FIRING UP CLEAN HYDROGEN IN TEXAS

C2ES CLIMATE INNOVATION 2050

by

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As a global energy leader and the ninth-largest economy in the world, Texas is well positioned to play a leading role in hydrogen market development in the United States and globally. Texas has unique local characteristics that may enhance the state's ability to build out a robust hydrogen ecosystem, including existing infrastructure that can be utilized for transport and storage, a cluster of localized demand from industrial facilities, access to large port capacity for trade, a highly-skilled energy workforce, expertise throughout the hydrogen supply chain, and a supportive regulatory and investment environment. With unprecedented levels of federal funding from the Bipartisan Infrastructure Law and the Inflation Reduction Act, Texas has an opportunity to leverage its expertise and industrial capabilities to become a global leader in hydrogen. This brief provides insights from a C2ES roundtable located in Houston and held in partnership with the Center for Houston's Future in June 2023 that explored the clean hydrogen opportunity and the associated market, regulatory, and technological challenges in Texas.

INTRODUCTION

REGIONAL ROUNDTABLES

Efforts to accelerate the transition to the low-carbon economy of the future are accelerating across all sectors of the economy. To chart a pathway to sustainable, long-term prosperity, communities must be able to leverage their unique strengths and capitalize on emerging economic opportunities, while addressing barriers that are often poorly understood outside of their communities.

To that end, the Center for Climate and Energy Solutions (C2ES) is hosting a series of regional roundtables to bring together local, state, and federal policymakers; businesses of all sizes; community organizations and nonprofits; academics and issue experts; trade associations; investors; philanthropy; economic development organizations; and others. These conversations are meant to elevate the perspectives of a diverse set of stakeholders who are deeply embedded in their communities and uniquely positioned to speak to the needs of their states and regions. They are also meant to create opportunities to integrate local perspectives into state and federal policy decisions and, importantly, identify concrete steps to better align the long-term vitality of these communities with the urgent task of reaching net-zero emissions economywide.

Our June 2023 roundtable, held in Houston, Texas, brought together approximately 40 participants, representing companies, nonprofits, government, colleges and universities, and community leaders. This brief summarizes key takeaways from the discussion and—building on insights from the event and other conversations with local stakeholders—provides C2ES recommendations meant to advance a hydrogen industry in the state in a way that achieves both climate and economic development goals.

FRAMING THE CLEAN HYDROGEN DISCUSSION IN TEXAS

As the second largest economy in the United States, and the ninth largest economy in the world, what happens in Texas has major effects on the trajectory of the global economy. Additionally, the energy generation and production sectors in the state play an important role in its economy. Texas is the top oil- and natural gas-producing state in the nation, accounting for 43 percent of crude oil production and 25 percent of marketed natural gas production in the United States in 2021; it is also home to almost a third of the nation's refining capacity.[1] At the same time, the state leads the United States in renewable energy production, accounting for more than a quarter of all U.S. wind-powered electricity generation. Indeed, West Texas hosts more than 11,000 wind turbines, generating even more energy than its transmission infrastructure can accommodate.[2]

As a current and historic leader in oil and gas production, Texas has a high "energy IQ," with well-developed industrial infrastructure and a highly skilled workforce. In addition to production and refining capacity, it also has a robust oil and gas transport network. Texas accounts for around one-fifth of all U.S. pipeline infrastructure, with more than 475,000 miles of pipeline spanning the state.[3] The state also hosts large industrial facilities concentrated along the Gulf coast. These facilities already utilize significant amounts of conventional hydrogen (i.e., hydrogen produced from unabated fossil fuels) and export liquid natural gas (LNG) to other markets. This existing market represents an opportunity for low-carbon-intensity hydrogen utilization to scale locally while also leveraging port infrastructure to export hydrogen in the form of clean ammonia to other markets.

For decades, hydrogen has experienced waves of interest as a potential clean energy solution. Now, federal support, technological advances, growing demand from end users, and a diverse and growing coalition of advocates have made this the moment for clean hydrogen to lift off. The Fuel Cell and Hydrogen Energy Association projects the U.S. clean hydrogen market could generate $140 billion in revenue by 2030.[4]

Taken together, the current state of Texas's energy economy—production, generation, utilization, and export—with growing interest in hydrogen create a perfect opportunity for the state to support the local economy and accelerate U.S. decarbonization ambitions.

Federal Clean Hydrogen Momentum

At the federal level, recent investment through the Inflation Reduction Act of 2022 (IRA), Infrastructure Investment and Jobs Act of 2021 (IIJA, also known as the Bipartisan Infrastructure Law), and the CHIPS and Science Act of 2022 has unleashed potentially transformative financial and technical support for the development of clean hydrogen. The IIJA created the Regional Clean Hydrogen Hubs program through the Department of Energy (DOE). Through this $7 billion program, DOE will establish six to 10 regional clean hydrogen hubs across the United States to demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen.[5] Applications for the first round of funding were due in April 2023, and there were three hub applications developed in Texas.[6] These included the HyVelocity Hub, led by the Center for Houston's Future, GTI Energy, and the University of Texas Austin; the Horizons Clean Hydrogen Hub, led by the Port of Corpus Christi; and the Leading in Gulf Coast Hydrogen Transition (LIGH2T) hub, led by the Southern States Energy Board.[7]

Separately, the IRA created and enhanced tax credits for clean hydrogen production. The hydrogen production tax credit (PTC) offers up to $3/kilogram (kg) for hydrogen produced with a carbon intensity of less than 0.45 kg of carbon dioxide equivalent per kg of hydrogen.[8] For comparison, hydrogen produced through conventional pathways currently produces around 12-13.5 kg of carbon dioxide equivalent per kg hydrogen.[9] Additionally, the enhanced 45Q tax credit for carbon capture, storage, and utilization increased the value of permanently sequestered carbon from $50 per ton to $85 per ton, incentivizing carbon capture to decarbonize hydrogen produced from natural gas.[10]

DOE has a goal through its Hydrogen Shot initiative—the first under its Energy Earthshots Initiative: to reduce the cost of clean hydrogen by 80 percent from 2021 levels to $1 per kilogram by 2031.[11] Led by the Hydrogen and Fuel Cell Technologies Office (HFTO) and the Office of Clean Energy Demonstrations (OCED), offices across DOE are coordinating research, development, and commercialization of technologies and projects to support the production, storage, delivery, conversion, and end use of clean hydrogen. In total, Congress appropriated more than $300 million in 2022 and more than $400 million in 2023 to support these DOE programs.[12]

There are also ongoing efforts that could shore up increasing demand for clean hydrogen. Through July 2023, DOE opened a request for information (RFI) on establishing a demand-side support mechanism for regional clean hydrogen hubs with a commitment of up to $1 billion in funding from the IIJA.[13] Suggested support mechanisms in the RFI included pay-for-difference contracts; fixed levels of support for projects (e.g., a fixed funding level in dollars per kg that could be stacked on top of other sources of revenue); funding to support feasibility analysis from potential offtakers; a "market-maker" for clean hydrogen to provide a ready purchaser/seller for clean hydrogen; and others. The agency plans to issue a broad agency analysis beginning in the fall of 2023.

Recent proposed regulations through the U.S. Environmental Protection Agency (EPA) on emissions from heavy-duty trucks and power plants could also accelerate clean hydrogen utilization. In April 2023, EPA proposed new federal emissions standards for heavy-duty trucks that would require automakers to meet zero emission vehicles (ZEVs) sales targets, including 50 percent of new sales of vocational vehicles, 34 percent of day cab tractors, and 25 percent of sleeper cab tractors by model year 2032.[14] Both battery electric and hydrogen fuel cell electric technologies can power zero-emission vehicles. However, hydrogen has significant advantages over battery electric to power the heaviest-duty vehicles, including performance improvements and reduced fueling times. For these advantages, it is likely that manufacturers will be encouraged to ramp up hydrogen fuel cell vehicle production by model year 2032 in order to meet these targets, and support the market for clean hydrogen fuel.

In May 2023, EPA proposed new emission limits and guidelines for carbon dioxide from fossil fuel-fired power plants, including setting limits on new gas-fired combustion turbines, existing coal, oil, and gas-fired steam generating units, and certain existing gas-fired combustion turbines. To continue operating under the proposed regulations, natural gas power plant operators would need to blend at least 30 percent hydrogen by 2032 and at least 96 percent hydrogen by 2038.[15] This would put significant upward pressure on demand as power plant operators look to source significantly more hydrogen. As currently drafted, this regulation would contribute to building certainty for suppliers to increase production to meet this forthcoming demand.

State-level clean hydrogen policy landscape

In Texas, clean hydrogen has broad political support among legislators from both parties as well as regulatory bodies. The fuel is largely seen as an opportunity to capitalize on the state's existing natural gas infrastructure while reducing emissions. During pre-roundtable calls, multiple stakeholders expressed a shared desire for Texas to transform from the "energy capital of the world," to the "clean energy capital of the world." That said, political support for renewable energy itself is mixed. Many legislators are concerned with the reliability of intermittent renewables like wind and solar. Senate Bill 624, which would have made it more difficult for new and existing renewable energy projects to operate, underscores this concern. The bill advanced in both houses of the state legislature in the 2023 legislative session before ultimately failing.[16]

House Bill No. 2847, passed weeks before the June 2023 roundtable, supported formalizing a framework for state-level jurisdiction over hydrogen pipeline siting, by giving the Texas Railroad Commission—which has primary regulatory jurisdiction over the oil and natural gas industry—jurisdiction over all hydrogen pipeline transportation and storage.[17] The bill also establishes the Texas hydrogen production policy council within the commission and charges it with studying and making recommendations relating to the commission's policy framework for hydrogen energy development.

BACKGROUND ON CLEAN HYDROGEN AND CARBON INTENSITY

Carbon intensity and the hydrogen rainbow

Hydrogen is often classified using a color system according to its production pathway, as seen in Figure 1. This approach has caused some confusion and led to a growing effort to reclassify hydrogen based on carbon intensity. The IRA has supported these efforts, using a carbon intensity metric to determine PTC amounts in place of the color system. This metric is more easily comparable across different production pathways and is more accurate in evaluating their associated climate impacts. For the purposes of our roundtable discussion, C2ES used the carbon intensity metric—that is, the relative amount of carbon dioxide equivalent emitted to produce a given amount of hydrogen. Both the IRA and C2ES's work use the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model to calculate carbon intensity.[18]

The value of the IRA's clean hydrogen PTC is determined by carbon intensity, as demonstrated in Figure 2. Only hydrogen emitting less than 0.45kg of carbon dioxide equivalent per kg of hydrogen produced is eligible for the full $3/kg credit, otherwise the credit drops to $1/kg for a carbon intensity up to 1.5kg of carbon dioxide equivalent per kg of hydrogen, and continues to fall thereafter.

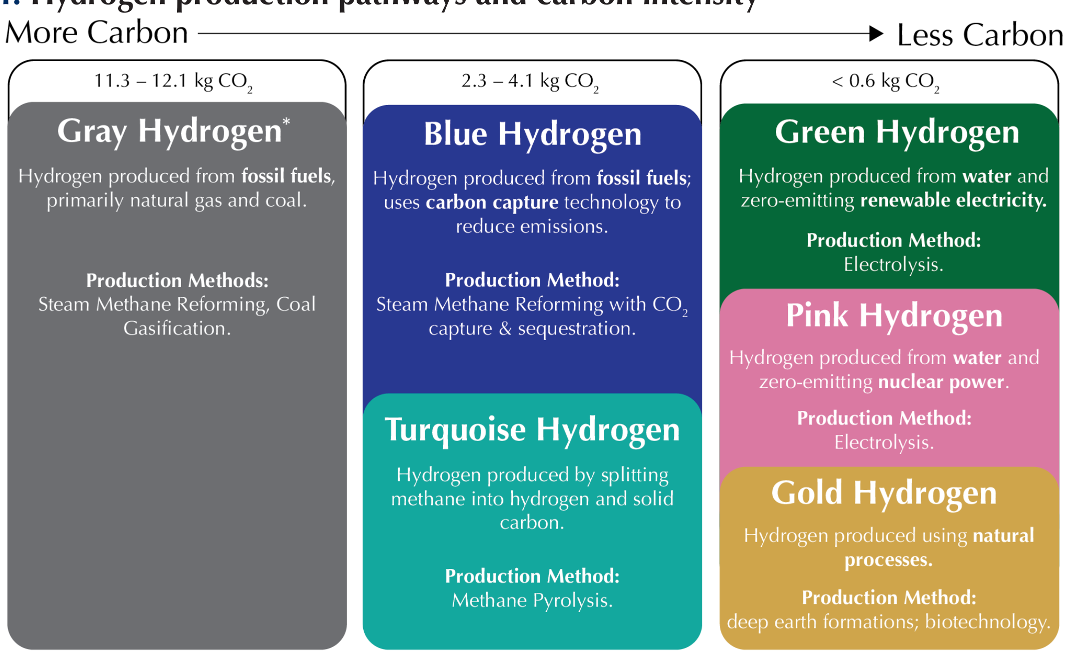
Different hydrogen production routes may produce significantly varying emissions, whether direct emissions at the point of production or upstream and midstream emissions, as seen in Figure 3. Hydrogen produced from fossil fuels, like coal gasification and steam methane reforming (SMR), produce the greatest emissions when unabated with carbon capture and sequestration. Hydrogen produced from renewable-powered electrolysis

FIGURE 2: Value of the hydrogen PTC by carbon intensity

CARBON INTENSITY (KG CO2E/KG H2)	MAX HYDROGEN PTC CREDIT ($/KG H2)
0–0.45	$3.00
0.45–1.5	$1.00
1.5–2.5	$0.75
2.5–4	$0.60

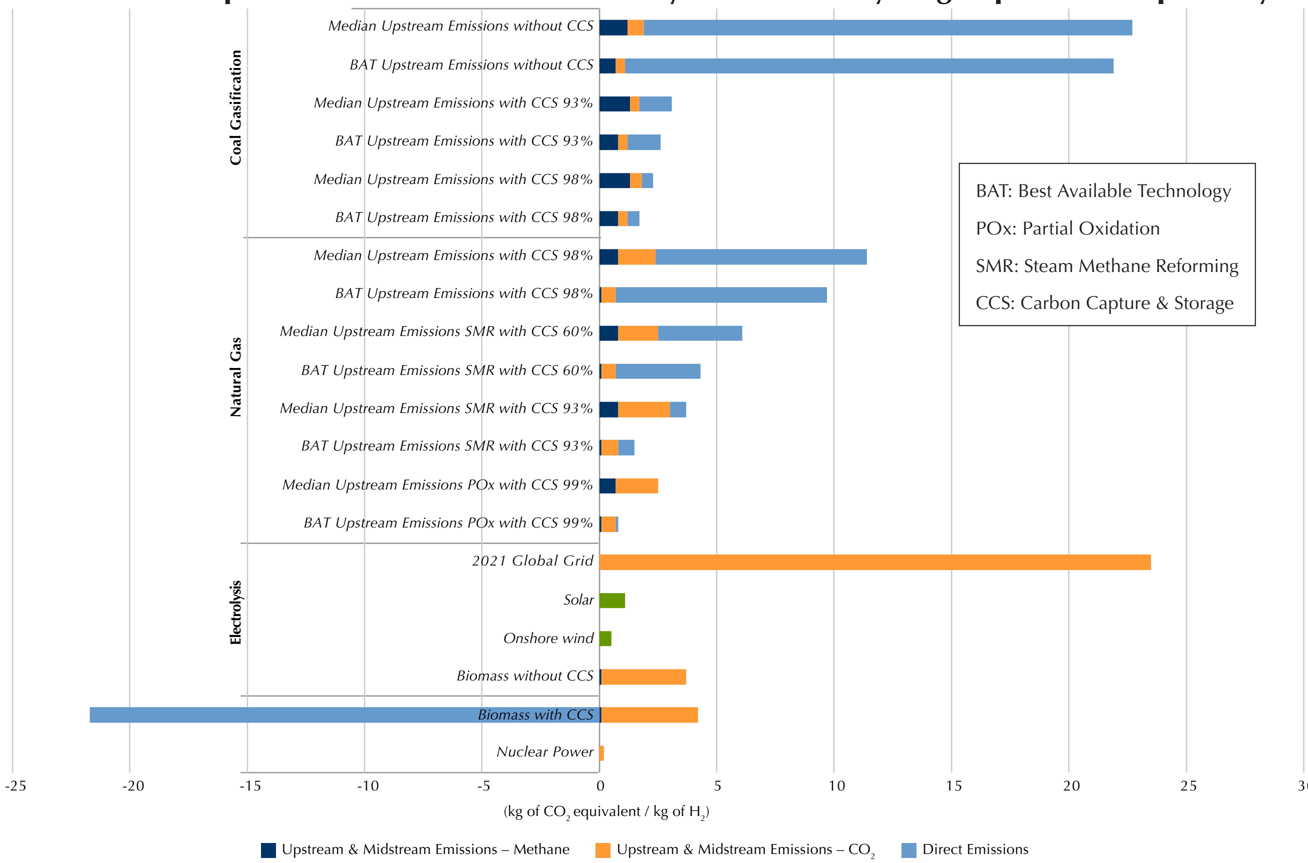
Source: Inflation Reduction Act

FIGURE 1: Hydrogen production pathways and carbon intensity



Source: Center for Climate and Energy Solutions (drawing on data from Ewing et al. (2020) and Elgowainy (2021))

FIGURE 3: Comparison of the emissions intensity of different hydrogen production pathways



Source: International Energy Agency, Comparison of the emissions intensity of different hydrogen production routes, 2021, (Paris, France: IEA, 2021), https://www.iea.org/data-and-statistics/charts/comparison-of-the-emissions-intensity-of-different-hydrogen-production-routes-2021.

produces the lowest emissions. However, when produced via electrolysis powered by the grid, the emissions may be as high as or higher than unabated fossil fuels, depending on the carbon intensity of the energy supplied by the grid in the location where the hydrogen is produced.

The definition of "clean" hydrogen produced robust discussion during the roundtable. When determining eligibility for federal incentives, this definition impacts the near- to mid-term ability of the industry to scale at the pace necessary to meet mid-century emissions reduction goals. Although hydrogen produced through renewable-powered electrolysis has the lowest carbon intensity, the high costs of electrolyzers and permitting timelines present challenges to building out new production facilities. Some participants raised concerns that it will likely scale at a much slower pace than hydrogen produced via SMR with CCS. To meet global demand in the near term under this scenario, an overwhelming proportion of hydrogen would need to be produced using this production pathway. Participants highlighted that, in this case, hindering the development of SMR with CCS by reducing its eligibility for the full PTC will slow the development of hydrogen infrastructure and domestic demand growth needed to scale the volume of low-carbon hydrogen that can be produced in the United States in the coming decades.

BOX 1: Key Recommendations

Localize positive impacts for communities and the workforce

- **CEQ** and **other federal agencies** should provide clear, transparent guidance on Justice40. They can do so by indicating, for example, how benefits are quantified and in what geographic radius the "communities" are defined.
- **The Texas legislature** should create a funding program to support paid local apprenticeship programs focused on clean hydrogen, covering curriculum development and coordination with community colleges, labor and trade associations, and private training programs relating to the energy transition.
- **Congress** should establish a funding program through DOE and EPA that facilitates engagement between developers of hydrogen infrastructure and communities—especially environmental justice communities, tribal communities, and energy communities. This program should focus geographically on proposed hydrogen hubs and/or on natural gas facilities or other existing infrastructure that will be utilized for hydrogen projects in the future. Information gained from listening sessions across all communities should be aggregated into a comprehensive report on existing community concerns and opportunities relating to clean hydrogen, while offering recommendations to update regulations and funding implementation guidelines to better meet the needs of communities.
- **Congress** should expand Department of Education resources for career and technical education that can support recent graduates and mid-career workers in skilled trades to acquire expertise relevant to the clean hydrogen industry, modeled on the Innovation and Modernization discretionary grant program under Perkins V, and accessible to educational institutions in Texas offering coursework under the Texas Career and Technical Education (CTE) Science, Technology, Engineering, and Mathematics (STEM)/Renewable Energy Career Cluster.[19] Congress should also fund K–12 outreach programs that educate young people—especially those in marginalized communities—on career opportunities and skills needs in the sector.

Maximize the climate benefit of shifting to hydrogen

- In future rulemaking (whether in the context of power plant emissions or other sources, **EPA** should adopt a similar approach to the IRA's "qualified clean hydrogen," allowing a wide range of technologies to achieve an emission reducing low-carbon hydrogen standard and ratcheting down the standard with time as the hydrogen industry gains its footing.
- **The Texas legislature** should pass additional legislation to integrate the production, distribution, and storage of hydrogen, including hydrogen produced via an electrolyzer, into regulations that apply to natural gas and other fuels, such as the Public Utility Regulatory Act or other relevant sections of the administrative code.
- **Congress** should expand the 45X advanced manufacturing production credit to include electrolyzers, treatment, processing, and hydrogen-powered compression equipment production.
- **Congress** should provide additional funding and guidance for research, development, demonstration, and deployment (RDD&D) efforts at DOE for innovative production, transport, and utilization pathways of clean hydrogen. This should include new funding through the Office of Fossil Energy and Carbon Management for developing innovative processes to produce hydrogen, including those that utilize existing fossil energy resources like methane pyrolysis and biotechnology. Additionally, this should include increasing existing funding to the Energy Efficiency & Renewable Energy Office of Hydrogen Fuel Cell Technologies for RDD&D for reducing costs and improving the efficiency of electrolyzers, retrofitting existing infrastructure to transport hydrogen, and integrating hydrogen in the industrial processes of end users, particularly the chemical, fertilizer, refinery, and primary steel sectors. Finally, this funding should include support for commercialization of proven technologies.
- **Congress** should establish a performance standard through the EPA for energy intensive industries to reduce industrial emissions. This performance standard should be designed to encourage industrial hydrogen users to shift to lower-carbon intensity hydrogen, especially in the petroleum and chemical refining and fertilizer production.

BOX 1: Key Recommendations (continued)

Facilitate the transport and distribution of clean hydrogen

- **The Argonne National Laboratory** should update and modernize its Heavy-Duty Refueling Station Analysis Model to prioritize hydrogen fueling station design with a focus on standardization, ease of deployment, and cost reduction.
- **Congress** should clarify that the Federal Energy Regulatory Commission (FERC) has jurisdiction to regulate the siting of interstate hydrogen infrastructure (e.g., pipelines, compressor stations, and storage facilities), inclusive of 100 percent hydrogen, as well as interstate hydrogen commerce. This jurisdiction should exclude intrastate hydrogen pipeline infrastructure (e.g., pipelines, compressor stations, and storage facilities) not part of the interstate project which initiates the FERC permitting review.
- **FERC** should provide guidance to states to facilitate the development of transparent, consistent regulations for new hydrogen pipeline construction and interconnection, such as developing a model rule that states could use to facilitate the development of their own regulations.

Accelerate clean hydrogen demand

- **EPA** should increase the stringency of greenhouse gas emissions regulations for the power sector. The regulations should be inclusive of the deployment of hydrogen in the power. However, EPA should consider in these that strict, highly prescriptive rules on an early stage developing industry like clean hydrogen could prevent it from developing at the necessary pace and scale.
- **Congress** should implement an economy-wide carbon price.
- **Congress** should establish a Low Carbon Fuel Standard, or clean fuel standard, for the transportation sector consistent with achieving net-zero emissions by midcentury. The new technology-neutral fuel standard should offer an “opt in” approach for aviation and maritime fuels until they achieve a specific milestone (e.g., a certain level of market penetration or a certain number of years after enactment). Furthermore, it should provide compliance flexibility by allowing credit trading and credits for captured carbon and direct air capture. The lifecycle carbon intensity of hydrogen production pathways should be considered in its design.
- **Houston**, along with **surrounding cities**, should create a matching program to connect clean hydrogen producers with potential customers who are willing to pay a premium for low-emissions hydrogen. This program could be modeled on DOE’s H_2 Matchmaker program.
- **Congress** should provide additional funding through the Department of Energy (DOE), distinct from the regional clean hydrogen hubs program, to support projects that demonstrate end-use industrial applications of hydrogen, including in the production of steel, glass, and chemicals, as well as projects in the transportation sector. Such funding should include the Industrial Technology Validation Program at the Industrial Efficiency and Decarbonization Office. Expanding the scope of this pilot program to include project funding, in addition to monitoring and validation, can spur projects to validate these technologies and help companies make confident investments to integrate hydrogen into their operations. Criteria for funding should prioritize projects with the greatest commercial viability and path to rapid scalability. **Developers** should make every reasonable effort to enter into community workforce agreements within the Justice40 framework as they build out these projects.
- **The DOE’s Office of Clean Energy Deployment** should follow through on its commitment to invest $1 billion in pay-for-difference contracts and other demand-side incentives. Additionally, Congress should provide additional support for this program to better align with the scale of market opportunity. Pay-for-difference contracts, in particular, would help to establish a transparent market price for clean hydrogen to support cost competitiveness.

THEMES FROM THE DISCUSSION

BOX 2: Key Roundtable Takeaways

- Houston is well-positioned to lead the energy transition by utilizing its skilled workforce, concentration of thousands of companies across the energy industry, existing infrastructure, and access to domestic and global markets.
- As the clean hydrogen industry scales up, infrastructure for each part of the value chain—from production to distribution, storage, and utilization—must keep pace with the other parts. To date, the private and public sectors have invested significant funding into the development of hydrogen production, but they have invested less into the development of transport, storage, and distribution infrastructure, constraining the development of the industry as a whole.
- Equitably and holistically involving all stakeholders early in the process, especially those who will be impacted by projects or working on them, is essential to creating a path forward for development.
- With the combination of large-scale deployment of renewables, federal funding, new industry players, and unprecedented investment from the DOE in RDD&D, the present moment could be the "golden age of hydrogen"—an opportunity for large-scale commercialization.

THE OPPORTUNITY IN HOUSTON

Participants agreed unanimously that Houston's status as a global energy leader positions it well to lead the energy transition by leveraging its skilled workforce, existing energy infrastructure, and access to domestic and global markets, advantages reflected by the presence of thousands of energy companies in the region.

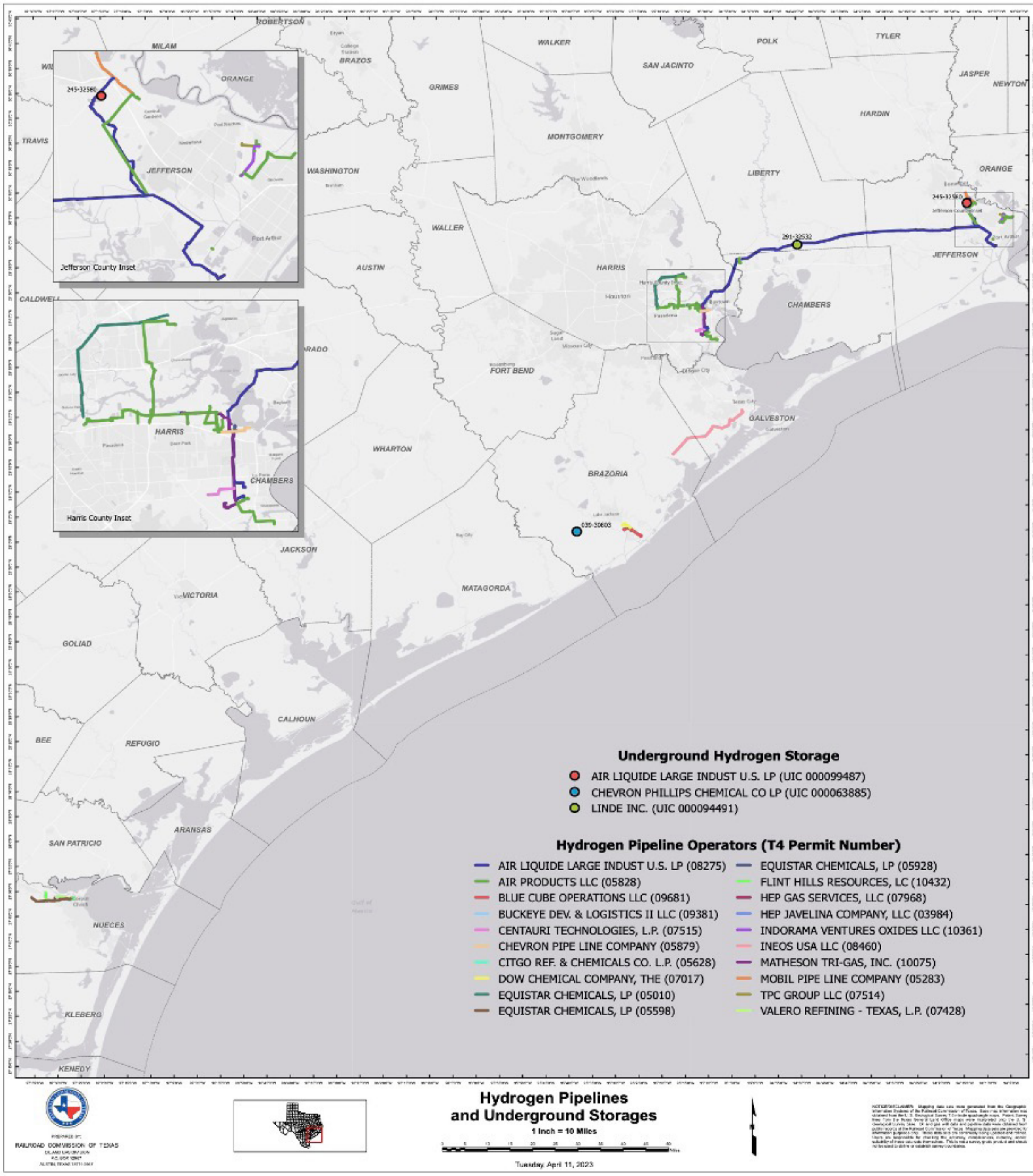
According to the Houston Energy Transition Initiative (HETI), Houston is home to more than 213,000 energy professionals and has more than 60,000 clean energy jobs; it also has more than 4,700 energy companies.[20] A robust college and university system presents career development and educational opportunities for new entrants to the field, and a clean energy-oriented startup and venture capital ecosystem promotes innovation, collaboration, and constructive competition among energy companies. The existing energy workforce in the Houston area is highly skilled in a variety of energy-related jobs, and well-positioned to leverage these skills to succeed in new clean energy technologies like clean hydrogen.

In addition to a favorable business environment, the Houston metro is already home to extensive and comprehensive energy-related infrastructure including pipelines, industrial infrastructure, and port facilities. While dedicated hydrogen pipeline infrastructure is currently limited, most of the United States' existing infrastructure is in the Houston metro region. Figure 4 shows the extent of current pipeline infrastructure in Texas, concentrated near Houston.

The industrial sector within Texas is robust and already uses a significant volume of hydrogen. In 2021, Texas accounted for 13.2 percent of U.S. gross domestic product in petroleum products, chemicals, plastics, and rubber manufacturing.[21] More than 47 percent of total U.S. petroleum refining capacity is located along the Gulf Coast, with 29 percent of U.S. capacity located in Texas.[22] This industry is a major existing consumer of hydrogen—globally, oil refining accounts for 33 percent of hydrogen use—and its geographic concentration makes it possible for clean hydrogen producers in Texas to access this existing market.[23] About a third of hydrogen used in refineries is produced on site, creating an opportunity for refineries to invest in clean hydrogen production capacity by adding CCS to their existing SMR facilities.[24]

Global demand for hydrogen is projected to reach up to 115 mega tons (Mt) by 2030, however, the Inter-

FIGURE 4: Hydrogen pipeline infrastructure in Texas



Source: Railroad Commission of Texas, 2023. Used with permission.

national Energy Agency projects that governments will need 200 Mt to put them on track to meet their existing emissions reduction pledges through 2030. Realizing the full market potential—increasing both the available supply and demand—for hydrogen will require additional policies from countries with climate pledges.[25] As interest in ammonia continues to grow internationally, there is also a growing opportunity to export clean ammonia to foreign markets. Port Houston, the largest port in Texas and the largest port in the United States by foreign and domestic waterborne tonnage, is well-positioned to realize this export opportunity with its proximity to clean hydrogen and ammonia production and existing export infrastructure.[26]

LOCALIZING POSITIVE IMPACTS FOR COMMUNITIES AND THE WORKFORCE

Community engagement and stakeholder consultation

Throughout the discussion, participants emphasized the need to equitably and holistically involve all stakeholders early in the process of developing new clean hydrogen production, transport, storage, and utilization projects. Communities that new infrastructure and project operations will impact the most need a seat at the decision-making, particularly those communities that have been adversely impacted by energy projects and infrastructure in the past. Often, community members will not only be living near projects but working on them. This creates an opportunity for companies to build buy-in among these communities by giving them a stake in the project, and heightens the obligations of companies to engage with communities proactively and comprehensively as they develop projects. In addition to promoting equity and justice, doing so will also reduce the likelihood of local opposition that could prevent a project from moving forward.

Engaging workers and communities

A key opportunity for companies is to integrate the new clean energy projects into their existing infrastructure and facilities. This is especially true in Houston and other communities in Texas, which have long worked on and hosted fossil fuel energy projects. In the case of clean hydrogen, as discussed above, much of the new infrastructure like pipelines and fueling stations necessary to transport it will be built in areas already hosting other pipelines or fueling stations, and even integrated into these existing structures. Participants were adamant that this presents an opportunity for developers and infra-

BOX 3: Key Takeaways on Localizing Positive Community and Workforce Benefits

- Project developers must proactively engage workers and communities in discussions and decisions about the energy transition, as they will be building and hosting the energy system of the future.
- There is a gap in public education about the opportunities and challenges of hydrogen deployment. In particular, communities that projects will directly impact must have access to transparent, comprehensive information about the fuel and its associated infrastructure.
- When deploying new clean hydrogen infrastructure, project developers and infrastructure owners should engage with local communities to seek input and build buy-in among the residents and workers who will be directly impacted, with engagement beginning long before any project development starts.
- Many of the necessary skills for work in the oil and gas sector are directly transferrable to work on clean hydrogen, not only in engineering and fabrication but also in business administration, construction, operations, and maintenance.
- Worker safety is crucial to growing and retaining the workforce in this industry. Many prospective workers are put off by the safety concerns associated with jobs in the oil and gas and chemical industries. As clean hydrogen production grows, and as clean hydrogen utilization in these industries scales up, private and public sector actors must engage with workers to ensure and improve safety.

structure owners to be more proactive than ever before in engaging local communities around the deployment of new infrastructure and technology.

A major concern participants raised was the baseline level of community awareness around hydrogen, which tends to be a niche topic limited to industry workers and experts. To compensate for this, participants urged developers to engage proactively with local communities—long before starting construction—to seek input and build buy-in among these residents who will be most directly impacted. They also highlighted that developers should engage local workers first, as they are often best suited to construct projects in their own communities. Hiring locally can also build community buy-in for a project as it creates a positive stake for host communities in the project's success.

Federal funding and guidelines currently encourage community engagement and community benefits, including through the Justice40 initiative. Participants celebrated efforts to use public-private collaboration to engage communities around the energy transition. They agreed that requirements to engage communities are necessary. However, they are not sufficient to the development of comprehensive positive community benefits plans. Companies must also demonstrate meaningful commitments to incorporate community feedback in a decision-making capacity and reflect community needs in benefits plans to make the engagement effective. Some participants expressed skepticism that Justice40 requirements around community benefit agreements and community engagement plans would be fulfilled by most projects.

One area of particular concern for participants was ports. Ports are often located within disadvantaged communities, producing harmful emissions that adversely impact public health and reduce the economic prospects of local residents.[27] Participants highlighted that shifting to hydrogen fuel for local operations could help reduce the air pollution impacting these communities. However, since many communities may be skeptical of or opposed to new hydrogen infrastructure, ports must proactively and continuously engage with communities to ensure their concerns are heard and addressed. Ports must also transparently communicate the air quality benefits of the shift to hydrogen.

Participants suggested that one way to transparently communicate to workers and communities the true impact of their projects would be for individual companies or potentially regulators to quantify the social impacts of projects in addition to their economic and environmental impacts. Communicating these metrics to communities could help to build buy-in and demonstrate positive opportunities that might not otherwise be captured in traditional metrics.

Education and outreach

As mentioned above, the public is not generally as knowledgeable about hydrogen as it is about many other energy topics. Misinformation abounds, including through pop-culture depictions of the relative dangers of combustion from hydrogen fuel, like the recent popular film Glass Onion.

To inform communities about the opportunities and risks associated with hydrogen production, transport, and storage, participants suggested that companies, local non-governmental organizations, and policymakers should build an education model informed by the real needs of communities about the energy system as a whole, as well as the specific role of hydrogen among all decarbonization solutions.

This model would have benefits for not only the communities but also for the developers. For communities, this can help elevate concerns directly to developers, provide insight towards potential projects in the region, and help establish a channel of communication for future conversations. For developers, this grants them direct access to communities and a better understanding of community concerns. This knowledge can be used to build and execute more robust community benefits plans—a key requirement of all DOE-run Bipartisan Infrastructure Law and Inflation Reduction Act funding opportunities—that directly targets these concerns. More importantly, this can help establish or repair trust between these two often opposed entities.

New hydrogen project development also presents an opportunity to develop a new model for community engagement that considers the quantified social impacts of projects. Testing the information and methods of communication included in the campaign among communities will ensure its effectiveness, and it can help to raise community concerns that may not have otherwise been addressed. At the same time, participants highlighted that how a community perceives the entity sharing the information will determine whether the campaign is successful. The information must be disseminated by a trusted messenger, which may mean a different messenger for different communities. For example, communities that have experienced negative impacts from fossil fuel companies may be skeptical of a campaign led by a fossil fuel company but receptive to one led by the federal government; other communities that prefer markets over the government may be more willing to listen to local business leaders.

Workforce development

Companies can build buy-in among local communities by hiring local workers for new projects, ensuring positive outcomes from the project are shared with the communities that host them. Participants pointed to local hiring targets as essential to encouraging the recruitment of local workers. In cases where local workers do not have the necessary skills to succeed in the emerging clean hydrogen industry, participants suggested paid, Department of Labor (DOL)-registered apprenticeship programs as an effective approach to help local workers build new skills to meet the needs of the industry while providing financial compensation and other wraparound support while workers are in training.[28] Another major opportunity of hiring, training, and providing training to local workers is to diversify the industry to better reflect the communities in which it operates.

Roundtable participants agreed that many of the job skills needed to work in the oil and gas industry are similar to those needed for clean hydrogen, making many jobs directly transferrable for existing oil and gas workers. In addition to engineering and fabrication work, these also include business administration, construction, operations, and maintenance jobs. That said, some skills are specific to clean hydrogen, creating opportunities for workers to grow in new fields, such as electrochemistry. College programs in Texas already offer coursework in these new fields, and outreach to students or young workers could encourage them to pursue these degrees, and ultimately careers, in the clean hydrogen industry.

Worker safety

Both the real safety concerns and societal perception of jobs in the oil and gas and chemical sectors as "dirty jobs" make many workers reticent to enter the field. In response to participants raising challenges in recruiting and retaining workers, some at the roundtable pointed to worker safety as a crucial element of the solution set. Forty-four oil and gas workers were fatally injured on the job in Texas in 2017 alone. Even adjusted for the higher number of oil rigs in Texas, this figure was higher than all other states except Oklahoma that year.[29] In order to attract and retain talent, the industry must both improve its safety record and its public perception.

Apprenticeship programs, as well as comprehensive and worker-driven training programs and policies can help improve both outcomes and perceptions about workers' safety. The transformation of the energy sector and development of the nascent clean hydrogen industry creates an opening for employers to re-evaluate job standards and make them safer, reflecting growing pressure from policymakers, employment markets, and broader social license considerations. Local and federal policies, employer practice changes, cross-sector collaboration, and worker training can reinforce this transformation.

Policy Recommendations:

- **CEQ** and other **federal agencies** should provide clear, transparent guidance on Justice40. They can do so by indicating, for example, how benefits are quantified and in what geographic radius the "communities" are defined.
- **The Texas legislature** should create a funding program to support paid local apprenticeship programs focused on clean hydrogen, covering curriculum development and coordination with community colleges, labor and trade associations, and private training programs relating to the energy transition.
- **Congress** should establish a funding program through DOE and EPA that facilitates engagement between developers of hydrogen infrastructure and communities—especially environmental justice communities, tribal communities, and energy communities. This program should focus geographically on proposed hydrogen hubs and/or on natural gas facilities or other existing infrastructure that will be utilized for hydrogen projects in the future. Information gained from listening sessions across all communities should be aggregated into a comprehensive report on existing community concerns and opportunities relating to clean hydrogen, while offering recommendations to update regulations and funding implementation guidelines to better meet the needs of communities.

- **Congress** should expand Department of Education resources for career and technical education that can support recent graduates and mid-career workers in skilled trades to acquire expertise relevant to the clean hydrogen industry, modeled on the Innovation and Modernization discretionary grant program under Perkins V, and accessible to educational institutions in Texas offering coursework under the Texas Career and Technical Education (CTE) Science, Technology, Engineering, and Mathematics (STEM)/Renewable Energy Career Cluster.[30] **Congress** should also fund K–12 outreach programs that educate young people—especially those in marginalized communities—on career opportunities and skills needs in the sector.

MAXIMIZING THE CLIMATE BENEFIT OF SHIFTING TO CLEAN HYDROGEN

The combination of abundant natural gas and renewable energy resources in Texas give the state's hydrogen industry a significant competitive advantage in both the United States and international markets. To be low-carbon, hydrogen produced from natural gas through steam methane reforming must be paired with carbon capture, utilization, and sequestration (CCUS). Recent incentives in the IRA significantly enhanced the tax credit for CCUS, but additional work at the federal and state levels is needed to approve projects that are already in the pipeline.

Hydrogen produced via an electrolyzer produces no emissions at the point of production and has the advantage of being able to be deployed where clean energy generation is abundant and cheap. In conversations leading up to the roundtable, participants highlighted this advantage for hydrogen as a means of storing excess renewable energy when power is curtailed. In 2022, the Electric Reliability Council of Texas (ERCOT) curtailed 5 percent of its total available wind and 9 percent of its total available utility-scale solar generation, and ERCOT projects these numbers to increase to 13 percent and 19 percent, respectively, by 2035.[31] A main barrier to this production pathway is the high cost of electrolyzers, which can be prohibitive and contributes to the high cost to consumers of clean hydrogen. High costs for electrolyzers largely result from supply chain challenges relating to the availability of critical minerals and lack of global production capacity—though the International Energy Agency predicts, green hydrogen will become 30 percent cheaper by 2030 as the industry scales up.[32]

Theoretically, clean hydrogen could be produced via an electrolyzer connected to the grid, as long as an equivalent amount of carbon-free energy is added to the grid to offset the additional electric load. A main question participants raised in this case is how to measure the carbon intensity of this hydrogen, and whether the additional electricity generation must occur simultaneously with hydrogen production (i.e., hourly matching) or could be averaged over a longer period (i.e., annual

BOX 4: Key Takeaways on Maximizing Clean Hydrogen's Climate Benefits

- The cost of electricity scales nearly linearly with the cost of fuel inputs used to produce it. Significant increases in the prices of fuel inputs for generating electricity (e.g., shifting from natural gas to hydrogen for power production currently results in around an eight-fold price increase). Therefore, increasing fuel costs will significantly increase the cost of electricity for businesses and residential consumers alike, creating or exacerbating an energy burden on many, particularly low-income customers.
- As the economics improve, utilizing hydrogen to produce dispatchable low-emission electricity to complement renewables could be a long-term solution for decarbonizing the electricity sector.
- However, in the long term, the application of clean hydrogen in hard-to-abate sectors including long-haul transportation, steel production, methanol production, biofuel processing, crude oil refining, and other high-heat industrial processes will yield greater overall decarbonization benefits and energy efficiency gains than in the power sector.

matching). Functionally, the Internal Revenue Service (IRS) will be the arbiter of this question when it releases the specific eligibility requirements for the hydrogen PTC under the IRA.[33]

More pathways for hydrogen development exist outside of the traditional SMR or electrolyzer production pathways; for example, hydrogen produced through biotechnology can utilize existing oil and gas reservoirs while producing few process emissions.[34] Another hydrogen production pathway is methane pyrolysis, which decomposes natural gas under high temperatures and generates no carbon dioxide, only hydrogen and solid carbon.[35] A clear and credible means of comparing the carbon intensity of these other production pathways is essential to enabling their inclusion into evolving regulatory and market frameworks.

It takes a significant amount of energy to produce hydrogen, regardless of the production pathway. End users of hydrogen must therefore prioritize lifecycle emissions reductions when strategically shifting to hydrogen utilization. Relatedly, incentives targeting hydrogen utilization should also prioritize opportunities for clean hydrogen to replace existing demand for conventional hydrogen as well as to deploy clean hydrogen in sectors where another cost-effective low-carbon alternative does not already exist.

Hard-to-decarbonize activities like fertilizer manufacturing, high-temperature process heat for manufacturing, long-haul heavy-duty trucking, shipping, and aviation are promising, high-impact candidates for clean hydrogen and/or ammonia utilization. In each of these use cases, a dispensable fuel that produces no carbon emissions at the point of utilization may be the most technologically and/or economically feasible pathway to decarbonization. To maximize the efficiency of incentives for the utilization of clean hydrogen, it will be important to target these sectors, rather than sectors where another, lower-cost or less energy-intensive pathway to decarbonization already exists.

Houston's concentration of industrial facilities, fertilizer producers, shipping, and heavy-duty truck traffic together represent an opportunity to aggregate demand, facilitating local hydrogen deployment at scale and creating significant reductions in air pollution that can benefit local communities.

Policy Recommendations:

- In future rulemaking (whether in the context of power plant emissions or other sources, **EPA** should adopt a similar approach to the IRA's "qualified clean hydrogen," allowing a wide range of technologies to achieve an emission reducing low-carbon hydrogen standard and ratcheting down the standard with time as the hydrogen industry gains its footing.
- **The Texas legislature** should pass additional legislation to integrate the production, distribution, and storage of hydrogen, including hydrogen produced via an electrolyzer, into regulations that apply to natural gas and other fuels, such as the Public Utility Regulatory Act or other relevant sections of the administrative code.
- **Congress** should expand the 45X advanced manufacturing production credit to include electrolyzers, treatment, processing, and hydrogen-powered compression equipment production.
- **Congress** should provide additional funding and guidance for research, development, demonstration, and deployment (RDD&D) efforts at DOE for innovative production, transport, and utilization pathways of clean hydrogen. This should include new funding through the Office of Fossil Energy and Carbon Management for developing innovative processes to produce hydrogen, including those that utilize existing fossil energy resources like methane pyrolysis and biotechnology. Additionally, this should include increasing existing funding to the Energy Efficiency & Renewable Energy Office of Hydrogen Fuel Cell Technologies for RDD&D for reducing costs and improving the efficiency of electrolyzers, retrofitting existing infrastructure to transport hydrogen, and integrating hydrogen in the industrial processes of end users, particularly the chemical, fertilizer, refinery, and primary steel sectors. Finally, this funding should include support for commercialization of proven technologies.
- **Congress** should establish a performance standard through the EPA for energy intensive industries to reduce industrial emissions. This performance standard should be designed to encourage industrial hydrogen users to shift to lower-carbon intensity hydrogen, especially in the petroleum and chemical refining and fertilizer production.

BALANCING DEVELOPMENT ACROSS THE FULL HYDROGEN VALUE CHAIN

Recent federal funding spurring the development of clean hydrogen has been largely focused on the production side, developing incentives to reduce the cost of clean hydrogen with the goal of approaching parity with conventional, carbon intensive hydrogen. However, a common concern of participants was the imbalance in similar incentives on the demand side. California is currently the only state placing stringent enough limits on emissions from heavy-duty trucks to create a market for hydrogen as a fuel for mobility, as this brief will cover in subsequent sections. However, these regulations do not prescribe the carbon intensity of the hydrogen fuel, offering conventional hydrogen the same support as clean hydrogen.

While some individual companies are piloting hydrogen blending in gas turbines or airplanes, without consistent, stringent, clear federal standards setting emissions limits on vehicles, aviation, and power plants, there is little regulatory push for these industries to scale up hydrogen utilization. Similarly, without incentives or emissions limits on industrial users of hydrogen, they will struggle to make investments in less carbon intensive forms of hydrogen, which is often one of a very limited number of pathways toward reducing emissions for industrial users. As global markets increasingly value lower carbon intensity goods, these challenges could have implications for the long-term competitiveness of these industries.

Another challenge with utilizing such standards to scale up demand is that most emissions limits are set at the point of utilization rather than at the point of production. As such, it is difficult for regulators to directly target the carbon intensity of the fuel itself. An alternative suggestion from roundtable participants included instituting a carbon tax or other market-based policy instrument to internalize the cost of carbon at the point of purchase, which would better reflect to consumers the true cost of high carbon-intensity products relative to low carbon-intensity products and therefore drive market shift toward lower carbon-intensity products overall.

TRANSPORTING AND DISTRIBUTING CLEAN HYDROGEN

A significant challenge to the scalability of clean hydrogen is the ability to transport it from the point of production to the point of end use. Current hydrogen transportation options include gas pipelines, gas trucking, and liquid trucking. While pipelines offer the highest throughput transportation of hydrogen in gaseous form, building one requires high upfront costs, credit-worthy long-term offtakers, and permitting approval. Hydrogen gas trucking has far lower capital costs, though hydrogen's low volumetric density limits the scalability of this approach, making it ideal for short distances and small volume transport. Conversely, on-road transportation of liquified hydrogen (liquid trucking) comes with greater capital costs than gas trucking but can transport greater volumes of hydrogen over longer distances, making it especially useful where pipelines are unavailable.

There is growing interest in retrofitting the extensive network of existing natural gas infrastructure to facilitate hydrogen transport. As explored in the following section, existing natural gas pipelines can, theoretically, be utilized, but there are significant technological, economic, and regulatory constraints to retrofitting this infrastructure for the transportation of hydrogen.

Considering the tradeoffs between retrofitting existing infrastructure and building new infrastructure

It is difficult, though not impossible, to retrofit existing natural gas pipelines to accommodate hydrogen; however, there are significant physical limitations. First, hydrogen (H2) is a much smaller molecule than methane (CH4) and is less energy dense. This makes it much easier for hydrogen to leak and increases the pipeline pressure and energy requirements needed to transport it through pipelines. Additionally, hydrogen gas can permeate metal, causing it to become brittle and easier to crack. This process, known as embrittlement, threatens the structural integrity of the pipes. Most transported hydrogen is therefore blended with natural gas or another transport medium to reduce the strain on the infrastructure, requiring it either to be used in blended form or separated at the point of use.

Building new pipelines is expensive and requires significant time and resources, particularly since the permitting process for new pipelines can take up to a decade.[36] New hydrogen pipelines could be built along existing natural gas pipeline rights of way to mitigate the additional impact on the surrounding environment. This is a particularly promising option in Texas, where there is already a robust pipeline network. However, if hydrogen is used as a transportation fuel, it is unlikely that fueling stations will already be located on or near existing pipelines, since they will need to be closer to highways and population centers.

Another possible reason for building new hydrogen pipelines in Texas is as a means of transporting energy from the western part of the state, where renewable energy is abundant, to the eastern part of the state, where electricity demand is concentrated.[37] A 2021 University of Texas whitepaper found that just one new hydrogen pipelines could transport the same amount of energy as five new high voltage transmission lines, and at a fraction of the construction cost and physical impact.[38] As noted above, there are challenges to cost-effectively utilizing hydrogen for power generation and energy storage, particularly given challenges in scaling production and the competition among sectors for a limited supply of clean hydrogen. However, participants expressed interest in utilizing hydrogen as an energy transport and storage medium to support the use of renewable energy that would be otherwise unable to reach demand centers.

One key question surrounding new hydrogen pipeline infrastructure is ownership. As most hydrogen pipelines are currently owned and operated privately, many companies cannot access networks of existing infrastructure. Private owners of pipeline infrastructure are understandably reticent to cede control over their infrastructure and open it for collective use, especially without a framework for cost and revenue sharing.

Roundtable participants pointed to the natural gas industry as a model for the burgeoning hydrogen industry, suggesting that an open access pipeline system for hydrogen would succeed as it has for natural gas. Under an open access system, pipelines are required to serve any actor willing to pay the set rate, which would facilitate diverse participation in the hydrogen market.[39] This system allows pipeline developers to secure commitments from multiple producers and end-users, which is crucial to secure financing for construction—a major bottleneck in pipeline development.[40] Additionally, participants pointed to long timelines and a lack of transparency in the permitting process as barriers to new pipeline construction; they called for consistency and transparency in the permitting process to facilitate the development of this infrastructure.

Policy Recommendations:

- **The Argonne National Laboratory** should update and modernize its Heavy-Duty Refueling Station Analysis Model to prioritize hydrogen fueling station design with a focus on standardization, ease of deployment, and cost reduction.
- **Congress** should clarify that the Federal Energy Regulatory Commission (FERC) has jurisdiction to regulate the siting of interstate hydrogen infrastructure (e.g., pipelines, compressor stations, and storage facilities), inclusive of 100 percent hydrogen, as well as interstate hydrogen commerce. This jurisdiction should exclude intrastate hydrogen pipeline infrastructure (e.g., pipelines, compressor stations, and storage facilities) not part of the interstate project which initiates the FERC permitting review.
- **FERC** should provide guidance to states to facilitate the development of transparent, consistent regulations for new hydrogen pipeline construction and interconnection, such as developing a model rule that states could use to facilitate the development of their own regulations.

ACCELERATING CLEAN HYDROGEN DEMAND

While short-term demand for clean hydrogen is largely limited to existing users of conventional hydrogen, over the long term, both domestic and international demand is projected to increase significantly as the global economy moves toward a low-carbon future and new end uses for hydrogen scale up. As mentioned throughout this brief, key barriers to scaling emerging hydrogen end-uses include expensive and inefficient transportation and distribution options creating untenable costs at the point of delivery. In many cases, companies want to switch to clean hydrogen, but the price premium is too high.

Price to consumers

There is often a high discrepancy between the price of clean hydrogen at the points of production and delivery. For example, the retail price of hydrogen as a transporta-

BOX 5: Key Takeaways on Accelerating Clean Hydrogen Demand

- First movers who are willing to pay incrementally more for clean hydrogen over high carbon intensity hydrogen could help jumpstart a global market for decarbonized hydrogen solutions. These first movers need an avenue to communicate to producers that they are willing to pay this premium for the fuel.
- In the industrial sector, switching to clean hydrogen requires companies to make significant up-front capital investments. Reducing the risks associated with these investments will be key to supporting growth in the market for hydrogen.
- There is often a significant discrepancy between the price of clean hydrogen at the point of production and delivery, due largely to the combination of costs associated with transportation and expensive and limited supplies of fueling equipment.
- A carbon tax or other market-based approach to internalizing the cost of carbon at the point of purchase could help shift purchasing behavior to lower carbon products by reducing the difference in the cost to consumer between conventional fuels and low-carbon fuels.

tion fuel incorporates the cost of liquefaction; transportation; chilling; and building, operating, and maintaining the fueling station. Taken together, costs may be as high as $40–50 per kilogram. With little innovation and investment in the design and deployment of hydrogen fueling stations, they may be costly, unreliable, or inefficient, making it more difficult for drivers to have the support and confidence they need to transition to hydrogen fuel cell powered vehicles.

Aging hydrogen fueling stations may also be difficult to repair due to the small number of stations in existence. Many were built to outdated specifications that may be less efficient because they were set to match hydrogen distributed using older technologies.[41]

Growing the domestic market for clean hydrogen

Currently, the greatest demand drivers for clean hydrogen in the United States are projected to be industrial processes, including petrochemical refining and processes that utilize high temperature heat. In the medium-to-long term, heavy-duty and freight mobility—both on-road and in aviation—are also expected to drive demand.

Transportation is currently the only sector where the existing policy framework is designed to incentivize greater demand for hydrogen. In addition to national greenhouse gas emissions limits on heavy-duty vehicles, which EPA is in the process of updating, California's low-carbon fuel standard (LCFS) and its zero-emission vehicle standards have supported the development of a national market for hydrogen fuel. The framework in California has led to almost all U.S. hydrogen fueling stations being currently located within the state.

While California's regulations on vehicles encourage the use of hydrogen fuel-cell vehicles, they do not prescribe the carbon intensity of the hydrogen fuel used to power them.[42] California's LCFS does, however, assign different credit values to hydrogen based on carbon intensity, determined by the production pathway.[43] Figure 5 shows that hydrogen produced through electrolysis using 100 percent renewable energy receives a carbon intensity (CI) score of 0 and a credit of $2.90 per kilogram; hydrogen produced through steam methane reforming using 100 percent dairy biomethane receives a credit of $6.50 per kilogram and a CI score of -300; hydrogen produced through SMR with conventional natural gas receives a CI score between 106 and 144, and a credit between $1.17 and $1.62 per kilogram.

The significant difference in credit value between hydrogen produced from renewables and hydrogen produced from conventional natural gas creates a significant incentive for producers serving the California fueling market to utilize the former pathway. Producers, as well as policymakers in other states, should consider the impact of California's LCFS on the U.S. hydrogen market.

Roundtable participants expressed optimism that the IRA's production tax credit could bring the cost to customers of clean hydrogen closer to par with the cost of

FIGURE 5: California's LCFS Credit Values for Selected Representative Hydrogen Pathways at $100/MT LCFS Credit Price

	100% RENEWABLE ELECTROLYSIS	100% DAIRY BIOMETHANE SMR	100% BIOMETHANE SMR	33% BIOMETHANE SMR	NATURAL GAS SMR (GASEOUS H2)	NATURAL GAS SMR (LIQUIFIED H2)
CI Score (gCO_2e/MJ)	0	-300	54	88	106	144
FCEV EER-adjusted CI	0	-120	22	35	42	57
Credit Value ($/kg)	$2.90	$6.50	$2.25	$1.84	$1.62	$1.17

Source: California Air Resources Board (CARB), Hydrogen in the LCFS Public Working Meeting for Stakeholders (Sacramento, CA: CARB, 2016), https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/lcfs_meetings/12052016handout_h2.pdf.

conventional hydrogen, facilitating its utilization in use cases such as industrial processes. However, they agreed that additional policies are needed across the United States to accelerate demand for clean hydrogen.

To support market certainty and enable producers to develop longer-term offtake agreements, participants suggested federal support in the form of pay-for-difference contracts. Through this system, a customer would agree to purchase clean hydrogen at the price of conventional hydrogen, and the federal government would pay the producer for the difference. OCED is considering this as a possible solution to scale up demand in relation to the hydrogen hubs program.[44]

Some participants pointed out that many companies are willing to pay higher prices for lower-carbon intensity fuels, especially those with net-zero pledges or other emissions reduction commitments. They suggested a matching program, either facilitated at the federal level through the Department of Energy or at the municipal level among major cities to connect producers of clean hydrogen with those companies that are willing to pay a premium for it. The advantages of a national-level program would be a greater ability of companies to find a match as their pool of prospective matches would be spread geographically much wider. However, to maximize the benefits of geographic proximity between hydrogen production and utilization, and to make the matchmaking experience more tailored to each company's needs, a municipal-level approach could be more successful in some contexts.

A version of this suggested program is already operating through the DOE Office of Fossil Energy and Carbon Management, called the H2 Matchmaker.[45] In this program, hydrogen suppliers and users can self-identify and work to find opportunities for collaboration. The program is the precursor to the Regional Hydrogen Hubs program, and applications are currently closed. City- or county-level matchmaking programs—for example among Houston, Austin, Dallas, and Corpus Christi—could achieve similar objectives for Texas companies while capitalizing on their geographic proximity.

DOE and the Clean Energy Ministerial launched the H2 Twin Cities program in July 2023. This program is a global initiative to connect cities across the world to collaborate and share best practices and lessons learned as they deploy clean hydrogen solutions.[46] The program will pair "Mentor and Mentee cities" with different levels of experience in the technology across different countries or even continents to support scaling up global hydrogen technology development and adoption.

Maximizing the opportunity to serve global markets

Foreign markets, especially Europe and Asia, are interested in importing hydrogen as a clean fuel source. For example, the Japanese government and European Union are setting targets to import 3 million and 10 million tons of hydrogen, respectively, by 2030.[47] Building out the infrastructure needed to deliver hydrogen oversees and meet that demand could help scale investment in domestic hydrogen transportation that can help grow the entire industry. To overcome the technical challenges of transporting hydrogen long distances, exporters can combine hydrogen gas with nitrogen to create ammonia, which can then be used as an energy carrier, and ship the product overseas.[48] Ammonia (NH4) is a larger molecule and therefore less prone to leakage than H2, is more energy dense, and requires less energy to liquefy than hydrogen. East Texas is already a major exporter of liquid natural gas (LNG), with the Freeport, Sabine Pass, and Corpus Christi facilities helping to make the United States the top global exporter of LNG.[49] The existing export infrastructure could be used to help scale up global ammonia export in the coming decades.

Policy Recommendations:

- **EPA** should increase the stringency of greenhouse gas emissions regulations for the power sector. The regulations should be inclusive of the deployment of hydrogen in the power. However, the regulations should consider that strict, highly prescriptive rules on an early stage developing industry like clean hydrogen could prevent it from developing at the necessary pace and scale.
- **Congress** should implement an economy-wide carbon price.
- **Congress** should establish a Low Carbon Fuel Standard, or clean fuel standard, for the transportation sector consistent with achieving net-zero emissions by midcentury. The new technology-neutral fuel standard should offer an "opt in" approach for aviation and maritime fuels until they achieve a specific milestone (e.g., a certain level of market penetration or a certain number of years after enactment). Furthermore, **Congress** should provide compliance flexibility by allowing credit trading and credits for captured carbon and direct air capture. The lifecycle carbon intensity of hydrogen production pathways should be considered in its design.
- **Houston**, along with **surrounding cities**, should create a matching program to connect clean hydrogen producers with potential customers who are willing to pay a premium for low-emissions hydrogen. This program could be modeled on DOE's H_2 Matchmaker program.
- **Congress** should provide additional funding through the Department of Energy (DOE), distinct from the regional clean hydrogen hubs program, to support projects that demonstrate end-use industrial applications of hydrogen, including in the production of steel, glass, and chemicals, as well as projects in the transportation sector. Such funding should include the Industrial Technology Validation Program at the Industrial Efficiency and Decarbonization Office. Expanding the scope of this pilot program to include project funding, in addition to monitoring and validation, can spur projects to validate these technologies and help companies make confident investments to integrate hydrogen into their operations. Criteria for funding should prioritize projects with the greatest commercial viability and path to rapid scalability. **Developers** should make every reasonable effort to enter into community workforce agreements within the Justice40 framework as they build out these projects.
- The DOE's Office of Clean Energy Deployment should follow through on its commitment to invest $1 billion in pay-for-difference contracts and other demand-side incentives. Additionally, Congress should provide additional support for this program to better align with the scale of market opportunity. Pay-for-difference contracts, in particular, would help to establish a transparent market price for clean hydrogen to support cost competitiveness.

CONCLUSION

Texas is already positioned as a global leader in energy production and export; the state now faces an opportunity to become a global clean energy leader, in part through clean hydrogen production, distribution, and utilization. In order to lead, however, the state must prioritize the needs of communities and workers in the low-carbon transition, including through education and outreach, workforce development, and authentic engagement with communities at the project level throughout the development process. Additionally, federal support from Congress, through direction for agencies like DOE and FERC is crucial. It is these agencies that are tasked with effectively deploying of federal funds, clarifying regulatory authority, and shortening permitting timelines. All of this work is essential to support the industry's ability to attract top talent, contributing to the success of the communities that build and host projects. Ultimately, as emphasized by participants in the June 2023 roundtable, a holistic approach to support the simultaneous scale up of the entire hydrogen value chain is necessary to truly capitalize on its potential to decarbonize crucial industries and support the long-term growth and sustainability of Texas's economy.

C2ES Resources

Regional Roundtables
https://www.c2es.org/accelerating-the-us-net-zero-transition/regional-roundtables/

Fueling a Low-carbon Future in Utah: The Role of Hydrogen
https://www.c2es.org/document/fueling-a-low-carbon-future-in-utah-the-role-of-hydrogen/

Setting the Stage for Direct Air Capture in Wyoming
https://www.c2es.org/document/setting-the-stage-for-direct-air-capture-in-wyoming/

Decarbonizing Louisiana's Industrial Sector: Community-Centric Approaches
https://www.c2es.org/document/decarbonizing-louisianas-industrial-sector-the-importance-of-community-centric-approaches/

A Building Block for Climate Action: Reporting on Embodied Emissions
https://www.c2es.org/document/a-building-block-for-climate-action-reporting-on-embodied-emissions/

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