power cars, buses, trains, and other vehicles, and will likely be an important feedstock for future aviation fuels.

Reflecting its importance, green hydrogen was named a specific priority for 2023 at the 27th United Nations (UN) Conference of the Parties (COP27),[2] where leaders discussed the importance of mobilizing capital to develop and scale green hydrogen projects, the role of policy as an instrument to drive down costs, and the need for standards and a certification system to enable trade.

Additionally, interest in green hydrogen is growing among the many companies setting ambitious science-based climate targets. More than a fifth of the world's 2000 largest companies have made net zero commitments by 2050.[3] According to the Science Based Targets initiative (SBTi), 1,524 companies globally and 202 companies in the US have committed to net-zero targets, of which 391 global and 63 US companies have an SBTi-approved target.[4] To reach these goals, companies need rapid development of infrastructure and deployment of low-carbon technologies such as green hydrogen.

In the United States, recent federal legislation, including the Infrastructure Investment and Jobs Act (IIJA; also known as the Bipartisan Infrastructure Law [BIL])[5] and the Inflation Reduction Act (IRA),[6] has put meaningful policy and billions of dollars of funding behind the push for clean hydrogen, including investment in RD&D and tax credits directly incentivizing clean hydrogen investment and production. The Department of Energy (DOE) recently announced its National Clean Hydrogen Strategy and Roadmap, a vital plan to build industry alignment and a path forward for the clean hydrogen economy.[7]

Challenges and Opportunities

Within this context and with these challenges and opportunities in mind, we examined the technical, economic, social, and political considerations bearing on the adoption of green hydrogen for industrial heat by evaluating the following questions:

- What is the technical and economic potential for scaling the use of green hydrogen for industrial process heat in a cost-effective, environmentally friendly, and socially responsible way?
- What are the major technological, financial, policy, and other barriers in the nascent hydrogen market in the United States?
- What are the potential pathways for scaling green hydrogen for industrial heat use in the United States?

Given the share of the industrial sector's GHG emissions, we focused on five priority subsectors, which together account for more than 70%[8] of industrial heat demand: oil refining, chemicals manufacturing, pulp and paper, iron and steel, and cement. Within these subsectors, hydrogen likely will see varying levels of adoption.

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1 EPA, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions "Sources of greenhouse gas emissions," last updated August 5, 2022. Accessed January 2023

2 © Argus Media group 2022. https://www.argusmedia.com/en/news/2390368-cop-27-breakthrough-agenda-set-hydrogen-priorities "COP 27: Breakthrough Agenda set hydrogen priorities," November 11, 2022. Accessed January 2023.

3 UN Climate Champions. https://racetozero.unfccc.int/21-of-major-companies-commit-to-net-zero/" 21% of major companies commit to net zero, March 23, 2021. Accessed March, 2023.

4 Science Based Targets, https://sciencebasedtargets.org/companies-taking-action SBTi target dashboard. Accessed January 2023.

5 White House, https://www.whitehouse.gov/build/ Delivering results from President Biden's Bipartisan Infrastructure Law." Accessed January 2023.

6 White House, https://www.whitehouse.gov/ostp/news-updates/2022/09/20/launching-a-transformative-decade-of-climate-action/ "Launching a Transformative Decade of Climate Action." Accessed March 2023.

7 DOE, https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf DOE National Clean Hydrogen Strategy and Roadmap, September 2022. Accessed November 2022. The DOE uses "clean hydrogen" in its publications, while this report uses "low-carbon hydrogen."

8 Ibid

Based on our analysis, insights and considerations were developed for large corporate energy buyers and other market and policy stakeholders. They include:

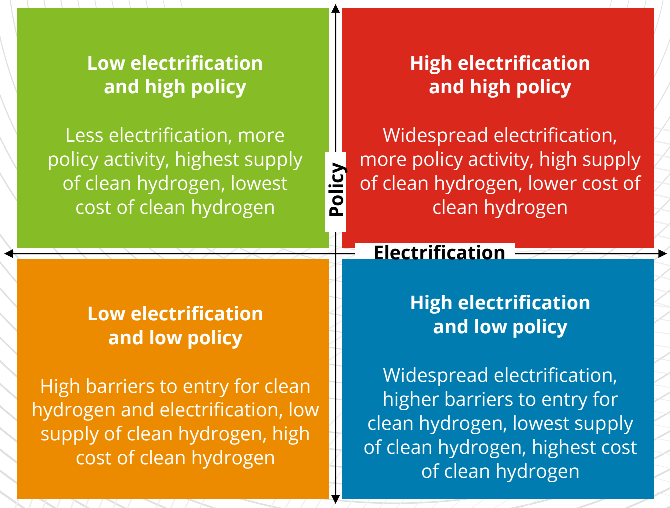
- The IRA aims to dramatically lower green hydrogen production costs. However, infrastructure and cost barriers persist in other parts of the hydrogen value chain. Transportation, storage, and retrofitting investments required on the end-use side still pose challenges to scaling the demand for green hydrogen. Overcoming these challenges likely will require additional policy support.
- Green hydrogen likely will be a key component of the decarbonization strategy for chemicals, cement, and iron and steel. Therefore, energy buyers in these subsectors will likely be early adopters and should begin to take advantage of current policies, like the IRA and regional hubs as part of a broader plan to decarbonize.
- Buyers outside these subsectors can still participate by leveraging their geographic proximity to green hydrogen hubs and establishing early relationships with hub developers. By taking proactive early actions, other sectors could have the opportunity to enter buyers' consortiums or teaming agreements with larger buyers to explore innovative procurement options. These early efforts will likely be important in accelerating the growth of the broader hydrogen economy.

Estimating hydrogen adoption rates by industrial heat users

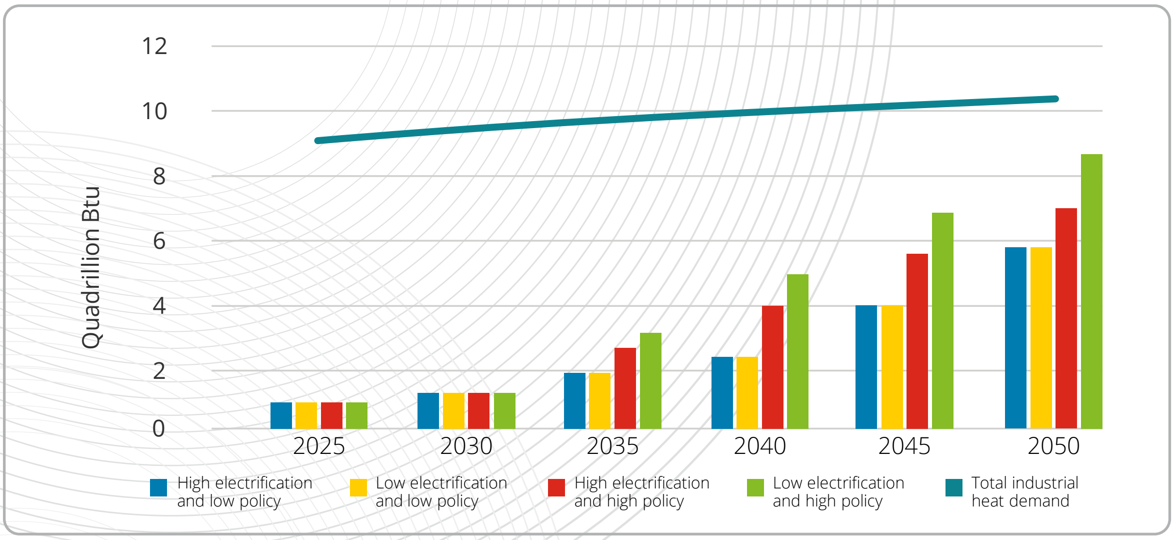
Given it is still early days in the hydrogen market, and future considerations are complex, forecasting remains difficult with the large number of unknowns. Our analysis addresses this challenge by leveraging desktop research and insights and constructing a model to estimate hydrogen adoption rates by industrial heat users across possible scenarios.

Scenarios describe hypothetical yet plausible future pathways that can lead to a particular outcome. They are not intended to represent a complete description of the future or to forecast how events will unfold; rather, they are intended to highlight critical elements and drivers of future developments.

Hydrogen adoption across the US industrial sector will likely depend primarily on the federal policy push to create a hydrogen ecosystem and the potential electrification of industrial heat processes compared to fuel-based alternatives. The modeling scenarios considered these two potential levers in a high/low environment and their impact on scaling green hydrogen.

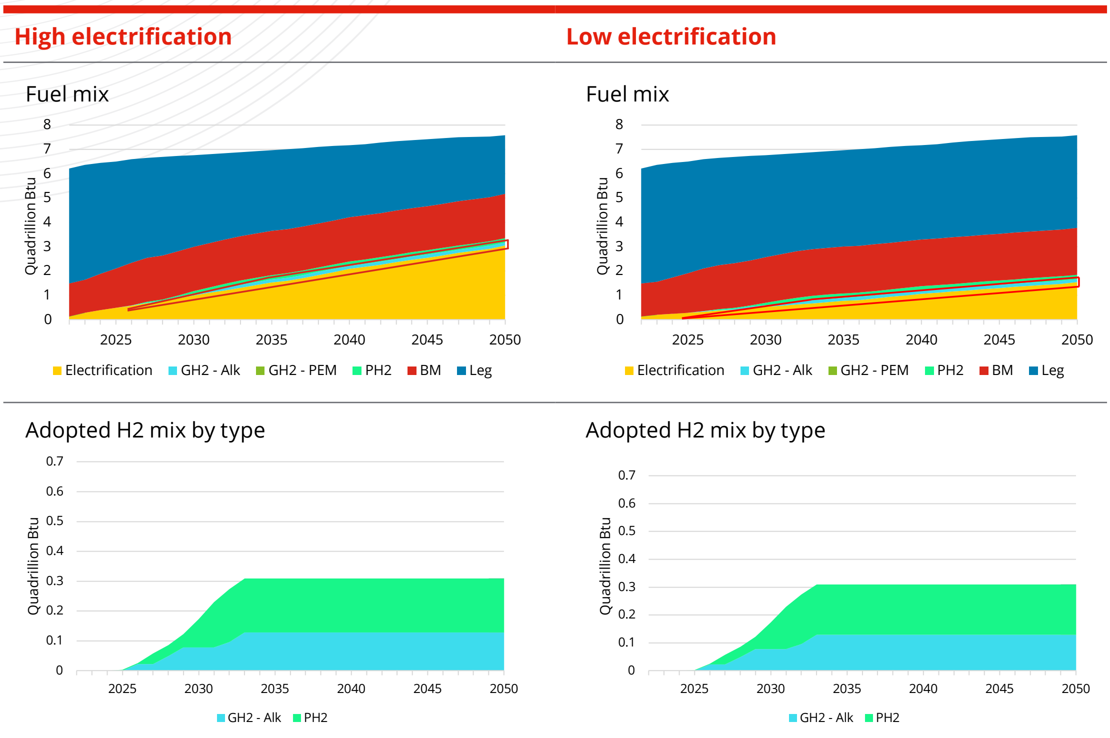


The model was composed of modules that calculate supply, demand, and the levelized cost of energy for different energy sources. The outputs of these modules are connected via a decision engine, yielding estimates for the uptake of green hydrogen (and other fuels) by various industrial subsectors. The figure below shows the base supply of hydrogen over time by scenario.



In each of the low policy scenarios, the total supply is in line with the DOE's draft plan for hydrogen development, and the total hydrogen supply is expected to be approximately 5.76 quadrillion British thermal units (quads) by 2050. The total supply increases by 20% in the high electrification and high policy scenario and by 50% in the low electrification and high policy scenario. The incremental adoption in the high policy scenarios is driven by lower marginal cost and low supply, which sends a demand signal through the model for incremental capacity to be developed in subsequent periods. Values are held constant through 2030, assuming that the DOE cannot increase the scale of hydrogen further than planned in the short term. It is assumed that the production of green hydrogen will use approximately 5% of the country's total renewable energy capacity in 2025 and about 10% of the total renewable capacity in 2030.[9] The further years assume that renewable energy supply is sufficient to meet production requirements given the DOE's states goals to fully decarbonize the grid by 2035. However, the nature of the grid's decarbonization is one of the challenges facing the green hydrogen industry.

For the low policy scenarios, the IRA incentives for hydrogen expire in 2033 for project placed into service after December 31, 2022. Carbon pricing is phased gradually after 2040, going from $0 to $67/Mt by 2050. Roughly 40% of industrial fuel use will electrify in the high electrification scenario case, driven by the pulp and paper, chemicals, and iron and steel subsectors. This drops to roughly 20% in the low electrification scenario. The figure below shows the fuel mix through 2050 for the low policy scenarios. The hydrogen adoption profile is the same in both low policy scenarios, and as such, the low electrification, low policy scenarios is not included in the sector analyses.



[9] EIA, https://www.eia.gov/outlooks/aeo/ Annual Energy Outlook 2022, March 3, 2022. Accessed November 2022.,

Summary results

High electrification

- Electrification, legacy fuels, and waste biomass are likely to be the major industrial heat energy sources accounting for 96%.
- Hydrogen potential in this scenario is limited, accounting for 4% of the total fuel supply.
- Hydrogen adoption occurs before incentives expire in 2033.
- Hydrogen utilization in this scenario is driven by pink hydrogen, with green hydrogen accounting for roughly 1% of total energy utilization by 2050.

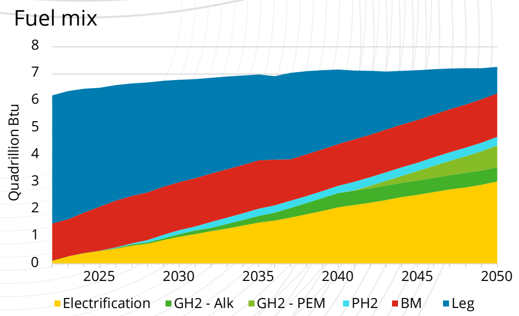
Low electrification

- Legacy fuels and waste biomass are likely to be the major industrial heat energy sources in this scenario
- The hydrogen adoption profile is similar to the high electrification scenario, accounting for 4% of the total fuel supply.
- Overall adoption in the low policy scenarios is roughly half of the current hydrogen utilization in the United States.
- Hydrogen utilization in this scenario is driven by pink hydrogen, with green hydrogen accounting for roughly 1% of total energy utilization by 2050.

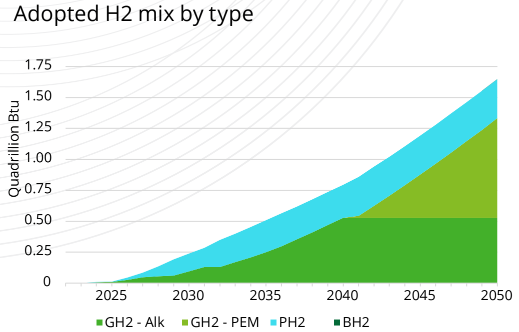
For high policy scenarios, the IRA incentives for hydrogen expire in 2040. Carbon pricing begins in 2030 at $171/Mt and increases to $477/Mt by 2050.[10] Roughly 40% of industrial fuel use will electrify in the high case, driven by pulp and paper, chemicals, and iron and steel subsectors. This drops to roughly 20% in the low electrification scenario. The figure below shows the fuel mix for each high policy scenario.

High electrification

Fuel mix[104]



Hydrogen mix

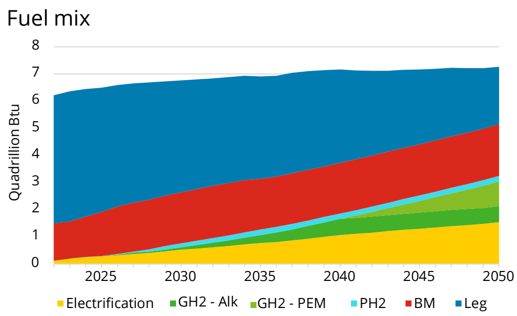


Summary results

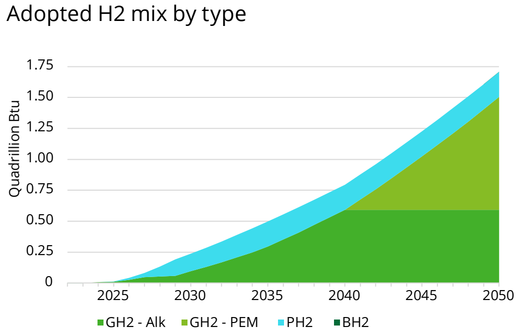
- Electricity and waste biomass are likely to be the major industrial heat energy sources.
- The use of legacy fossil fuels is expected to decline over time and will account for 13% of total thermal energy use in this scenario by 2050.
- Hydrogen adoption will occur consistently through 2050 due to tax credits and carbon pricing.
- Roughly 1.3 green hydrogen quads are likely to be used in industrial heating (twice today's hydrogen use).
- Green hydrogen is likely to account for 18% of total thermal energy use in this scenario.
- PEM overtakes alkaline hydrolysis as the most cost-effective production method around 2040 and is the dominant source of green hydrogen in industrial heating.

Low electrification

Fuel mix



Hydrogen mix



Summary results

- Electrification will be slow and account for 21% of total thermal energy use in this scenario by 2050.
- The use of legacy fossil fuels is expected to decline over time; however, it will continue to be one of the primary energy sources for industrial heat.
- The potential for hydrogen in industrial heating is relatively unchanged by decreased electrification, primarily due to barriers for adoption in high heat applications.
- 1.5 quads of green hydrogen will be adopted in this scenario vs. 1.3 quads in the high electrification case.
- Earlier adoption of green hydrogen (due to higher supply) crowds out pink hydrogen adoption, decreasing the adoption of pink hydrogen in this scenario by roughly 30%.

[10] This is in line with the IEA's Net Zero Scenario for developed economies, factoring in inflation.

The potential utilization of green hydrogen in industrial heating processes is highly dependent on policy in the short term and on the price and availability of green electricity in the long term.

Considerations and actions for energy buyers

The modeling analysis supports the strong role of government policy in determining the scope and scale of the green hydrogen economy. Policy incentives, especially for end users, will likely be critical to the development of a green hydrogen market for industrial heating given the capital expense required for industrial end-users to incorporate hydrogen into their processes.

As the green hydrogen economy grows, so will its impacts. Areas likely to host significant green hydrogen production, use, and related infrastructure will likely see profound changes in their communities. Green hydrogen production requires water, significant amounts of renewable electricity, and the physical footprint of plants, pipes, and storage media. Therefore, it should be designed and developed carefully and sustainably to avoid negative impacts on local community, water, land and biodiversity.

Matching electricity consumption on an hourly basis with locally procured, “additional” clean generation may support emissions saving from green hydrogen production. Without proper requirements for grid-connected hydrogen producers to procure clean electricity, emissions from hydrogen produced through electrolysis could be worse than those produced via conventional, unabated fossil pathways. Therefore, as the demand for green hydrogen grows, stakeholders will likely need to have methods in place to track and confirm that hydrogen is truly green.

As green hydrogen is scaled, stakeholders likely will need to help develop sensors, leak detection, improved infrastructure and supportive policy measures to prevent environmental damage. Combustion reactions that heat air to high temperatures can create harmful pollutants called nitrogen oxides (NO and NO2, known together as NOx).[11] While the production and use of green hydrogen are free of CO2, hydrogen combustion does produce NOx. Given the health impacts associated with NOx, consideration should be given to minimizing these impacts.

Our model and research sheds light on the need to overcome the capital costs required to utilize hydrogen in the industrial heating space. Buyers can consider employing hydrogen when phasing in new facilities, implement internal carbon prices, and engage in research and development efforts to decrease the cost of hydrogen fueled heating equipment to facilitate hydrogen adoption.

[10] Christopher Douglas, Benjamin Emerson, Timothy Lieuwen, Tom Martz, Robert Steele, and Bobby Noble, https://research.gatech.edu/sites/default/files/inline-files/gt_epri_nox_emission_H2_short_paper.pdf NOX emissions from hydrogen-methane fuel blends, Georgia Tech University's Strategic Energy Institute, January 2022..

Large corporate energy buyers and other stakeholders can begin addressing the challenges facing the green hydrogen economy to drive market expansion. There are several policy, market, and technology actions that these groups could consider in order to accelerate its scope and scale:

Technology | Market | Policy and Regulatory

Considerations	General opportunities	Energy buyer actions
Hydrogen policy extensions, and new policy create market certainty Advocating for timely extensions to IRA tax credits through 2040 or 2050 (as well as less likely policies, such as a carbon price) could bring down hydrogen cost curves, enable adequate infrastructure build, and allow hydrogen to become cost competitive with other heating fuels over the long term.	Form working group to: • Develop industry perspective • Create advocacy campaigns • Participate in public commenting periods for local, state, and federal proposed policy and programs • Work with government actors to develop and implement policy	• Take advantage of current policies and benefits to green hydrogen development • Stay active in conversations with policymakers on benefits of current legislation • Participate in public commenting periods for local, state, and federal proposed policy and programs
Planning, permitting, and approval reduce costs, and time constraints Increasing coordination between different planning, permitting, and approval authorities can reduce time constraints and cost burdens for a rapid build-out of clean energy generation and transmission, without compromising valuable regulatory safeguards.	Form working group to: • Develop an industry perspective • Share desired reforms with planning, permitting, and approval authorities at the local, state, and federal levels	• Work with project proponents, including executing commitment letters or other agreements, to signal demand for projects
Hub ecosystems foster dependable supply, and demand Locating industrial heat users geographically around effective hubs (either funded by the DOE program or privately) will provide more dependable supply and developed logistics that could incentivize using or transitioning to green hydrogen.	• Develop industry coalitions between private and public sector to create DOE or privately funded hubs • Coordinate across the value chain to enable community engagement throughout design and development	• Geographically assess hub proximity to operations • Secure relationship with hub developers • Enter offtake agreement to secure supply

Considerations	General opportunities	Energy buyer actions
Rapid deployment of renewable generation assets supports green hydrogen expansion Planning and deploying renewable generation assets and grid infrastructure early and rapidly, above what will be required to meet current electricity demand, can help avoid long lead times, enable current green hydrogen demand, and enable long-term grid decarbonization. Deployment in grid regions and regions with low-average electricity prices could accelerate the deployment of green hydrogen.	• Develop working groups to create industry coalition and unified voice on renewables to enable green hydrogen • Invest in renewable energy project to secure PPAs and VPPAs • Collaborate with regulators and approval authorities for rapid infrastructure deployment	• Take early stance on demanding green hydrogen supply for industrial heat • Team with hydrogen producers, network infrastructure providers, and regulatory and approval authorities to enable scaling of renewable energy projects and related hydrogen infrastructure
Increase social license to operate Developing appropriate outreach and education efforts can generate broad public support and grant social license for the hydrogen economy.	• Develop industry message • Leverage existing relationships and engagement models to reinforce the community benefits of hydrogen • Roll out public surveys to gauge public perception on hydrogen • Develop public education and marketing campaigns	• Provide spaces where communities can ask questions and engage in dialogue • Develop educational and interactive content to share benefits of new projects
Community engagement during design, and development for a just transition Building strong relationships with local groups and engaging in open dialogue early to build trust, understand community circumstances, and enable collaboration during the design and development phases for hydrogen projects can help enable a just transition when scaling green hydrogen.	• Develop and share transparent design and development plans with local groups, nonprofits, and nature conservation organizations • Create public surveys to gather community feedback • Host local events to educate and encourage dialogue • Build job and skills training programs for green hydrogen roles	• Develop and share transparent design and development plans • Share consistent communications with local communities and consumers

Considerations	General opportunities	Energy buyer actions
Information campaigns on green hydrogen for potential value chain players Educating energy buyers on the environmental benefits of green hydrogen and current policy instruments can help foster a greater sense of community among energy buyers and help them define their role in the broader energy transition.	• Develop educational content on green hydrogen (e.g., decarbonization benefits) • Create marketing materials on current/available policies and cost benefits to green hydrogen production • Host webcasts and events to create open dialogue and answer questions to develop buyer community	• Engage in working groups to improve overall knowledge of green hydrogen • Collaborate with nonprofits and industry coalitions to increase participation in the broader hydrogen movement
Standardizing supply contracts eases market entry Increasing standardization of supply contracts and other relevant market instruments related to hydrogen could improve transparency and lower transaction costs, risks, and uncertainty in order to ease entry into contracts, reduce the risk to early adopters, and allow for bilateral and OTC trading, which could eventually enable a wholesale hydrogen commodity market with standard contracts.	• Develop point of view, set industry standard, and encourage regulatory adoption of low-carbon hydrogen definition • Align stakeholders on common contracting process and methodology • Develop position on contract transparency • Understand and develop hydrogen commodity trading department	• Understand carbon intensity of supply to purchase green hydrogen specifically • Collaborate with buying consortia to increase overall volume purchased and price certainty to help reduce transport costs
Develop sustainability criteria for hydrogen Developing sustainability criteria for hydrogen and confirming only electricity is being used from renewables can increase certainty that hydrogen is "green" and that grid-connected electrolyzers provide hydrogen without negative impacts.	• Develop point of view, set industry standard, and encourage regulatory adoption of sustainability criteria • Participate in public commenting periods for local, state, and federal proposed policy and programs • Work with government actors to develop and implement policy	• Participate in public commenting periods for supportive policies and standards • Work with NGOs and organizations to update GHG accounting protocols

Considerations	General opportunities	Energy buyer actions
Consistent technical and safety standards can ill policy gaps Building hydrogen health and safety standards that address the full value chain through collaboration with standard-setting bodies and intentional RD&D efforts can help promote investment and generate public support to scale green hydrogen.	• Establish leading practices and a clear message on safety future blueprints with standard-setting organizations • Work with government actors to develop and implement policy • Collaborate with national labs, universities, and corporations to promote RD&D efforts	• Collaborate with industry associations to establish blueprint for future safety standards • Work with government actors to fill policy gaps
RD&D, and investments enable scale, and decrease costs across the value chain Allocating RD&D and investments from government and private ssector (especially for high-heat applications) to lower the costs and increase efficiencies across electrolysis, storage, and transportation of green hydrogen, as well as innovating to reduce retrofitting costs for use in industrial heating, is essential for a sophisticated green H2 economy. Retrofitting high-temperature processes like chemical cracking is prohibitive and may limit adoption in industry.	• Identify and allocate capital for RD&D investment (e.g., developing the green hydrogen value chain) • Advocate for policy to incentivize RD&D • Pilot new technologies and solutions	• Develop teaming arrangements with startups, national labs, investors, and universities to develop end-use considerations • Communicate with equipment providers to understand work done to incorporate hydrogen into existing process and the requirements for retrofitting • Develop focused RD&D to address environmental issues (e.g., NOx emissions and fugitive emissions)

Implementing these and other considerations can let market and policy stakeholders accelerate the just and sustainable deployment of hydrogen for industrial process heat in priority subsections, realizing meaningful GHG reductions.

This a summary of the full report which can be found here.