Building the Gulf Coast Clean Hydrogen Market

Summary of Public Workshop and Private Roundtable

September 2022

ENERGY FUTURES INITIATIVE

About the
ENERGY FUTURES INITIATIVE

The Energy Futures Initiative advances technically grounded solutions to climate change through evidence-based analysis, thought leadership, and coalition-building. Under the leadership of Ernest J. Moniz, the 13th U.S. Secretary of Energy, EFI conducts rigorous research to accelerate the transition to a low-carbon economy through innovation in technology, policy, and business models. EFI maintains editorial independence from its public and private sponsors. **www.energyfuturesinitiative.org**

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EXECUTIVE SUMMARY

The Energy Futures Initiative (EFI) convened two virtual events, titled "Building the Gulf Coast Clean Hydrogen Market." A 2.5-hour public webinar was held June 1, 2022, followed by a 1.5-hour private roundtable on June 2. The purpose of these workshops was to hear from tenured hydrogen companies in the Gulf Coast about the opportunities and challenges of leveraging the region's infrastructure and expertise for transitioning to clean hydrogen (hydrogen that is produced with low- or zero-carbon emissions).

A major focus of the discussions centered around the economic considerations in animating additional investment in clean hydrogen.

A major focus of the discussions centered around the economic considerations in animating additional investment in clean hydrogen. Contrasting with previous waves of interest over the past 50 years, interest in hydrogen as a low-carbon resource has been increasing lately due to the need to decarbonize energy systems. Like electricity, hydrogen is an energy carrier, meaning that it is produced from other primary energy sources. Decarbonization is achieved when low-carbon primary energy is used as feedstock for hydrogen production, or when carbon dioxide (CO_2) emissions are captured during production. Also, like electricity, hydrogen is versatile and can be used in several applications (e.g., long-term renewable energy storage, on-road mobility, rail, maritime and aviation transportation, buildings, industrial heating, and hard-to-abate industrial sectors, such as cement, steel, and chemical production).

Public Workshop Takeaways

The June 1 public workshop consisted of three moderated panel discussions open to the public as a webinar. The intent was to highlight the region's expertise and deep knowledge of hydrogen, while identifying strategies for clean hydrogen market formation and decarbonization of the region's economy. The public discussion demonstrated that this region has vast experience and knowledge in hydrogen production and that the mature players in the Gulf Coast clearly have certain advantages in making a clean hydrogen hub a reality.

The public workshop resulted in four major takeaways related to the opportunities and challenges of forming a clean hydrogen market in the Gulf Coast today, with a major emphasis on hydrogen's potential role in decarbonizing the economy, and its additional benefits to the region's economic development.

Takeaway 1: The Gulf Coast can leverage its existing infrastructure, workforce expertise, and natural resources to become a regional hydrogen hub. The Gulf Coast has infrastructure (e.g., hydrogen producers, dedicated hydrogen and CO_2 pipelines, and demand from ammonia, methanol, and petrochemical refineries), workforce expertise, and natural resources (e.g., onshore and offshore salt domes, natural gas resources, water resources, renewable energy production) to leverage in becoming a regional hydrogen hub. The region provides important conditions for existing hydrogen suppliers to scale a clean market.

Takeaway 2: The Gulf Coast can be a major contributor to clean hydrogen demand creation. Building from the existing Gulf Coast hydrogen market, the region could support new demand across a handful of sectors. Participants considered export market development and blending hydrogen into the existing natural gas pipeline system as near-term options to encourage demand. The public event also discussed how pricing structures and contracts could impact clean hydrogen demand.

Takeaway 3: The Gulf Coast may be a first mover for clarifying hydrogen carbon intensity, permitting, and jurisdictional authority requirements. Participants covered these barriers to investment and considered a variety of policy mechanisms to clarify jurisdictional authority, develop a carbon intensity framework for hydrogen production, and expedite permitting processes. These objectives were acknowledged as major factors to increase investment and help the clean hydrogen market scale up.

Takeaway 4: Hydrogen hub development in the Gulf Coast would support the U.S. Department of Energy's (DOE's) clean hydrogen deployment goals. These goals are largely focused on reducing production costs and

enabling a variety of production pathways for hydrogen. There was also a thorough discussion regarding the need for an environmental justice strategy for the region that takes advantage of the existing regional social and intellectual infrastructure and creates an environment that acknowledges the historical injustices of the energy industry while also providing a safe space for the co-creation of pathways for market formation that can benefit frontline communities.

Private Workshop Takeaways

The second day, June 2, consisted of a private virtual roundtable of thought leaders from the region addressing the ideal ingredients for a fully functioning clean hydrogen hub and how DOE funding could impact broader clean hydrogen market formation. The group also discussed what is needed from regulators, elected officials, and community stakeholders to support and sustain these goals. The roundtable kicked off with three distinct sets of questions framed by leaders at EFI and was held with the understanding that, to allow for a more candid and open discussion, no statements in this report would be attributed to any person or organization.

The robust discussion led to three major takeaways that highlighted the region's world-class hydrogen expertise and the varied motivations, incentives, policies, and investments needed to shift the region into a global clean hydrogen hub.

Takeaway 1: The incumbent hydrogen industry can inform the ingredients for a fully functioning hub. The conversations found that regional actors want federal funding for hydrogen hub development to build upon what already exists in the Gulf Coast and provide a path for new market entrants, rather than start a clean market from scratch.

Takeaway 2: Clean hydrogen market signals must be clarified for Gulf Coast hub development to occur. To encourage hub development, the discussion covered topics including the need for regional and interstate coordination mechanisms, alongside CO_2 storage facility permitting to enable clean hydrogen market growth. The participants also conveyed their confusion with policymakers regarding the technological neutrality or pathway dependency when defining "clean hydrogen."

Takeaway 3: Clean hydrogen developers must align decarbonization and infrastructure priorities with community goals. Generally, there was agreement that the emphasis should be on carbon intensity requirements and decarbonization. At the same time, it was acknowledged that decarbonization goals must be matched with priorities and objectives of local communities, emphasizing that new approaches for increased community involvement in infrastructure projects are needed.

Ernest Moniz, CEO of EFI and 13th U.S. Secretary of Energy, hosted both convenings. Participants for both days included executive and senior level representatives directly or actively interested in hydrogen, decarbonization, and economic development in the Gulf Coast. Other organizations that may become stakeholders in a regional clean hydrogen market were also included.

INTRODUCTION

Globally, major economic regions and entire nations have committed to net-zero carbon emissions targets to mitigate the most drastic impacts of climate change and keep global temperature rise to 2 degrees Celsius above pre-industrial levels, while pursuing efforts to limit the increase to 1.5 degrees. To meet this challenge, the United States has pledged to reduce emissions 50 percent by 2030 relative to 2005 levels and achieve net-zero emissions by midcentury. The challenge of reducing emissions in the existing U.S. energy system and spurring the unprecedented investment in clean energy technologies to reach these goals is largely the result of a complex energy system developed over a century with overlapping infrastructure, markets, and regulatory structures. Given that energy and electricity systems are vital to all levels and sectors of the economy and society, large-scale changes are thoroughly regulated and incremental to guarantee the provision of energy resources is not disrupted. The energy transition could also affect energy assets, jobs and the fossil-fuel dependent workforce, and frontline communities historically mistreated by the energy industry.

With such concerns in mind, there is strong interest in reusing and repurposing existing infrastructure, knowledge bases, and skill sets to employ economies of scale and co-locate necessary assets that will benefit an entire region. This type of development will rely on fuel versatility to support many potential end uses and on accommodating regional differentiation in infrastructure, mitigation options, and economic structures. Clean hydrogen presents a potential pathway to meet nationwide decarbonization goals and smooth the impacts of the clean energy transition across applications and sectors. Although a growing number of companies and other actors globally are pursuing the development of hydrogen technologies across the value chain (i.e., the steps or processes from the production of hydrogen through its transport, distribution, and end use), the United States has a distinctive mix of production, demand, and infrastructure in different regions of the country that could place it at the forefront of the nascent clean hydrogen industry.

A major factor driving interest in the formation of hydrogen hubs nationwide is the formal announcement from DOE that the Office of Clean Energy Demonstrations (OCED) intends to issue an $8 billion funding opportunity announcement (FOA) entitled “Regional Clean Hydrogen Hubs” (H_2Hubs). OCED anticipates issuing the FOA sometime in September or October 2022, and the FOA will be funded by the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law.[1] Note that this event occurred prior to the enactment of the Inflation Reduction Act, which was signed into law in August 2022 and which included significant policy support for clean hydrogen.

For more than a year, EFI has been developing a multi-part study of hydrogen market formation in the United States. Our first major report explored the viewpoints of the investment community on hydrogen market formation. In September 2021, EFI published its report, *The Future of Clean Hydrogen in the United States: Views from Industry, Market Innovators, and Investors*, which provided the results of interviews with 72 organizations actively exploring or investing in hydrogen across the value chain to better understand what they are interested in, what is driving their investment decisions, and what is needed to activate more investments. This report finds that investors believe that the country's "natural resources, energy infrastructure, innovation ecosystems, and technology expertise" contribute to the optimistic view that the U.S. market has high potential for the large-scale growth of hydrogen. Additionally, these interviews highlighted that the opportunities related to decarbonization are driving investor interest in hydrogen. Although our findings indicated substantial interest in backing hydrogen, EFI also concluded that much is needed to animate commercial-scale investment in clean hydrogen projects.

EFI followed that report with a series of regional workshops to understand, from the bottom up, what certain communities and stakeholders are doing in clean hydrogen and what is needed to galvanize a clean hydrogen market. The Gulf Coast workshop is the third in this series, following one on the Ohio River Valley—which was hosted as part of the Labor Energy Partnership (LEP) between EFI and the AFL-CIO—and then another focused on the Carolinas region. The underlying motivation for these workshops and reports remains focused on the need for more policy to activate the clean hydrogen market (Figure 1).

Figure 1 | Main Takeaways from Previous Regional Workshops on Hydrogen Market Formation

Key Insights from the EFI/LEP Workshop: THE OHIO RIVER VALLEY

Findings	Considerations
Hydrogen is seen as a unique opportunity to **decarbonize the industrial heartland**	Hydrogen and CCUS are a crucial part of any climate economic development goals
OH, WV, PA have the **human and energy resources** to support a hydrogen hub	Hydrogen can be produced from multiple resources by multiple methods in the region
Developing a hub could be key to **"aggregating hydrogen demand"** in the region	Aggregating hydrogen demand in a hub can take advantage of economies of scale to incentivize hydrogen production

Key Insights from the EFI Workshop: THE CAROLINAS

Findings	Considerations
Developing a **regional hub vision** is seen as an important building block	Shared vision among anchor players would provide a credible demand signal that could induce interest
Identifying **"bankable" offtakers** is a priority for regional development	Given a clear demand signal, the supply (of given attributes) would eventually appear
Who pays matters a lot	Commercialization should not occur on the backs of those least willing to pay for it
High cost and low scale leads to a **"chicken and egg problem"**	Any actions on a hydrogen hub ought to align with the region's differentiators

EFI's previous workshops in the Ohio River Valley and the Carolinas highlight the need for additional policies to help activate clean hydrogen markets in their respective regions and nationwide.

In July 2021, LEP hosted a workshop, "Hydrogen and CCS Hub Market Formation in the Ohio River Valley," to convene leaders from government, labor, and industry to discuss the value of hydrogen and carbon capture, utilization, and storage (CCUS) for the local economy, the energy transition, and what is needed from government, labor, and industry to facilitate hydrogen's development. This workshop found that the Ohio River Valley has the elements for a hub and accelerating market formation. Additionally, developing a hub could be crucial to aggregating hydrogen demand in the region. Hydrogen hubs can help regions, such as the Ohio River Valley, that have been hit hard by the industrial and energy transitions, especially by creating manufacturing and infrastructure jobs. This potential hydrogen hub and industry in the region will depend on strong partnerships and trust building among industry, academia, labor, and the local community.

In October 2021, EFI hosted a workshop, "The Potential for Clean Hydrogen in the Carolinas," exploring ongoing activities across sectors including utilities, industry, transportation, and manufacturing to identify the next steps for local, state, and federal governments to harness the region's interest in hydrogen. This workshop illustrated how hydrogen is viewed as a low-carbon pathway and enabler of economic growth for the Carolinas and surrounding regions. The Carolinas have an active hydrogen industry and interest, with utility projects and end-user investments; robust energy resources (e.g., solar, offshore wind, nuclear); infrastructure (e.g., electricity, ports, trucking corridors); and human resources (e.g., Savannah River National Laboratory has the largest collection of hydrogen experts in the country) to support hydrogen market formation. Participants also viewed hydrogen demand as the main starting point for a Carolinas hydrogen hub. Despite these regional drivers, cost and identification of who pays for the transition to a hydrogen economy are persistent issues to hydrogen's growth in the region. To help address these concerns, the workshop participants agreed on the importance of developing a shared vision to build a broad coalition.

Each of EFI's regional workshops has focused on specific aspects of a region's existing interest in hydrogen—from industries, political leaders, and local communities—and its current and potential resources that could support hydrogen market growth. A fully functioning clean hydrogen market could begin with strategic regional investments to build hydrogen infrastructure connected to existing industrial assets. These factors are especially relevant in the Gulf Coast, where a large portion of the U.S. hydrogen industry operates. This region offers a variety of resources, capabilities, and interests to support regional clean hydrogen market formation:

- Access to production resources such as renewables and natural gas
- Proximity to major onshore and offshore salt domes with the capacity to store captured CO_2
- Hydrogen producers with extensive assets (e.g., infrastructure for hydrogen, oil, and natural gas production) and a strong knowledge and innovation base in the region
- Demand for hydrogen resources in a variety of prominent regional economic sectors (e.g., chemicals such as ammonia and methanol, and petrochemical refining)
- Proximity to U.S. ocean ports with easy access to international export markets

- A trained workforce familiar with operating hydrogen infrastructure along the value chain (i.e., hydrogen production, distribution, and end use)
- A growing number of industry- and state government-led coalitions to support the development of hydrogen hubs across the region
- Prominent environmental justice groups and advocacy activities throughout the region
- A growing number of new market entrants focused on low- and zero-carbon hydrogen production, transport, and end use

These characteristics position the Gulf Coast to be a potential leader in an emerging clean hydrogen industry. The main goal of the Gulf Coast workshops was to hear directly from some of the most tenured and experienced stakeholders in the hydrogen sector on how to accelerate the path to clean hydrogen market formation and how important hydrogen hubs are to these outcomes.

PUBLIC WORKSHOP FORMAT AND PARTICIPANTS

Public Workshop: June 1, 2022, 10:30 a.m.-12:00 p.m. Central Time

The private roundtable kicked off with opening remarks from Carol Battershell (EFI Distinguished Associate) and Ernest Moniz, followed by three moderated panels with guided questions. The webinar was closed with a fireside chat between Moniz and former Sen. Mary Landrieu (D-LA). The panel moderators, participants, topics, and discussion questions are detailed below (Table 1).

Table 1. Public Workshop Panel Topics and Participants

Panel 1: Ideas for Leveraging Existing Gulf Coast Infrastructure	Participants
What useful first steps may extend to clean hydrogen development? (e.g., how can pilot projects help with the transition to clean hydrogen? How can existing contracts be repurposed for clean hydrogen?) Are there lessons learned from regional experience with developing, building, and operating hydrogen projects that may help inform the next wave of clean hydrogen projects? (e.g., how could the permitting process be improved?)	**Moderator:** Kenneth Medlock, *Senior Director of the Center for Energy Studies at Rice University* **Panelists:** Simon Moore, *Air Products Vice President of Investor Relations, Corporate Relations, and Sustainability* Dilanka Seimon, *Energy Transfer Vice President of Alternative Fuels* Colette Honorable, *Former Commissioner of the Federal Energy Regulatory Commission (FERC) and current Partner at ReedSmith LLP*

Table 1. Public Workshop Panel Topics and Participants (cont'd.)

Panel 2: Role of The U.S. Department of Energy H_2Hubs	Participants
What opportunities exist for H_2Hubs to create the basis for broader hydrogen market formation? How should local communities and the local workforce be engaged? What lessons can the Gulf Coast learn from other regions about low-carbon industrial clusters and other hydrogen activities?	**Moderator:** Charles Boustany, *Former U.S. Congressman for the State of Louisiana* **Panelists:** Jason Beckfield, *Professor of Sociology at Harvard University* Janice Lin, *Founder and President of the Green Hydrogen Coalition* Brett Perlman, *CEO, Center for Houston's Future*

Panel 3: Role of Current and Potential Offtakers	Participants
What is the role of demand in the chicken/egg problem and what can be done about it? What is the main impediment to clean hydrogen demand: lack of supply, cost, regulations, or weak market signals? How are current offtake agreements between producers and consumers structured for "gray" hydrogen? What are some characteristics from those gray hydrogen arrangements or other commodity pricing that could be applied to clean hydrogen prices?	**Moderator:** Lisa Frantzis, *Partner in Energy, Sustainability, and Infrastructure at Guidehouse* **Panelists:** Ramanan Krishnamoorti, *Professor/Chief Energy Officer at the University of Houston* Hunter Johnston, *Partner, Steptoe & Johnson LLP* Brad Markell, *Executive Director of the Industrial Union Council at AFL-CIO*

Fireside Chat: How Public-Private Partnerships Can Help Support Hydrogen Market Formation	Participants
Is the funding dedicated in the infrastructure bill appropriate for addressing hydrogen development? How should we begin to address the major regulatory gaps for hydrogen development? Where should the focus be, on the emissions or on the fuels?	Ernest Moniz, *CEO, EFI* Mary Landrieu, *Former U.S. Senator, State of Louisiana*

PRIVATE WORKSHOP FORMAT AND PARTICIPANTS

Private Workshop Format: June 2, 2022, 10:30 a.m.- 12:00 p.m. Central Time

The private roundtable began with opening remarks from Carol Battershell (EFI Distinguished Associate) and Ernest Moniz (EFI), followed by three distinct discussion sections with questions framed by EFI executives Joseph Hezir (EFI Principal), Alex Kizer (EFI Senior Vice President of Research), and Melanie Kenderdine (EFI Principal), respectively. These sections and main discussion questions are detailed in the table below (Table 2).

Table 2. Private Workshop Discussion Sections and Questions

Section 1: What ingredients are needed to establish fully functioning, successful clean hydrogen hubs in the Gulf Coast? *Discussion led by Joseph Hezir (Principal of EFI)*
What do you see as the most important ingredients for successful formation of a Gulf Coast hydrogen hub? Minimum essential? Desirable?
What do you see as the need for—and scope of—a governance structure above and beyond a set of bilateral contracts connecting individual projects?
What do you see as the role for state and local governments in the Gulf Coast hydrogen hubs development?
What do you see as the path of evolution from an initial DOE-funded hub to a larger scale regional hydrogen market? What are the major challenges? What are the steps needed beyond initial DOE hub funding?
Section 2: How can DOE hydrogen hubs have the greatest impact on broader clean hydrogen market formation? *Discussion led by Alex Kizer (Senior Vice President of Research, EFI)*
With finite resources spread across multiple regions, what aspects of a H_2Hub project would benefit most from DOE funding?
How, specifically, can the Gulf Coast's existing hydrogen industry support its development of a clean hydrogen hub?
Do you think collaborating among H_2Hub awardees, sharing lessons learned, would benefit a hub project?
How much funding flexibility is needed for project developers to carry out their objectives?
Section 3: What new policies (federal, state, local) are needed to support hydrogen market development in the region? *Discussion led by Melanie Kenderdine (Principal of EFI)*
What aspects (e.g., carbon intensity methodologies, overall value, etc.) of a hydrogen PTC are most important to driving new clean hydrogen projects?
What demand-side policies do you think can help with hydrogen market formation?
How should local communities be engaged and involved in the process of H_2Hubs?

The following participants (in alphabetical order) contributed to answering these questions. Short biographies for participants from both events can be found in the appendix:

Carol Battershell, *Distinguished Associate, EFI*

Jason Beckfield, *Robert G. Stone Jr. Professor of Sociology, Harvard University*

Luis Birolini, *Managing Director Thermal & Supply North America, ENGIE*

Charles Boustany, *Former Congressman, State of Louisiana*

Jeff Brown, *Research Fellow, Stanford Graduate School of Business*

David Edwards, *Director and Advocate for Hydrogen Energy, Air Liquide*

Lisa Frantzis, *Partner, Energy Sustainability, and Infrastructure, Guidehouse*

Joseph Hezir, *Principal, EFI*

Hunter Johnston, *Partner, Steptoe & Johnson LLP*

Melanie Kenderdine, *Principal, EFI*

Alex Kizer, *Senior Vice President of Research, EFI*

Ramanan Krishnamoorti, *Chief Energy Officer, University of Houston*

Mary Landrieu, *Former U.S. Senator, State of Louisiana*

Janice Lin, *Founder and President, Green Hydrogen Coalition*

Brad Markell, *Executive Director, AFL-CIO, Working for America*

Kenneth Medlock, *Senior Director, Center for Energy Studies, Rice University*

Justin Mirabal, *Senior Managing Associate, Dentons*

Ernest Moniz, *CEO and Founder, EFI*

Simon Moore, *VP, Investor Relations, Corporate Relations and Sustainability, Air Products*

Erik Oswald, *Vice President, Strategy & Advocacy, ExxonMobil*

Brett Perlman, *CEO, Center for Houston's Future*

Dilanka Seimon, *Vice President, Alternative Energy, Energy Transfer*

PUBLIC WORKSHOP TAKEAWAYS

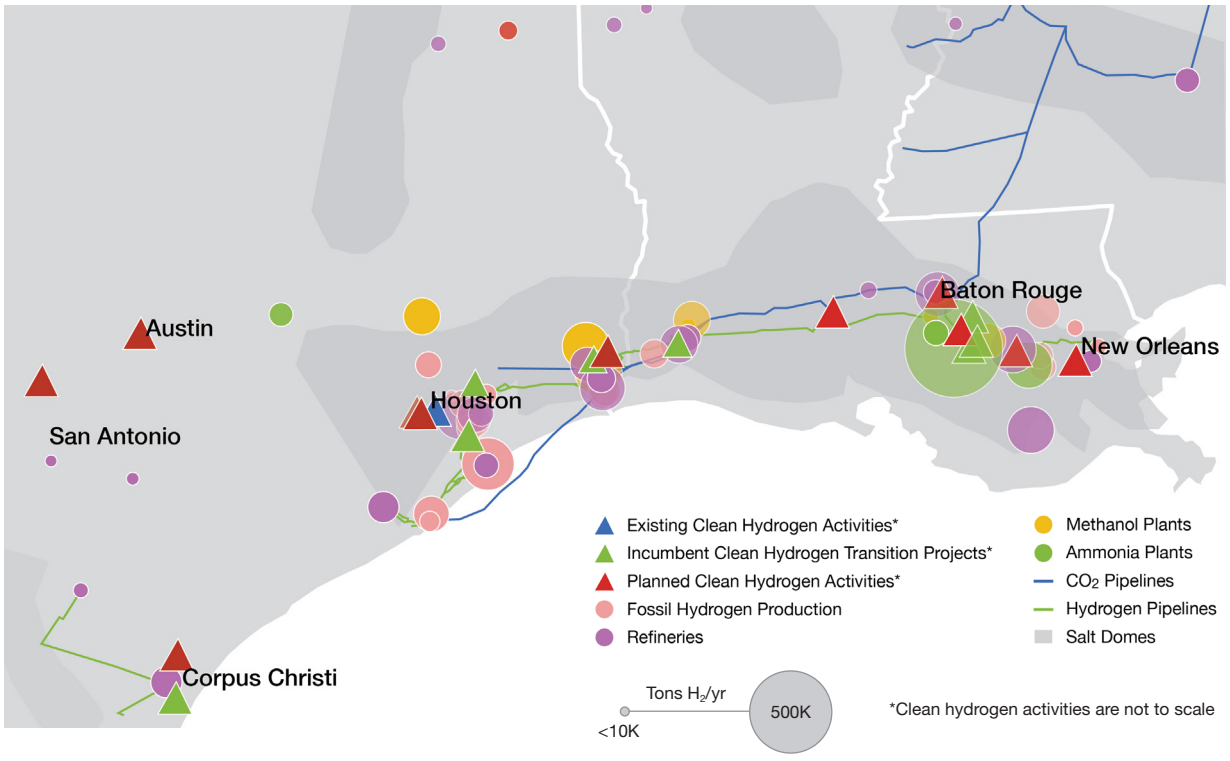
The objectives of the public workshop covered three main topic areas: How can the Gulf Coast leverage infrastructure assets and industry actors; what role could the H_2Hubs play in a region like the Gulf Coast; and what is the role of current and potential hydrogen offtakers (i.e., end users of hydrogen) in the Gulf Coast to encourage demand and support regional market formation. The discussions were led by regional experts, former policymakers, and thought leaders. Each of the topics was covered by a panel of regional actors along the hydrogen value chain, including incumbent hydrogen producers, regulators, hydrogen hub coalition leaders, academics specializing in energy development and justice concerns, legal experts on offtake agreements, and labor representatives.

TAKEAWAY 1: The Gulf Coast can leverage its infrastructure, workforce expertise, and natural resources in becoming a regional hydrogen hub.

Multiple participants emphasized that the Gulf Coast is already a world class hub for oil and gas and has the potential to become a low- and zero-carbon energy hub. More than 47 percent of total U.S. petroleum refining capacity is located along the Gulf Coast, as well as 51 percent of total U.S. natural gas processing plant capacity.[2] This experience with a large multi-state industrial complex gives the region industrial players who understand the benefits of concentrated supply and demand in the Gulf Coast, and state and local governments who see the economic advantages and regional benefits of public-private cooperation to permit facilities.

The Gulf Coast has strong potential to become a renewable energy hub as well. The National Renewable Energy Laboratory determined that the United States could generate nearly 510,000 megawatt hours (MWh) of offshore wind energy per year in the Gulf Coast alone, which is twice the current energy needs of all five states bordering the Gulf of Mexico (Texas, Louisiana, Mississippi, Alabama, and Florida).[3,4] Texas already has the largest wind power generation fleet in the United States (i.e., more than 26 percent of the nation's operating capacity), 10 percent of the country's installed solar capacity, and 10 percent of the country's installed battery capacity on the electricity grid.[5,6] It is worth noting that the growth of the renewable power industry in Texas occurred without the policy support often found in other states with high renewable penetration, but instead as a result of competitive market structures, flexible natural gas power for grid firming, and transmission capacity investment.[7] These conditions could help support the growth of hydrogen produced via renewable or grid-powered electrolysis—the process of using an electric current to split water molecules into hydrogen and oxygen gas—to create clean hydrogen.

Figure 2 | The Existing Gulf Coast Hydrogen Industry Alongside Current and Planned Clean Hydrogen Activities



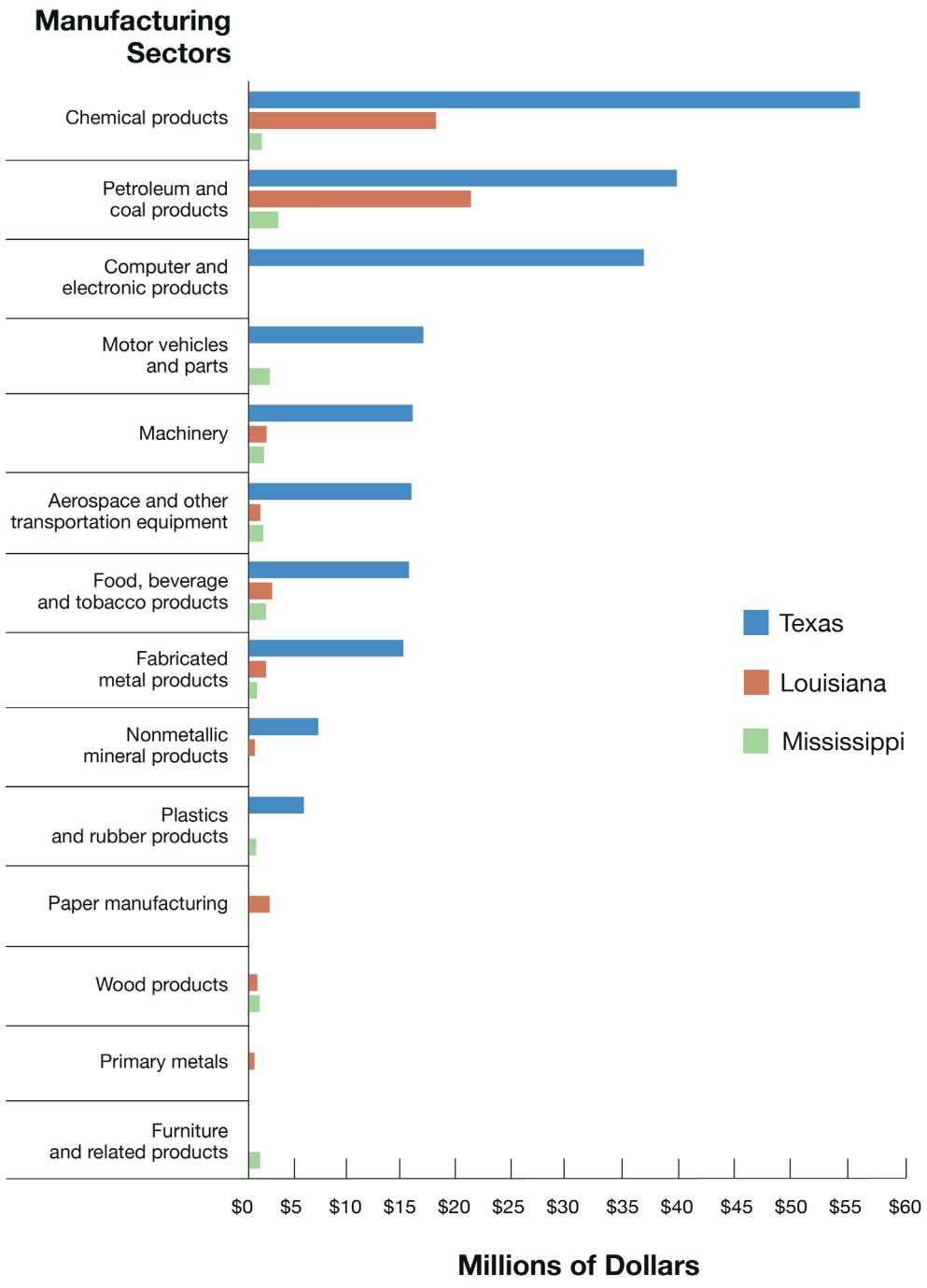
The existing fossil fuel-based hydrogen production, petrochemical refineries, ammonia plants, methanol plants, accessible geologic storage, and dedicated pipelines for both CO_2 and hydrogen provide a robust base for hydrogen hub development in the Gulf Coast. Current and planned clean hydrogen activities in the region further suggest the Gulf Coast's importance in bringing clean hydrogen technologies to scale.

The region also has substantial hydrogen infrastructure across the value chain and multiple new facilities are in planning or development (Figure 2). Existing demand from ammonia, methanol, and refineries in the Gulf Coast amount to just more than 3 megatons of hydrogen per year (Mt H_2/yr), which is more than a quarter of total existing hydrogen demand in the United States. Approximately half of total U.S. hydrogen production occurs in the Gulf Coast as well.[8,9] In the Gulf Coast, Air Products owns the world's largest hydrogen supply pipeline network, and the company has more than 20 hydrogen plants and more than 600 miles of pipeline stretching from the Houston Ship Channel in Texas to New Orleans, Louisiana (Simon Moore, Air Products).[10] A substantial portion of existing dedicated hydrogen and CO_2 pipelines can be found in the Gulf Coast. As of December 2020, there were more than 1,600 miles of dedicated hydrogen pipeline in the United States, with nearly all of these pipelines located across Texas and Louisiana in the Gulf Coast.[11] The region also has a little more than 1,000 gigatons (Gt) of onshore and offshore CO_2 storage capacity.[12,13] The natural geology makes the Gulf Coast an ideal location for CCUS, especially as Louisiana already has laws in place to grant permits for carbon storage (Mary Landrieu, former U.S. senator).[14] Demand sources for hydrogen, such as ammonia plants, methanol plants, and petrochemical refineries already exist in the region as well. Taken together, these existing components of a hydrogen value chain give the Gulf Coast a strong foundation for a larger, cleaner hydrogen market.

When asked about the Air Products board of directors approval of a $4.5 billion investment in Louisiana for clean hydrogen, Moore (Air Products) explained that the Gulf Coast region has market advantages that can be used to justify large-scale investments in this growing industry. An investment ecosystem already exists in Louisiana and does not have to be created from scratch. Additionally, the Louisiana State Mineral and Energy Board has already granted a permit for carbon storage in the state, providing important precedent for companies like Air Products considering where to establish operations that will require CCUS. In parallel, many of the regional oil and gas companies—who are already customers of hydrogen for its use in petrochemical refining—are looking for ways to lower their carbon footprint, and clean hydrogen presents a potential pathway (Moore, Air Products). These conditions create a regional market environment where suppliers can scale, as opposed to regions of the country where there is little to no existing hydrogen industry.

The Gulf Coast is also connected to some of the largest and most impactful ports in the United States. There are 26 major ports across Texas, Louisiana, and Mississippi, the largest of which handle most of the coal, crude oil, petroleum coke, and refined petroleum products being produced or consumed in the region. The Port of Houston is the largest port in the United States in terms of tonnage, and six of the 10 largest U.S. ports can be found in the Gulf Coast.[15] Importantly, ports across the U.S. Gulf Coast already have facilities for liquefying, storing, and loading gases onto vessels. Additionally, many of the major port areas are connected or could connect to the existing hydrogen pipeline network and are near major geologic storage sites.[16] Through these ports, companies in the region could facilitate the growth of a hydrogen export market through a handful of options, such as blending hydrogen with natural gas in liquified natural gas (LNG) cargo or converting and shipping hydrogen in the form of liquid ammonia.[17]

Figure 3 | Top 10 Manufacturing Sectors, in Millions of Dollars, in the Gulf Coast as of 2019 (Texas, Louisiana, Mississippi)[18,19,20]



Data on the primary manufacturing sectors across Texas (top), Louisiana (middle), and Mississippi (bottom) show the petroleum and coal products and chemicals sectors have the most impact in terms of economic output for each state. Source: National Association of Manufacturers, 2021.

The Gulf Coast has an extensive skilled workforce in the region that could be employed across the value chain. Figure 3 shows that the largest manufacturing sectors across Texas, Louisiana, and Mississippi are petroleum and coal products and the chemicals industry. Across all three states, the petroleum industry comprised more than $60 billion in output annually, while the chemicals industry reached almost $75 billion in annual output as of 2019. As of 2020, the estimated number of manufacturing employees for Texas was 881,000, 130,000 for Louisiana, and 146,000 for Mississippi. Taken together, this data suggests the strength of the regional workforce in the energy industry and the potential to facilitate the transition toward clean hydrogen production, transport, and end use.

> **As of 2020, the estimated number of manufacturing employees for Texas was 881,000, 130,000 for Louisiana, and 146,000 for Mississippi.**

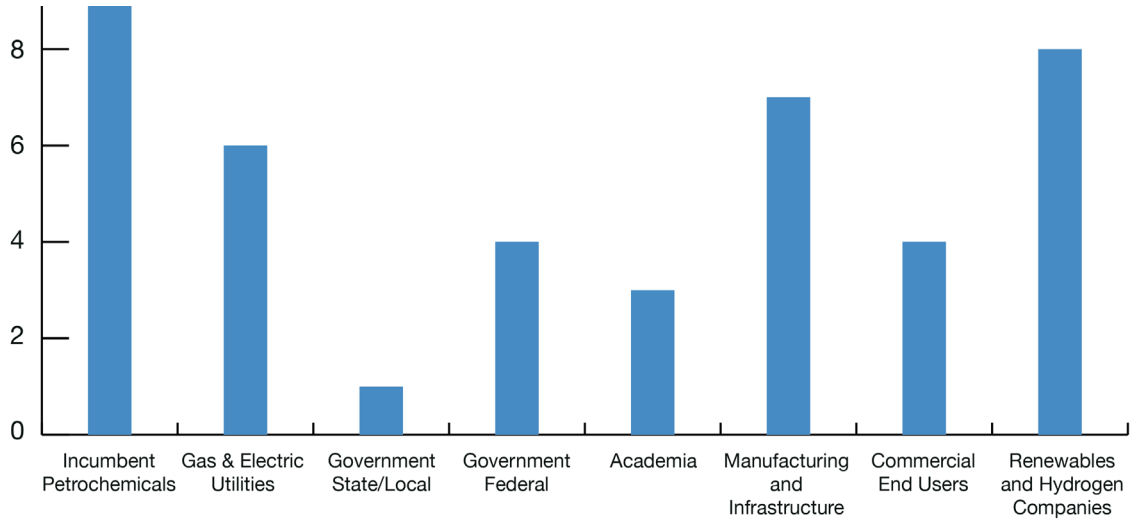
In addition to the incumbent hydrogen industry, EFI is tracking operational and planned clean hydrogen projects. As of June 2022, there were 27 clean hydrogen activities operational or planned in the Gulf Coast. Regarding these projects' business models, the majority have already secured production pathways for clean hydrogen, but almost half of the clean hydrogen activities are still unclear on the exact orientation of demand for hydrogen. Most of the existing and proposed clean hydrogen activities rely on partnerships among petrochemical companies, utilities, and infrastructure companies (Figure 4).

TAKEAWAY 2: The Gulf Coast can be a major contributor to clean hydrogen demand creation.

It is crucial for hydrogen hubs and broader market formation to incentivize demand for clean hydrogen, including developing export markets. Companies are already capable of producing clean hydrogen, so the focus should be on how to stimulate demand (Simon Moore, Air Products). Multiple participants highlighted California's Low Carbon Fuel Standard (LCFS) as a potential policy template to encourage demand. The program places a required carbon intensity reduction on transportation fuels that are sold, supplied, or offered in the state, which can generate credits that can be sold to other fuel producers that have not met the carbon intensity requirements.[21] The LCFS already provides incentives for hydrogen used as a low-carbon transportation fuel to generate these credits.[22]

A system that generates credits or similar incentives would likely be necessary for hydrogen's use in new sectors, such as steel or cement (Mary Landrieu, former U.S. senator). A carbon border adjustment mechanism was mentioned in this context to support overall low-carbon energy transitions since it could create a level playing field by making importers or end users face the same costs and incentives to mitigate carbon that producers face.[23] Incentives could be comparable to a renewable portfolio standard (RPS) for clean hydrogen (Brett Perlman, Center for Houston's Future). A recent report by the Center for Houston's Future projects regional demand growth for clean hydrogen across different end-use cases using input from 70 companies and 100 subject matter experts.[24] There is also interest from the industrial sector in a production tax credit (PTC) for electrolyzers (Lisa Frantzis, Guidehouse).

Figure 4 | Types of Partners in Clean Hydrogen Activities Across the Gulf Coast (Texas, Louisiana, and Mississippi)



Using EFI's internal database on clean hydrogen activities, the types of partners participating in activities in the Gulf Coast were distinguished to determine the diversity of actors, both along the value chain and in terms of industry incumbency.

Since these events occured prior to the passage of the Inflation Reduction Act in August 2022, it is worth noting the new legislation includes a clean hydrogen PTC that is expected to stimulate demand in the region, as well.

Blending hydrogen into the existing natural gas pipeline system in the Gulf Coast could also help to encourage hydrogen demand in the region. "Natural gas pipelines carry 85 billion cubic feet per day (bcf/day), so adding 10 percent hydrogen into the natural gas pipelines would result in 8.5 bcf/day, or 7.7 million tons/year" (Ramanan Krishnamoorti, University of Houston). This amount is double the demand of current Gulf Coast hydrogen production currently—or about the same volume as hydrogen produced nationally today. There is literature that suggests that, at concentrations between 5 to 15 percent hydrogen by volume, storing and delivering hydrogen seems viable without significantly increasing risks associated with the blend's utilization in end-use devices and appliances, safety, or the integrity of the existing natural gas pipeline network. However, appropriate concentration levels will depend on the pipeline network systems and natural gas compositions, suggesting that such decisions should be made at the network or regional level and on a case-by-case basis.[25]

Near-term growth in clean hydrogen demand will likely come first from existing hydrogen customers who are looking to clean up their fuel supply, and then will come from extending hydrogen's use to new end-use applications—such as steel making or cement making—in the future (Brad Markel, AFL-CIO). The majority

of the growth in demand for hydrogen recently in the Gulf Coast has come from the methanol and ammonia sectors, both of which could support the decarbonization of shipping by using methanol and ammonia as substitutes for bunker fuels (Box 1) (Hunter Johnston, Steptoe & Johnson). Orsted and Maersk have recently announced the development of methanol facilities in the Gulf Coast to fuel large container vessels by 2025.[26] Heavy-duty transportation and freight transport are generally seen as big opportunities for hydrogen demand in the Gulf Coast. Learning from the micro-networks being developed in the United Kingdom and the Netherlands at the Port of Rotterdam, there is an opportunity to build a "network for heavy-duty transportation" in the Gulf Coast with existing heavy freight transport corridors centered in areas such as Dallas and Houston (Ramanan Krishnamoorti, University of Houston).

To effectively scale, hydrogen pricing needs to move toward a diverse user base and spot market. The participants recognized that the Gulf Coast does not just need a hub, but ultimately also a network of markets. Currently, there is no liquid market for hydrogen because the existing contracts in the Gulf Coast are single-maker and single-user (Krishnamoorti, University of Houston). Multiple pricing structures and contract types were discussed that are used for other commodities in the region, such as LNG tolling and reserving liquefaction capacity, a project developer model with project costs turned into a formula price, ammonia pricing, or power purchase agreements with utilities for hydrogen as storage.

From this discussion, take-or-pay contracts or tolling agreements (i.e., power purchase agreements) were considered the most likely to be adopted for a clean hydrogen market network. This conclusion is largely because the

Box 1: Ammonia as an Energy Carrier

Ammonia can be used as a liquid carrier for hydrogen and can be stored and transported at room temperature. Transport by ammonia pipelines or ships is less expensive than hydrogen transport.[27] Ammonia also has fewer safety issues—it is toxic but has an odor threshold (200 parts per million [ppm]) lower than the mandated exposure threshold (300 ppm), and is less flammable than odorless hydrogen.[28,29] Moreover, an extensive network of ammonia infrastructure already exists (worldwide, some 180 million metric tons of ammonia is produced annually, and 120 ports are equipped with ammonia terminals) given the use of ammonia in agricultural fertilizers for a century.[30]

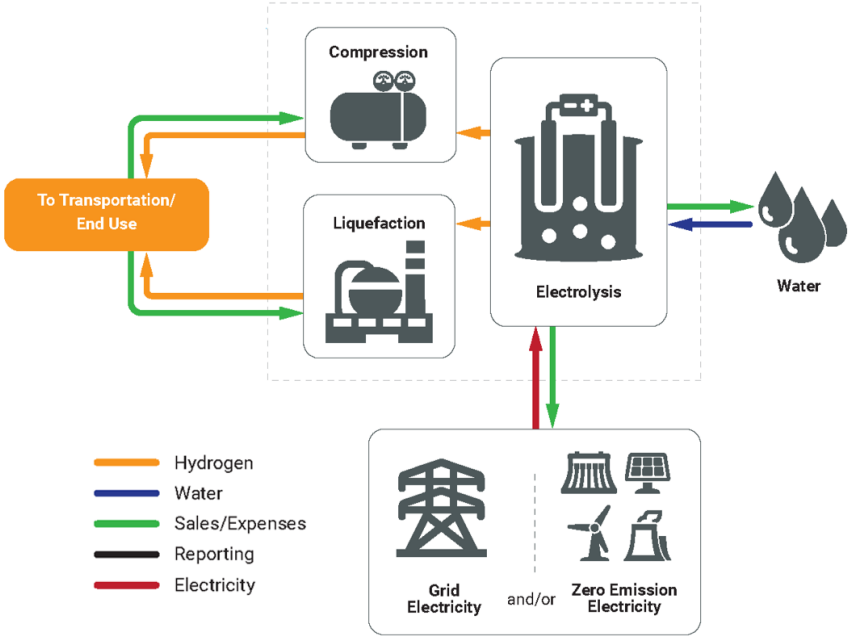
Although ammonia can be used as a feedstock for fuel cells, once the ammonia is converted, reconverting it to hydrogen (i.e., ammonia "cracking") requires energy and reduces overall efficiency—roughly, the energy penalty of converting the hydrogen to ammonia and back is the same as chilling hydrogen.[31] Using ammonia without conversion (e.g., combustion in a turbine) releases nitrogen oxides (NO_x) emissions, which are 300 times more potent than CO_2 as a greenhouse gas, and it depletes the ozone layer.[32] NO_x emissions also have many negative impacts on human health. They are one of the main ingredients in smog in densely populated urban areas and prolonged exposure can damage heart and respiratory function, impair childhood lung development, and lead to premature deaths.[33,34,35]

commodity risk is the biggest concern and is something the banks financing projects are not likely to take on. "If there could be an index for hydrogen that is similar to what Henry Hub is for natural gas, that could do more than almost anything else to drive investment and price certainty for the project developers" (Hunter Johnston, Steptoe & Johnson).

Hydrogen equipment supply chains are vulnerable to global market disruptions and must be analyzed and secured. For example, the current disruption of the global fertilizer market—and subsequently the ammonia market—is the result of China, Russia, and India embargoing any exports of fertilizer for their own production. Additionally, fertilizer production elsewhere would shut down if natural gas costs are greater than $25 per million British thermal units (MMBtu). There are further disruptions to the food markets and ammonia markets as sanctions on Russia and the blockade of Ukrainian ports have taken a large portion of grains out of the market, and farmers in other countries are planting and harvesting less due to the high cost of fertilizer.[36]

One side effect is that in Europe every electrolyzer produced can be sold. Janice Lin (Green Hydrogen Coalition) has previously discussed electrolyzer production outside of the workshop, saying "electrolysis equipment is modular and scalable, and you can site it anywhere that you have water and an electricity connection. So, when you think about it, it's a very controllable, dispatchable load that can be strategically sited anywhere you have electric service"[37] (Figure 5). The European Union is leading the United States in this area. Many of the electrolysis market leaders are Europe-based and the industry there has made recent gigawatt-scale factory announcements.

Figure 5 | Components of Modeled Electrolysis-Based Hydrogen Production



This diagram depicts the potential value chain for electrolysis applications in the Gulf Coast.

The U.S. hydrogen industry is more focused on fuel cells and less on electrolysis equipment. This focus could serve as an opportunity for U.S. manufacturers of modular electrolyzers, depending on how quickly U.S. electrolyzer production could be ramped up to meet demand for European electrolyzer sales if hydrogen is economic at $3 to $4 / kg H_2. Such a ramp up in production could also result in a competitively lower

cost for U.S. modular hydrogen or ammonia production equipment in the longer term.

TAKEAWAY 3: The Gulf Coast may be a first mover for clarifying carbon intensity, permitting, and jurisdictional authority requirements.

A carbon intensity framework for clean hydrogen is required to improve investment. A framework for the carbon intensity requirements—measuring carbon from well to gate—for clean hydrogen was viewed as foundational among many public event panelists. This framework would help encourage investments in decarbonizing hydrogen production and other difficult-to-decarbonize sectors in the Gulf Coast. Some organizations have begun establishing their own standards. For example, the Green Hydrogen Coalition is working on its own carbon intensity framework to provide increased transparency and encourage greater investor certainty (Janice Lin, Green Hydrogen Coalition). Other panelists also mentioned the importance of creating carbon intensity standards, and how a regional interstate organization could help in setting standards for verifiable carbon intensity across different production pathways. A carbon intensity framework is an essential building block from which many legal and regulatory decisions can be made and further guide where and how hydrogen is used in the Gulf Coast (Lin, Green Hydrogen Coalition).

Carbon intensity requirements were also a topic of discussion during the public event fireside chat with Moniz and Mary Landrieu (former U.S. senator). Landrieu recommended that carbon intensity metrics focus on emissions, leaving the market to decide which fuels fit those criteria. She said this focus would enable the Gulf Coast to be a "clean energy powerhouse." She said the region could build on the long-term economic success of the natural gas industry and that laws and regulations need to be "color blind"—allow all kinds of technologies, including fossil fuels, if they fit the carbon intensity requirements. While there are many infrastructure and workforce advantages, and companies in the region willing to invest, Landrieu said "we just need the right signals" from regulators and legislators for the regional market to take off.

Improved infrastructure permitting processes, for hydrogen and enabling systems, are needed to support regional hydrogen market development. While a substantial hydrogen pipeline network exists, many participants agreed that additional hydrogen pipelines will be needed to support a regional hub as sources and uses grow. Additionally, as CCUS is added to existing and new hydrogen production processes, additional carbon storage sites will also be needed. Both types of infrastructure (i.e., hydrogen pipelines and carbon storage) have complex and lengthy permitting processes that need to be improved. It was recognized that infrastructure permitting should not be streamlined to reduce its efficacy in protecting natural environments and communities; rather, as these have relatively untested permitting processes, it is important that transparent and clear timetables are developed to improve investor certainty.

With current permitting processes, if a 100-mile pipeline route has even small deviations, it can interrupt and extend the process. Despite these permitting barriers, "many common-sense steps can be taken to expedite" the pipeline permitting process (Landrieu, former U.S. senator). For example, petrochemical infrastructure could be reused and retrofitted to use hydrogen and other

clean fuel alternatives such as biofuels. Another way to work around the lengthy permitting is to use existing rights of way for additional infrastructure, such as dedicated hydrogen pipelines (Dilanka Simeon, Energy Transfer). An additional option is to facilitate permitting for dual use, which allows a developer to get started early and save time in the future on requests (Simeon, Energy Transfer).

A lengthy discussion among audience members also offered ways to avoid costly infrastructure delays. Participants agreed that it is generally best practice to use hydrogen when it is produced and to co-locate the production and end use of hydrogen. Using zero-carbon electricity (e.g., renewable energy or nuclear) and electrolyzers to make hydrogen closer to load or end-use could avoid the need for some hydrogen pipelines. This co-location reduces transportation and storage overhead expenses and eliminates any safety issues that could come from long-distance transport.

Storage needed for a hydrogen hub also has permitting challenges. Currently, salt storage takes six-12 months for permitting and another 18-24 months for drilling (Simeon, Energy Transfer). Air Products did receive approval for permanent storage of the CO_2 from the Louisiana State Mineral and Energy Board, within the Louisiana Department of Natural Resources. However, a permit to drill the injection wells is still needed, and the permitting is currently under federal authority. Carbon storage permits continue to be multi-jurisdictional and lengthy, although improvements in the process are being pursued in Louisiana and Texas. Box 2 details the main components of the existing permitting process at the state and federal level for CCUS in the Gulf Coast and the growing interest for jurisdictional authority across the country.

Box 2. CCUS Permitting Process and Recent Interest

From the early 1980s through 2010, the Environmental Protection Agency's (EPA) Underground Injection Control (UIC) program regulated five classes of wells (Class I-V). In 2010, the EPA created a sixth well class (Class VI) for the injection of CO_2 into deep subsurface rock. Although at that time very few projects were sequestering CO_2 to reduce greenhouse gas emissions, the federal government anticipated that the technology would be vital to domestic decarbonization.[38]

Class II and Class VI wells are most relevant to CO_2 injection. About 80 percent of active Class II wells are used for enhanced oil recovery (EOR), where fluids, including CO_2, are injected into oil-bearing formations to recover residual oil and natural gas. Although some CO_2 remains underground during the EOR process, Class II wells are not intended to inject CO_2 for long-term storage. Class VI, on the other hand, are for long-term underground storage, or geologic storage. Of the more than 700,000 well permits issued under the UIC program to date, there are approximately 180,000 active Class II wells but only two active Class VI wells in the United States (both at an Archer Daniel Midland's ethanol plant in Illinois). For these permits, the time from application to permit was approximately three years, though the entire permitting process can take up to six years.

The UIC program allows states and territories to apply for primary enforcement authority, or "primacy," which grants them the responsibility and authority to oversee the UIC program in their state. States, territories, and Native American tribes may apply for all well classes, Classes I to V, or Class VI only. Currently, 16 states and three territories have Class II primacy. States that have primacy can issue permits more quickly. For example, it takes the Texas Commission on Environmental Quality approximately 60 days to issue a Class V well permit once a complete application has been submitted.[39]

Although having primacy makes well permitting faster, the process of gaining primacy is not fast. The primacy process can take years, even if those states have Class II primacy, which is why only a few states have sought Class VI primacy. North Dakota applied for Class VI primacy in 2013 and was granted primacy in 2018. Wyoming submitted its complete primacy application in 2019 (notably after several years of discussion with EPA Region 8) and was granted primacy the following year.[40]

In June 2021, Texas took an important step to simplify its primacy application with the enaction of Texas H.B. 1284, giving the Texas Railroad Commission sole jurisdiction over carbon storage wells. (Previously jurisdiction was shared with the Texas Commission on Environmental Quality.) On May 3, 2022, the Railroad Commission approved submittal to the EPA of a pre-application for Class VI wells and a request that the governor formally ask the EPA for Class VI UIC well program approval.[41]

Louisiana's Class VI primacy application is with the EPA and currently in the "completeness determination" phase. Although previous primacy reviews have taken years longer, Louisiana had hoped to receive approval in early 2022. Citing that the application had not moved forward since October 2021, Senator Bill Cassidy (R-LA), on February 14, 2022, announced a hold on the Biden administration's EPA nominees. The senator noted that the Biden administration itself has expressed support for carbon capture projects, with the White House Council on Environmental Quality recognizing "the imperative for CCUS actions to be considered in a timely manner and in the context of a strong regulatory regime."[42] The state of Louisiana anticipates that primacy will be granted in late 2022 or early 2023.[43]

In March 2022, Sens. Shelley Moore Capito (R-WV), Ranking Member of the Senate Environment and Public Works Committee, and Joe Manchin (D-WV), and Rep. David B. McKinley (R-WV) sent a letter to the EPA urging them to work expeditiously to approve applications from states that will allow them primacy.[44] Even with these delays, the outlook for carbon storage seems more promising than it has been in a decade. Indications that CCUS is turning the corner include industry and political support for new storage projects, states with great potential for geologic storage of CO_2 (e.g., Louisiana and Texas) seeking primacy, political support for CCUS at the state and federal level, and the recently increased 45Q tax credit (Section 45Q of the Internal Revenue Code provides a tax credit for CCUS).

Regional stakeholders seek clarity on federal jurisdiction as the hydrogen market scales. Several participants remarked on the lack of clarity on regulations for hydrogen pipelines. The Pipeline and Hazardous Materials Safety Administration (PHMSA) under the Department of Transportation (DOT) regulates pipeline safety, including the safety of hydrogen pipelines. The Federal Energy Regulatory Commission (FERC) within DOE does not regulate hydrogen pipelines. Panelists during the public event included a former FERC commissioner and former chair of the Senate Committee on Energy and Natural Resources who helped provide an informed perspective on regulation authority improvements. Both panelists saw a role for FERC in hydrogen pipeline regulation. Regulation of hydrogen pipelines should fall under purview of a Senate energy committee (e.g., FERC) rather than transportation committee (e.g., PHMSA) (Landrieu, former U.S. senator). "FERC clearly has a solid role to play…. With a mandate from Congress, it could easily jump in here" (Colette Honorable, Reed Smith). Discussing whether hydrogen development should be project-led or policy-led, panelists agreed they expect development to be project-led and regulators will have to catch up. However, in the absence of regulations, some projects—such as those intending to blend hydrogen into natural gas pipelines—cannot proceed. Box 3 provides a deeper dive into the regulatory uncertainties for hydrogen and natural gas blending projects and highlights the necessity of authority clarification for these types of projects to gain investor backing and proceed.

Box 3. Regulations Regarding Hydrogen and Natural Gas Blending

The regulatory authority for dedicated hydrogen pipelines and hydrogen blended into natural gas pipelines rests in different federal agencies. Furthermore, siting, commercial service, security, and safety standards and regulations are further divided across federal and state agencies. At the federal level, the relevant agencies include the Surface Transportation Board (STB), FERC, the Transportation Security Administration (TSA), and PHMSA.[45]

Multiple uncertainties exist regarding converting natural gas pipelines to carry hydrogen. One issue would be FERC's regulation of gas quality for blended methane and hydrogen carried in natural gas transmission pipelines during a hydrogen transition. FERC has asserted its authority to regulate gas quality and interchangeability standards under its general rate authority when such specifications are included in pipeline tariffs. As the commission has stated, "where gas quality and interchangeability issues are of concern to the transporting pipeline, tariff standards are essential terms and conditions of service."[46] However, most interstate natural gas pipeline operators do not have specifications for hydrogen content in their tariffs; conversely, most tariffs likely give operators the discretion to exclude extensive hydrogen concentrations from their systems.[47] Furthermore, FERC has not established an overall rate-making policy specifically to support shipping large volumes of hydrogen in the interstate natural gas pipeline system.[48] Although the commission's policy states that "pipelines and their customers should develop gas quality and interchangeability specifications," hydrogen specifications are not required in FERC-regulated tariffs.[49]

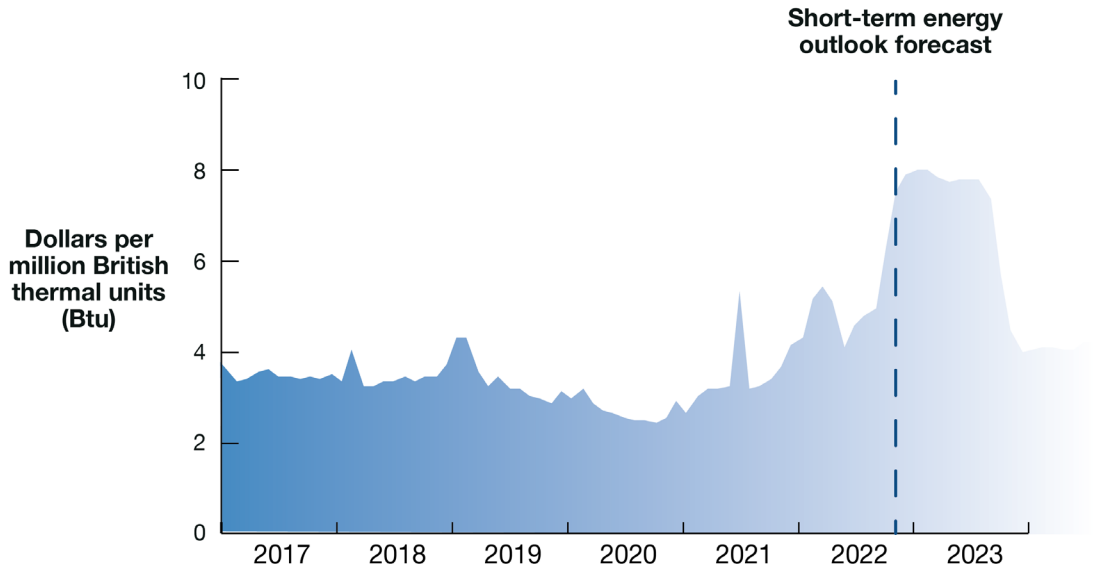
TAKEAWAY 4: Hydrogen hub development in the Gulf Coast would support DOE's clean hydrogen deployment goals.

Public event panelists agreed the primary objective of regional hydrogen hubs should be meeting DOE's Hydrogen Shot cost targets of $1 per kg in one decade. In particular, the participants discussed how a hydrogen market would benefit the region while also helping DOE achieve its Hydrogen Shot cost targets. The Hydrogen Shot seeks to reduce the cost of clean hydrogen by 80 percent to $1/kg in one decade. DOE's Request for Information (RFI) on the H_2Hub funding provided through the Bipartisan Infrastructure Law recognizes that regional hydrogen hubs will be a major component of the hydrogen cost reduction targets for electrolyzers (i.e., $2/kg H_2 by 2026) and help DOE's Hydrogen Program (led by the Hydrogen and Fuel Cell Technologies Office) reach its Hydrogen Shot goals.[50] Hydrogen hubs can contribute to production cost decreases because the co-location of large-scale clean hydrogen with a diversity of end-use applications will encourage the development of supporting infrastructure, stimulate hydrogen activity in more market segments, create near-term and longer-term job opportunities, build the tax revenue base for regional economies, and reduce emissions.[51] Achieving the Hydrogen Shot's cost reduction goal can unlock new markets for hydrogen, including steel manufacturing, clean ammonia, energy storage, and heavy-duty trucks. If the Hydrogen Shot goals are achieved, scenarios show the opportunity for at least a fivefold increase in clean hydrogen use. "A U.S. industry estimate shows the potential for 16 percent CO_2 emissions reduction by 2050, as well as $140 billion in revenues and 700,000 jobs by 2030"[52] (Colette Honorable, ReedSmith).

The region sees upside potential for multiple hydrogen production pathways, especially "blue" hydrogen in the near term. Especially among industry participants in the Gulf Coast, "blue" hydrogen—or hydrogen produced from steam methane reforming with CCUS—has been viewed as the most viable, near-term option to scale up low-carbon hydrogen while also reducing costs and providing the foundation for more cost-effective production from electrolysis in the coming years. It was also mentioned that DOE's goal of $1/kg H_2 may need to be re-examined considering current events and the substantial increase in natural gas prices. Public webinar participants discussed whether this goal was still reasonable in the wake of high gas prices, sanctions on Russia, mothballing of Nord Stream 2, and the reduction in fracking given previously lower gas prices. The cost reduction goals of DOE's Hydrogen Shot were set in June 2021 when in the previous several years' natural gas prices were ranging from $3 to $4/MMBtu. However, the price of natural gas has recently skyrocketed in the United States. At Henry Hub, spot prices averaged more than $8/MMBtu in May 2022, and the effects of the Russian invasion of Ukraine are expected to have a long-lasting impact on North American natural gas markets.[53,54] The U.S. Energy Information Administration's (EIA) June 2022 Short-Term Energy Outlook forecasts U.S. natural gas prices will remain high through the rest of 2022 (Figure 6).

Consumption of natural gas in the electricity sector remains elevated despite high natural gas prices. As of June 2022, U.S. exports of LNG were expected to remain high through the summer, partly as a result of Russia's full-scale invasion of Ukraine. To date in 2022, 75 percent of total U.S. LNG cargos have gone to Europe, compared to 34 percent in 2021. EIA forecasts U.S. production of natural gas to increase in 2022, but not as much as demand.[55]

Figure 6 | Henry Hub Natural Gas Historical and Forecasted Spot Price[56]



As of June 2022, the U.S. Energy Information Administration's (EIA's) short-term energy outlook expected natural gas prices to remain high through 2022. Source: EIA, 2022.

These trends may exacerbate the challenge of decreasing clean hydrogen production costs.

Environmental justice and equity will be important components of the successful deployment of DOE's H_2Hubs. The regional hubs funded by the Bipartisan Infrastructure Law's $8 billion program are required to consider factors such as environmental justice, community engagement, consent-based siting, equity, and workforce development.[57] "It is essential in any justice strategy to include community groups from the very beginning," not just because the DOE program requires it, but because you get more creativity and it helps problem solving (Jason Beckfield, Harvard University). "Deep empathy and listening are needed… to create a safe space where you can co-create" a clean hydrogen market (Janice Lin, Green Hydrogen Coalition). Dr. Robert Bullard, known as the father of environmental justice, said "people are problem solvers," and it is important to tap into that resource and their creativity because different people solve problems in different ways. There may be history between industry and a community. Rather than trying to avoid history, hub developers should "dive into the mess and… acknowledge the messy history" (Beckfield, Harvard). This pursuit is particularly important in the Gulf Coast, where the extensive energy infrastructure and industry impact has disproportionately affected low-income communities and communities of color. Box 4 details environmental injustice in the Gulf Coast and the development of Cancer Alley between Baton Rouge and New Orleans, Louisiana. Hub developers were also encouraged to seek out the social and intellectual infrastructure that already exists in the region as resources (e.g., historically Black colleges and universities) (Beckfield, Harvard). The Gulf Coast could also become more likely to attract federal grant money if

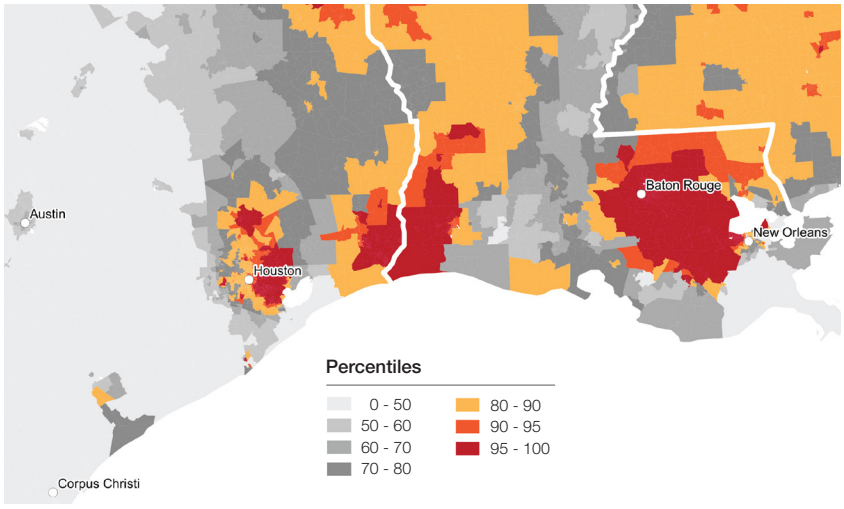
it shows it is able to "address these difficult challenges" (Charles Boustany, former U.S. congressman).

If proper community engagement is established, both in hub development in the Gulf Coast and elsewhere, it will be important to guarantee that there are shared benefits for all community stakeholders (Brett Perlman, Center for Houston's Future). A diversity of engagement in the hub's development would help to build knowledge and understanding around different value propositions, because not only do you need a business value proposition, but it is also important to have a "community value proposition" (Janice Lin, Green Hydrogen Coalition). The systems approach is laudable but must also include the people in that system—not just physical infrastructure. (Lin, Green Hydrogen Coalition).

Box 4. Cancer Alley: Historic and Current Environmental Injustice in the Gulf Coast

Cancer Alley is an 85-mile stretch along the Mississippi River in Southern Louisiana that has historically served as an industrial hub for the state, containing nearly 150 oil refineries, plastics plants, and chemical factories.[58] While these facilities have stimulated the state's overall economy, they have also contributed many negative health and environmental impacts to surrounding communities and ecosystems. This industrial area has heavily polluted waterways and poorer air quality that predominately exposes low-income, largely African American residents in St. James Parish to respiratory diseases, cancer, and other negative health impacts.[59] Figure 7 shows that these industrial facilities make the stretch between Baton Rouge and New Orleans, Louisiana, some of the most dangerous in the country in terms of cancer risks as a result of air toxins. The areas surrounding metropolitan Houston and many of the communities along existing hydrogen infrastructure (i.e., between Houston and New Orleans) also have high risk levels because of this industrial activity.

Figure 7 | Air Toxics Cancer Risk (2017 National Percentiles)[60]



This map highlights the regions of the Gulf Coast with the highest levels of cancer risk due to localized air toxins. Source: U.S. EPA EJScreen Tool, 2022.

PRIVATE ROUNDTABLE TAKEAWAYS

This session was held privately; direct quotes from participants are shared, but no attributions are given.

The private roundtable served as a follow-up discussion, building upon the conversations and findings from the public event and diving deeper into the near-term needs for Gulf Coast clean hydrogen market formation. EFI executives led three primary areas of discussion and opened to all the participants for ideas and comments. In the first session, participants discussed ingredients for a successful clean hydrogen hub in the Gulf Coast, focusing on governance structures and the role of state and local governments. In the second session, participants sought to determine how DOE's H_2Hubs could have the greatest impact on broader market formation, and how it could best use available funding and work with industry in the Gulf Coast. The final session focused on new policies that could support clean hydrogen market development, such as a hydrogen production tax credit (PTC), demand-side policies, and policies to increase local community engagement in hub development.

TAKEAWAY 1: The incumbent hydrogen industry can inform the ingredients for a fully functioning hub.

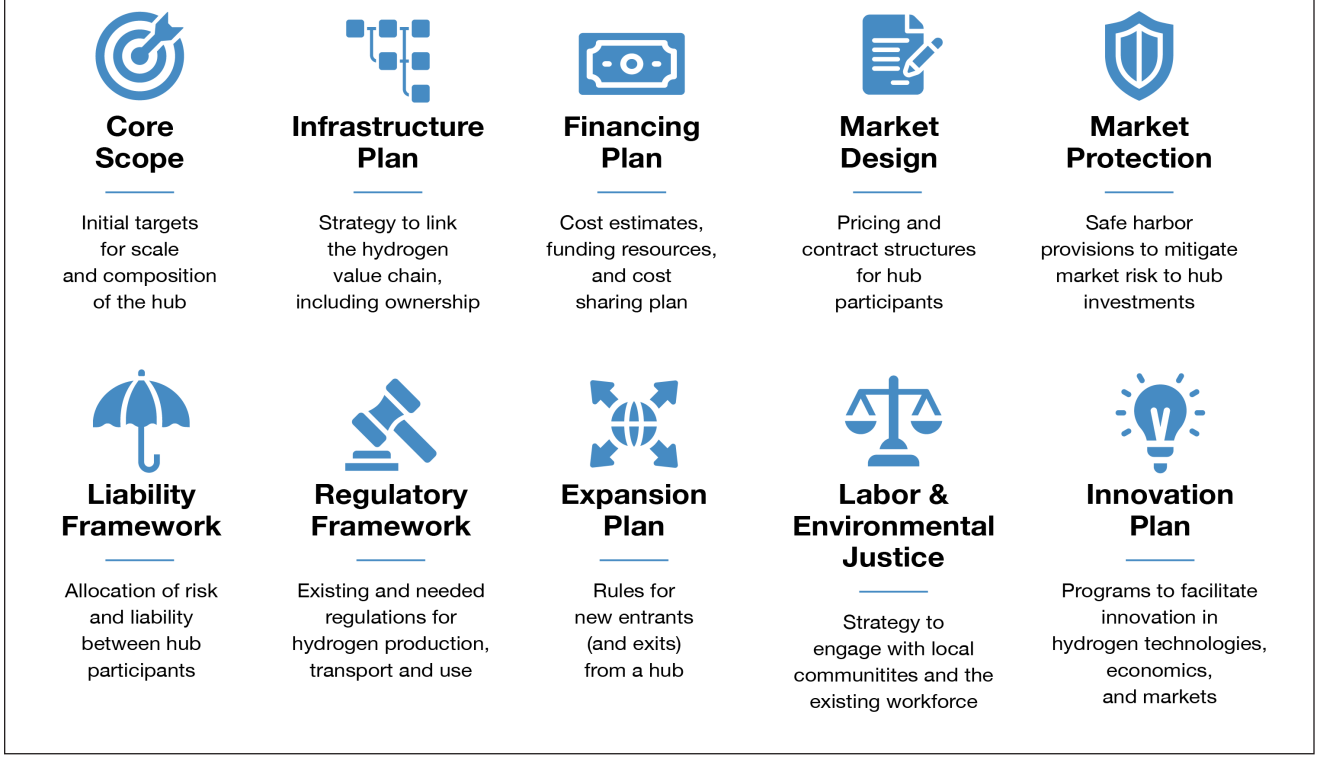
Well-functioning H_2Hubs could contribute to market formation. Many ingredients are needed to establish a functional hydrogen hub (Figure 8).

The roundtable participants discussed moving from bilateral supply and demand today to an open market, as well as the need for new pricing and regulatory structures. They also discussed other focus areas for hydrogen hubs, including workforce development, social equity, market protection, and regulatory standards. Each of these ingredients would be explored during hub development and inform best practices for broader market activity in the future.

It was also mentioned that, while regional hubs should certainly aid market formation, they are not in themselves market formation. After the hub, an incentive structure is needed that allows it to succeed without continued grant money. It is necessary that the goal be a network of markets to help hydrogen become a large-scale, multi-sectoral commodity. The initial formation of multi-state hubs as opposed to individual state hubs was also discussed, considering if multi-state coalition may better enable the eventual linking of hubs into a national market.

Hydrogen incumbents expressed concerns that the new DOE-funded hubs should "not break what we already have." Several attendees described the U.S. Gulf Coast as virtually the only global example of an existing hydrogen hub. There are many things already in place in the Gulf Coast that are not in place in other parts of the United States (e.g., dedicated hydrogen pipelines, hydrogen production and demand, skilled workforce). It is important to not disrupt what already exists, but instead build upon it by enabling the entrance of new players that are complementary to the industry. Consider that bilateral sales—big suppliers to big consumers who want long term steady supply—do not need to be rearranged for the creation of a liquid market for clean hydrogen to co-exist. The region should accommodate existing contracts but start working toward a system that uses and

Figure 8 | Proposed Ingredients to Establish a Fully Functioning Hydrogen Hub



The ingredients depicted in this figure represent the core concepts being explored in EFI's hydrogen market formation project, as well as the main points of discussion during the hub development portion of the private event.

prices hydrogen as an energy commodity, not a specialty chemical.

Cheap, abundant, clean hydrogen is needed to build this market. Many participants said CCUS is likely the fastest way to low-cost, low-carbon hydrogen in the Gulf Coast. Moving to replace existing hydrogen production pathways today with low-carbon alternatives is the first step. The next step after low-carbon production pathways was seen as a much bigger investment risk. New markets that could arise would require different types of investment as they are not interconnected with the current pipeline system.

This region is already in the hydrogen business and the Gulf Coast needs to be careful not to focus too much on "trying to go places that are difficult to go to and overlooking what is already here."

Hydrogen hubs should consider the needs for regional and interstate involvement, and new coordination mechanisms are needed. "There is not a piece of infrastructure that clean and green hydrogen doesn't touch." Thus, a full energy systems view is needed to optimize infrastructure investments for a regional hydrogen market (i.e., infrastructure for electricity, hydrogen, CO_2, ammonia, water).

There is an opportunity for a different collaboration model in the Gulf Coast, one that is focused primarily on building out a regional coordination function. Louisiana, Mississippi, and Texas already have CO_2 pipelines crossing their states, but additional policy is necessary to coordinate this infrastructure as the regional hydrogen market grows. State- and region-led forums could facilitate collaboration on the co-optimization of infrastructure. An interstate compact was raised as a potential coordinating mechanism. Interstate compacts are formal, legislatively enacted agreements between two or more states that bind them to certain provisions, including cooperatively addressing and reaching agreement on complex policy issues, establishing state authority over areas reserved for states, and allowing states to present a unified voice on these issues to the rest of the country.[61] There is also the people side of a market; people are ultimately the ones who make markets. This social side of markets should help to motivate regional integration and governance structures and the coordination of labor market development.

TAKEAWAY 2: Clean hydrogen market signals must be clarified for Gulf Coast hub development to occur.

Actors in the Gulf Coast are receiving mixed signals from policymakers regarding whether clean hydrogen is technology neutral or pathway dependent. The Bipartisan Infrastructure Law (BIL) specified that the H_2Hub program have geographic diversity, a range of end uses, and multiple clean hydrogen production technologies (natural gas, renewables, and nuclear). The BIL also directs that "to the maximum extent practicable, at least 2 regional clean hydrogen hubs shall be located in the regions of the United States with the greatest natural gas resources."[62] Box 5 details all the hydrogen-related provisions that passed in the BIL. Yet, in other legislation, such as the Inflation Reduction Act passed in August 2022, renewable-based hydrogen is preferred, and fossil fuel-based hydrogen is

Box 5. Hydrogen-Related Components of the Bipartisan Infrastructure Law[63]

DOE's RFI for H_2Hub funding from the BIL mentions that the goal is for the H_2Hubs to be sustainable beyond the BIL funding (i.e., without additional government funding). In order to achieve this goal, it is important to understand the components and requirements of the funding dedicated in the BIL and how that could impact the sustainability of a hydrogen industry in the United States. Looking at the language of the legislation, the H_2Hubs program must:

- "…aid in the achievement of the clean hydrogen production standard" by DOE in consultation with EPA "using a definition of clean hydrogen to mean hydrogen produced with a carbon intensity of less than 2 kilograms of CO_2e produced at the site of production per kilogram of hydrogen produced"
- "…demonstrate the production, processing, delivery, storage, and end use of clean hydrogen"

- "…can be developed into a national clean hydrogen network to facilitate a clean hydrogen economy"

The BIL defines a regional hydrogen hub as "a network of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in close proximity." To select these hubs, the BIL outlines specific criteria for DOE to use to the maximum extent practicable in making its hub selections:

- Feedstock diversity: At least one hub shall demonstrate the production of clean hydrogen from fossil fuels, renewable energy, and nuclear energy.
- End-use diversity: At least one hub shall demonstrate the end use of clean hydrogen in the electric power generation sector, industrial sector, residential and commercial heating sector, and transportation sector.
- Geographic diversity: Each regional clean hydrogen hub shall be located in a different region of the United States and shall use energy resources that are abundant in that region.
- Hubs in natural gas-producing regions: At least two regional clean hydrogen hubs shall be located in the regions of the United States with the greatest natural gas resources.
- Employment: DOE shall give priority to regional clean hydrogen hubs that are likely to create opportunities for skilled training and long-term employment to the greatest number of residents in the region.

The BIL also requires additional details and qualifications on clean hydrogen production standards. Ultimately, the Regional Clean Hydrogen Hubs program must support the development of hubs that demonstrably aid the achievement of this clean hydrogen production standard. To meet this goal, no later than 180 days after enactment of the law, the DOE secretary and EPA administrator (with input from industry/stakeholders) shall develop a standard for carbon intensity of clean hydrogen production that:

- Supports clean hydrogen production from fossil fuels with CCUS, hydrogen-carrier fuels (e.g., ethanol and methanol), renewable energy including biomass, and nuclear energy.
- Defines "clean hydrogen" as hydrogen produced with a carbon intensity equal to or less than 2 kg carbon dioxide equivalent (CO_2e) produced at the site of production per kg H_2 produced.
- Considers economic and technical feasibility.

These requirements will apply to all activities carried out under this section of the BIL (i.e., the regional hubs program, electrolysis program, and recycling and manufacturing program). Additionally, five years following the development of the standard, the DOE secretary must determine if the "clean hydrogen" definition should be adjusted and carry out the adjustment.

There is other analysis to suggest that, if supported by the right policies, hydrogen produced from SMR with CCUS could be a valuable clean alternative particularly in industries already using fossil fuel-based hydrogen…

disadvantaged. Gulf Coast actors saw the then-proposed tax packages as "stacked against blue hydrogen" to the extent that it will make natural gas-based hydrogen inaccessible in the market because producers "can't stack tax credits." The Inflation Reduction Act, which was signed into law a couple of months after this workshop, established a hydrogen PTC that awards up to $3/kg H_2 to projects with life cycle carbon intensity levels that are no greater than 4 kg CO_2e / kg H_2.[64] The lower the emissions intensity of a hydrogen production pathway, the higher the percentage tax credit received. The maximum tax credit is reached for projects that have life cycle greenhouse gas emissions lower than 0.45 kg CO_2e/kg of hydrogen produced, are built within a given period, meet certain prevailing wage, apprenticeship, and domestic content requirements, or are located in an energy community. The hydrogen PTC can be stacked with other tax credits (e.g.: clean electricity production and investment tax credit), but not with the 45Q tax credit. Besides the PTC, the IRA introduces several other credits and incentives to support projects in the hydrogen value chain.[65]

The challenge with natural gas-based hydrogen under some incentives is the assignment of upstream emissions associated with the production of natural gas. Some recent literature suggests that the associated emissions from "blue" hydrogen production are only marginally better than "gray" hydrogen production (i.e., hydrogen produced from steam methane reforming [SMR] without any CCUS or carbon mitigation) and may be worse than existing fossil fuel pathways largely because of the potential for fugitive methane emissions along the supply chain.[66] There is other analysis to suggest that, if supported by the right policies, hydrogen produced from SMR with CCUS could be a valuable clean alternative particularly in industries already using fossil fuel-based hydrogen, such as oil refining or ammonia production.[67] Considering the various components of life cycle emissions for hydrogen production from SMR with CCUS—including the CO_2 and methane from reforming and heat, the CO_2 and methane from electricity for carbon capture, and upstream emissions of CO_2—it will be essential for policies to incentivize life cycle greenhouse gas emissions reductions.[68] One type of policy proposed in U.S. Senator Tom Carper's (D-DE) bill (the Clean H_2 Production Act) would require producers of hydrogen from SMR with CCUS to reduce life cycle greenhouse gas emissions below a certain threshold to receive higher levels of a subsidy.[69] For a life cycle analysis, experts in the private roundtable advocated that project-specific methane emissions (as opposed to a national average) be allowed to use these incentives. The Inflation Reduction Act also considers life cycle emissions for the provision of a hydrogen PTC, alongside other tax incentives that could benefit clean hydrogen. However, both the public and private conversations occurred before the IRA was enacted so it was not able to be incorporated into these discussions.

While the Infrastructure Investment and Jobs Act funding for regional hydrogen hubs is an important driver of interest in clean hydrogen, these limited resources should be spent on preparing regions for broader market formation. It was acknowledged that DOE has a lot of experience with energy technology demonstration projects but much less using funding to seed a market. In discussing how to spend the finite DOE resources most productively, the attendees saw value in investments beyond just assets and those associated with a single company. DOE could direct the funding to develop physical, human, and financial infrastructures.

For physical infrastructure, hydrogen infrastructure could be connected through a competitive renewable energy zone process. Renewable energy zones (REZ) have been used to align the development of renewable energy (e.g., solar and wind) and the transmission grid by planning new transmission lines into a region's best areas for renewable electricity generation.[70] This way, the difference in timescales associated with building transmission lines, which takes about 10 years, and renewable electricity generation, which are deployed within two to three years, are ameliorated. Prior to the implementation of REZ, many wind and solar developments faced uncertainty. Such an approach, which could be adapted for hydrogen development, creates a favorable environment for private investment.

Besides physical infrastructure, BIL funding could be disbursed to support investments in human capital infrastructure with workforce development programs focused on transitioning to a clean fuel economy. The Regional Clean Hydrogen Hub selection criteria in the BIL states that the secretary of energy must prioritize hubs that will create opportunities for skilled training and long-term employment for the most residents in a region.[71] The Gulf Coast region is home to a rich and skilled workforce, which already has experience in the hydrogen industry. Additionally, emphasis should be given to workforce capacity building in environmental justice communities. Finally, using hub funding to assess how to create and measure trading schemes would help build up the necessary financial infrastructure to streamline hub development.

> **Hydrogen produced from natural gas with CCUS is essential to getting things off the ground because of its current low-cost process and ability to scale quickly.**

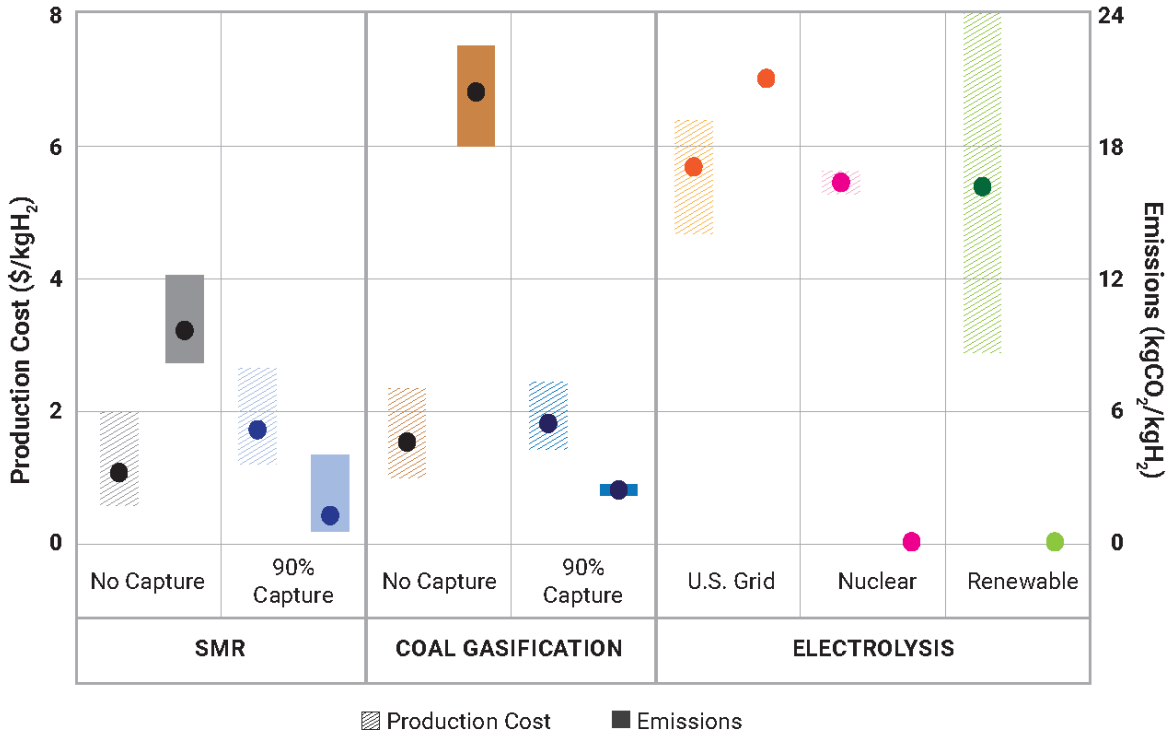
Permitting CO_2 storage facilities is seen as an important enabler of early low-carbon hydrogen in the U.S. Gulf Coast. Hydrogen produced from natural gas with CCUS is essential to getting things off the ground because of its current low-cost process and ability to scale quickly. Storage permits are essential for the early phase of a hydrogen market in the Gulf Coast, so urgency is needed on this pathway. Near Houston, there are only 300 square miles available for large storage, which is not enough area for onshore; offshore geologic storage is needed as a result. This need for more capacity requires the federal government (i.e., the U.S. Department of Interior) to establish a leasing program that employs a different method than the permitting for natural gas exploration. The Gulf Coast needs storage systems, not just sites, that can support operational redundancy in the region.

One idea proposed during the private roundtable was to incentivize cooperation between companies or even regional hubs for large-scale, centralized CO_2 storage systems. This joint effort would exploit geographies with the proper geologic conditions while also facilitating the growth of hydrogen production and demand in areas of the country that may not have those resources. The Gulf Coast region has the geography to provide the foundation for a centralized CO_2 storage system.

A related discussion on storage was about the pyrolysis process for producing hydrogen from natural gas. Methane pyrolysis does not need CCUS as it has no CO_2 emissions, but instead produces solid carbon known as "carbon black." Value could be created by selling carbon black that is created from carbon captured during clean hydrogen production. However, a more developed market for carbon black is needed.

The focus should be on decarbonizing—emphasize carbon intensity not hydrogen colors. Similar to the public event, the private roundtable concluded that the focus should be on decarbonization, carbon intensity, and transitioning using the existing resources in

Figure 9 | The Costs and Carbon Intensities of Various Hydrogen Production Pathways



This graphic shows the cost of production of hydrogen ($/kg H_2) (left vertical axis) and the carbon intensity (kg CO_2/kg H_2) (right vertical axis) for different technologies. The colors of each cost and emissions intensity range correspond to those colloquially used to distinguish between production pathways. Source: Energy Futures Initiative, The Future of Clean Hydrogen in the United States: Views from Industry, Market Innovators, and Investors, September 2021, https://energyfuturesinitiative.org/wp-content/uploads/sites/2/2022/03/The-Future-of-Clean-Hydrogen-in-the-U.S._Report-1.pdf, p.22.

the Gulf Coast, including natural gas and CCUS. Activities in this region should focus on decarbonizing existing hydrogen production then building out new demand. Not all attendees liked naming hydrogen with various colors, but there was agreement on the importance of carbon intensity. Policies need to be technology neutral, and incentives should be based on life-cycle greenhouse gas emissions. "It should be emissions, not fuels, in political discussions." Figure 9 depicts the current average prices for different hydrogen production pathways and the carbon intensity estimates for each. It is worth noting that the current Hydrogen Shot goal of \$1/kg H_2 in the next decade is still below all the clean hydrogen production pathways to date.

TAKEAWAY 3: Clean hydrogen developers must align decarbonization and infrastructure priorities with community goals.

An overhaul of infrastructure permitting was discussed as a necessary focus given the urgency of climate change and the length of current infrastructure permitting processes. Ideas discussed to expedite permitting included repurposing existing pipelines; making use of existing rights of way, particularly for railroads or existing pipeline systems; and a greater emphasis on community engagement and participation.

New approaches for increased community involvement in infrastructure projects are needed. Industry cannot obtain infrastructure permits without community involvement. Even when new infrastructure will contribute to major emissions reduction, frontline communities frequently oppose new infrastructure because of the impact of historic injustices, other socioeconomic priorities, and historically inadequate communication from industry. "Carbon reduction needs to be matched to community goals." A hydrogen hub can be an opportunity to engage differently with the local community. "We need to begin early—bring community leaders in early—do more than tokenize and give them a voice." Hub development in the Gulf Coast should seek to build organizational capacity and provide community stakeholders with the resources—mainly bandwidth and funding—to engage with and benefit from these activities.

A hydrogen hub can be an opportunity to engage differently with the local community. "We need to begin early—bring community leaders in early—do more than tokenize and give them a voice."

The Gulf Coast could combine two of its market advantages. "There isn't a region with higher density in the field of community organizing and environmental justice organizations." Still, community engagement is hard to do in an inclusive way; a new approach focused on early communication, building organizational capacity, and providing resources to frontline communities so they can help guide hub development could make the region stand apart for what it does. Another advantage is infrastructure. Both the existing network and the ability to build infrastructure relatively quickly compared with other parts of the country make the Gulf Coast an ideal location to increase community involvement in infrastructure buildout and to work to promote infrastructure development that can be done in a just and equitable manner.

CONCLUSIONS AND NEXT STEPS

Both the public workshop and the private roundtable illustrated a shared viewpoint from industry incumbents, community and labor advocates, hydrogen and regulatory experts, and political leaders that the Gulf Coast region could become the foundation for a clean hydrogen market in the United States. The Gulf Coast already has hydrogen producers and extensive transport infrastructure that can facilitate the use of clean hydrogen. The workforce in the Gulf Coast is already familiar with the production, distribution, and use of hydrogen. And there are existing demand sectors (e.g., ammonia, methanol, petrochemical refining) in the region, as well, that would serve to encourage demand for clean hydrogen by transitioning existing demand away from emissions-intensive hydrogen production.

Importantly, there was agreement across both the public and private sessions that hub development in the Gulf Coast will be essential for DOE to meet the Hydrogen Program requirements outlined in the BIL and achieve the goals set forth in the Hydrogen Shot Initiative. Not only will the existing hydrogen expertise and infrastructure in the region be useful across the value chain as a clean hydrogen hub takes shape and demand is created, but also other components, such as the connection to potential export markets, and pricing and contract structures between actors already in the region, can provide a platform for the development of a liquid market for clean hydrogen. Similarly, the Gulf Coast was described as the ideal location to acknowledge and work to improve environmental justice concerns and community engagement related to clean hydrogen development, given historical injustices and the prevalence of environmental justice activities in the region today.

Looking forward for clean hydrogen market participants in the Gulf Coast, it will be necessary to address concerns related to the carbon intensity, permitting, and jurisdictional authority requirements at the state and federal level. These conversations occurred before the enactment of the Inflation Reduction Act and its clean hydrogen-related provisions, legislation that will incentivize additional production and demand in the Gulf Coast region. Participants in both events agreed that the primary focus should be clarifying carbon intensity requirements and streamlining regulatory processes so that the value chain across the Gulf Coast can decarbonize at the pace necessary for the United States to meet its climate goals. It will also be necessary to take a full energy systems view of the Gulf Coast to build regional and, potentially interstate, coordination on clean hydrogen and CO_2 infrastructure. Similarly, community engagement is a necessary next step, with participants across both events agreeing that addressing community concerns and working to achieve community goals should occur at the very beginning of regional clean hydrogen hub development.

APPENDIX

Public Event Moderator and Panelist Biographies

(in chronological order)

**Note: Biographies for individuals who participated in both events are located in the public event section only.*

Carol Battershell
Distinguished Associate, EFI

Carol J. Battershell served as Principal Deputy Director in the Office of Policy at the U.S. Department of Energy. In this position she was one of the agency's senior executives and worked closely with members of the Secretary of Energy and the Under Secretaries Offices. In her 10 years with DOE (2008-2018), Battershell led multi-billion dollar technical programs; ran the Energy Efficiency and Renewable Energy field operations office, which at its peak was responsible for approximately $7 billion of grants, research and construction; and was a leading contributor on two multi-agency energy policy reviews. Prior to DOE, Battershell worked for 25 years (1983-2008) in the energy industry for BP. With BP she worked in a variety of locations in the United States and spent 10 years living and working in Europe. In her career at BP, she held roles in operations management, strategy development, financial management, and policy development.

Ernest Moniz
CEO and Founder, EFI

Ernest J. Moniz is the CEO of EJM Associates and the Energy Futures Initiative. He served as the 13th U.S. Secretary of Energy from 2013 to January 2017. As secretary, he advanced energy technology innovation, nuclear security and strategic stability, cutting-edge capabilities for the American scientific research community, and environmental stewardship. He strengthened DOE's strategic partnership with its 17 national laboratories and with the Department of Defense and the broader national security establishment. Specific accomplishments included producing analytically based energy policy proposals that attracted bipartisan support, implementing legislation, leading an international initiative that placed energy science and technology innovation at the center of the global response to climate change, and negotiating the historic Iran nuclear agreement alongside the secretary of state. He reorganized a number of DOE program elements, elevated sound project and risk management, and strengthened enterprise-wide management to improve mission outcomes.

Panel 1

Kenneth Medlock (Moderator)
James A. Baker, III, Susan G Baker Fellow in Energy and Resource Economics, Senior Director, Center for Energy Studies, Rice University

Kenneth B. Medlock III, Ph.D., is the James A. Baker, III, and Susan G. Baker Fellow in Energy and Resource Economics at the Baker Institute and the senior director of the Center for Energy Studies. He is also the director of the Masters of Energy Economics program and holds adjunct professor appointments in the Department of Economics and the Department of Civil and Environmental Engineering at Rice University. Medlock is also a Distinguished Fellow at the Institute of Energy Economics, Japan, and is a member of the Advisory Board of the Payne Institute at Colorado School of Mines. Medlock has published numerous scholarly articles in his primary areas of interest, which include natural gas markets, electricity markets, energy commodity price relationships, transportation, national oil company behavior, economic development and energy demand, energy use and the environment, and various energy transitions topics ranging from engineered and nature-based carbon capture to hydrogen to the economic drivers of technology adoption.

Simon Moore (Panelist)
Vice President, Investor Relations, Corporate Relations and Sustainability, Air Products

Simon R. Moore is Vice President, Investor Relations, Corporate Relations and Sustainability, at Air Products. He is responsible for building and maintaining relationships with investors and analysts through an ongoing dialogue about Air Products' corporate, business, and financial objectives and growth opportunities. He has responsibility for the company's Corporate Relations organization, including global government relations, community relations and philanthropy. He also has global leadership responsibility for sustainability at Air Products. Moore joined Air Products in 1990 as a Merchant Gases sales representative in Los Angeles. In 1995 he transferred to Allentown to support hydrogen on-site business development, and in 1998 he relocated to Houston, where he was named tonnage business manager of the West Gulf Coast pipeline system. Moore relocated to Taiwan in 2004 when he was named director, fab development for Electronics and then global director, Electronic Materials, in 2007. He returned to Allentown in 2010 as director, Investor Relations. He became responsible for Corporate Relations in 2016 and Sustainability in 2020.

Dilanka Seimon (Panelist)
Vice President, Alternative Energy, Energy Transfer

Dilanka Seimon is the Vice President, Alternative Energy at Energy Transfer. Seimon will be responsible for developing alternative energy and carbon capture projects for Energy

Transfer along with various ESG initiatives including the development of carbon offset programs that are accretive to the partnership's operations. Seimon spent eight years with BHP, most recently as Vice President Global Sales & Marketing, Oil, Gas, Power & Carbon. Prior to BHP, he held positions with Southwest Energy, Wells Fargo Commodities and Sequent Energy Management. He received a Bachelor of Science degree in economics and finance in 2003 from Georgia College & State University. He also received a Master of Business Administration degree from Duke University in 2008 and completed Harvard Business School's General Management Program in 2018.

Colette Honorable (Panelist)
Partner, ReedSmith

Colette Honorable leads the ReedSmith's Energy Regulatory group and is a member of the firm's executive committee. She is also a member of the firm's ESG group and is resident in the Washington, D.C. office. Honorable is a highly regarded thought leader and strategist in domestic and international energy sectors and recently served as commissioner at the Federal Energy Regulatory Commission (FERC). She was nominated by President Barack Obama in August 2014, and unanimously confirmed by the U.S. Senate, serving from January 2015 until her term expired in June 2017. At the firm, Honorable is a trusted advisor and counselor to several Fortune 500 energy companies, investor-owned utilities, and renewable energy and technology companies.

Panel 2

Charles Boustany (Moderator)
Former Congressman, State of Louisiana

Dr. Charles Boustany, Jr. is a former congressman (R-LA) and prominent heart surgeon, and now a partner with Capitol Counsel, LLC. During his 12 years in Congress, Boustany served on the influential House Committee on Ways and Means, where he was chairman of the Subcommittees on Tax Policy, Oversight, and Human Resources. As a Ways and Means Committee member, Boustany established himself as an expert and leader on tax, trade, health care, and entitlement policy. Boustany is a leader in trade assistance and enforcement issues and has led seminars on the conduct of legislative oversight for members of parliament from emerging democracies. He has authored numerous opinion pieces on health care, energy, trade, and foreign policy in Politico, The Hill, The Wall Street Journal, and in the peer-reviewed journal Asia Policy. For 14 years, Boustany had a private practice of medicine in the field of thoracic and cardiovascular surgery in Lafayette, Louisiana.

Jason Beckfield (Panelist)
Robert G. Stone Jr. Professor of Sociology, Harvard University

Jason Beckfield is the Robert G. Stone Jr. Professor of Sociology at Harvard University, where he is also the Associate Director of the Center for Population and Development Studies. He took his PhD in sociology in 2005 at Indiana University in Bloomington, and later taught at the University of Chicago before joining the Harvard faculty in 2007. His research and teaching are in the areas of social stratification, political sociology, population health, and climate change. Currently, he is investigating the sociology of energy transitions, with a focus on the petrochemical-rich region of the U.S. Gulf Coast.

Janice Lin (Panelist)
Founder and President, Green Hydrogen Coalition

Janice Lin is the Founder and President of the Green Hydrogen Coalition and the Founder and Chief Executive Officer of Strategen. She brings more than two decades of experience in clean energy strategy, market development, and corporate strategy to Strategen. During this time, she has advised a diverse range of clients including renewable energy equipment manufacturers and service providers, large corporations diversifying into clean energy, and real estate developers building sustainable communities. In 2009, Lin co-founded the California Energy Storage Alliance, and served as its Executive Director until 2019. Lin has also served on the Electricity Advisory Council of DOE, the Board of Advisors for the Energy Policy Initiatives Center, and the Energy Storage Committee of Joint Venture Silicon Valley.

Brett Perlman (Panelist)
CEO, Center for Houston's Future

Brett A. Perlman serves as the CEO of the Center for Houston's Future, a nonprofit organization working to address matters of highest importance to the long-term future of the greater Houston region. His career has spanned senior positions in business, government, and community service organizations. Perlman served for four years as a Commissioner on the Public Utility Commission of Texas, where he was appointed in 1999 by then-Gov. George W. Bush. He holds advanced degrees in public policy from Harvard University and in law from the University of Texas and was a Phi Beta Kappa graduate of Northwestern University.

Panel 3

Lisa Frantzis (Moderator)
Partner, Energy Sustainability, and Infrastructure, Guidehouse

Lisa Frantzis is a partner in Guidehouse's Energy, Sustainability, and Infrastructure segment, responsible for decarbonization go to market initiatives such as clean hydrogen, e-mobility, and renewable energy solutions. Throughout her 40 years of consulting experience, she has determined clean energy integration options for utility companies; identified energy program options for international government agencies; developed business strategies for clean energy manufacturers; and conducted due diligence for financial firms considering clean energy investments.

Hunter Johnston (Panelist)
Partner, Steptoe & Johnson LLP

Hunter Johnston has a leading practice focused on carbon capture and storage policy, as well as renewable energy and decarbonization policy. Johnston's legal experience over a 35-year career includes representation of clients on matters involving legislative, regulatory, and transactional practice areas with a particular focus in public policy and project finance regarding energy, tax, and decarbonization practice areas. Hunter has extensive experience developing and financing greenfield energy projects, both domestically and internationally. A recognized leader in carbon capture policy, he has been an advisor to the carbon capture coalition that was responsible for passage of the rewrite of the 45Q tax credit and implementing regulations. He also counsels clients regarding the wind production tax credit and other matters in the wind industry.

Brad Markell (Panelist)
Executive Director, AFL-CIO, Working for America

Brad Markell serves as the Executive Director of both the AFL-CIO Industrial Union Council and the Working for America Institute. He also leads the federation's climate and energy policy work and is a cleared trade advisor for the AFL-CIO. Prior to the AFL-CIO, Markell worked for the UAW, where he represented the union during the negotiations for the 2009 and 2012 tailpipe emissions standards, helped develop and pass the legislation establishing DOE's ATVM program, and participated in several rounds of national bargaining in the automobile, aerospace, and heavy-truck industries.

Ramanan Krishnamoorti (Panelist)
Chief Energy Officer, University of Houston

Ramanan Krishnamoorti is a Professor and the Chief Energy Officer at the University of Houston. Krishnamoorti leads the University of Houston Energy initiative, an effort across the University of Houston system to position the university as a strategic partner to the energy industry by producing trained workforce, strategic and technical leadership, research, and development for needed innovations and new technologies. Krishnamoorti is a Professor of Petroleum Engineering and Chemistry at the William A. Brookshire Department of Biomolecular Engineering at the University of Houston and has more than 25 years of teaching experience.

Fireside Chat

Mary Landrieu
Former U.S. Senator, State of Louisiana

Mary Landrieu grew up in Louisiana in a politically active family. Inspired by the women in her life and political pioneers like Rep. Lindy Boggs of Louisiana, Landrieu began her political career by winning a race for the Louisiana House of Representatives in 1979. When she took her oath of office in January 1980, Landrieu was one of only three women then serving in the state legislature. She was elected state treasurer in 1988. She was the first woman in Louisiana to be elected to a full term in the Senate. When Landrieu entered the Senate in 1997, she was one of only nine women serving at that time. She was the first Democratic woman to serve on the Armed Services Committee and went on to chair the Small Business Committee, Energy Committee, and Appropriations Committee Subcommittee on Homeland Security. In her 18-year Senate career, Landrieu was a leader on a diverse range of issues, including energy policy, education reform, and child adoption.

Private Event Moderator and Participant Biographies

Joseph Hezir (Moderator)
Principal, EFI

Joseph Hezir joined Moniz and fellow Principal Melanie A. Kenderdine in founding EFI, a non-profit organization dedicated to driving innovation in energy technology, policy, and business models. He is the Managing Principal and lead executive on top EFI research projects, including reports examining federal support for carbon dioxide removal (CDR) research technologies, the U.S. nuclear enterprise and its role in national security, and white papers on DOE's budget priorities and federal tax incentives for energy innovation. He is also currently a member of the Advisory Board of the Scott Institute for Energy Innovation at Carnegie Mellon University.

Melanie Kenderdine (Moderator)
Principal, EFI

Melanie Kenderdine joined Moniz and Hezir in founding EFI, a non-profit organization dedicated to driving innovation in energy technology, policy, and business models. Kenderdine worked in the Administration of President Barack Obama at DOE from May 2013 to January 2017. She served concurrently as Energy Counselor to the Secretary and as the Director of DOE's Office of Energy Policy and Systems Analysis. Her 100-person office was responsible for analysis and policy development in areas that included DOE's role in the annual review of the Renewable Fuel Standard Program requirements, energy innovation, and climate change.

Alex Kizer (Moderator)
Senior Vice President of Research, EFI

Alex Kizer is the Senior Vice President of Research and Analysis at EFI. He develops and manages projects on cross-cutting issues related to technology, policy, and innovation in energy sectors at home and abroad. An expert in developing and managing major analytical initiatives, Kizer supports funders and sponsoring organizations with advice on navigating the interaction between technology disruptions and legacy markets and systems. At EFI, Kizer oversees all qualitative and quantitative analysis for EFI reports, including "Optionality, Flexibility & Innovation: Pathways for Deep Decarbonization in California," "Advancing the Landscape of Clean Energy innovation" for Bill Gates' Breakthrough Energy, and "Investing in Natural Gas for Africans," a project sponsored by the Africa50 infrastructure fund. This analytical work has also included white papers on blockchain technology applications for energy, an examination of the U.S. nuclear enterprise and the role it plays in national security, studies on large-scale carbon management, and a variety of budgetary analyses.

Luis Birolini (Participant)
Managing Director Thermal & Supply North America, ENGIE

Luis Birolini is the Managing Director of Thermal & Supply, North America. Prior to his managing director position, he was the Vice President of business development. He was general counsel at GDF Suez Energy and a visiting attorney at Kirkland & Ellis LLP. He received his bachelor's degree at Pontificia Universidade Catolica de Sao Paulo.

Jeff Brown (Participant)
Research Fellow, Stanford Graduate School of Business

Jeffrey D. Brown is a Lecturer for the joint Law School/Business School course "Clean Energy Project Development and Finance," co-taught with Professor Dan Reicher and fellow Lecturer Dave Rogers. In that course, first taught in Winter 2015, the instructors expose law, business, and engineering students to the interrelated economic, financial, legal, engineering, and policy factors that must be successfully managed to bring a clean

energy project into production. Brown was named a Research Fellow at the Steyer-Taylor Center for Energy Policy and Finance in June 2016. He is researching the interactions of federal energy and environmental regulation, state and ISO power markets regimes, and federal clean energy grants and tax incentives upon the financial feasibility of projects to decarbonize the power and industrial sectors.

David Edwards (Participant)
Director and Advocate for Hydrogen Energy, Air Liquide

David Edwards is a Director and Advocate for Hydrogen Energy for Air Liquide in the United States. Edwards is responsible for establishing and maintaining internal and external partnerships with industry, academia, and government entities to advance the technology and business opportunities in Hydrogen Energy. He has been with Air Liquide for more than 25 years. He has a PhD in engineering and has spent his career in energy related fields including nuclear reactor design, cryogenics engineering, and hydrogen energy.

Justin Mirabal (Participant)
Senior Managing Associate, Dentons

Justin J. Mirabal is a member of Dentons' Energy practice. He counsels energy industry clients on regulatory, project finance, and transactional issues. Mirabal has represented electric utilities and natural gas and oil pipelines in various proceedings before FERC and state public utility commissions. Mirabal also advises clients on FERC enforcement and compliance matters. He has achieved successful outcomes in litigation and helped craft consensus agreements between regulated entities and their customers in settlement negotiations. Mirabal draws on a strong subject-matter background to navigate the energy industry's evolving regulatory and business landscape. His practice engages issues dealing with the Federal Power Act, the Natural Gas Act, the Interstate Commerce Act, the Commodity Exchange Act, and the National Environmental Policy Act.

Erik Oswald (Participant)
Vice President, Strategy & Advocacy, ExxonMobil

In this role, Erik Oswald is leading the company's efforts to advocate for the appropriate government policies and regulations that will be needed to incentivize the wide-scale development and deployment of carbon capture and storage technology around the world. Prior to his current position, Oswald was most recently Vice President, Exploration and New Ventures Americas, for ExxonMobil's Upstream Business Development Company, where he oversaw ExxonMobil's exploration projects in Guyana and Brazil, among others.

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