CLEAN HYDROGEN: DEMAND-SIDE SUPPORT POLICY RECOMMENDATIONS

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Center for Climate and Energy Solutions

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Meeting our long-term climate goals will require the large-scale deployment of a multitude of new, innovative technologies and low- and zero-carbon fuels across every sector of the economy. First-of-a-kind technologies will need to rapidly reach commercial scale without sacrificing safety, social equity, or sustainability. This can only be achieved through systemwide collaboration between corporate incumbents, financiers, innovators, communities, and policymakers. To help meet this challenge, C2ES has created four distinct technology working groups focused on the technologies of engineered carbon removal, sustainable aviation fuel, long duration energy storage, and clean hydrogen. This brief presents findings and recommendations from the clean hydrogen working group.

OVERVIEW

To mitigate climate impacts, major greenhouse gas emission reductions will be required across the United States economy. Rapid decarbonization will necessitate the development and deployment of new clean technologies, as well as low- and zero-carbon fuels as substitutes in emissions-intensive sectors. In particular, the petroleum refining, chemical, aviation, maritime, and heavy-duty long-haul trucking industries are limited in their ability to directly substitute emissions-intensive fuels and feedstocks with clean electricity. Many of these activities could benefit from the use of clean hydrogen as a versatile, low-carbon energy carrier which can be used as a primary input in the production of lower-carbon fuels and chemicals, store energy, combusted for industrial process heat, or passed through a fuel cell to create electricity. However, virtually all of the hydrogen used in the United States today is generated through an emissions-intensive processes that, while relatively inexpensive, emits significant volumes of greenhouse gases. Achieving emission reductions with clean hydrogen will require converting current hydrogen users to clean hydrogen and expanding demand in new sectors to replace polluting practices. To address this challenge, the Center for Climate and Energy Solutions (C2ES) formed a technology working group that convenes stakeholders from across the hydrogen ecosystem to examine the key technical, market, and policy solutions required to expand clean hydrogen demand. This brief offers a shortlist of five policy recommendations following the working group's inaugural year.

INTRODUCTION

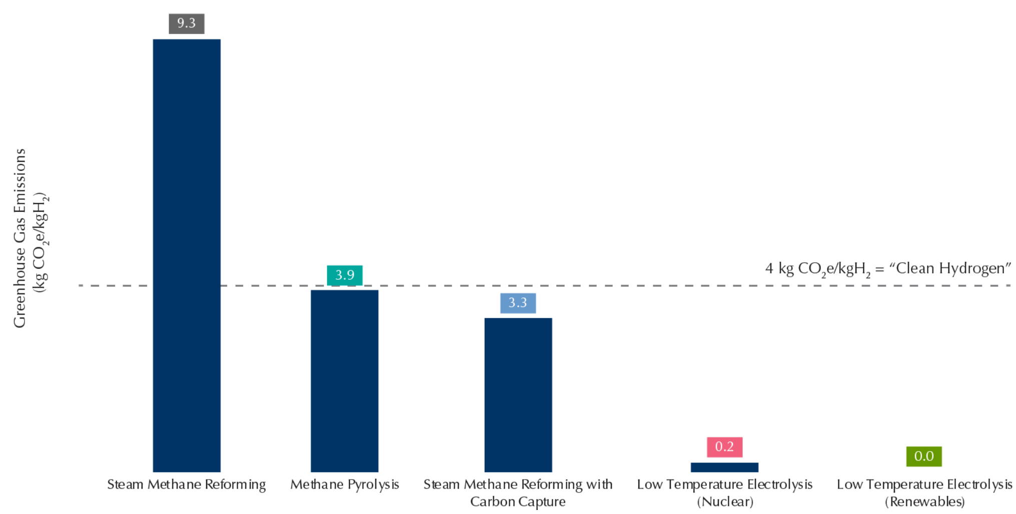
Hydrogen is the most abundant element in the universe, yet extracting and isolating it has to date employed methods that release unabated greenhouse gases into the atmosphere. If those methods are replaced with cleaner production technologies, hydrogen can be a promising solution to many complicated decarbonization problems: it can be used as feedstock for fuel and chemical production, a replacement for fossil fuels in industrial processes, and in many other applications. The dominant production process for making hydrogen—steam methane reforming (SMR) without carbon capture (i.e., gray hydrogen)—is very carbon intensive, producing approximately 10 kilograms of carbon dioxide per kilogram of hydrogen.[1]

Clean hydrogen, on the other hand, can be produced through multiple pathways, each with its own "color code" shorthand, including but not limited to SMR with carbon capture (blue hydrogen), electrolysis (green or pink hydrogen, if powered by renewable or nuclear energy respectively), and methane pyrolysis (turquoise) (see Figure 1).[2] Each production pathway ranges in lifecycle emissions. Hereafter, "clean hydrogen" refers to hydrogen produced with lifecycle emissions not greater than four kilograms of carbon dioxide per kilogram of hydrogen, which corresponds to the highest emission rate eligible for the 45V Credit for Production of Clean Hydrogen.[3]

THE GROWING IMPORTANCE OF MARKET DEMAND FOR CLEAN HYDROGEN

Each year, companies in the United States produce ten million metric tons (MMT) of gray hydrogen, leading to the addition of 100 MMT of carbon dioxide equivalent emissions to the atmosphere.[4] In 2023, the U.S. Department of Energy (DOE) released the U.S. National Clean Hydrogen Strategy and Roadmap, which describes the important role clean hydrogen could play as a cost-competitive way to decarbonize several key sectors (see Figure 2).[5] The roadmap highlights multiple opportunities to replace the ten MMT of gray hydrogen with clean hydrogen by 2030, reducing U.S. economy-wide emissions by ten percent by midcentury.[6] However, while there are many opportunities for clean hydrogen to act as a vital decarbonization tool, the demand for it does not match the urgency at which such tools should be deployed. Relative costs, regulatory clarity and certainty, and available use cases, are among the various challenges affecting clean hydrogen uptake.

FIGURE 1: Hydrogen Production Pathways



Non-exhaustive examples of hydrogen production pathways: SMR (steam methane reforming with natural gas), MP (methane pyrolysis with natural gas), SMR with CCS (steam methane reforming with 96.2% carbon capture), and LTE (low temperature electrolysis) with electricity sourced from nuclear power and renewables. Figures are examples of well-to-gate lifecycle emissions derived from the "R&D GREET" model and represented in the source below. Actual values will range based on individual circumstances.

Data source: Elgowainy A, Vyawahare P, Ng C, Frank ED, Bafana A, Burnham A, Sun P, Cai H, Lee U, Reddi K and Wang M (2024) Environmental life- cycle analysis of hydrogen technology pathways in the United States. Front. Energy Res. 12:1473383. doi: 10.3389/fenrg.2024.1473383

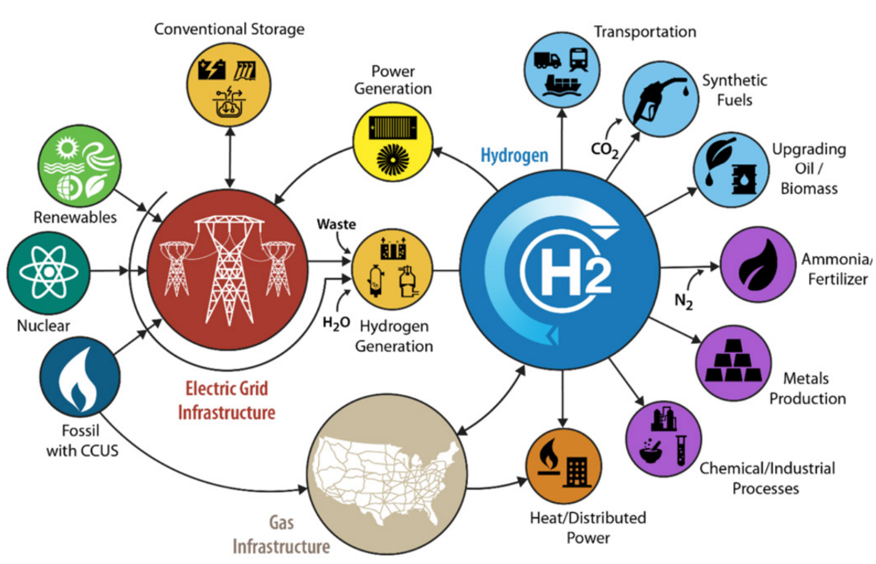
The cost differential between gray hydrogen and clean hydrogen is a key challenge to growing demand; gray hydrogen costs about $1.00 per kilogram, compared to estimates of about $2.00 per kilogram for blue hydrogen and $3.00 to $7.00 per kilogram for green hydrogen.[7] Cost estimates for green hydrogen range significantly as a function of projected clean electricity costs, which varies by region, as well as the cost and performance of electrolyzers.[8] Additionally, transporting green hydrogen from regions with cheap renewable energy to regions with greater hydrogen demand will involve additional distribution and storage costs which can significantly increase the delivered price of hydrogen.[9]

Current hydrogen demand is concentrated in three end-uses: petroleum refining (55 percent) and producing ammonia and methanol (collectively 35 percent).[10] Existing gray hydrogen users in the United States largely produce their own supply of hydrogen. As a result, they currently have no financial incentive to procure clean hydrogen, because the cost of doing so would greatly exceed the cost of their current supply.[11]

Barriers to scaling up new demand include ineffective price signals, nascent transportation and storage infrastructure, and a lack of commercial-scale technology demonstrations. While clean hydrogen can play a significant role in the transportation, chemical, and industrial sectors, each of these potential demand pools is subject to its own price sensitivities that do not currently align with clean hydrogen market dynamics.[12] These issues are further compounded by the uncertainty of ongoing regional hydrogen hub negotiations and pending rules for the 45V production tax credit. Formulating federal policy to address these challenges and help unlock private sector demand is key to growing the clean hydrogen industry.

Both the administration and Congress are working to alleviate cost-competitiveness concerns via policy and legislation. The 2021 Infrastructure Investment and Jobs Act (IIJA) appropriated $9.5 billion in support of clean hydrogen, including up to $8 billion to establish clean hydrogen hubs around the United States, $1 billion for the Clean Hydrogen Electrolysis Program to reduce the costs of producing hydrogen with clean electricity, and $500 million for Clean Hydrogen Manufacturing and Recycling Initiatives to support manufacturing and supply chains.[13] In 2022 Congress established the 45V Credit for Production of Clean Hydrogen, which provides tiered tax incentives based on the lifecycle emissions of the hydrogen produced. Currently, the administration is drafting and publishing guidance on how these incentives will be structured, including eligibility requirements for various levels of incentives. However, demand for clean hydrogen must be robust and durable for companies to fully leverage these resources and effectively reduce emissions.

FIGURE 2: Clean Hydrogen Prospective Use Cases



* DOE's H2@Scale initiative to enable decarbonization across sectors using clean hydrogen.

Source: U.S. Department of Energy, U.S. National Clean Hydrogen Strategy and Roadmap (Washington, D.C.: DOE, 2023), https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf?sfvrsn=c425b44f_5

ABOUT THE C2ES CLEAN HYDROGEN TECHNOLOGY WORKING GROUP

In January 2024, the Center for Climate and Energy Solutions (C2ES) formed the clean hydrogen technology working group to address the challenge of how to grow the near-term market for clean hydrogen among existing and prospective use cases. This working group convenes leading companies across the hydrogen ecosystem, including current and prospective hydrogen consumers, producers, energy companies, technology companies, infrastructure providers, capital providers, and other key stakeholders. Recognizing the diversity of hydrogen production pathways, the working group supports the use of hydrogen from all production methods that meaningfully reduce hydrogen lifecycle emissions.

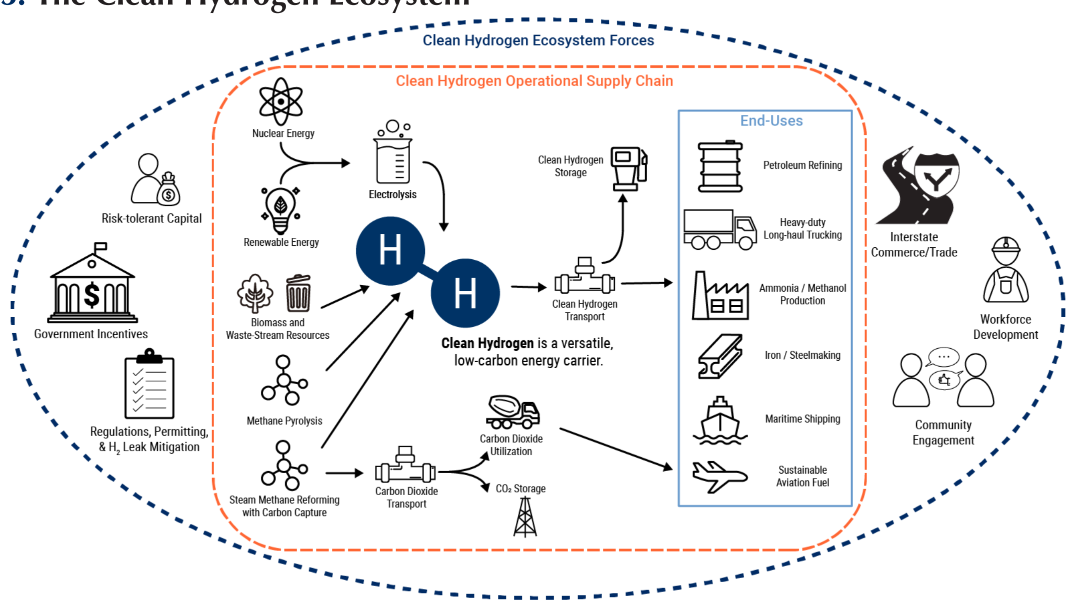
Through expert presentations and interactive discussions, the working group identified and examined the most significant obstacles impeding market demand for clean hydrogen. The following demand barriers were identified and ranked roughly in order of relevance by participants:

1. On a dollar-per-kilogram basis, the price for clean hydrogen will generally exceed the price of gray hydrogen for the next five to ten years.
2. On a carbon abatement cost basis (i.e., $/tCO2e), the current costs of switching to clean hydrogen for gray hydrogen and/or natural gas users can be less attractive than more accessible decarbonization methods.
3. Limited capacity to store and transport hydrogen at an acceptable financial cost constrains production and demand.
4. The cost (including potential downtime or performance risk) of retrofitting equipment/processes to switch from natural gas to hydrogen exceeds any expected financial benefits of switching to clean hydrogen.
5. Lack of price transparency for clean hydrogen impedes investments in demand-side uptake.
6. The capital and efficiency costs of retrofitting existing gray hydrogen production facilities with carbon capture technology exceeds any expected financial benefits.
7. The cost of re-arranging supply chains for existing (gray) hydrogen users exceeds any expected financial benefits of switching to clean hydrogen.
8. The demand for electricity grid infrastructure for new renewable energy production exceeds that available for the next five to ten years.
9. The demand for end-use equipment (e.g., fuel cells, generators) exceeds market supply.

ON INNOVATION

Policymakers must play a central role in accelerating innovation across the nascent clean hydrogen ecosystem (see Figure 3). Without innovation, clean hydrogen will remain at an extreme disadvantage in the market, since hydrogen is currently a commodity with limited existing

FIGURE 3: The Clean Hydrogen Ecosystem



end-uses. Innovation is needed to make new end-uses feasible, transportation safer, and production more affordable. A holistic policy framework that encourages rapid development and continual improvement of new clean hydrogen technologies should support the full innovation process (See Figures 4 and 5)—from research and development through full-scale adoption and diffusion—and thread the needle between multiple complex dynamics: balancing supply- and demand-side incentives; encouraging innovation in components as well as end-to-end systems for production, distribution, and use; and focusing attention on cost reduction through innovations that achieve greater efficiency and economies of scale.

Because hydrogen has so many potential end-uses, a wide range of policies—from application-specific approaches to sectoral or economy-wide efforts—may impact the industry's progress. At the same time, whether these policies are actually successful will depend on a variety of factors, including how stringent those policies are, the alternatives available to end-users, and the price of clean hydrogen as market opportunities grow and diversify. During the first year of our clean hydrogen working group, we explored these dynamics in detail.

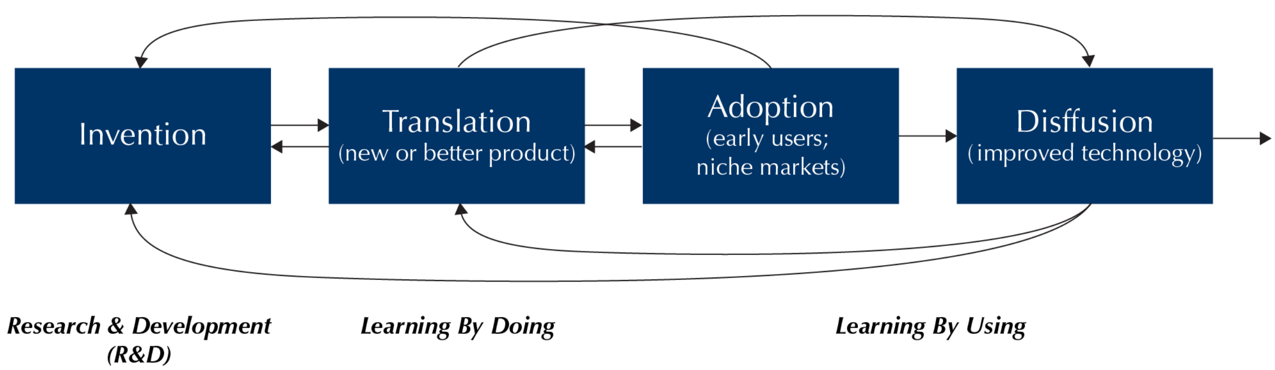
C2ES will continue to build on this work, integrating learnings from other technology working groups (i.e., long-duration energy storage, sustainable aviation fuels, and engineered carbon removal), and helping to align each technology ecosystem around a vision for innovation that can effectively and responsibly speed the commercial deployment of this critical set of technologies.

FIGURE 4: Project Stages of a New Innovation

As an innovation is developed and evolves, it moves through different stages before achieving commercial deployment and widespread diffusion. Throughout these stages, different feedback loops of the innovation process are triggered, helping enable continuous improvement.

Process graphic adapted from: David Ye, "From FOAK to NOAK", *CTVC by Sightline Climate* (blog), April 19, 2024, https://www.ctvc.co/from-foak-to-noak/?ref=ctvc-by-sightline-climate-newsletter.

FIGURE 5: The Innovation Process



The innovation process is made up of four interrelated stages: invention, translation, adoption, and diffusion. From ITIF: "Programs and policies across these stages shape a complicated innovation ecosystem that includes a diverse network of institutions. Few technologies move from research to market in a linear fashion. Most are aided by feedback from later stages to earlier ones, so that downstream learning is incorporated into design and development."

Source: Jetta L Wong and David Hart, "Mind the Gap: A Design for a New Energy Technology Commercialization Foundation" ITIF, May 2020, https://d1bcsfjk95uj19.cloudfront.net/sites/default/files/2020-mind-gap-energy-technology.pdf.

OVERVIEW OF POLICY RECOMMENDATIONS

C2ES has produced the following shortlist of high-impact policy recommendations based on discussions over the first year of the clean hydrogen technology working group. These recommendations are focused on specific actions the federal government can take to help unlock demand for clean hydrogen, and fall into three categories: creating market certainty, transmission and distribution, and demand-side funding. **Table 1** summarizes the legislative and administrative policy priorities outlined in this brief.

TABLE 1: Summary of policy priorities

CATEGORY	POLICY PRIORITY	LEAD
Demand-side funding	1. Provide additional funding for demonstration and commercial-scale projects under the Office of Clean Energy Demonstrations	L A
Transmission and distribution	2. Grant the Federal Energy Regulatory Commission the authority to regulate interstate hydrogen infrastructure and commerce	L
Creating market certainty	3. Update the Renewable Fuel Standard	A L
	4. Enact a federal Clean Fuel Standard	L
	5. Enact federal economy-wide carbon pricing	L

The column labelled "lead" indicates whether the policy falls under legislative L and or administrative A purview.

1. PROVIDE ADDITIONAL FUNDING FOR DEMONSTRATION AND COMMERCIAL-SCALE PROJECTS UNDER THE OFFICE OF CLEAN ENERGY DEMONSTRATIONS

SUMMARY

Congress should increase funding for demonstration and commercial-scale clean hydrogen applications under the DOE's Office of Clean Energy Demonstrations (OCED), pending the finalization of the office's award negotiations with the Regional Clean Hydrogen Hubs and the design of the Clean Hydrogen Hubs Demand-Side Support Mechanism. The hydrogen demand-side initiative funded through OCED will support market demand for clean hydrogen while it scales toward cost-competitiveness. It is important that OCED have the funding needed to mobilize private capital investments in these early stages of the clean hydrogen economy and effectively leverage incentives on the supply-side.

RATIONALE

In October 2023, OCED announced seven awardees of the $7 billion available to launch Regional Clean Hydrogen Hubs. An additional $1 billion has been allocated to support a demand-side initiative designed to establish market certainty for producers and users of clean hydrogen in the hubs (e.g., through a contract-for-difference mechanism).[14] The exact mechanism through which the demand-side program will allocate resources is still under development. Awards to seven selected Regional Hydrogen Hubs are still under negotiation, with the first three hubs (California Hydrogen Hub, Pacific Northwest Hydrogen Hub, and Appalachian Hydrogen Hub) signing agreements in July and August of 2024. The Regional Hydrogen Hub resources—in combination with the future implementation of the 45V production tax credit—present a critical window of opportunity to build a domestic, globally competitive hydrogen industry. A lack of near-term demand within the Regional Clean Hydrogen Hubs would significantly undermine the future of clean hydrogen in the United States.

In the absence of structural incentives like carbon pricing or a Clean Fuel Standard, demand-side support is needed until prices for clean hydrogen decrease. This need is further compounded by uncertainty around the business case for Regional Hydrogen Hubs participation. Since the Regional Hydrogen Hub awards were announced, some companies have withdrawn their development plans, citing concerns about costs and the unfinalized rules for the 45V tax credit. With an average of less than $150 million available for each hub through the Regional Hydrogen Hubs demand-side mechanism, the existing one-time funding may prove insufficient.

For the hubs to operate as building blocks for the wider domestic industry, policymakers must be prepared to respond to dynamic market conditions to bolster sustained and early participation. Congress and the administration should signal now their intention to provide further support after the Regional Hydrogen Hub award negotiations and final design of the demand-side support program are completed.

INNOVATION LENS

The hydrogen hubs are intended to demonstrate the economic viability of the end-to-end clean hydrogen system of production, transportation, and use. As part of this, robust demand will be essential to proving that this new system has a viable path to meet the price and performance milestones that will unlock the market over the long-term. The process of securing buyers will serve as a pragmatic test for the diverse clean hydrogen production techniques, transportation methods, and end-uses being demonstrated in the hubs. This diversity is a core design principle of the program. Incentivized by the demand signal, innovators will be drawn to the production, transportation, and end-uses that are proving to have the greatest market potential. This will focus efforts on overcoming bottlenecks and filling gaps in those specific systems, whether these are narrow deficiencies of individual components or broad integration challenges. In the meantime, systems that are unable to demonstrate the potential to meet key milestones will fall by the wayside. This weeding-out process will be most valuable if it occurs at scale and with sufficiently robust market demand.

IMPLEMENTATION

Congress should request that OCED prepare a gap analysis of demand-side support needs and existing resources among the Regional Hydrogen Hubs, based on the finalization of award negotiations and the design of the demand-side support program. Workshops and committee hearings should invite updates on the Regional Hydrogen Hubs from government authorities, private-sector sponsors, and other stakeholders experienced in the development, challenges, and opportunities of those programs. Congress should provide additional funding for OCED's Regional Hydrogen Hubs demand-side support program based on the needs identified through this process.

2. GRANT THE FEDERAL ENERGY REGULATORY COMMISSION THE AUTHORITY TO REGULATE INTERSTATE HYDROGEN INFRASTRUCTURE AND COMMERCE

SUMMARY

Congress should grant the Federal Energy Regulatory Commission (FERC) the authority to regulate the transportation of hydrogen in dedicated interstate pipelines, including siting approval and regulation of pipeline rates. Establishing clear federal regulatory authority and jurisdiction over interstate hydrogen infrastructure will improve planning of new dedicated hydrogen pipelines while safeguarding the public's interest.

RATIONALE

Safe, reliable, and affordable delivery of clean hydrogen is an important prerequisite to building demand. While significant work remains to resolve leakage and material science questions, reduce high capital costs, and address right of way issues, pipelines are the safest and most cost-effective transportation method for large volumes of hydrogen at long distances.[15] Most of the 1,600 miles of existing hydrogen pipelines in the United States are located in the Gulf Coast region.[16] Therefore, options for connecting new clean hydrogen production (e.g., in regions where it can be produced at lower cost) with distributed sources of demand and storage are extremely constrained. Building out and expanding a network of dedicated interstate hydrogen pipelines is both time and capital intensive. It therefore demands strategic siting and requires greater certainty of long-term hydrogen demand volumes and locations. In the near-term, it is important to establish the regulatory framework under which interstate hydrogen pipelines must operate.

FERC is an independent agency within the Department of Energy tasked with regulating the interstate transmission of electricity, natural gas, and oil. Included in these authorities is the siting of interstate natural gas infrastructure, a useful analog to siting hydrogen pipelines. Before the construction and operation of interstate natural gas pipelines, developers must obtain a "certificate of public convenience and necessity" from FERC to demonstrate that the project has been evaluated for its bearing on the public's interest. FERC weighs several factors when reviewing interstate natural gas pipeline applications including whether the proposed project is needed, as well as potential adverse impacts on the applicant's existing customers, on the environment, on landowners, and on affected communities. Once a certificate is granted, the holder may acquire property by exercising the right of eminent domain for lands required for construction.[17]

No federal authority has oversight over the siting of new dedicated interstate hydrogen pipelines, despite FERC's analogous expertise relating to the siting of natural gas infrastructure.[18] Instead, siting regulation falls to the individual requirements of each state's regulatory authority through which a pipeline is expected to be built.[19] While state regulators can be highly experienced, particularly along the Gulf Coast where Texas, Louisiana, and Alabama account for 90 percent of the United States' dedicated hydrogen pipelines, the buildout of interstate hydrogen infrastructure beyond this region will especially benefit from federal siting authority and its evaluations in the public interest.[15]

Beyond siting considerations, the federal government regulates rates for oil, natural gas, and hydrogen pipelines to ensure that rates are "just and reasonable" for customers while also providing sufficient return for pipeline owners and investors. Ratemaking for natural gas pipelines has been under FERC's jurisdiction since the 1938 Natural Gas Act.[20] Then, FERC gained oil pipeline jurisdiction when Congress created the Department of Energy in 1977 and transferred the jurisdiction from the Surface Transportation Board (STB).[21]

Currently, the STB maintains jurisdiction over rates for interstate hydrogen pipelines, despite hydrogen's role as an energy carrier and practical similarities to oil and natural gas in its transportation through pipelines. Consequently, the regulation of rates and common carrier terms of service is more limited for hydrogen due to the STB's inability to investigate or change rates unless petitioned by another party.[22] This stands in contrast with FERC's authority to set initial rates, approve rates and rate changes, and require rate changes when rates are no longer seen as just and reasonable.[23] Shifting ratemaking authority from the STB to FERC, as Congress did for oil in 1977, would provide more consistent oversight over energy-related pipeline rates.

Meanwhile, as hydrogen molecules can be challenging to contain, the planning and buildout of dedicated hydrogen pipelines should prioritize the mitigation of hydrogen emissions from leakage, venting, and diffusion. This prioritization is critical to maintaining both safe operations and community support while also mitigating the indirect warming potential from hydrogen emissions into the atmosphere.[24] The DOE's Hydrogen and Fuel Cell Technologies Office is pursuing 2025 milestones to create hydrogen pipeline permitting guidance, develop sensors to detect low-level hydrogen leakage, and advance quantification technologies to monitor emissions.[25] FERC should coordinate with the DOE to properly integrate these efforts in its exercise of regulatory jurisdiction over interstate hydrogen infrastructure. FERC should similarly coordinate with the Pipeline and Hazardous Materials Safety Administration (PHMSA), which maintains regulatory jurisdiction over interstate hydrogen pipeline safety.

INNOVATION LENS

Greater regulatory certainty for pipeline transportation will aid innovation in the deployment stage of the clean hydrogen industry's development. Clean hydrogen producers and end-users will be more likely to invest in scaling up if they have confidence that the pipelines they need to connect to one another will be built to rigorous standards on a firm timeline. In addition to strengthening confidence in pipeline construction, regulators can also provide credible information about leakage rates and locations that can help focus the efforts of innovators seeking to reduce them.

IMPLEMENTATION

Congress should provide FERC with explicit authority to regulate the siting and rates of interstate hydrogen pipelines. Congress could realistically pursue one of two paths to grant pipeline authority to FERC: either by amending the Natural Gas Act or by passing standalone legislation. In amending the Natural Gas Act, Congress would need to distinguish hydrogen from its treatment of artificial gas and expand FERC's existing authorities over natural gas to also apply to hydrogen. In passing standalone legislation, Congress could mirror the authorities under the Natural Gas Act to recognize and transfer any rate regulation practiced by STB for dedicated hydrogen pipelines to FERC while establishing new interstate hydrogen infrastructure siting authorities.

Workshop and committee hearings should examine whether and how to allow FERC the flexibility to deviate from the exact processes under which it regulates natural gas in recognition of the hydrogen market's distinct characteristics (e.g., diversity of hydrogen applications and customers in energy and non-energy markets, stage of market development). Any new legislation should include guidance ensuring that FERC coordinate with DOE and relevant government regulatory authorities (i.e., PHMSA) to study and address the potential for hydrogen to leak from pipeline infrastructure, including quantifying the potential risk and identifying measures to mitigate or eliminate it in the siting of interstate hydrogen pipelines.

3. UPDATE THE RENEWABLE FUEL STANDARD

SUMMARY

The Environmental Protection Agency should update the Renewable Fuel Standard (RFS) to broaden eligibility for hydrogen-based transportation fuels. New kinds of advanced hydrogen-based fuels, like liquid e-fuels, can be blended with conventional fuel and used in today's vehicles and aircraft. Scaling the domestic production of these low-carbon fuels aligns with the objectives of the RFS to reduce dependence on foreign oil and greenhouse gas emissions. So long as the RFS Program generates revenue and market certainty for traditional biofuels, its rules should be maintained to ensure emerging classes of renewable fuels have access to those same incentives.

RATIONALE

Congress created the RFS program under the Energy Policy Act of 2005 and expanded the program under the Energy Independence and Security Act of 2007.[26] The program, administered by the EPA, sets annual volume targets for renewable fuel, which is defined as "fuel that is produced either from renewable biomass or from a biointermediate produced from renewable biomass" and used to "replace or reduce the quantity of fossil fuel present in a transportation fuel".[27] Refiners and importers of gasoline and diesel fuel are required to meet EPA's annual obligations by generating credits from the production of eligible renewable fuels or purchasing those credits from other producers. The RFS is a successful policy; it is one of several key drivers that has scaled U.S. production of fuel ethanol and other biofuels from less than four billion gallons in 2005 to 18.7 billion gallons in 2022.[28] However, new clean transportation fuels have emerged since the passage of the RFS that, despite meeting the objectives of the RFS, must now compete against RFS-credited fuels.

E-fuels are an emerging class of low-carbon synthetic fuels produced from clean hydrogen (using clean electricity) and carbon dioxide with applications in the ground transportation (i.e., e-gas and e-diesel), aviation (i.e., e-SAF), and maritime (i.e., e-ammonia and e-methanol) sectors. When produced from clean hydrogen and biogenic carbon dioxide (e.g., carbon dioxide from ethanol fermentation), e-fuels can reduce greenhouse gas emissions by 90–108 percent compared to fossil fuels.[29] The maturation of e-fuels as a commercially-viable renewable fuel would represent a durable source of demand for clean hydrogen: if all globally announced e-fuel projects reached production stage, they would demand nearly 14 MMT of clean hydrogen).[30] As with any an emerging technology, e-fuels face challenges with scaling and production costs; however these are exacerbated by outdated rules under the RFS. Not only do e-fuels lack a clear path to qualify as a credit-generating "renewable fuel" under the RFS, producers of e-gas and e-diesel are treated as obligated parties who must acquire renewable fuel credits to meet annual requirements.

Ensuring that e-fuels are eligible under the RFS aligns with Congress' intent for the program to promote energy independence and the production of clean renewable fuels.[31] Hydrogen-based fuels satisfy those goals, and including e-fuels as credit-generating fuels removes the regulatory disadvantage that stifles stable demand for hydrogen in the transportation sector. The EPA has clear authority to establish an eligibility pathway for e-fuels produced from biogenic carbon dioxide under the statutory language of the RFS. Congress can further expand hydrogen demand under the RFS by crediting pure hydrogen dispensed as a transportation fuel and e-fuels produced from non-biogenic carbon dioxide (e.g., carbon dioxide captured from point sources or from direct air capture).

INNOVATION LENS

The demand pull created by an updated RFS could help advance the e-fuel industry, encouraging support for demonstration, early deployment, and ultimately broad diffusion of e-fuels across a range of applications. The scale of this demand creation will depend on the extent to which RFS-derived revenue can compensate for the relatively higher production costs that first-of-a-kind-projects have before they achieve economies of scale. Progress in light-duty vehicle electrification could blunt the impact of an updated RFS on e-gas and e-diesel. As a result, e-fuel use in hard-to-electrify modes of transportation (e.g., aviation) will likely be a potent source of demand. Boosting demand by amending the RFS could enable new e-fuel production processes to scale to commercial levels, revealing challenges and opportunities that are not necessarily evident at the R&D and pilot stages. For example, innovations that will cut production costs—for instance, scale economies, improved system integration, and greater efficiency—are only likely to emerge if the technology can reach commercial-scale production. Allowing e-fuels to generate RFS credits could help to solve the chicken-and-egg conundrum of e-fuel production: commercial-scale innovations depend on demand growth from transportation end-users, but market-based demand for e-fuels depends on the lower costs enabled by these innovations.

IMPLEMENTATION

Within its current authority, the EPA should amend RFS regulations to define "produced from renewable biomass" in Title 40 Code of Federal Regulations (CFR) 80.2 with the meaning that the mass or energy in the finished fuel was sourced from renewable biomass. This change was previously contemplated in the proposed Renewable Fuel Standards for 2023, 2024, and 2025.[32] This definition is inclusive of e-fuels which may derive mass from renewable biomass (e.g., biogenic carbon dioxide), but not energy. The same definition would permit e-fuel using hydrogen produced from the energy of renewable biomass (e.g., hydrogen produced from electricity generated from biogas) to qualify. The EPA should further amend 40 CFR 80.2 by changing the definition of "biointermediate" to include "biogenic carbon dioxide," which would provide certainty to e-fuel producers that fuel produced from biogenic carbon dioxide is a renewable fuel (and can therefore generate revenue from RFS credits).

Separately, the administration and Congress should examine options and work toward expanding the RFS beyond renewable fuels produced from biomass. Amendments to the RFS under 42 U.S. Code (U.S.C.) 7545(o)(2) should prioritize the eligibility of feedstock-neutral low-carbon fuels including clean hydrogen dispensed for fueling vehicles and e-fuels produced from non-biogenic sources. Congress should also examine options for the inclusion of clean hydrogen-derived maritime fuels. Amending the RFS program should include coordination with the DOE, U.S. Department of Transportation (DOT), and the U.S. Department of Agriculture (USDA) to conduct analyses of production capacities and relevant changes to volume obligations. Congress should develop policy principles, draft legislation, conduct workshop discussions, and hold committee hearings to maximize stakeholder input and minimize counterproductive market distortions. Congress should also analyze the additive value of the RFS if a federal Clean Fuel Standard (CFS) is implemented in a way that similarly incentivizes clean transportation fuels.

4. ENACT A FEDERAL CLEAN FUEL STANDARD

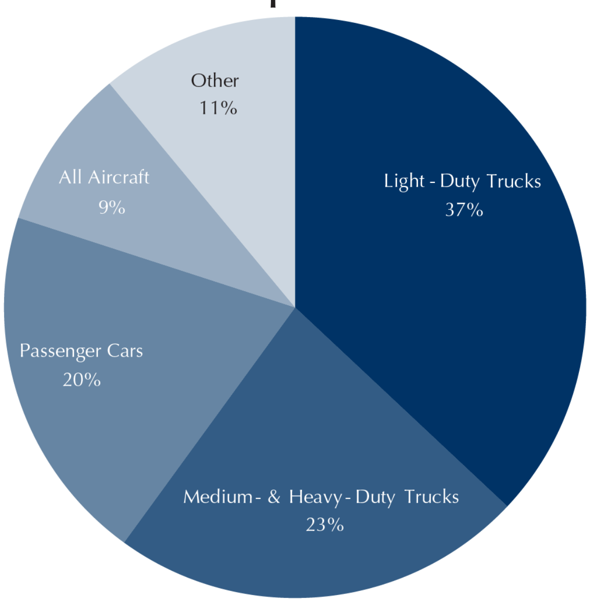
SUMMARY

Congress should implement a federal Clean Fuel Standard (CFS) to accelerate progress toward net-zero emissions in the transportation sector by 2050. A federal CFS would encourage market innovation by allowing all fuels to compete on a technology-neutral basis to reduce lifecycle emissions toward annual benchmarks. The role of low-carbon fuels in meeting those benchmarks supports demand for hydrogen and hydrogen-based fuels (i.e., e-fuels).

RATIONALE

Increasingly stringent standards for transportation fuels would provide a stable and predictable demand signal for clean hydrogen as both a refining input as well as an energy carrier and liquid fuel feedstock. Transportation emits more greenhouse gas emissions than any other sector of the United States economy.[33] More than half of transportation emissions come from passenger cars and light-duty trucks, like SUVs and minivans; 23 percent from medium and heavy-duty trucks; nearly 10 percent from aircraft; and the remainder from rail, marine, and other forms of transportation (see Figure 6).[34]

FIGURE 6: U.S. Transportation Emissions



Source: U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022, EPA 430-R-24-003 (April 18, 2024). Retrievable from: https://www.epa.gov/system/files/documents/2024-04/us-ghg-inventory-2024-main-text_04-18-2024.pdf

With high emissions from fossil-based fuels, the transportation sector represents massive demand potential for clean hydrogen, particularly if incentive structures prioritize lower-carbon fuel. For long-haul medium- and heavy-duty trucks, hydrogen fuel cell electric vehicles could become cost-competitive by 2035, demanding 7.8 MMT of hydrogen by 2050 or 14 percent of that segment's market share.[35] For aviation, replacing the estimated 35 billion gallons of annual jet fuel consumption in the United States by 2050 with biofuel and e-fuel would further boost demand by another 2–6 MMT of hydrogen.[36]

A CFS for transportation fuels would complement existing vehicle standards by establishing annual carbon-intensity benchmarks for transportation fuel. Fuels with a carbon intensity below the benchmark would generate credits and fuels above the benchmark would generate deficits. Importers, refiners, and wholesalers of transportation fuels (i.e., the obligated parties) would be required to demonstrate that they cover any deficit accrued with a matching amount of earned or purchased credits. Crediting low-carbon fuels on a technology-neutral basis incentivizes their production while providing flexibility to obligated parties in addressing their respective deficits. The predictable carbon-intensity benchmarks of a CFS, combined with the incentive structure of market-based crediting, would signal support for durable demand for clean hydrogen while allowing the market to determine where the application of clean hydrogen is most efficient. The lack of flexibility inherent to more technology-specific compliance options can make meeting performance targets more expensive, while also stifling creativity by focusing innovators on an artificially narrow set of possible technological solutions.

Broadening a CFS to reward improvements in petroleum refining could generate additional demand for clean hydrogen beyond its use in low-carbon fuels. Petroleum refining is currently the largest source of demand for hydrogen, accounting for about 6 MMT of hydrogen, much of which is produced through the carbon-intensive process of SMR or as a byproduct of the refining process.4 Substituting existing consumption with clean hydrogen could reduce the carbon intensity of petroleum refining by 12 percent.[37]

INNOVATION LENS

The demand pull a federal CFS creates would impact innovation in the clean hydrogen industry in a manner similar to an updated RFS, but with a broader reach if refiners as well as the full suite of transportation users were included in its scope. The inclusion of end-uses with limited emissions-reducing alternatives, such as refining and maritime shipping, could be particularly potent for demand creation. This impact would be enhanced by a stringent standard, although the degree of stringency might need to be calibrated so that demand growth does not outrun supply and drive up the price of clean hydrogen. CFS credit sales might also support innovators serving these markets by providing them with an additional revenue stream, although credit trading is likely to dampen prices overall. CFS-driven scale-up of clean hydrogen and e-fuel production would reveal challenges and spotlight opportunities that were not evident at smaller scales. Innovations that will cut production costs through scale economies, improved system integration, and greater efficiency are only likely to emerge if commercial-scale production can be reached. A federal CFS could be a powerful source of commercial demand and substantially accelerate the market. It might also spur interest in developing interstate hydrogen infrastructure, which is unlikely to be built in response to state-level standards.

IMPLEMENTATION

The administration and Congress should examine options and work toward enacting a CFS that could contribute to the achievement of net-zero emissions by 2050. Work on such a program should include analyses of carbon intensity milestones on the pathway to net-zero emissions which incorporate a technology-neutral approach to compliance, market-based crediting of low-carbon fuels, and cost-containment design measures. Workshop and committee hearings should seek engagement from stakeholders in the private sector, academia, and civil society to design a flexible and durable policy, the predictable implementation of which would support long-term private investments in innovation.

Following the U.S. Supreme Court overruling the Chevron doctrine, congressional proposals should directly authorize a federal agency to set annual carbon intensity targets, which may be adjusted by that agency as technologies and markets develop.[38] Congress should provide explicit guidance on a technology-neutral approach, under which hydrogen-related emissions should be accounted for as both a deficit generator (i.e., gray hydrogen for petroleum refining) and a credit generator (i.e., clean hydrogen to reduce refining emissions and clean hydrogen as a lower-carbon transportation fuel).

5. ENACT FEDERAL ECONOMY-WIDE CARBON PRICING

SUMMARY

The administration and Congress should work toward enacting an economy-wide market-based carbon pricing program to contribute toward the achievement of net-zero emissions by 2050. Setting a price on carbon—whether through a carbon tax or a cap-and-invest program—confers a clear market value to emission reductions commensurate with the environmental, societal, and economic benefits that reducing global greenhouse gas pollution provides. Revenue generated from a carbon price could be used to support hydrogen adoption specifically, or for other purposes, such as lowering government deficits or reducing taxes.

RATIONALE

Increasing market demand for clean hydrogen requires, among other things, that the price of clean hydrogen is attractive compared to gray hydrogen. Forecasts of clean hydrogen prices and timelines for price parity with gray hydrogen vary considerably depending on assumptions and methodologies.[39] The inherent uncertainty in economic conditions, technology advancements, and regional variability make it more difficult to justify the business case for clean hydrogen adoption today. A well-implemented 45V Credit for Production of Clean Hydrogen will reduce the price premium for eligible clean hydrogen. However, this does not ensure cost-competitiveness in the near term, in part because the market today does not reflect the cost of pollution from gray hydrogen production, nor does it sufficiently value the emissions reductions realized using clean hydrogen in current and prospective applications.

Gray hydrogen producers and users in the United States currently lack financial motivation to switch to clean hydrogen. This is particularly the case in the chemicals and petroleum industries, which pay less for hydrogen than other sectors due to their large-scale consumption and capacity to produce it themselves.[40] A price on carbon would assign a cost to producing hydrogen from carbon-intensive production methods. Combining a predictable carbon pricing program with existing clean hydrogen supply-side incentives would accelerate the timeline for clean hydrogen's market favorability.[41] For those consumers who currently produce or plan to produce their own carbon-intensive hydrogen, a carbon pricing policy could also incentivize retrofitting hydrogen production assets with carbon capture systems, whereas the capital costs and remaining useful life of those assets may otherwise be cost-prohibitive barriers. Carbon pricing would further serve to broaden the demand pool for clean hydrogen in emerging or prospective use cases for which cheaper fossil fuel or gray hydrogen is currently used. Diesel fuel for long-haul trucking, heavy fuel oil for shipping, and petroleum-based jet fuel for aviation are among the applications for hydrogen and hydrogen-based fuels for which a price on carbon could contribute to making continued use of fossil fuels financially unattractive.[42]

Market-based policies drive innovation and reduce greenhouse gas emissions by giving emitters the flexibility to find the lowest-cost options for reductions.[43] Considering the wide range of potential use cases and respective price sensitivities for hydrogen, a price on carbon would focus hydrogen adoption to uses that lack compelling alternatives to decarbonize. It would also help the market coalesce around the most stable sources of hydrogen demand. The demand stability and corresponding reductions in production costs spurred by a carbon price would allow clean hydrogen to become increasingly viable to more diverse decarbonization options.

INNOVATION LENS

A carbon price would strengthen existing and future prospective policies aimed at accelerating the deployment of clean hydrogen technologies, as well as other emerging low-carbon technologies. It could impact the entirety of the innovation process as well as all innovation project stages. Economywide carbon pricing should—like an updated RFS and a federal CFS, but with a broader potential scope—strengthen demand for clean hydrogen, enabling commercialization and deployment of end-uses where clean hydrogen proves to be the most cost-effective solution for emissions reductions. These end-uses could extend well beyond transportation, including electricity generation, industrial process heat, and seasonal energy storage. However, there is no guarantee that clean hydrogen will prove to be the most attractive mitigation option for all applications. As the scope of its use expands, potential clean hydrogen buyers may find themselves competing not only with providers of alternative solutions, but also with one another for a limited supply.

There are additional opportunities that a carbon price would enable. As with the CFS, demand pull induced by carbon pricing could stimulate interstate hydrogen infrastructure development. Funds generated by the carbon price could also be used to finance future innovation. If some of the revenue generated by this policy were directed to DOE's hydrogen research, development, and demonstration units, the agency could target these resources to any pressing innovation challenge facing the clean hydrogen industry.

IMPLEMENTATION

The administration and Congress should examine options and work toward enacting an economy-wide market-based carbon reduction program that could contribute to the achievement of net-zero emissions by 2050. The program should be designed to implement a price for greenhouse gas emissions, which would both increase the costs of emissions-intensive hydrogen production as well as reduce costs for companies that lower their emissions through the adoption of clean hydrogen, clean hydrogen derivatives, or other means. Policy principles should prioritize science-based emissions reductions, technology-neutral approaches, and economic health. Analyses should consider carbon abatement costs and price sensitivities across economic sectors and the development and availability of emissions reduction technologies.

Following the U.S. Supreme Court overruling the Chevron doctrine, congressional proposals should directly address which sources of greenhouse gas emissions should be included within the carbon pricing program (i.e., clearly include emissions related to hydrogen production). Congress should also provide guidance to an authorized government agency on how emissions mitigating technologies and practices (e.g., switching from gray hydrogen to a clean hydrogen) should be calculated and credited and how revenue may be allocated.[36]

CONCLUSION

The U.S. federal government has demonstrated a commitment to accelerating decarbonization using clean hydrogen as a versatile, low-carbon energy carrier and feedstock. Existing federal programs and incentives such as the Regional Clean Hydrogen Hubs Program, the Clean Hydrogen Electrolysis Program, the Clean Hydrogen Manufacturing and Recycling Initiatives, and the 45V Credit for Production of Clean Hydrogen are significant but policy must target sustained demand to meet the goals of the U.S. National Clean Hydrogen Strategy and Roadmap. Established users of emissions-intensive hydrogen have no financial incentive to procure clean hydrogen at current prices. Ineffective price signals that fail to account for climate impacts, nascent transportation and storage infrastructure, and a lack of large-scale technology demonstrations slow the maturation of prospective use cases in heavy-emitting sectors.

The following policy recommendations, developed through discussions with stakeholders across the clean hydrogen ecosystem, offer a potential path forward to addressing demand-side barriers to scaling clean hydrogen: (1) Provide further funding for demonstration and commercial-scale projects under OCED; (2) Grant FERC authority to regulate interstate hydrogen infrastructure and commerce; (3) Update the RFS; (4) Enact a Federal CFS; and (5) Enact federal economy-wide carbon pricing. Federal policy is essential to drive private sector demand for this critical-path technology. Strengthening existing programs and introducing new, market-focused initiatives will inject stability as the domestic clean hydrogen industry grows.

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AIR COMPANY
Arcadia eFuels
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Additional Resources

Clean Hydrogen Working Group (Webpage)
https://www.c2es.org/accelerating-the-us-net-zero-transition/c2es-technology-working-groups/clean-hydrogen/

Room for improvement: Digging into Treasury hydrogen guidance (Blog)
https://www.c2es.org/2024/02/room-for-improvement-digging-into-treasury-hydrogen-guidance/

The stakes for hydrogen just got higher (Blog)
https://www.c2es.org/2023/05/the-stakes-for-hydrogen-just-got-higher/

Firing up Clean Hydrogen in Texas (Brief)
https://www.c2es.org/document/firing-up-clean-hydrogen-in-texas/

Hydrogen Hubs Seek to Build on Regional U.S. Strengths (Blog)
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