



ENERGY FUTURES
— INITIATIVE —

**PUBLIC WORKSHOP & PRIVATE ROUNDTABLE
DISCUSSION SUMMARY**

The Potential for Clean Hydrogen in the Carolinas

January 2022

ABOUT ENERGY FUTURES INITIATIVE

The Energy Futures Initiative (EFI) 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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The Energy Futures Initiative would like to thank the following organizations for sponsoring this report.

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- Toyota Research Institute
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Suggested Citation: Energy Futures Initiative. “Workshop Summary: Public Workshop & Private Roundtable Discussion Summary: The Potential for Clean Hydrogen in the Carolinas,” January 2022.

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Introduction

The Energy Futures Initiative (EFI) hosted two convenings on the Potential for Clean Hydrogen in the Carolinas on October 28 and 29, 2021 from 11:00am-1:00pm ET each day. The purpose was to explore a hydrogen hub concept in North Carolina and South Carolina (“the Carolinas”) and the surrounding regions.

The timing of the gatherings was germane; federal, state, and local policymakers were actively considering infrastructure funding, economic development pathways, and jobs creation tactics in light of the COVID-19 pandemic recovery and longer-term climate change mitigation strategies tied to the Paris Climate Agreement (Box 1). In principle, a hydrogen hub concept could offer progress on all these fronts: building a future economy while making the best use of existing infrastructure, resources, capabilities, and talent. The overall goal of the meetings was to explore the extent to which a hydrogen hub concept would be a worthy topic of further exploration in the Carolinas.

The meeting on October 28 consisted of a virtual, public-facing set of moderated panel discussions with the intent to determine regional aspirations for hydrogen, highlight the activities of other model hydrogen hubs currently underway, and explore ongoing and potential actions that could underpin a hydrogen economy in the Carolinas. The public panel discussion demonstrated that hydrogen is viewed as both a low-carbon pathway and an enabler of economic growth for the Carolinas. The discussion made clear that

the Carolinas have significant natural and human resources to support hydrogen market formation. There are multiple active clean hydrogen projects in the region, as well as a community of firms that are interested in supporting more coordinated hydrogen-based investments. A long-term commitment from policymakers and key stakeholders in the region is seen as a critical next step to coordinate current hydrogen activities and enable a regional hydrogen market.

The second day, October 29, consisted of a private virtual roundtable of key thought leaders from the Carolinas. Through a pair of facilitated discussions, participants shared their viewpoints on: regional interest in hydrogen and how this might translate into a hub model; key informational, economic, climate, policy, or other barriers and opportunities; and the collaborations required from local, regional, and federal actors across sectors such as industry, community advocacy, academia, and regulatory entities to further explore hydrogen market formation in the region. The private roundtable discussion resulted in ten major findings related to the opportunities and challenges of forming a hydrogen market in the Carolinas today, with emphasis on leveraging



the region's existing resources (e.g., solar and nuclear generation, natural gas pipelines and power plants, ports and transportation hubs), capabilities (e.g., academic and industrial research and development [R&D], manufacturing base, logistics and transportation), and interests. These findings also stressed the importance of stakeholder commitment to developing a hydrogen market in a just, locally appropriate, and cost-efficient manner.

Ernest Moniz, CEO of EFI and the 13th U.S. Secretary of Energy, hosted both convenings. Participants for both days included executive and senior level representatives from firms actively interested in hydrogen, decarbonization, and economic development in the Carolinas. These meetings also included organizations that will be critical stakeholders in a hydrogen market for the region.

Motivation & Context

The United States—along with most other countries—is grappling with how to meet the consensus requirement of net-zero emissions by midcentury. Currently, the United States has pledged to reduce emissions by about 50 percent by 2030 relative to 2005 levels and has set an aspiration to reach net-zero by 2050. Reaching these targets requires enormous investments in clean energy technologies and pathways for reducing emissions from the existing system.

At the same time, nations and regions committed to net-zero targets must address the inherent difficulties of such commitments. Energy systems are immensely complex and have evolved incrementally over many decades due to their size, costs, value, and market and regulatory structures.

This slow pace of change in part reflects a level of regulatory attention that underscores the essential services that energy systems provide—and must continue to provide—to all levels of society.

Box 1. U.S. Federal Activity in Supporting Hydrogen

The \$1.2 trillion bipartisan Infrastructure Investment and Jobs Act (IIJA) signed into law on November 15, 2021 will provide \$8 billion over five years for developing at least four hydrogen hubs, two of which must be located in natural gas-producing regions.¹ At least one hub would be required to demonstrate hydrogen production from fossil fuels, renewable energy, and nuclear power. At least one hub needs to demonstrate hydrogen use in the electric power, industrial, residential and commercial, and mobility sectors. The IIJA also dedicates \$1 billion to hydrogen demonstration projects on storage techniques, integration with power systems, and large electrolysis facilities.

R&D for hydrogen technologies included in the IIJA will support broad, economy wide application of clean hydrogen.² R&D focus areas include consumption from a variety of end uses (e.g., mobility, power, industrial, residential), production from several pathways (e.g., using fossil fuels with carbon capture and storage [CCS], using nuclear energy, using renewable energy), and various modes of transport (e.g., using an energy carrier like methanol, repurposing pipelines, blending hydrogen into natural gas pipelines). The IIJA will also direct the U.S. Department of Energy (DOE) to develop a national clean hydrogen strategy and roadmap.

Further, the president's policy agenda for climate and energy, the American Jobs Plan (AJP), also includes substantial support for hydrogen. Large components of the AJP not included in IIJA are expected to be in a more comprehensive bill for budget reconciliation legislation. The AJP called for a production tax credit for 15 clean hydrogen demonstration projects and \$15 billion for hydrogen and CCS R&D.³

The clean energy transition, while critical, threatens to strand both assets and jobs. There is increasing interest to reuse and repurpose existing infrastructure and skillsets that could connect real and intellectual assets in new ways, taking advantage of economies of scale and beneficial spillovers afforded to shared and co-located infrastructure. Historically, the energy system has benefited from fuel versatility, where the needs of multiple end uses and users could be met using common fuels and infrastructure. At the same time, regional differences in infrastructure, mitigation options, and economies must be accommodated. This has placed a renewed focus on the range of existing technology options and regional solutions to meet net-zero targets, both across the United States and around the world. Fundamental considerations include: the ease and speed at which these solutions can be widely deployed; the economic, community, and equity impacts of the clean energy transition; the need for large and accelerated investments in innovation, deployment, infrastructure, and supply chains; and new regulatory policies and market structures to appropriately support these needs, investments, and actions.

While hydrogen has gone through several waves of interest over the past 50 years, none has translated into ongoing investment and broader adoption in energy systems across the United States. However, the recent focus on economy wide decarbonization—coupled with the scale-up and accelerated growth of low-carbon technologies—has sparked a new wave of interest in the potential of hydrogen. As an energy carrier, hydrogen could produce long-term energy storage and encourage increasing uptake of renewables in power generation. Additionally, hydrogen—either in its elemental form or as part of a low-carbon fuel—could play a substantial role in decarbonizing transportation (e.g., heavy duty on-road, rail, marine, aviation), buildings, industrial heating, and harder-to-abate industrial sectors like cement, steel, and chemical production. In short, hydrogen may address many of the challenges for the rapid decarbonization of critical sectors in the U.S. economy.

Across Europe, Asia, and specific regions in the United States, existing and new companies along the value chain are simultaneously developing, evaluating, and deploying hydrogen production, transportation, and consumption technologies.



Provided the mix of industries, technologies, competitive positioning, and public policy, multiple solutions and business models are emerging. In the United States specifically, there are hubs such as California, the Pacific Northwest, and the Gulf Coast where location-specific arrays of hydrogen supply and demand are in their early days. These examples offer the prospect of cross-industry, regional decarbonization that is cost-efficient and economically advantageous.

A fully functioning market could begin with strategic regional investments to build out hydrogen infrastructure that connects to existing industrial assets. The Carolinas region may offer the potential for hydrogen market formation because of its capabilities, resources, and interests:

- High growth of low-cost renewable energy, coupled with the opportunity to transition away from higher emitting power generation sources
- High-capacity factor nuclear generation
- An abundance of biogenic feedstocks that could be responsibly gathered to produce low-carbon intensity hydrogen
- Internationally recognized manufacturing and logistics capabilities

- Multiple companies that are currently using hydrogen (e.g., pharmaceutical manufacturing, chemical production, electronic components), and/or potentially could utilize hydrogen (e.g., fulfillment/distribution centers, cement, steel, power)
- Inland ports with intermodal transportation capabilities, coupled with marine ports with access to international waters
- Technology-focused workers and research base with a history exploring hydrogen
- A growing coordination of interested commercial entities
- Motivated governments to support market formation through policy efforts

The Carolinas region has a history of excellence in hydrogen R&D, broad industrial capabilities, and an array of potentially amenable existing infrastructure to enable the formation of a hydrogen hub. A new market based on this industrial coordination could benefit the Carolinas through economic enhancement, job creation, regional partnerships, and bolstering the innovation ecosystem.



Public Panel & Private Roundtable Format: Ground Rules & Participants

The public panel consisted of three sessions: a fireside chat, a panel focusing on the hub concept with case studies from the United States and Europe, and a panel highlighting perspectives from industrial actors within the Carolinas.

The roundtable was organized and managed to maximize contributions from the participants on two issue areas: barriers, opportunities, and existing activities related to the development of a hydrogen hub in the Carolinas; and exploration of potential collaborative efforts to align interest and activities toward a hydrogen hub in the region. Each session was initiated with a brief table-setting presentation and followed by a facilitated open discussion. Participants contributed

substantively throughout the discussions, while attendees were set to listen-only status with the ability to submit questions via the online Q&A function.

The roundtable was conducted under the Chatham House Rule whereby no statements in this report are attributed to any person or organization.

OCTOBER 28 PUBLIC PANEL PARTICIPANTS

Swati Daji, Senior Vice President, Enterprise Strategy and Planning, Duke Energy

Neva Espinoza, Vice President of Energy Supply and Low Carbon Resources, Electric Power Research Institute (EPRI)

Lynn Good, CEO, Duke Energy

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Part 1. Public Discussion Key Takeaways

The objectives of the public discussions were to understand the existing interests, capabilities, and resources that could support a hydrogen market in the Carolinas. These discussions were led by regional thought leaders who described their vision for hydrogen across the region.

Organizations performing R&D of hydrogen shared their aspirations for hydrogen in the Carolinas. Representatives from hydrogen hubs currently underway elsewhere in the United States and internationally described their lessons learned and discussed how they may apply to the Carolinas. Additionally, potential actions that could underpin a hydrogen economy in the Carolinas were explored.

HYDROGEN IS VIEWED AS A LOW-CARBON PATHWAY AND AN ENABLER OF ECONOMIC GROWTH FOR THE CAROLINAS

Panelists throughout the sessions universally agreed there is promise for hydrogen to serve multiple goals within the Carolinas. Four of these goals featured prominently: 1) enable economywide decarbonization, especially for difficult-to-abate sectors such as heavy-duty transportation, industrial processes, military installations, and an electricity grid with increasing generation from intermittent renewables; 2) support new industry growth, especially in the domains of advanced manufacturing and logistics; 3) provide a pathway for a just transition, especially for those communities that rely on fossil

fuel-fired electricity generation facilities for jobs; and 4) build upon the current pool of talent and technological expertise across economic sectors.

Hydrogen could have direct and indirect material effects on economic sectors that constitute approximately 80 percent of both North and South Carolina's gross domestic product (GDP) (Figure 1). Given that renewables are expected to increase in the region over the coming years, hydrogen could be used to store energy produced from their intermittent oversupply and make clean electricity available across time scales. Industries such as chemicals, steel, and pulp and paper may use hydrogen directly as a component of decarbonized processes or as an emissions-free heat source. The Carolinas are home to an array of transportation manufacturing suppliers that could be configured to also make hydrogen fuel assemblies, mobile storage tanks, electronics, and thermal control systems. As hydrogen may become more prominent in transportation globally, there may be an increasing demand for such components. The Carolinas also contain a variety of existing coal and natural gas generation facilities, many of which have or will go offline soon because they have come to the end of their operational life, or they are no longer cost-

competitive with renewable generation. Hydrogen may offer a way to repurpose such facilities, allowing them to operate cost-effectively with a lower emissions profile and retain jobs within the communities that rely on such plants as economic

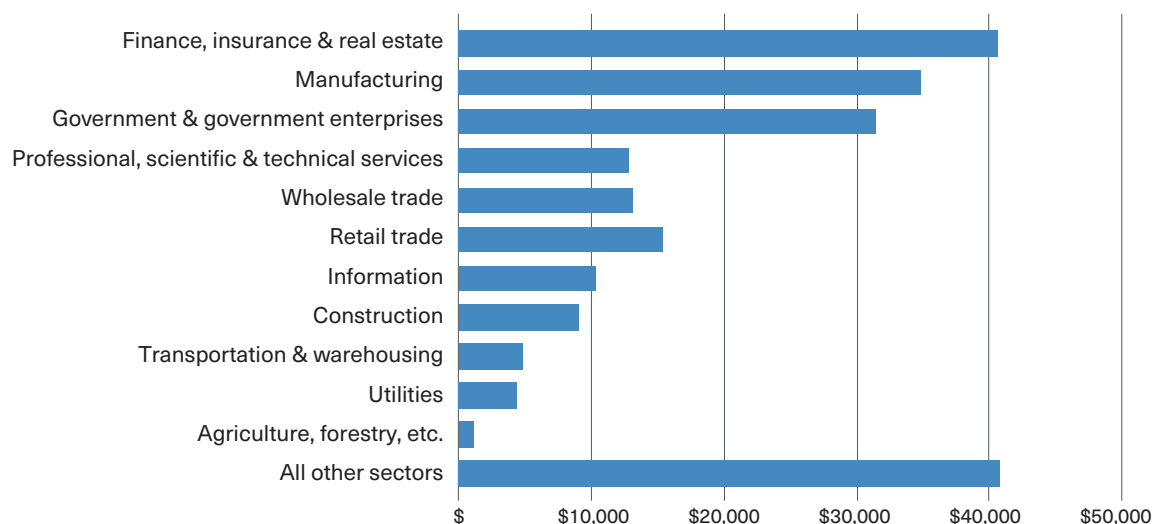
cornerstones. Finally, hydrogen is a familiar topic of R&D across an array of academic and industrial entities, providing a deep resource pool that could design, develop, and deploy the components of a hydrogen hub in the region.

Figure 1. North Carolina and South Carolina GDP by Industry⁴

2021: Q2 North Carolina GDP by industry (millions of chained 2012 dollars)



2021: Q2 South Carolina GDP by industry (millions of chained 2012 dollars)



Hydrogen could have a material direct and indirect effect on economic sectors in both North Carolina and South Carolina that in aggregate comprise of over 80 percent of each states' GDP. Source: U.S. Bureau of Economic Analysis (BEA), 2021.

Given that hydrogen can be produced, transported, and consumed in a variety of ways across multiple industries, there was a broad consensus that a multisectoral approach to align all the components of the value chain within an industrial hub has merit.

The Carolinas' extensive and diverse industrial base is generally seen as an opportunity to co-locate supply and demand and use existing infrastructure to link them. A multisectoral approach would also facilitate the exploration and deployment of solutions that could fulfill corporate decarbonization goals. At the same time, it was highlighted that a hub in the Carolinas is at the very earliest stages of conceptualization, with no shared vision on a regional basis.

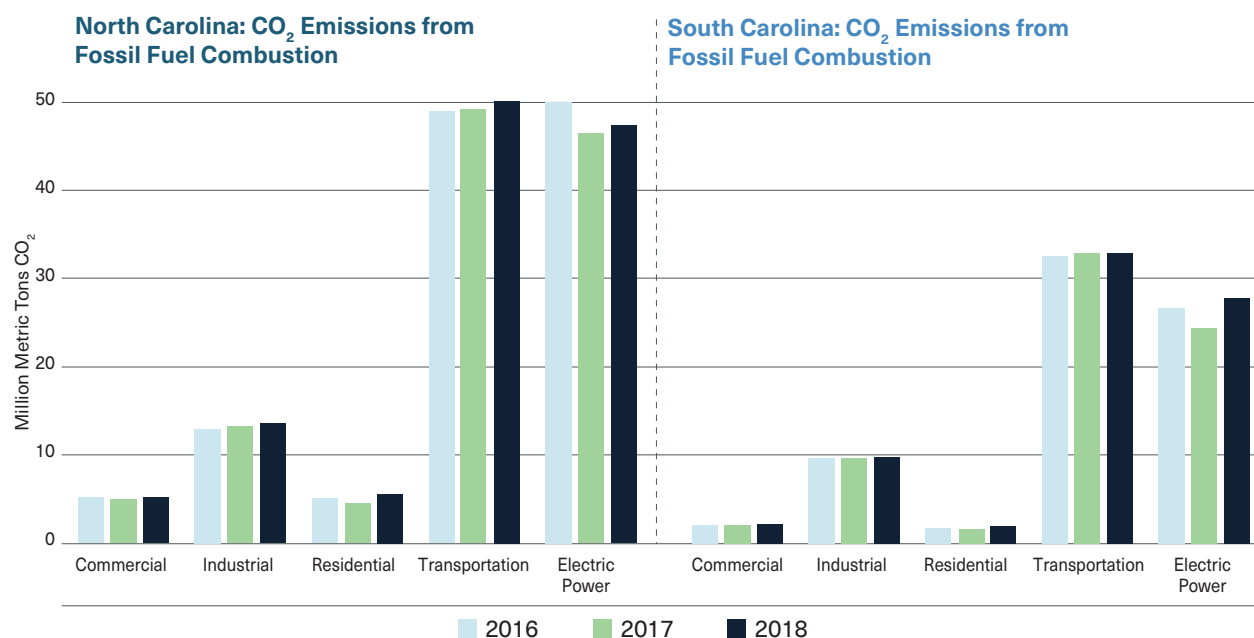
Hydrogen is seen as a pathway within a just transition for the region's energy sector, but more work is needed to substantiate this point of view. Hydrogen may be able to address concerns about a just transition away from fossil fuel generation facilities. Communities that rely on current fossil fuel generation are concerned that retiring such plants—especially premature plant retirements due to cost and emissions profile—could negatively impact relatively well-paying jobs in the region. It was cited that the White House has recognized that communities must be actively engaged throughout the clean energy transition.

This engagement will require promoting the dual concepts of environmental justice for those communities that have been disproportionately affected by energy projects, and for communities (some overlapping) that have become dependent on fossil fuels. Hydrogen may offer the prospect of keeping such facilities operational if costs can fall, while reducing (and perhaps ultimately eliminating) the emissions profile. Given the potential local air quality benefits and economic opportunities, hydrogen could offer a way to meaningfully engage with communities and address long-standing environmental justice issues. There was a general belief across the panelists that involving communities is important and there may be an outsized opportunity to repurpose workforces—potentially mirroring the repurposing of existing assets—but there was little substantiation of these beliefs. Given the region's relatively large nuclear fleet, there may also be an opportunity to keep those facilities operational through hydrogen production, bolstering the economic profile of a relatively inflexible, zero-carbon electricity source and helping to achieve regional climate goals. For example, Duke Energy has made commitments to reduce emissions at least 50 percent from its electricity generation business from 2005 levels by 2030 and become “net-zero” by 2050. Accordingly, there is “a clear line-of-sight” (Lynn Good, Duke Energy) on how

to achieve the 2030 target (retire coal, increase renewables, etc.). Beyond 2030, however, it is unknown how to achieve those targets. Blending of hydrogen in still operationally viable natural gas combined cycle (NGCC) plants may be a way. These activities related to electricity generation would help reduce carbon dioxide (CO₂) emissions from the electricity sector, which is the second largest source of emissions in both states (Figure 2).

Most emissions from fossil fuel combustion in the Carolinas originate from the transportation and electricity generation sectors. Hydrogen could play a role in reducing electricity-related CO₂ emissions through co-firing NGCCs with higher concentrations of hydrogen (i.e., to displace natural gas) and through storing energy produced by intermittent renewable generation such as solar and wind, potentially allowing such zero-emissions generation to be deployed across timescales.

Figure 2. North Carolina and South Carolina CO₂ Emissions from Fossil Fuel Combustion 2016-2018⁵



Emissions estimates are based on energy consumption data from the U.S. Energy Information Administration's (EIA) State Energy Consumption, Price, and Expenditure Estimates (SEDS) released Summer 2020. Source: U.S. EIA, 2020.

THE CAROLINAS REGION HAS SIGNIFICANT NATURAL AND HUMAN RESOURCES TO SUPPORT HYDROGEN MARKET FORMATION

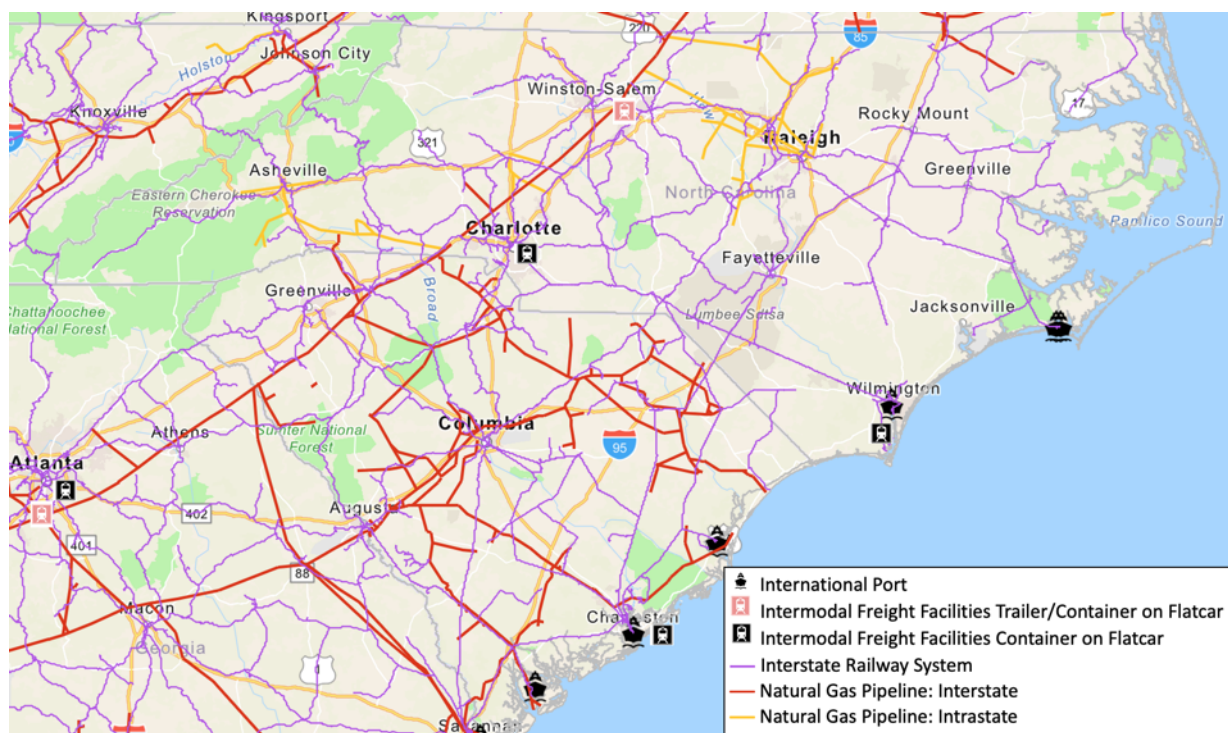
The Carolinas contain a wide array of existing infrastructure and knowledge assets for a hydrogen market (Figures 3 and 4). This region hosts large multimodal rail hubs that connect to the Norfolk Southern Railway, the largest consolidated rail system in the United States.

Between the two states, there are five international seaports linked to intermodal rail, inland shipway, and/or interstate highways. These large inland port systems connect manufacturing and distribution hubs in the interior of both states to the Port of Charleston, one of the busiest marine ports

in the United States.⁶ The Carolinas also have multiple inter-and-intrastate natural gas pipelines, strategically linking supply in the Gulf Coast to populations centers in the U.S. Northeast (Figure 3). The network of pipelines themselves may provide critical conduits for the bulk movement of hydrogen, especially in the formation of rights-of-way to expedite future construction of 100 percent hydrogen pipelines. Further, the zero-emissions electricity generation facilities within the

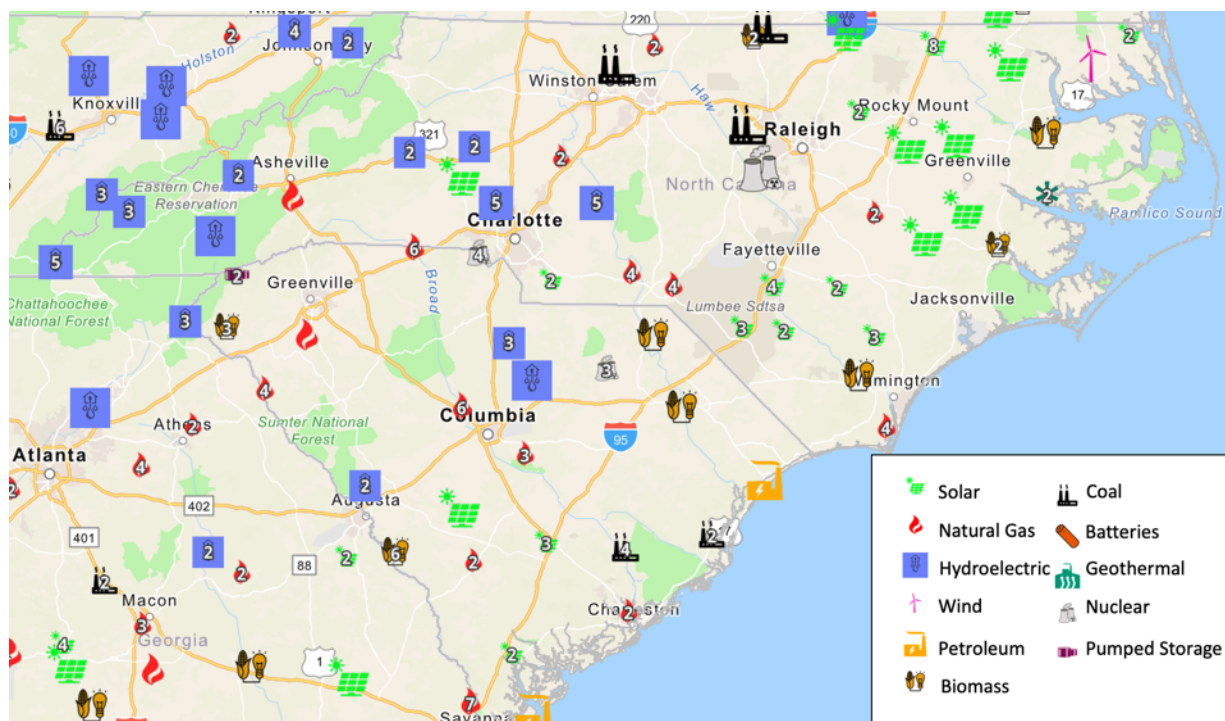
Carolinas are diverse, with a mix of hydroelectric in the west, solar toward the east, and multiple nuclear plants close to demand locations (Figure 4). Finally, North Carolina and South Carolina also contain essential human resources with existing interest in hydrogen, including acclaimed research universities, the Savannah River National Laboratory (SRNL), industrial research facilities, skills development programs, and collaborative partnerships across sectors (Box 2).

Figure 3: Existing Transportation Infrastructure in North Carolina, South Carolina, and the Adjacent Regions of Surrounding States



The Carolinas and immediate surroundings contain multiple existing transportation and logistics assets and infrastructure that may be repurposed, retrofitted, or complementary to supporting various configurations of a clean hydrogen hub. Map created in arcGIS using data layer services from: NOAA, USGS, EPA, Oak Ridge National Laboratory, Argonne National Laboratory, Decision and Infrastructure Sciences Division, National Geospatial-Intelligence Agency, Homeland Security Infrastructure Program Team, Bureau of Transportation Statistics, GeoSystems Global Corporation in association with National Geographic Maps and Melcher Media, Inc.

Figure 4: Existing Electricity Generation Facilities in North Carolina, South Carolina, and the Adjacent Regions of Surrounding States



North Carolina and South Carolina contain a mix of zero-emissions generation facilities that could be used to produce hydrogen, in addition to natural gas power plants that could use increasing concentrations of hydrogen as part of an effort to decarbonize the existing fleet. Electricity generation facilities that are 20 megawatts (MW) or larger have been geographically clustered based on their locations. Map created in arcGIS using data layer services from: NOAA, USGS, EPA, Oak Ridge National Laboratory, Argonne National Laboratory, Decision and Infrastructure Sciences Division, National Geospatial-Intelligence Agency, Homeland Security Infrastructure Program Team, Bureau of Transportation Statistics, GeoSystems Global Corporation in association with National Geographic Maps and Melcher Media, Inc.

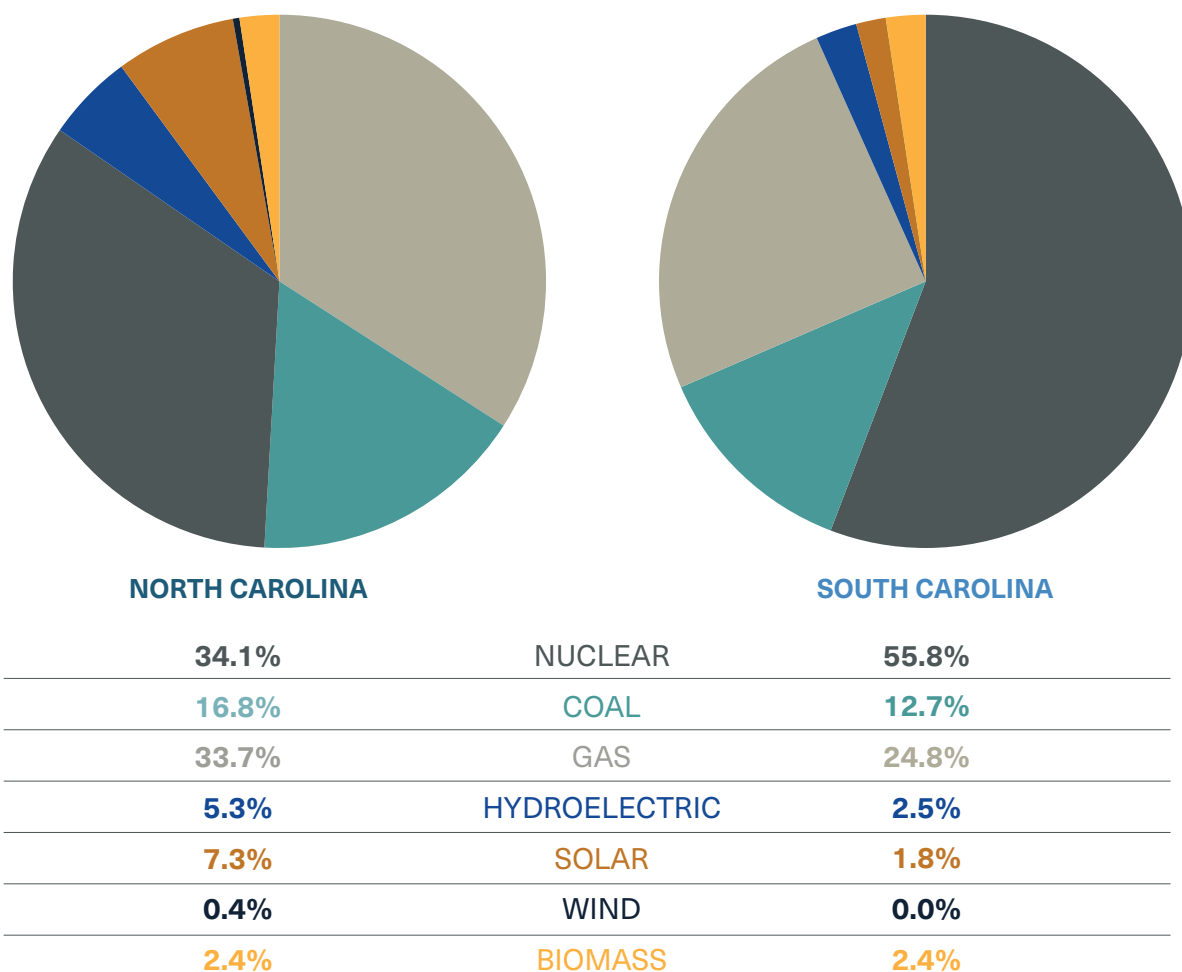
The region is home to a diversity of assets to potentially support multiple hydrogen production pathways. The Carolinas boast “a broad array of potentially amenable existing infrastructure” (Ernest Moniz, EFI) such as electricity production methods (e.g., natural gas, coal, nuclear, solar), a strong multimodal logistics and infrastructure network (e.g., airports, seaports, inland ports, electricity transmission lines, gas pipelines with rights-of-way) and a

density of “advanced technology manufacturing facilities” (Scott McWhorter, SHEA). Many of these could be repurposed to accommodate hydrogen production. Foremost, clean electricity—mainly provided by solar energy (fourth largest installed capacity in the United States)—was expressed as the “backbone” of clean hydrogen supply alongside a large nuclear fleet that provides over 50 percent of the region’s electricity generation (Figure 5). With respect to clean hydrogen

production via electrolysis, electricity is the largest cost component and these types of generation technologies are seen as complementary assets that “will lead hydrogen to commercialization” (Swati Daji, Duke Energy). Additionally, the Carolinas have “untapped potential in offshore wind” and energy infrastructure that is “begging to be invested in” (Roger Martella, GE), ultimately bringing more carbon-free electricity to the

Carolinas. As a portfolio, solar, wind and nuclear could provide an abundant portfolio of emissions-free, high-capacity factor electricity to reduce hydrogen production costs. At the same time, hydrogen can serve as a way to store renewable electricity generation to make it available “across time horizons” (Swati Daji, Duke Energy) when it is needed most.

Figure 5: North Carolina and South Carolina percent net electricity generated 2020, respectively^{7,8}



Nuclear generation is the dominant electricity generation method employed in the Carolinas, which could serve as the means for emissions free hydrogen production. Source: U.S. EIA, 2020.

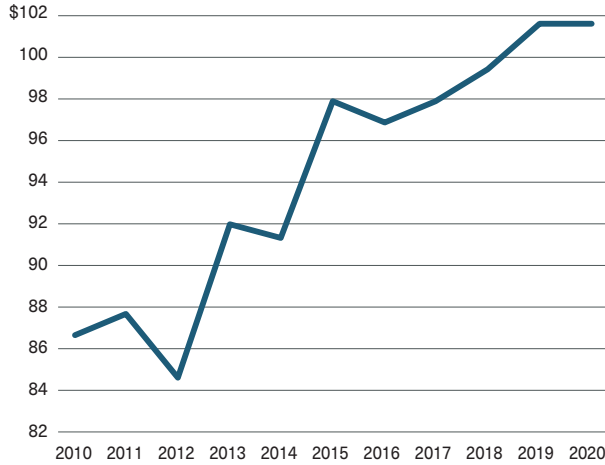


The region's economy may be well aligned to transition to hydrogen end uses. In terms of hydrogen transportation, the Carolinas already contain potential transmission and distribution modes through existing natural gas pipelines, which could carry 10 percent to 20 percent hydrogen by volume with effectively no upgrades or retrofits. The region's interstate highways and well-maintained industrial roads may also be fit for on-road transport of hydrogen. From an end-use perspective, the wealth of advanced technology manufacturing—especially in aerospace, motor vehicles, other transportation equipment, and

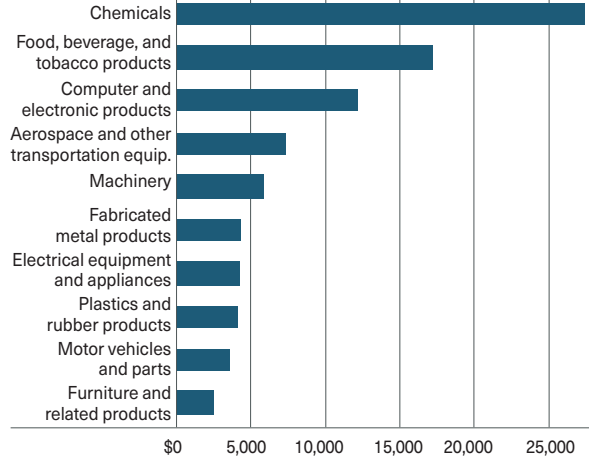
specialized equipment providers to chemical, industrial, and agricultural industries—strongly suggests that the development of hydrogen-consuming technologies could be applied in existing manufacturing facilities (Figure 6). Repurposing is a common strategy for hydrogen hubs in other jurisdictions. For example, the European hydrogen backbone strategy outlines a vision for pipeline infrastructure projects across the continent to be progressively built out toward a 2050 goal, consisting of 70 percent repurposed gas pipelines and the remainder comprised of greenfield projects.

Figure 6. Manufacturing Statistics for North Carolina and South Carolina^{9,10}

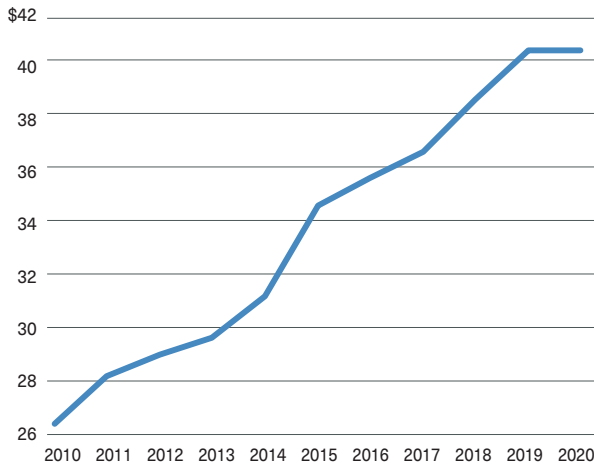
North Carolina Manufacturing Output, in Billions of Dollars, 2010-2020



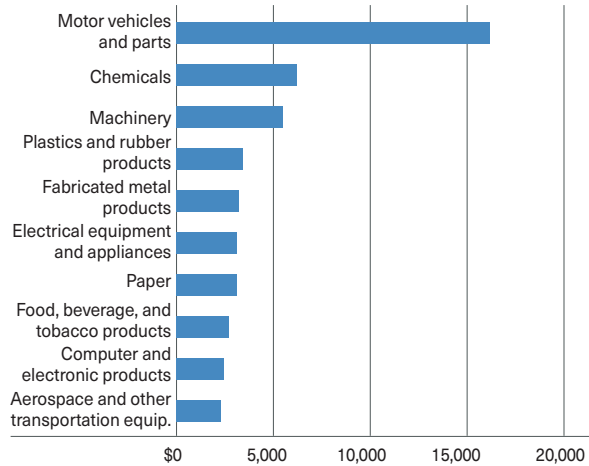
Top 10 North Carolina Manufacturing Sectors, in Millions of Dollars, 2019



South Carolina Manufacturing Output, in Billions of Dollars, 2010-2020



Top 10 South Carolina Manufacturing Sectors, in Millions of Dollars, 2019



North Carolina and South Carolina boast diverse, technically advanced, and growing manufacturing capabilities that could contribute to the production and end use of hydrogen. Especially in the areas of motor vehicles and parts, aerospace, machinery, and chemicals, the region has the base skillset and assets necessary to expand and support a hydrogen hub in the region and abroad. Source: National Association of Manufacturers (NAM), 2021.

Box 2. Carolinas Knowledge Base

Both North and South Carolina contain multiple tier 1 research universities, industrial research facilities, and infrastructure for technical training and skill building. In terms of hydrogen-specific expertise, the Savannah River National Laboratory (SRNL) has a long history in hydrogen R&D and has attracted the largest collection of hydrogen experts in the country. The lab hosts the Hydrogen Storage Engineering Center of Excellence and its expertise ranges from molecular and process modeling to the development of new materials and storage techniques. SRNL is also applying its hydrogen gas handling knowledge to a variety of advanced production and application projects through the U.S. Department of Energy's (DOE) Fuel Cell Technology Office. Additional hydrogen-relevant projects include the University of South Carolina Hydrogen and Fuel Cell Center,¹¹ the Clemson University International Center for Automotive Research,¹² the University of North Carolina Charlotte's Hydrogen Fuel Cell Laboratory,¹³ the Energy Production and Infrastructure Center,¹⁴ and North Carolina State University's Clean Energy Center.¹⁵

Beyond research laboratories, the Carolinas are home to several industrial research facilities and the infrastructure for skills development that could directly support hydrogen technology deployment. These industrial research facilities and programs include the North Carolina Center for Automotive Research,¹⁶ the North Carolina Global Transpark,¹⁷ and the South Carolina Research Authority's facilities and programs.¹⁸ There are also existing programs that have successfully contributed to workforce development in the region at the South Carolina Manufacturing Extension Partnership,¹⁹ the South Carolina Technical College System,²⁰ and North Carolina Agricultural and Technical State University.²¹

Hydrogen industry coordination is also prevalent in the Carolinas. The Southeast Hydrogen Energy Alliance (SHEA)—a nonprofit collaborative partnership of government, business, academia, and citizens—is working to advance the commercialization of hydrogen and fuel cell technologies while also enabling regional and national energy security that minimizes environmental footprint.²² The H2-Orange project in Greenville, South Carolina is co-sponsored by Siemens Energy, Duke Energy, Clemson University, and DOE. The project plans to use hydrogen for energy storage and to produce energy for Duke Energy's combined heat and power plant at Clemson University, exemplifying the region's current cross-industry coordination to advance hydrogen knowledge.²³



THERE ARE ACTIVE PLAYERS IN THE CAROLINAS DEVELOPING AND TESTING HYDROGEN SOLUTIONS

The region maintains strong hydrogen expertise at its universities, laboratories, and other research institutions. Regarding the subject of hydrogen, research institutions based in the Carolinas feature prominently as measured by journal paper authorship. In addition to the long history of hydrogen exploration through SRNL (Box 3), “North Carolina State University, University of North Carolina - Chapel Hill, Duke University, University of South Carolina, and Clemson University are all top publishers on various dimensions” (Vahid Majidi, SRNL) of the subject. Complementary to this academic research experience is the ongoing commercially focused R&D of organizations such as EPRI, the Gas Technology Institute (GTI), and their joint work through the Low-Carbon Resources Initiative. While experience is growing in the domain of

hydrogen demonstration projects by interested parties (including those that are members of SHEA), most of the work remains technical and focused on increasing technology maturity. Given the diversity of interest, the Carolinas can act as a “testbed” (Roger Martella, General Electric) for new technology solutions. Moreover, interested parties from international firms may increasingly rely on the region’s expertise to support a diversity of hydrogen applications. One example is the manufacturing experience being developed by local tier 1 and 2 firms that act as suppliers to companies such as BMW, Toyota and Siemens Energy. “All OEMs rely on others for expertise” (Brian Storey, Toyota) and the Carolinas could have an advantage compared to other regions given its concentration of automotive manufacturing. In short, there seems to be an “ecosystem” (Swati Daji, Duke Energy) of motivated and capable collaborators to move forward the hydrogen hub concept in the Carolinas.

Box 3. A History of Hydrogen Expertise at the Savannah River National Laboratory

SRNL, located near Jackson, South Carolina, has been developing and deploying hydrogen technology for over 50 years. Established in 1951, the lab gained experience with hydrogen early on through its role at the U.S. Department of Energy's (DOE) Savannah River Site researching tritium, a radioactive hydrogen isotope used in nuclear materials for national defense.²⁴ Today, SRNL's hydrogen operation has expanded to focus on the development of safe, cost-effective hydrogen handling methods that promote long-term energy security and a cleaner environment.²⁵

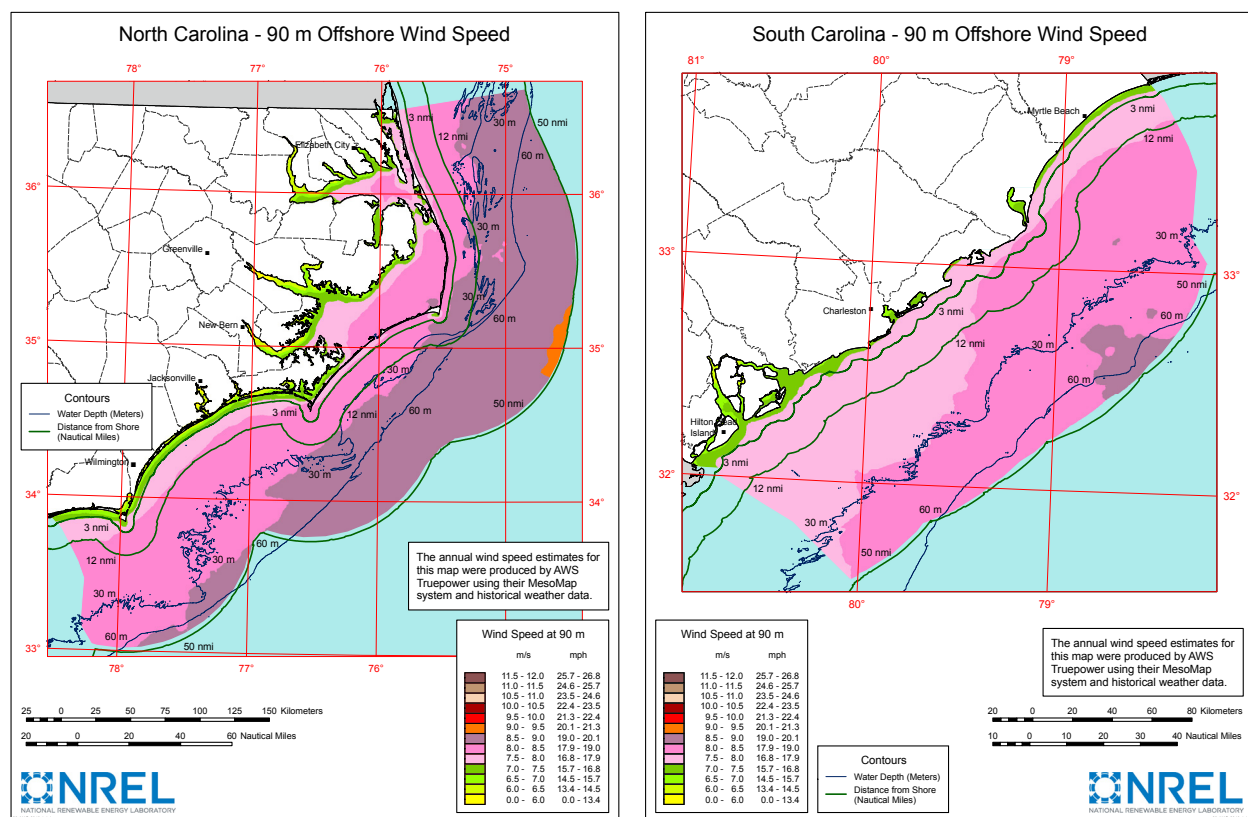
Currently, SRNL employs over 80 scientists and engineers focused on its hydrogen and tritium missions, making the lab the largest collection of hydrogen experts in the country. Their work is geared toward three challenges regarding hydrogen market formation: clean hydrogen production; lightweight, cost-effective hydrogen storage; and hydrogen separation technologies.²⁶ In the area of hydrogen production, SRNL is exploring the technical and economic feasibility of advanced nuclear reactors and solar furnaces, production from algae when exposed to sunlight, and production from water using thermochemical cycles such as advanced nuclear reactors.²⁷ The lab is also a leader in hydrogen storage research, particularly using solid-state metal hydrides. SRNL's patented metal hydride hydrogen storage is safe, compact, efficient, and has already been used in public transit and industrial fuel cell vehicle demonstrations.²⁸

These hydrogen R&D activities are based out of SRNL's Center for Hydrogen Research. Additionally, SRNL leads DOE's Hydrogen Storage Engineering Center of Excellence, bringing together partners from universities, industrial corporations, and other federal laboratories to develop effective and efficient hydrogen storage systems for fuel cell light-duty vehicles.²⁹ The Hydrogen Technology Research Laboratory (HTRL)—which SRNL runs at the Savannah River Site—conducts additional hydrogen R&D activities to support the National Nuclear Security Administration and other national labs involved in tritium projects. HTRL is also part of Aiken County's Applied Research Center, which seeks to facilitate technology transfer between researchers and industry and help improve the region's ability to attract and retain hydrogen-related industries.³⁰

The Carolinas region is home to projects exploring the expanded use of hydrogen, particularly in the areas of emissions-free hydrogen production, storage, and end uses in electricity generation and heavy-duty transportation. Duke Energy, as part of a strategic exercise, has examined the potential of using nuclear-generated electricity to power electrolyzers and produce zero-carbon hydrogen. General Electric has been advocating for further development of offshore wind along the entire Atlantic seaboard. Analysis from the National Renewable Energy Laboratory (NREL) supports the potential for offshore wind in the Carolinas, showing that significant portions of both states'

coastlines receive the average wind speeds required for offshore wind energy production (Figure 7). With respect to hydrogen storage, non-geologic storage remains an area of active research and a vector to reduce system costs. SRNL is actively examining multiple forms of storage, such as pressurized containers and solid-state storage, to meet the wide needs of various applications. Duke Energy and Siemens Energy are industrial partners to the H2-Orange project which is examining the effects of blending hydrogen with natural gas in existing turbine applications. Finally, Toyota and BMW have joint activities focused on fuel cell development in sports cars and heavy-duty trucking.

Figure 7. Offshore Wind Potential for North Carolina and South Carolina^{31,32}



Areas with annual average wind speeds of 7 meters per second (m/s) and greater at 90m height are generally considered to be suitable for offshore wind energy development. Source: NREL, 2011.

COORDINATING HYDROGEN ACTIVITIES IS SEEN AS CRITICAL TO SCALING THE MARKET

More investment is needed to align hydrogen activities and drive down costs. There exists a substantial cost premium in new hydrogen-enabled end uses such as steel production, energy storage, and heavy-duty transportation. At the same time, methods to produce hydrogen at low-to-zero emissions—such as water electrolysis—are relatively limited in volumes and not cost-competitive with incumbent methods (e.g., steam methane reforming). To a substantial extent, these costs reflect a general immaturity in a variety of components that would promote hydrogen in new end-use applications and produce it emissions free. It was widely acknowledged that the recently announced Hydrogen EarthShot, with its ambition of achieving zero-emissions hydrogen at a production cost of \$1/kilogram (kg) by 2030, provides a strong signal in the right direction. However, it was also acknowledged that this goal is only one component of enabling hydrogen at scale, as the transportation and end-use questions will require a “big effort” in the words of Secretary Moniz. This sentiment was reflected in an idea expressed by Cosma Panzacchi (Snam) that there is a “crucial element” in aligning potential end users to adopt hydrogen through adaptive technologies and incorporate it in their processes (e.g., ceramics, glass, tire makers, steel makers) to make the process as efficient as possible without changing the end product.

Experiences from hydrogen hub development activities in other regions can inform the Carolinas. The hydrogen hub concept is currently being explored in multiple regions of the world, with some activities already having multiple years

of effort behind them (Box 4). Examples include the HyNet North West industrial cluster (United Kingdom), the Port of Rotterdam European hub (Netherlands), HyDeal Los Angeles (United States), and the development of multiple projects by Snam SpA and partners (Italy). A common thread across these hubs is the multiparty, concurrent assessment of technology, economics, and policy to drive toward concept specificity while also identifying and addressing emerging cost, risk, and regulatory challenges. It was acknowledged that no two clusters will be the same, owing to the various mixes of existing assets, capabilities, scale, and goals. As mentioned by Cosma Panzacchi (Snam), “...different clusters can have different types of hydrogen as the right choice for the energy transition.” However, across these examples there are best practices that can be applied to any hydrogen hub initiative, such as forming a multisectoral coalition, meaningfully including proximate community input early and often, dedicating time and resources to deeply understand the regulatory environment, combining “bottom-up” industry ambition and “top-down” policy direction, and sharing risk across stakeholders. The Carolinas are well positioned to learn from other jurisdictions and benefit from a “second-mover” position.

Multisectoral coalitions are viewed as key to gaining clarity on the prospects of a hydrogen hub in the Carolinas. The discussions emphasized the importance of coordinated and intentional collaborations to iteratively identify opportunities, reduce associated risks, and develop a plan for a hub with increasing specificity. As stated by Neva Espinosa (EPRI): “A successful energy transition requires extensive cross-sector collaboration to harness innovation, prioritize

investments, and advance new capabilities.”

The Carolinas have a history of working across sectors (e.g., logistics, manufacturing, aviation, pharmaceuticals) and combining efforts from its academic and government research institutions (e.g., SRNL) with operational expertise that resides in industry. A multisectoral coalition would include foundational technology and solution providers, but also those actors that have direct—though further removed—influence on the shape of a hydrogen economy in the region, namely finance, policymakers, regulators, and concerned communities. Such partners could self-organize and exchange knowledge and capabilities to jointly form a shared vision of a hydrogen hub. Organizing this way would be “pre-RFP, pre-competition” (Janice Lin, GHC) and would then set the contours for more focused innovation and competition to drive costs and quality. Drawing on hubs from around the world, such activities would identify a bankable offtaker while also identifying various regulatory and technology hurdles and pathways to overcome such hurdles.

Developing a vision for a regional hydrogen hub is seen as an important building block.

Aside from the general need for a cross-sectoral coalition to adequately explore a hub opportunity, one question that was raised was how to organize such a collaboration. In essence, such a coalition would be built “bottom-up,” starting with anchor players that span the ecosystem. Put simply, “you have to bring everyone forward together” (Janice Lin, GHC). The anchor (or sets of anchors) would provide an offtake which is “bankable”—a credible demand signal for hydrogen that could then induce interest upstream along the supply chain. This idea is predicated on the notion that with a

material willingness to pay that can overcome the first cost “green premium,” suppliers will organize to fulfill that demand. In Los Angeles, for example, this entity is the municipal utility which has a commitment of 100 percent clean energy by 2035.

In the case of the Port of Rotterdam, it worked with existing clients to verify “that clean hydrogen would indeed be the best way to decarbonize their operations” (Randolf Weterings, Port of Rotterdam). On the back of this demand, the port has been able to develop a long-term vision that starts with existing infrastructure that will connect facilities already using hydrogen to new forms of production, thereby increasing the proportion of clean hydrogen to existing demand in a phased approach. As more production comes online, the marginal cost per unit of hydrogen will decrease and attract new kinds of demand, such as heavy-duty trucking.

For HyNet North West, this project was founded by a self-organized group of geographically co-located industrial companies that are each facing similar decarbonization goals and ambitions to move away from methane. These companies are joined with consumers, innovators, and distribution operators who all want to “champion the opportunities around hydrogen in the northwest of England.” With a unified voice, this core group of actors has shown government that there is real demand which then lowers the barrier for public support and increases the coalition’s “social license to operate” (Joe Howe, University of Chester). One additional suggestion for how to organize such a coalition, drawing upon the experience of the HyDeal Europe project, is to collectively



identify areas of risk and concern which would then serve as the foundation to create working groups across the organization and resolve those unknowns regarding regulation, technology, cost-competitiveness, and scale, among others. Another example of how to encourage coalition building is forming agreements to share “any IP from first implementation of technologies” (Cosma Panzacchi, Snam).

LONG-TERM POLICY SUPPORT IS SEEN AS A CRITICAL ENABLER FOR HYDROGEN MARKET GROWTH

Many participants viewed clear support for hydrogen from policymakers as an important next step to market formation. Coupled to prospective actions taken by industrial, research, community-based, and academic organizations was the panelists’ call to action for policymakers to clearly signal long-term support for hydrogen. Such signaling fell into two buckets: economic support mechanisms and infrastructure

regulation clarification. Given the lacking cost-competitiveness of hydrogen in new applications alongside the financial risk to build supply and demand simultaneously, there was a clear call for incentives and cost defrayment, especially for the heavily regulated energy sector. There was excitement regarding the Infrastructure Investment and Jobs Act (IIJA), which has set aside \$8 billion to support hydrogen hubs across the country. The clean hydrogen production tax credit (PTC) was also mentioned as a welcomed incentive, though noted that it is proposed in the 2021 Build Back Better Act and will be subject to more negotiation. There was no real mention of any state-level economic incentives.

With respect to infrastructure regulation, aside from the general desire for expedited permitting, the issue of interstate hydrogen transport fuel via pipelines remains unresolved.

This is the case for both pure and blended hydrogen. The Gas Act, which regulates the interstate movement and commerce of natural gas, was mentioned as the appropriate legislation in which guidance on hydrogen should be contained. However, there remains “enough ambiguity that will inhibit investment” (Janice Lin, GHC). Given that this is already an issue in other parts of the United States, prospective hubs from all over the country should push for a resolution. It was emphasized across the panels that, given the long lead times required to craft and implement regulatory changes, urgency should be placed on seeking resolution if there is a desire for hydrogen to move forward at scale. The HyNet North West industrial cluster offers a glimpse of how a leading coalition can work with regulators to develop and share knowledge in order to reach an amenable

resolution expeditiously. Specifically, a working group within the cluster works closely with the UK Health and Safety executive to inform blended and pure pipeline transportation standards for hydrogen. This is important because end users may require different hydrogen quality (i.e., purity level) depending on the application, for example heat versus input feedstock to a chemical process.

In the Carolinas context, a hub coalition could contribute meaningfully to the “back half” of the Hydrogen Earthshot by lowering delivered cost (as opposed to production cost) and be well positioned to contend for infrastructure funds.

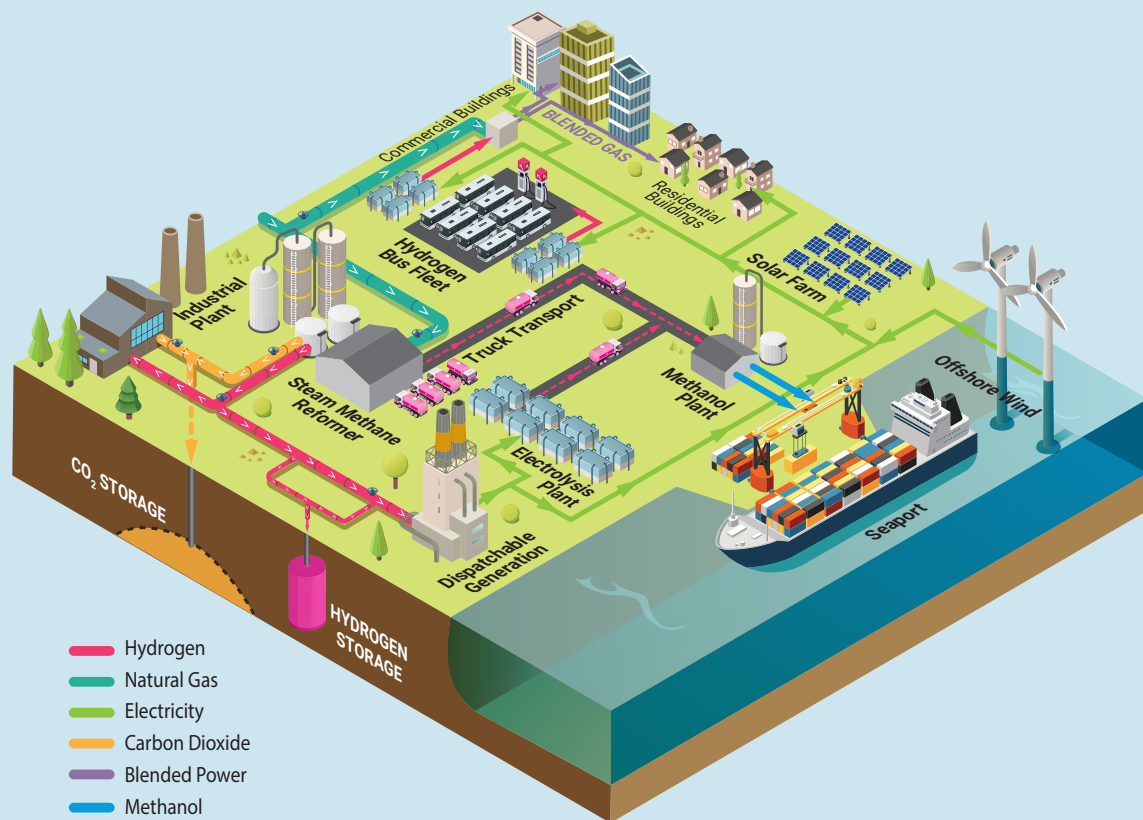
Box 4. The Hydrogen Hub Concept

The value of industrial hubs lies first and foremost in their contribution as incubators of technological capability and innovation.³³ Low-carbon industrial hubs can address several political and economic concerns simultaneously such as providing a focus for jobs growth through public-private partnerships and infrastructure development. Industrial hubs can encourage support for core infrastructure that is modern, efficient, and low-carbon. The formation of industrial hubs can also facilitate the integration of multiple technologies across multiple sectors (e.g., power, manufacturing, transportation, shipping) which may help provide broad political support, reduce overall cost and cross-chain risk, and take advantage of local skilled labor pools for planning, operations, and safety.³⁴

The potential for hydrogen to play multiple roles in decarbonization across the economy, as well as the challenges often associated with transporting hydrogen long distances, present opportunities for localized shared infrastructure and hydrogen hub development. Regional opportunities for clean hydrogen can incorporate multiple pathways for production, transport, storage, and end use. As shown in Figure 8, a hydrogen economy can include centralized production using electrolysis powered by renewable and/or nuclear energy, a dedicated pipeline and/or transport and storage infrastructure, and decentralized production that generates hydrogen near the end use. Both centralized and decentralized production can benefit from broader market formation activity. For example, end users of hydrogen that rely on truck transport can receive hydrogen from both large, centralized producers, and smaller, decentralized producers. Multiple transport methods enable producers to follow market trends and seasonal variation, preferencing dispatchable generation in periods of low renewable output or mobility during peak seasons of travel. Production facilities in a hydrogen hub can

benefit from shared infrastructure. Large customers, for example, can share dedicated pipelines that flow from a nearby production facility. Large hydrogen producers using renewable natural gas in an autothermal reformer with carbon capture can also share CO₂ transport and storage infrastructure with nearby emitters. For producers and consumers relying on truck-based transport, sharing roadways and decompression infrastructure can also lower operating costs.

Figure 8. Hydrogen Economy Integration Across Multiple Sectors and Production Pathways



A regional hydrogen hub can provide pathways to decarbonize multiple sectors and use multiple production and transport pathways. In this example, hydrogen is produced by electrolysis and autothermal reformer that uses carbon capture and several electrolysis facilities. Hydrogen is transported by both pipe and truck and used in the industrial, electric power, mobility, buildings, and shipping sectors. Electrolysis facilities use power from the bulk power supply as well as dedicated renewable resources. [Reproduced from Energy Futures Initiative. "The Future of Clean Hydrogen in the United States: Views from Industry, Market Innovators, and Investors." September 2021.]



EXAMPLES OF HYDROGEN HUBS FROM OTHER LOCATIONS

Representatives from four hydrogen hubs in other geographies described the purpose and industrial arrangement for each initiative. The Port of Rotterdam (Netherlands), the HyNet North West industrial cluster (United Kingdom), the HyDeal Los Angeles hydrogen platform (United States), and the hub activities of Snam SpA (Italy) each have different mixes of existing assets, collaborations, source of supply and demand, timelines, and scale. Collectively, they can provide useful case studies for the Carolinas as the region considers its hydrogen hub design. A high-level case description of each of the hubs represented at the public workshop are provided below.

Port of Rotterdam

The Port of Rotterdam, located in eastern Netherlands, is the largest European seaport and the largest port outside of East Asia. The port contains multiple cargo ship berths, petrochemical facilities, railway hubs, and oil refineries. Multiple existing hydrogen users (currently provided through traditional fossil fuel production pathways that emit about $10 \text{ kgCO}_2 / 1 \text{ kgH}_2$ produced), logistics, and shipping lines at the port are already

connected via chemical and hydrogen pipeline infrastructure, making the region an ideal setting for a clean hydrogen hub.

The vision for a hydrogen hub began with a collaborative research effort between the port, co-located industrial firms, and countries located in northwest Europe, particularly Germany. As a result of this exercise, these stakeholders set the goal of distributing 20 megatons per year (Mt/yr) of clean hydrogen through the port by 2050 which would reduce CO_2 emissions in Northwest Europe by $200 \text{ MtCO}_2/\text{yr}$. Of the total quantity of hydrogen, 10 percent would be produced locally via offshore wind and electrolysis, with the remainder being imported given the strength of logistics at the port.

To realize this vision, the first step is to decarbonize current supply through carbon capture and storage (CCS) attached to the existing steam methane reforming facilities by 2030, taking advantage of the technology and the amenable proximate geology (i.e., offshore saline aquifers). Concurrent developments include the buildout of at-scale electrolyzers to be powered by offshore wind and the expansion of the port's ability to import hydrogen by ship.

HyNet North West

The HyNet North West industrial cluster is located in the northwest of the United Kingdom (encompassing northwestern England and northern Wales), connecting facilities in Manchester, Liverpool, Chester, and Wrexham. Multiple existing hydrogen users, power plants, and renewable energy projects will be connected via hydrogen and CO₂ pipelines to enable a clean hydrogen hub based on CCS. The goal is to significantly decarbonize the region by replacing the direct use of natural gas with hydrogen in industrial processes, expanding firm renewable energy, and providing hydrogen fuel to the transportation sector. The project will take advantage of amenable offshore geology to sequester the captured CO₂ (i.e., saline aquifers) and provide a low-cost option for hydrogen storage (i.e., salt formations). The project has an interim goal of producing 3.5 to 4 gigawatts (GW) of hydrogen (about 600 kt H₂/yr) in the 2028 to 2029 timeframe.

HyDeal Los Angeles

HyDeal Los Angeles is an initiative that has a goal of delivering clean hydrogen to the Los Angeles basin by 2030 with a price between \$1.50 to \$2/kg. The project would eventually span three states—California, Nevada, and Utah—with hydrogen production via electrolysis powered by renewable energy in Utah, geologic storage located in Utah and Nevada, and pipeline transportation into California's demand center via new and existing hydrogen pipelines. The project will begin with hydrogen production in the Los Angeles basin via electrolysis and above ground storage. In the

mid-term (2025 to 2030), hydrogen will be injected into existing natural gas pipeline infrastructure for delivery. Looking longer-term (2030 to 2035), the \$1.50/kg target is achievable via dedicated hydrogen pipelines and underground storage in natural formations. The project calls for 26 GW of solar capacity, 20 GW of electrolysis capacity and 2,000 kilometers (km) of greenfield hydrogen pipelines. The total cost of the project is \$27 billion, which is 25 percent of what is projected to be spent on decarbonization efforts by Southern California's utilities. This investment will largely come from private investment (as opposed to utility investment that is largely ratepayer supported).

Snam SpA

Snam, one of the largest energy infrastructure developers and operators in the world, has designed five “hydrogen valleys” within Italy to help decarbonize strategic sectors such as steel, ceramics, glass, and heavy transport. The industrial clusters (valleys) range in size from 38 ktH₂/yr within the Puglia Valley in southeastern Italy to 245 ktH₂/yr within the Emilia Valley in the highly industrialized corridor of central northern Italy. The hubs will have differentiated end users and methods for hydrogen production (e.g., electrolysis or steam methane reforming with CCS). Development of these hubs will rely on strong links to advanced skillsets—such as those available through universities—to help with “adaptive” technologies, which are those needed to integrate hydrogen into an existing process for the purpose of decarbonization.

Part 2. Private Roundtable Key Findings

The private roundtable was designed to build on the public discussion to understand the near-term needs for hydrogen market formation. The discussion was framed around specific questions, articulated below, and aimed to better understand: 1) the level of interest in hydrogen regionally and how this might translate into a hub model; 2) key informational, economic, climate, policy, or other kinds of barriers and opportunities; and 3) the kinds of collaborations required from local, regional, and federal actors across sectors including industry, community advocacy, academia, and regulatory entities to further explore hydrogen market formation in the region.

The following questions were posited to roundtable participants during each session to guide discussion and solicit feedback on the prospects for a clean hydrogen hub in the Carolinas.

What could a Carolinas hydrogen hub look like?

1. To what extent can a Carolinas hydrogen hub help address a “just transition” for communities facing fossil-fueled plant closures?
2. Starting from a current low-hydrogen production state, how do we start building a hydrogen hub?
3. Low cost of energy is the culture in the Southeast, including North Carolina and South Carolina. How will the Carolinas be a hydrogen production demonstrator in a low-cost economy?
4. To what extent are the Carolinas’ investor-owned utilities the bankable offtaker? Or is it another industry?

What are the next steps for hydrogen market formation in the Carolinas?

1. To what extent is there a convergence on the hydrogen hub opportunities in the Carolinas?
2. Who are the stakeholders in a hub and what may be the impact on them (including communities and supply chains)?
3. What questions remain and how are these resolved through actionable next steps?

DEFINING DEMAND IS VIEWED AS A STARTING POINT FOR A CAROLINAS HYDROGEN HUB

Identifying “bankable” offtakers for hydrogen in the Carolinas is a priority for market development. Substantial time was devoted to “where to start” on the premise that cost and scale are coupled; scale would drive down cost, but costs are high so generating scale is relatively risky. As noted previously, both supply and demand in the Carolinas do not exist at scale, so the group initially struggled to identify a clear starting point. The conversation eventually focused on demand, largely through the observation of what has occurred in Europe. This first mover demand must be a bankable, creditworthy offtaker that has a clear case for hydrogen to address a strategic and/or regulatory requirement. Given a clear demand signal, it was posited—and most people generally agreed—that the supply would eventually appear.

There is the prospect of clustering demand from a “club” of bankable offtakers within the Carolinas with a few immediate suggestions being—in addition to utilities—warehouses, logistics, and drayage facilities, all of which are increasingly using hydrogen as a fuel in vehicles such as forklifts and yard trucks. The region is also home to some fertilizer and steel companies which may also be able to make use of hydrogen. Another suggestion on aggregated demand was the H2-Orange project—already examining hydrogen—being proximate to a nuclear facility which could provide a potential kernel of demand. A final suggestion was the Clean Cities Coalition, including the Palmetto Clean Fuels Coalition and Triangle Clean Cities, each of which works

with vehicle fleets, fuel providers, community leaders, and other stakeholders to save energy and promote the use of domestic fuels and advanced vehicle technologies in transportation.

Another line of debate surrounded the “small vs. large” strategies to determine a starting point for a hydrogen market. The “small” strategy called for a focus on those already using hydrogen and building a track record using an incremental approach of technology underwriting that would make the case for hydrogen and start conversations, especially with those who would want to join in principle but are unsure. Essentially, there needed to be proof that hydrogen can be both equitable and cost-effective. Proving hydrogen’s equitability and cost-effectiveness will necessarily lead to “many mistakes” or opportunities to learn. Trying to “address everything all at once is sometimes too difficult,” which is why there is an appetite to start small and build up. The advantage of this strategy from a cost perspective is that it would lower total cost and could receive funding from federal grants. The focus would also be on end-use experimentation, essentially building the case for greater supply through technology development. In contrast, the “large” strategy would seek to identify at least one bankable offtaker, which could then attract others through a pooled resource and de-risking approach. This strategy would focus on low unit costs, but there would need to be some government support to defray the large capital outlay. In the end, the group generally agreed that demand may be a good starting point, but there was no consensus as to minimum scale because of the general uncertainty of how such demand might evolve.

COST AND IDENTIFYING WHO PAYS FOR THE TRANSITION TO A HYDROGEN ECONOMY ARE SIGNIFICANT ISSUES

Who pays matters a lot. One conversation during the roundtable attempted to explore the possibility of getting rate recovery on pilot projects tied to electricity. However, it was quickly acknowledged that “tackling” ratepayer issues is a “big lift.” In the electricity sector, there might be limited ability to experiment and commercialize hydrogen solutions given the cost-minimization posture of governing regulations. At the same time, there was an expressed sensitivity that economically vulnerable communities need to be shielded from such proposals, given the existing burden of energy costs on these groups. While the idea of hydrogen as a decarbonization pathway for the electricity sector is of interest, including how it may enable adjacent industries to lower emissions, individual consumers such as households and small businesses were in no position to shoulder the high costs associated with projects. Put another way, the cost of commercialization should not fall on those least willing to pay for it or those who will not directly benefit from it in the short term. It was also vocalized that there is currently “a low level of trust” across the environmental justice community—which is “not a monolith”—toward projects where the payoff is not clear. This perspective emanates from a perceived history of marginalization by the energy industry on a range of environmental justice issues in the region. As such, active and sustained engagement from a wide variety of community constituents will be necessary to rebuild a social license.

High cost and low scale lead to a “chicken and egg problem.” A dominant line of discussion was the current high cost of hydrogen compared

to incumbent technologies. Specifically, this conversation focused on the high costs of clean hydrogen production and utilization outside of its established industries (e.g., refining or ammonia) relative to existing, carbon-intensive methods. Given that hydrogen from any source is not used in material quantity in the Carolinas, any conception of hydrogen use within the region would be “new” or associated with emerging technologies such as heavy-duty transportation, fuels for shipping and/or rail, or as a method to store energy for stationary purposes. Put simply, it was initially conceived that both demand and supply would have to grow concurrently but this discussion highlighted that these two ideas—cost and scale—were intertwined. This means that high costs exist because scale is lacking in emerging hydrogen use cases and, as a result, scale is hampered because the costs for new, clean sources of supply or demand are relatively high. The “chicken and egg problem” terminology was used more than once to describe this conundrum. At the same time, one participant suggested that the Carolinas do have the competitive advantage in terms of infrastructure, transportation, talent, and a friendly tax environment. Any hydrogen hub action should align with these regional differentiators.

There are limitations on experimenting and piloting technologies in a regulated industry.

Cost is a dominant consideration when it comes to public sector decision-making in the Carolinas. It is a challenge for policymakers and regulators to balance between economic development and climate action. It was generally acknowledged that utility innovation and piloting clashes with the requirement of cost prudence, meaning that technologies deployed by utilities “better work or you don’t get paid.” Still, it was implied that the

utility sector could be a first mover by developing clean supply pathways (via electrolysis coupled to renewable generation and/or repurposing existing nuclear fleets) and creating demand (via co-firing hydrogen fuel blends in existing NGCC turbines). This could begin to solve the chicken and egg problem, driving down costs for subsequent producers and users.

THERE ARE ONGOING HYDROGEN ACTIVITIES IN THE REGION, THOUGH AWARENESS IS LIMITED

It is important to think beyond the grid. While a utility has attributes that make it an attractive anchor for hydrogen hub development, one participant reminded the group to “think beyond the grid,” where other entities—or groups of entities in a coalition—may not be as cost-sensitive and able to experiment more freely. This statement was an indication, especially for those focused on retail electricity and natural gas, to widen the aperture of what might be possible. At the current stage of hydrogen commercialization, carbon-free production and new end uses are small, costly, and emerging. These dynamics alongside the current business model for regulated utilities make it difficult for utilities to take the lead on scaling up. At the same time, utilities should remain involved as part of a consortium to gain experience and capabilities through commercialization development (e.g., the H2-Orange project). To this end, it was acknowledged that a utility could be a bankable offtaker once cost and demand questions have been more adequately resolved.

The Carolinas are not starting from zero.

Essentially, there are “pockets” of pre-commercial development within and adjacent to the Carolinas.

Multiple participants from the industrial sector indicated that they are experimenting with small-scale hydrogen pilots to understand how it could serve their purposes. These pilot projects spanned across power generation, end-use resiliency, heavy-duty transportation, logistics, fuels, and renewables integration in the Carolinas and the surrounding region. Through these individual activities, there was clear enthusiasm that hydrogen could play a significant role in their respective businesses and could grow larger with the right partnerships. The H2-Orange project was presented as a good example of a collaborative effort across actors to better understand technological capabilities and market formation.

Awareness of the diverse uses of hydrogen is not evenly distributed; neither is trust in its value to the environment/climate change.

Outside of those firms that are already experimenting and thinking about hydrogen as part of their business, there were questions regarding efficacy, suitability, and cost. Those not fully focused on hydrogen had only indirect information about it and wanted “proof” of the technology’s application and a path to cost reduction. Further, there was vocal concern that some marginalized, environmental justice communities were skeptical of hydrogen’s purpose, especially as promulgated publicly. “Trust but verify” was a posture expressed by one participant regarding projects that make certain environmental claims. It was also noted that North Carolina has a carbon reduction goal and there should be verification that projects clearly and explicitly align with this mandate. Moreover, there seemed to be lacking trust that community voices would be adequately heard and that the costs would not be apportioned to those least willing to pay for them. In response, one participant



expressed that, in hydrogen discussions going forward, the environmental justice dimension should be more action oriented and focus on more than just cost within its scope. Groups such as the North Carolina Justice Center and the North Carolina Department of Environmental Quality could help facilitate this kind of discussion.

IT IS IMPORTANT TO DEVELOP A SHARED VISION TO BUILD A BROAD COALITION

It was generally acknowledged that there was substantial interest from organizations spanning the public and private spheres to support a hydrogen economy. This interest ranged from individual industrial and research activities to regulators, potential hydrogen users, and environmental advocacy groups. This could encourage a road-mapping and knowledge-sharing exercise that would leverage both the region's knowledge and best practices from other regions. Forming such a "fact-finding" coalition would also signal that the region is seriously considering the role of hydrogen, increasing the

salience for potential solution providers and acting as an invitation for many diverse stakeholders to voice their perspectives. The product of this exercise would be a vision document that concretely states the potential and general shape of hydrogen in the region.

As part of the visioning exercise, it was widely agreed that participant diversity is a "source of strength" and that the process itself—one that is especially welcoming of a wide set of stakeholders—would be an important trust building exercise. Regarding the environmental justice community, it was emphasized that it is not a monolith and "the table would need to be a lot bigger" to fairly represent those various perspectives and have these stakeholders understand what is possible with the current (and future) state of technologies. This conversation highlighted the need for direct representation from communities who can speak on their own behalf. At the same time, the group was encouraged by one participant to "think beyond the element" and consider this vision development as an exercise to understand how these solutions—linked together

in a hub—may improve higher order aspirations such as resilience, human health, and national security. In other words, hydrogen may be a subject where the general public and non-experts have trouble understanding its purpose, costs and benefits. Instead of focusing on hydrogen itself, the group was encouraged to start with the problems that hydrogen can address—especially beyond an energy context—and think about it as part of a portfolio of solutions that can address the basic needs of stakeholders.

While no conclusion was reached, there was conversation surrounding “who will lead” the coalition tasked with building the vision statement. One idea was to form a new organization to signal inclusive participation through a thoughtful selection of entities as the coalition founders. Another idea was to have the consortium placed within a public entity to help ensure balanced participation and visibility as an honest broker.

OUTLOOK & NEXT STEPS

The public workshop and private roundtable discussion on the potential for clean hydrogen in the Carolinas yielded a shared view that hydrogen could be a viable low-carbon pathway and economic growth engine for the region. Given that the Carolinas already have significant human, technical, and infrastructural resources—including pre-existing and ongoing hydrogen development activities across academia, SRNL, and industry—all the ingredients appear available to build a coordinated, shared vision for hydrogen. A shared

vision could act as a coordinating mechanism and is widely viewed as a critical next step to form a hydrogen market. Moreover, acting together on a regional basis would position the Carolinas to actively engage in community, industry, regulatory, and policy spheres to fully realize a long-lasting hydrogen hub.

To that end, the formation of a coalition emphasizing stakeholder breadth and knowledge sharing would be the natural next step coming out of the discussions held on October 28 and 29. The task of the coalition would be to develop a shared vision for a hydrogen hub that focuses on the aspirational needs (e.g., resiliency, human health, decarbonization, jobs) while also identifying pathways to address key concerns such as cost, just transitions, and long-term policy support. Such a process would ultimately identify a set of hydrogen demand signals and the means to satisfy such demand through a mix of public and private actions. The coalition, through its process, could build relationships across stakeholders and better position the Carolinas as the region pursues federal support for its hydrogen ambitions.

Endnotes

- 1 Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, 2021.
- 2 Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, 2021.
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