Hydrogen Power Study Task Force Legislative Report Outline

This report has been prepared by the Strategen Consulting on behalf of the Connecticut Green Bank for submission to the Connecticut Legislature consistent with the requirements of Special Act 22-8.

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1 Executive Summary

Economy-wide decarbonization is urgently needed to mitigate climate change and protect our communities' public health and infrastructure. To fully decarbonize energy systems, a "clean molecule" that has little or zero carbon characteristics, such as clean hydrogen, will be required to replace fossil fuels in many applications.

Clean hydrogen can play a major role in eliminating harmful greenhouse gas (GHG) emissions across the global economy as a carbon-free form of fuel and energy storage. Its versatility to provide heat, fuel, and power system services can be leveraged in multiple vital economic sectors that are challenging to decarbonize, such as aviation, maritime applications, heavy-duty trucking, and high-temperature industrial processes, among others. With numerous ways to produce hydrogen, the specific approach chosen significantly impacts the carbon intensity – the fuel's life cycle greenhouse gas emissions per unit of fuel or energy delivered – of the hydrogen produced as well as its associated decarbonization benefits. Federal guidance from the proposed Clean Hydrogen Production Standard established "clean hydrogen" as that with less than 4 kg of CO_2e/kg H_2 on a lifecycle basis (well-to-gate).

Interest in the production and use of clean hydrogen in Connecticut is growing, due in no small part to the state's deep experience with fuel cell and electrolyzer manufacturing, the billions of dollars in new federal grants and tax credits available in the near term via the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA), and state and regional climate and clean energy goals. However, stakeholders have raised concerns regarding hydrogen safety, end use prioritization, cost effectiveness, community impacts, and appropriate definitions for clean hydrogen.

Clean hydrogen can play an important role in Connecticut's decarbonization efforts and overall economic growth. However, the scale of its role will be determined not only by economic and market forces but also by actions taken at the state, regional, and federal level. This report presents the findings and recommendations of the Hydrogen Power Study Task Force (Task Force) established by Special Act 22-8, which required a study of the regulations and legislation needed to guide the development of hydrogen power in Connecticut, an examination of incentives and programs created by federal legislation, and an investigation of sources and uses for potential clean hydrogen power.

1.1 Summary of Findings

The Task Force developed a set of fact-based findings based on (a) research on current state of funding, policy activities, and infrastructure best practices; (b) original analysis on hydrogen costs and availability based on publicly available datasets; and (c) stakeholder feedback, recommendations, and resources. The Task Force found that clean hydrogen is an essential component of a just and sustainable clean energy transition, addressing Connecticut's economy-wide deep decarbonization goals and other issues related to energy equity and energy justice.

As a low or zero-carbon fuel, hydrogen can reduce reliance on existing fossil fuel end uses that have negative climate and human health impacts. Moreover, given the similar infrastructure required for molecular energy sources like hydrogen and natural gas, investment in hydrogen infrastructure can help to facilitate a just transition, particularly for workers currently employed by the fossil fuel industry. Investing in hydrogen provides additional equitable benefits by helping to unwind many harmful impacts of the fossil fuel economy, including disproportionate impacts on environmental justice communities and low-income and minority residents

Low or zero-carbon hydrogen fuel can be used in hard-to-decarbonize end uses such as aviation, maritime, heavy-duty trucking, and high-temperature industrial processes. Certain hydrogen-compatible applications, such as material handling equipment like forklifts, can economically convert to hydrogen fuel today. Other hydrogen end uses such as aviation or maritime shipping will not be ready until closer to 2030 when costs for delivered hydrogen and infrastructure should decline due to global and federal investments and economies of scale.

Developing a cost-effective hydrogen economy requires deployment of at-scale hydrogen production, storage, transport, and offtake infrastructure. One challenge for scaled hydrogen production via electrolysis is the total electricity required to produce hydrogen. While Connecticut has significant resources for hydrogen production across on- and off-shore wind, solar, biogas, and nuclear, many of these resources must also support achievement of the state's zero-emissions electric sector goals. Offshore and on-shore wind and utility-scale solar, as well as on-shore wind, represent the most abundant and lowest cost sources for hydrogen production. However, Connecticut has limited on-shore and off-shore wind projects that directly interconnect into the State, relying on a regional transmission grid for delivery of those resources. Thus, additional study is necessary to ensure the simultaneous attainment of the state's existing decarbonization objectives and potential new hydrogen deployment goals.

Hydrogen transport and storage are critical components of the hydrogen value chain and significantly impact overall delivered costs of hydrogen and additional greenhouse gas emissions. Hydrogen can be stored at smaller scale in liquified or compressed form, or via an alternative compound such as ammonia, but the most cost-effective method is large-scale hydrogen storage in underground storage facilities, such as salt domes. Salt domes are naturally occurring geological features, and the closest salt dome formations are located in western New York. There are two primary mechanisms for scaled hydrogen transport – first, transporting hydrogen molecules via pipelines, or transporting electricity via transmission lines to power distributed electrolyzers that create hydrogen molecules.[1] Today, most hydrogen transport occurs via truck, which contributes significantly to overall delivered costs. Funding support from state and federal sources will support affordability and jump start deployment of hydrogen infrastructure and offtake opportunities.

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[1] Other forms of scaled hydrogen transport, such as rail or maritime shipping, can also be evaluated for cost-effectiveness and suitability.

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Recent federal legislation, such as the IIJA and the IRA, earmarked significant funding for hydrogen investments throughout the value chain. These opportunities include grants for developing regional hydrogen hubs; zero-emissions mobility programs that apply to hydrogen-fueled heavy-duty trucks, material handling equipment, cargo ships, and aviation fuels; tax incentives for hydrogen production ; and funding for manufacturing and workforce development. A full list of these opportunities can be found in Appendix D. However, much of this funding depends upon various requirements, including supplying non-federal match funding and compliance with the federal government's "Justice40" initiative. Connecticut is well positioned to capitalize on federal funding opportunities given its many competitive strengths, including its participation in the Northeast Regional Hub application effort, its strategic positioning along high-volume transit corridors, its presence of a robust and nation-leading fuel cell and electrolyzer industry, and its existing efforts to support community engagement, particularly within disadvantaged communities. However, given federal match funding requirements and the imminent timing of funding applications, Connecticut must urgently consider its resources and funding strategy if the state wishes to capture significant federal funding.

Fuel Cell Deployment in the Fuel Cell State

As the "Fuel Cell State," Connecticut is known nationally and internationally for its strong stationary fuel cell manufacturing sector. There is also a growing fleet of fuel cells being deployed in Connecticut. The following tables provide a breakdown of fuel cell projects and installed capacity in development (i.e., application approved) or energized from 2010 through 2022 by manufacturer.

There are approximately 130 fuel cell projects in Connecticut totaling nearly 180 MW of fuel cell deployment – of which nearly 60% of the installed capacity are using Connecticut manufactured fuel cells.

Behind the Meter projects are located on the customer side of the meter, including:

Company	Projects	Installed Capacity (MW)
Bloom	35	20
HyAxiom	9	13
FuelCell Energy	71	52
Total	**115**	**86**

Grid Tied projects are directly connected to the grid, including several Shared Clean Energy Facility Program projects in development:

Company	Projects	Installed Capacity (MW)
Bloom	2	15
HyAxiom	11	57
FuelCell Energy	2	19
Total	**15**	**91**

Connecticut has strong policy commitments to decarbonization[2], which provides robust support to develop a clean hydrogen economy to support state goals. Clean hydrogen can play an important role in Connecticut's decarbonization efforts, depending on actions taken at federal, regional, and state levels. State regulatory and policy action can help create regulatory clarity and a harmonized state-level vision that will advance clean hydrogen development and deployment in Connecticut by providing market certainty and addressing stakeholder concerns related to hydrogen.

1.2 Summary of Recommendations

The Task Force has developed recommendations based on in-depth analyses and research, expert input, and stakeholder feedback. Recommendations identify potential actions that state entities could take to enable the growth of a clean hydrogen economy in Connecticut and are structured according to which entity that should lead such activities, including (1) the Legislature; (2) State Government Agencies; and (3) Industry and Academia. Of note, other organizations, including communities, environmental organizations, and labor, will be critical contributors to ongoing and recommended stakeholder processes.

1.2.1 Actions to be taken by the Legislature

There are opportunities for direct action by the Legislature to support the development of Connecticut's hydrogen economy. Legislative recommendations are focused on required statutory changes, funding for hydrogen development, and enabling actions to promote community engagement and transparency.

To enable community engagement, outreach, and education efforts, the Legislature should:

- Create a transparent source for municipalities, cities, and other local applicants to access resources, such as match funding and/or application guidance.
- Provide funding to increase community engagement and decrease the burden of engagement on communities.
- Consider amending requirements for community benefit agreements, through Public Act 21-43, to lower the minimum project size from 2 MW to 1 MW, explicitly note the inclusion of hydrogen, and consider the development of similar requirements for all hydrogen projects.

To provide support for high value end uses for hydrogen, the Legislature should:

- Consider appropriating grant funding to support federal match requirements.
- Consider tax exemptions for hydrogen vehicles and critical facilities that produce or use clean hydrogen.
- Evaluate broader policies that would facilitate the decarbonization of hard-to-electrify sectors, including long-haul heavy-duty trucking, aviation, shipping, and industrial processes.

[2] Connecticut Gen. Stat. Sec. 22a-200a, as amended by the Global Warming Solutions Act (GWSA) (2008).

1.2.2 Actions to be taken by State Government Agencies

State Government Agencies have opportunities to lead further investigation into clean hydrogen planning, funding, and policy, and to create appropriate venues to engage with critical ecosystem stakeholders on crosscutting issues related to the future of hydrogen in the state. Relevant topics include of additional investigation of hydrogen production, infrastructure and end uses; identification and expansion programs relevant to hydrogen; evaluation of additional funding needs; and advancing actions to promote community engagement and transparency.

1.2.2.1 Actions to be taken by DEEP

The Connecticut Department of Energy and Environmental Planning (DEEP) is the appropriate entity to address hydrogen-related activities core to energy and environmental planning for the state, and should consider undertaking the following actions:

- Conduct further investigation to ultimately establish a definition of clean hydrogen that would be most appropriate for Connecticut.
- Continue to evaluate the sufficiency of zero-emission electricity sources to meet both electric sector decarbonization goals and hydrogen production targets.
- Investigate accounting mechanisms that encourage hydrogen producers to certify the carbon intensity of produced hydrogen.
- Investigate the possibility of focused policy and market development support for clean hydrogen production and use in the highest priority end uses. These highest priority end uses include:
    - Aviation (long- and medium-haul)
    - Cargo ships
    - Critical facilities (24-hour backup need)
    - High heat industrial processes
    - Hydrogen fuel cells for peak power generation
    - Long-haul trucks
    - Material handling equipment with long uptimes and charging space or time constraints
- Further investigate into high priority hydrogen end uses and the possibility of coordinating support measures with other hydrogen efforts. These include:
    - Ferries
    - Freight rail
    - Heavy-duty vehicles with charging constraints (e.g., drayage trucks, some commuter buses)
    - Hydrogen blending for non-core customers (i.e., power generation and industrial heat)
    - Long-distance buses
    - Specialty fleet vehicles with long uptimes and specific refueling locations
- Explore market-based approaches to incent reductions in the carbon intensity of fuels for mobility end use applications.

- Identify and potentially expand clean transportation incentives to include on-site port handling equipment, harbor crafts, and ocean-going vessels, in collaboration with other state and federal agencies.
- Investigate the need for hydrogen fueling stations to support multi-sectoral mobility applications, and as appropriate, coordinate with CT Department of Transportation to develop more specific strategies for optimizing siting and funding.
- Lead interstate and interagency coordination to develop a hydrogen roadmap and strategy that identifies hydrogen supply and demand scenarios; approaches to a clean hydrogen backbone to enable cost-effective scaled transport; and other research and infrastructure investment opportunities to inform policy development and funding and research, development, and deployment (RD&D) strategy, in consultation with ecosystem stakeholders.
- Require feedback and guidance from the Connecticut Equity and Environmental Justice Advisory Council (CEEJAC) to advance community impact, environmental justice, and energy equity discussions on hydrogen and to support the development of a framework that outlines both a vision and goals for Connecticut's clean hydrogen policies.

1.2.2.2 Actions to be taken by PURA

The Connecticut Public Utilities Regulatory Authority (PURA) is the appropriate entity to incorporate hydrogen into electric distribution company (EDC) and local distribution company (LDC) planning and update relevant programs that may be relevant to hydrogen, and should consider undertaking the following actions:

- Evaluate the role of stationary hydrogen fuel cells for critical backup power and peak power generation and identify approaches to incorporate recommendations into appropriate planning venues.
- Consider whether existing renewable energy, flexible and/or interruptible load tariffs could be applied to electrolytic hydrogen production and determine if a specific electrolytic tariff would be required.

1.2.2.3 Actions to be taken by DECD

The Connecticut Department of Economic and Community Development (DECD) is the appropriate entity to provide support for the suite of brownfield funding opportunities, and should consider undertaking the following actions:

- Evaluate the need for additional funding for the Brownfield Loan and Grant programs to help meet the clean energy needs of the state and its subsequent land requirements.
- Establish a Strategic Innovation Fund with bond funds to encourage research, development, and deployment (RD&D) that will accelerate technology transfer and commercialization of innovative products, processes, and services related to hydrogen with guidance from an Industry Advisory Board.

1.2.2.4 Actions to be taken by the OWS

The Connecticut Office of Workforce Strategy, working in collaboration with UCONN, community colleges, and local universities, should address hydrogen and fuel cell related workforce development needs:

- Lead coordination – in partnership with UCONN; community colleges; vocational high schools; regional comprehensive universities; Workforce Investment Boards; trades with expertise in hydrogen technologies and relevant skillsets; labor-led workforce development programs and training programs; LDCs, EDCs, and other employers; and any other relevant workforce or training programs – between existing entities such as the Governor's Workforce Council and DEEP to establish a comprehensive program for engagement with local experts to understand workforce development needs and potential specific to hydrogen and hydrogen technologies such as fuel cells and electrolyzers as well as upstream suppliers.
- Partner with relevant state agencies and UCONN; community colleges; vocational high schools; regional comprehensive universities; Workforce Investment Boards; trades with expertise in hydrogen technologies and relevant skillsets; labor-led workforce development programs and training programs; LDCs, EDCs, and other employers; and any other relevant workforce or training programs to further advance the development of a skilled hydrogen workforce and durable supply chain.

1.2.2.5 Interagency Actions

Given the nascency of the clean hydrogen industry, and recent developments in federal funding, some actions are best undertaken collaboratively by multiple state agencies. Specifically, interagency coordination will be required to address hydrogen infrastructure, safety, and community protection:

- DEEP and PURA may wish to consider promoting hydrogen end uses that are currently commercially viable through the existing clean energy programs, including projects developed by both third parties and affiliates of the EDCs and LDCs. PURA's consideration should include how any changes would affect the programs' existing objectives and cost-effectiveness.
- DEEP and DECD should continue maintaining the Connecticut Brownfields Inventory as a resource for potential developers to identify prospective project sites and should consider expansion of the list to include those potentially eligible as "energy communities" under the Inflation Reduction Act.[3]
- DEEP and PURA should consider implementing an intervenor compensation program to increase community participation in hydrogen-related proceedings.
- DEEP and DECD should continue supporting development of clean energy projects on brownfields and projects that have community support and/or have completed community benefits agreements.
- DEEP should clarify and work with relevant agencies and stakeholders to explore the acceleration of permitting for clean hydrogen infrastructure, while ensuring appropriate guardrails to avoid unintended adverse impacts.

[3] As defined in the Inflation Reduction Act (2022) Sec. 13101.

- State agencies should identify appropriate leads to coordinate on hydrogen safety with local and federal organizations to allow for alignment and clear flow on best practices, policy developments, trainings, and certifications.
- DECD and OPM should identify opportunities for tax incentives or programs to retain Connecticut's leadership in the electrolyzer and hydrogen fuel cell manufacturing industry and prevent offshoring of manufacturing in line with federal policy.

1.2.3 Actions to be taken by Industry and UCONN

Industry and academia will play a key role in developing the hydrogen workforce and supporting ecosystem development:

- With regard to hydrogen infrastructure insurance, steps should be taken to ensure clear rules and policies for hydrogen infrastructure to support insurance industry workforce opportunities.
- UCONN, working in collaboration with community colleges; vocational high schools; regional comprehensive universities; Workforce Investment Boards; trades with expertise in hydrogen technologies and relevant skillsets; labor-led workforce development programs and training programs; LDCs, EDCs, and other employers; and any other relevant workforce or training programs, should identify opportunities to support development of the hydrogen workforce and advance research and development in hydrogen electrolyzers and hydrogen fuel cells, and should identify resources and funding needs to implement and contribute to the development of a hydrogen roadmap led by DEEP.
- UCONN should host a "learning laboratory" funded by the state which would include facilities (e.g., hydrogen production, hydrogen stations), and capabilities (e.g., fuel cell buses, stationary fuel cells) to host integrated technology demonstration projects, with the primary objective of addressing technical barriers to the deployment of fuel cells, hydrogen, and other clean energy technologies.
- Eligible entities should pursue federal funding for manufacturing capabilities for electrolyzers and hydrogen fuel cells, to further advance development in the state.

2 Background

2.1 Special Act 22-8 Background and Motivation

House Bill No. 5200, "An Act Establishing a Task Force to Study Hydrogen Power," was introduced in the Connecticut House of Representatives in February of 2022.[4] The bill calls for the establishment of a Task Force composed of industry leaders, utilities, environmental advocates, and regulators to study the regulations and legislation needed to guide the development of hydrogen power, examine incentives and programs created by federal infrastructure legislation, and investigate sources for potential clean hydrogen power. The bill was sponsored by State Representatives David Arconti (D-109), Joseph Gresko (D-121), and Holly Cheeseman (R-37).[5]

[4] Connecticut General Assembly (2022), Connecticut House Bill 5200.
[5] *Ibid*.

2.2 Special Act 22-8 Mandate

On May 23, 2022, the Senate and House of Representatives in General Assembly approved Special Act 22-8 establishing a Task Force to study hydrogen chaired by the Connecticut Green Bank. Special Act 22-8 mandates a study that must include, but is not limited to, the following items:

(1) A review of regulations and legislation needed to guide the development and achievement of economies of scale for the hydrogen ecosystem in the state;
(2) An examination of how to position the state to take advantage of competitive incentives and programs created by the federal Infrastructure Investment and Jobs Act;
(3) Recommendations for workforce initiatives to prepare the state's workforce for hydrogen fueled energy-related jobs;
(4) An examination of the sources of potential clean hydrogen, including, but not limited to, wind, solar, biogas and nuclear;
(5) Recommendations for funding and tax preferences for building hydrogen-fueled energy facilities at brownfield sites through the Targeted Brownfield Development Loan Program;
(6) Recommendations regarding funding sources for developing hydrogen fueled energy programs and infrastructure; and
(7) Recommendations for potential end uses of hydrogen-fueled energy.

Per Special Act 22-8, the Task Force is required to submit a report on its findings and recommendations to the joint standing committee of the General Assembly and shall terminate on the date that it submits such report or January 15, 2023, whichever is later.

2.3 Hydrogen Background

Hydrogen (H) is the simplest and most abundant element in the universe. Naturally occurring as two bonded H atoms (H_2), hydrogen is the lightest of all molecules. It is a colorless, odorless, and tasteless gas under standard conditions. On Earth, hydrogen is primarily bound within molecules of water or hydrocarbons. Most are familiar with hydrogen as paired with oxygen, forming H_2O, or water.

Hydrogen gas is a well-established and globally traded commodity. It is primarily used as an industrial feedstock or as an intermediate chemical feedstock in many industrial processes, such as oil refining, methanol production, and ammonia production for fertilizer. In addition, hydrogen can serve as a fuel or energy source.

Hydrogen has the highest energy density by mass of today's most-used fuels, including diesel, natural gas, and gasoline.[6] Since hydrogen has a very low volumetric density at ambient temperature, hydrogen energy is typically measured by weight in kilograms (kg) instead of by volume (as with natural gas). For example, 1 kg of hydrogen contains approximately the same energy as 1 gallon (2.8 kg) of gasoline.

There are numerous ways to produce hydrogen, but the carbon intensity of the hydrogen produced varies. Below is an overview of the most common methods for hydrogen production:

[6] Green Hydrogen Coalition (2022), Green Hydrogen Guidebook, 2nd Edition.

- **Reformation:** Most hydrogen produced today in the United States is made via steam-methane reforming. In reformation, synthesis gas—a mixture of hydrogen, carbon monoxide, and a small amount of carbon dioxide—is created by reacting natural gas with high-temperature steam. The carbon monoxide is reacted with water to produce additional hydrogen. Natural gas reforming using steam accounts for the majority of hydrogen produced in the United States annually.
- **Electrolysis:** Electrolysis is a method of using energy from an electric current to split a molecule into simpler components. The feedstock for electrolysis is water which gets split into the components oxygen and hydrogen. Electrolysis is accomplished using a commercially available device called an electrolyzer. In the process of electrolysis, the source of electricity generation utilized will contribute to the lifecycle carbon intensity of the hydrogen produced.
- **Thermal Conversion/Gasification:** Thermal conversion, or gasification of organic matter, works by applying high heat and/or pressure on organic matter to transform the material from a solid state to a gaseous state. The resulting components of the process are mainly hydrogen, carbon monoxide, and carbon dioxide, which are further purified to produce hydrogen or methane that can be used for fuel. Organic matter can come from forestry waste, agricultural waste, organic municipal solid waste, or animal waste.

Currently, there is worldwide demand for about 70 million tonnes (Mt) of pure hydrogen, primarily for oil refining and ammonia production for fertilizers. Additionally, there is demand for45 Mt of hydrogen gas mixtures, as fuel or feedstock, for processes including methanol production and steel production. The majority of dedicated hydrogen produced today is from fossil fuels, such as oil and natural gas. Less than 0.7% of current hydrogen production is from renewables or from fossil fuel plants equipped with carbon capture technology as demonstrated in Figure 1.[7]

Figure 1. Hydrogen Production Sources and End Uses

[7] International Energy Agency (2019), The Future of Hydrogen.

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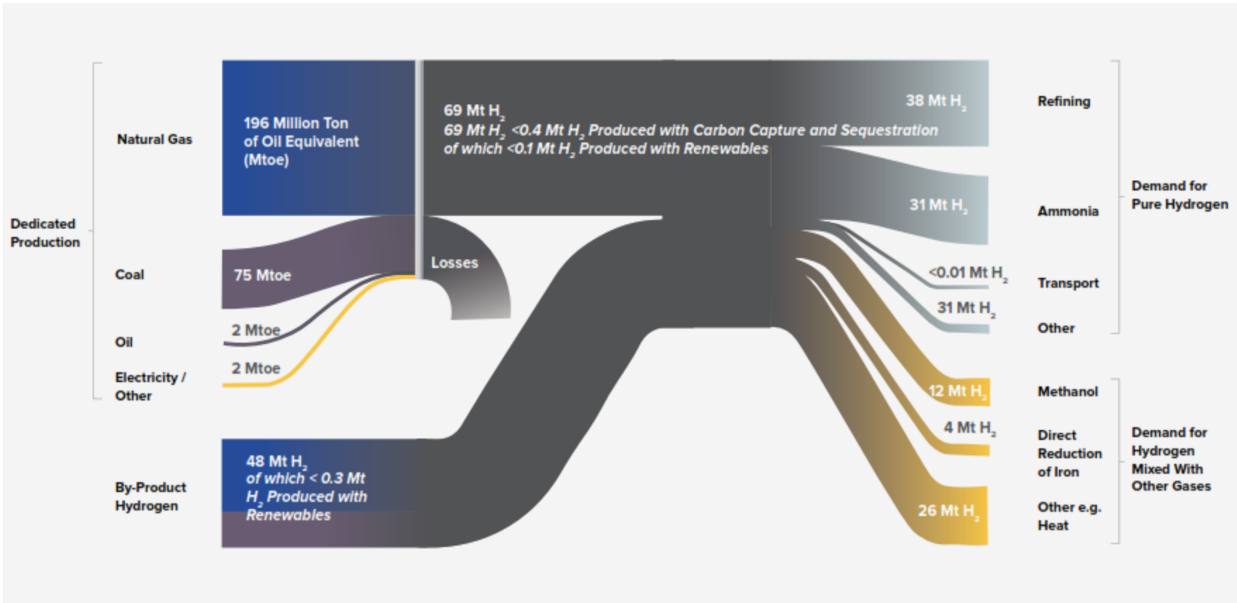


Source: International Energy Agency (2019), The Future of Hydrogen.

While hydrogen is a colorless gas, it has been given color codes such as green hydrogen, pink hydrogen, blue hydrogen, and so on to indicate the primary feedstocks, energy sources, and production processes used to produce the hydrogen. Figure 2 provides an illustrative example of a hydrogen color spectrum.

Figure 2. *The Colors of Hydrogen*

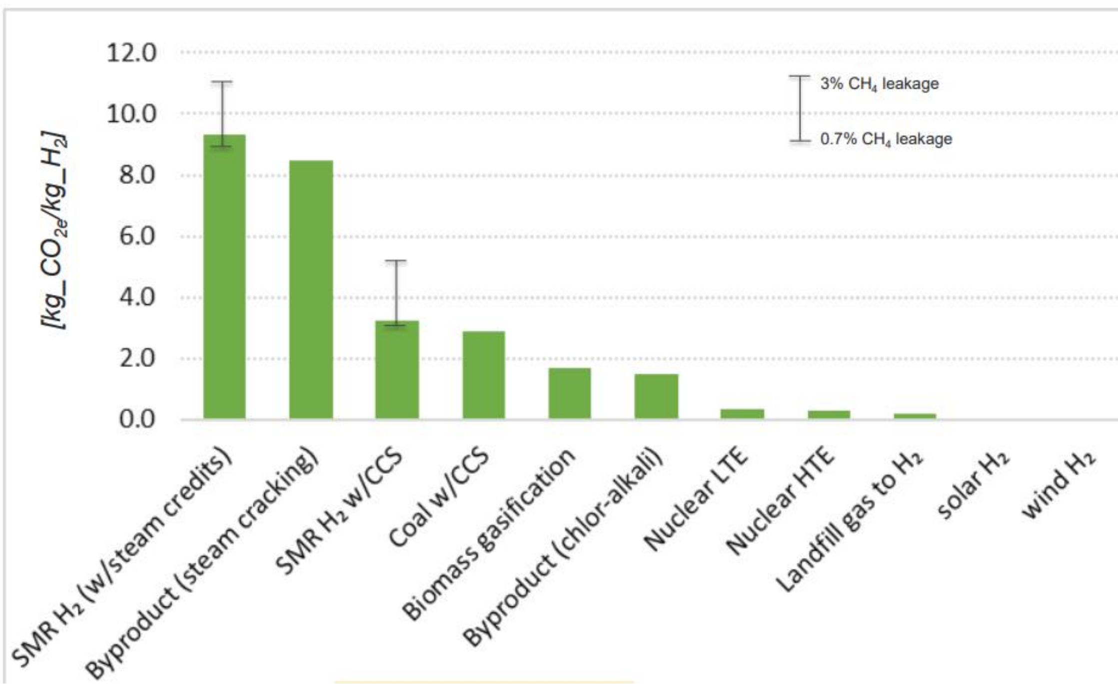
Color	Primary Feedstock	Primary Energy Source	Primary Production Process	Carbon Intensity $kgCO_2e/kgH_2$
Brown	Coal or Lignite	Chemical Energy in Feedstock	Gasification & Reformation	
Gray	Natural Gas	Chemical Energy in Feedstock	Gasification & Reformation	
Blue	Coal, Lignite, or Natural Gas	Chemical Energy in Feedstock	Gasification with Carbon Capture and Sequestration	
Pink	Water	Nuclear Power	Electrolysis	
Green	Water	Renewable Electricity	Electrolysis	
	Biomass or Biogas	Chemical Energy in Feedstock	Gasification, Reformation, & Thermal Conversion	

Source: Green Hydrogen Coalition (2022), Green Hydrogen Guidebook.

There is growing interest in moving from color-coding hydrogen to a more quantifiable method. One such alternative is evaluating hydrogen based on its carbon intensity. Carbon intensity is defined as a fuel's life cycle greenhouse gas emissions per unit of fuel or energy delivered. This accounts for life cycle greenhouse gas emissions,[8] not just those that are emitted when the fuel is consumed. Hydrogen's carbon intensity can be measured in kilograms of CO_2 equivalent (CO_2e) per kilogram of hydrogen. For any quantity and type of greenhouse gas, CO_2e signifies the amount of CO_2 that would have the equivalent global warming impact.

A study using the GREET model from Argonne National Laboratory identified the lifecycle carbon intensity associated with hydrogen production pathways. Clean hydrogen as defined by the Clean Hydrogen Production Standard can be produced by diverse feedstocks including nuclear, solar, wind, landfill gas, and even potentially fossil fuels with carbon capture and sequestration assuming minimal methane leakage as demonstrated by Figure 3.

Figure 3. Well-to-Gate GHG Emissions of Hydrogen Production Pathways



Source: Argonne National Laboratory (2022), GREET Model for Hydrogen Life Cycle GHG Emissions.

Defining hydrogen based on its carbon intensity provides a quantitative, technology-agnostic approach, as it only considers the life cycle emissions from the hydrogen source. As a result, the door is open for competition to flourish so long as the hydrogen production pathway in question can meet the desired life cycle emissions threshold. Federal guidance from the Infrastructure Investment and Jobs Act (IIJA) defines clean hydrogen as having a carbon intensity equal to or less than 2 kilograms

[8] The term "lifecycle greenhouse gas emissions" is defined by subparagraph (H) of section 211(o)(1) of the Clean Air Act (1955) (42 U.S.C. 7545(o)(1)). This term means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes) related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.

$CO_2e/kg\ H_2$ produced at the site of production while the proposed Clean Hydrogen Production Standard defines clean hydrogen as that with less than 4 kg of $CO_2e/kg\ H_2$ on a lifecycle basis (well-to-gate).[9]

For the purpose of this report, clean hydrogen is defined as hydrogen with de minimis carbon emissions on a lifecycle basis. Further discussion on this topic is included in Section 4.2.1.

2.4 Relevance of Action on Hydrogen

Economy-wide decarbonization is urgently needed to mitigate climate change and protect our communities' public health and infrastructure. To fully decarbonize energy systems, a clean molecule, such as clean hydrogen, will be required to replace fossil fuels in many applications.

Clean hydrogen can play a major role in eliminating harmful greenhouse gas (GHG) emissions across the global economy as a carbon-free form of fuel and energy storage, but the scale and decarbonization benefits provided by hydrogen will be determined by actions taken at the state level, including determining eligibility of different clean hydrogen production sources. Its versatility to provide heat, fuel, and power system services can help decarbonize multiple vital economic sectors, such as aviation fuel, maritime applications, heavy-duty trucking, and high-temperature industrial processes, among others.

Recent passage of federal legislation, particularly the IIJA and the IRA created a tipping point for domestic action on clean hydrogen. Specifically, the Regional Clean Hydrogen Hubs funding opportunity included in the IIJA spurred the development of regional partnerships to advance and incentivize clean hydrogen market development across the nation. In addition, there is an ever-increasing amount of policy related to hydrogen, and more specifically, clean hydrogen. In the last 3 years, approximately 120 hydrogen bills passed across the nation. Of these, about one third were specific to clean/renewable/green hydrogen.[10]

Notably, stakeholders raised concerns regarding hydrogen safety, end use prioritization, cost effectiveness, community impacts, emissions intensity, and compatibility with state climate goals. The findings and recommendations presented by the Task Force provide a basis for Connecticut to begin to develop a clean hydrogen economy while addressing key stakeholder concerns.

2.5 Inclusion of Hydrogen in the 2022 Comprehensive Energy Strategy

The Comprehensive Energy Strategy (CES), developed DEEP examines future energy needs in the state and identifies opportunities to reduce costs for ratepayers, ensure reliable energy availability, and mitigate public health and environmental impacts of Connecticut's energy use, such as GHG

[9] U.S. Department of Energy (2022), Clean Hydrogen Production Standard Draft Guidance and United States Congress (2021), H.R.3684 – Infrastructure Investment and Jobs Act.
[10] Strategen Consulting analysis.

emissions and emissions of criteria air pollutants.[11] Under Section 16a-3d of the Connecticut General Statutes, DEEP is charged with preparing a CES every four years.[12] In planning for effective management of Connecticut's energy system – including electricity, heating, cooling, and fuels used for transportation – the CES provides recommendations for legislative and administrative actions that will aid in the achievement of interrelated environmental, economic, security, and reliability goals.

The 2022 Comprehensive Energy Strategy will build on and/or potentially modify findings and recommendations of prior Comprehensive Energy Strategies released in 2013 and 2018 and will also consider emerging issues and recommendations that may not have been addressed in prior years. Further, Governor Lamont's Executive Order 21-3 directs DEEP to include in the next CES a set of strategies to: (1) provide for more affordable heating and cooling for Connecticut residents and businesses, (2) achieve reductions in GHG emissions from residential buildings and industrial facilities as needed to enable the state to meet the economy-wide GHG reduction targets for 2030 and 2050 established in the Global Warming Solutions Act, and (3) improve the resilience of the state's energy sector to extreme weather events, fuel commodity price spikes, and other disruptions.[13]

On February 17, 2022, DEEP held a scoping meeting to seek public input on the scope of topics that the CES will focus on.[14] Among the topics included in DEEP's draft CES scope was emerging technologies and the role they can provide in meeting Connecticut's climate goals and resource adequacy, including but not limited to, clean hydrogen.[15] In addition, on April 6, 2022, DEEP held a virtual Hydrogen Technical Meeting regarding the incorporation of a strategy for hydrogen development into the 2022 CES.[16] DEEP also held a technical session on alternative fuels (including hydrogen) for the CES on November 4, 2022.[17] The inclusion of hydrogen in the 2022 CES recognizes the role that hydrogen is expected to play in Connecticut's decarbonized future and provides signals for further regulatory and legislative action over the next several years to further advance the hydrogen economy.

The activities of the Task Force are separate from DEEP's Comprehensive Energy Strategy Process, but it is expected that the findings and recommendations provided by the Task Force will be informative for DEEP's processes related to hydrogen.

2.6 Connecticut Regional Hub Participation

Connecticut joined New York, New Jersey, Maine, Rhode Island, New Hampshire, and Massachusetts to develop a proposal to become one of at least four regional clean hydrogen hubs designated through

[11] Connecticut DEEP (2022), Comprehensive Energy Strategy.
[12] Connecticut Gen. Stat. §16a-3d (2021).
[13] Connecticut Legislature (2021), Executive Order 21-3.
[14] Connecticut DEEP (2022), 2022 Comprehensive Energy Strategy Scoping Meeting.
[15] Connecticut DEEP (2022), Notice of Technical Meeting and Request for Written Comment on Hydrogen Opportunities.
[16] *Ibid*.
[17] Connecticut DEEP (2022), CT 2022 Comprehensive Energy Strategy Technical Session 6: Alternative Fuels.

the IIJA Regional Clean Hydrogen Hubs program. If selected, the hub will receive from $400 million to $1.25 billion to develop and deploy a hydrogen hub in the northeast region within an eight-to-twelve-year timeframe. The New York State Energy Research & Development Authority (NYSERDA) leads the effort, and Connecticut represents the gateway to New England as well as a key segment of the I-95 corridor. As part of the multi-state collaboration, DEEP is partnering with Connecticut entities representing the entire chain of hydrogen producers, end users, technology and equipment manufacturers; utilities; and the research and development community including university leaders. These partners are expected to work together to accomplish the following:[18]

- Define the shared vision and plans for the regional hydrogen hub that can advance safe clean hydrogen energy innovation and investment to address climate change, while improving the health, resiliency, and economic development of the region's residents.
- Perform research and analysis necessary to support the hub proposal and align on an approach to quantifying greenhouse gas emissions reductions as a result of deploying this technology.
- Develop a framework to ensure the ecosystem for innovation, production, infrastructure, and related workforce development is shared across all partner states.
- Support environmentally responsible opportunities to develop hydrogen, in accordance with participating states' policies.

The activities of the Task Force are separate from Connecticut's participation in the Regional Clean Hydrogen Hubs, but it is expected that the recommendations provided by the Task Force will provide support for regional hydrogen market development and set Connecticut to become a leader in the hydrogen ecosystem.

3 Process

3.1 Task Force Composition and Nomination Process

Special Act 22-8 established the Task Force and dictated its composition. The act designated five (5) specific Task Force members and provided assignments to members of the Senate and House of Representatives to nominate sixteen (16) additional Task Force members. According to Special Act 22-8, the Task Force would consist of the following:

- The president of the Connecticut Green Bank, who shall be the chairperson of the Task Force;
- Two representatives from the electricity division of an electric distribution company that has a service area of eighteen or more cities and towns, one of whom shall be appointed by the speaker of the House of Representatives and one of whom shall be appointed by the minority leader of the House of Representatives;
- Two representatives from the electricity division of an electric distribution company that has a service area of not more than seventeen cities and towns, one of whom shall be appointed by the president pro tempore of the Senate and one of whom shall be appointed by the minority leader of the Senate;

[18] Office of Governor Ned Lamont (2022), Governor Lamont Announces Connecticut Partners with New York, New Jersey, and Massachusetts to Develop Regional Clean Hydrogen Hub Proposal.

- A representative from the gas division of an electric distribution company that has a service area of eighteen or more cities and towns, who shall be appointed by the majority leader of the House of Representatives;
- A representative from the gas division of an electric distribution company that has a service area of not more than seventeen cities and towns, who shall be appointed by the minority leader of the Senate;
- A representative from an eligible nuclear power generating facility, as defined in section 16a-3m of the general statutes, who shall be appointed by the minority leader of the House of Representatives;
- A representative of the building trades, who shall be appointed by the majority leader of the Senate;
- Three representatives of Connecticut manufacturers of hydrogen fueled energy technology, one of whom shall be appointed by the speaker of the House of Representatives, one of whom shall be appointed by the president pro tempore of the Senate and one of whom shall be appointed by the minority leader of the House of Representatives;
- Three representatives of environmental organizations that advocate for renewable energy, one of whom shall be appointed by the president pro tempore of the Senate, one of whom shall be appointed by the majority leader of the House of Representatives and one of whom shall be appointed by the minority leader of the Senate;
- Two members of the Connecticut Hydrogen-Fuel Cell Coalition, one of whom shall be appointed by the majority leader of the House of Representatives and one of whom shall be appointed by the minority leader of the Senate;
- The chairperson of the Public Utilities Regulatory Authority, or the chairperson's designee;
- The Commissioner of Energy and Environmental Protection, or the commissioner's designee;
- The president of The University of Connecticut, or the president's designee; and
- The director of energy initiative at the Connecticut Center of Advanced Technology (CCAT).

Fourteen out of sixteen Task Force members were nominated and approved by the Senate and the House of Representatives. The final composition of the Task Force is as follows:

Table 1. Task Force Appointees

Appointer	Name	Title and Organization
Ex Officio	Katie Dykes	Commissioner, DEEP
Ex Officio	Marissa Gillett	Chairwoman, PURA
Ex Officio	Radenka Maric	President, UCONN
Ex Officio	Joel Rinebold	Director, CCAT
Ex Officio (Chair)	Bryan Garcia	President, Connecticut Green Bank
Ex Officio (Co-Chair)	Sara Harari	Associate Director of Innovation & Advisor to the President, Connecticut Green Bank

President Pro Tempore	Enrique Bosch	Director of Innovation, Avangrid
	Sridhar Kanuri	Chief Technology Officer, HyAxiom
	Shannon Laun	Vice President & Director, Conservation Law Foundation
Majority Leader Senate	Keith Brothers	Business Manager & Secretary Treasurer, AFL-CIO
Minority Leader Senate	Adolfo Rivera	Senior Director, Avangrid
	Frank Reynolds	President & CEO, Avangrid
	Unfilled	Environmental Advocate
	Unfilled	Connecticut Hydrogen Fuel Cell Coalition Representative
Speaker of House	Digaunto Chatterjee	Vice President of System Planning, Eversource
	Katherine Ayers	Vice President of Research & Development, Nel Hydrogen
Majority Leader House	Nikki Bruno	Vice President of Clean Technologies, Eversource
	Samantha Dynowski	State Director, Sierra Club
	Anthony Leo	Vice President & CTO, Fuel Cell Energy
Minority Leader House	Jennifer Schilling	Vice President of Grid Modernization, Eversource
	Mary Nuara	State Policy Director, Dominion Energy
	William Smith	President & CEO, Infinity Fuel Cell

3.2 Technical Consultant Support

Strategen was selected via a competitive RFP per the operating procedures of the Connecticut Green Bank to provide administrative support and technical expertise on behalf of the Task Force and its Working Groups.[19] The funding source for this engagement was directed by the Connecticut General Assembly through the passage of Special Act 22-8 designating the Connecticut Green Bank as the Chair of the Task Force with funds from the Renewable Energy Investment Fund.[20] Strategen led research functions associated with the undertaking of the numerated tasks in Special Act 22-8, convened and facilitated stakeholder forums, including Task Forces and Working Groups, and provided support as needed to the administrative functions (e.g., notes, minutes, plans) of the Task Force, and its Working Groups.

[19] Connecticut Green Bank (2021), Operating Procedures Pursuant to Section 16-245n of the Connecticut General Statutes.
[20] Per Conn. Gen. Stat. 16-245n(a), "clean energy" includes "hydrogen production and hydrogen conversion technologies".

Strategen is a globally connected, impact-driven firm on a mission to decarbonize energy systems. Strategen is a minority and woman-owned business headquartered in Berkeley, California with offices in Portland, Oregon and Brisbane, Australia. Since 2005, Strategen's 60-person multidisciplinary team of economists, business strategists, regulatory and policy experts and energy modelers has helped clients envision, accelerate, and create a clean energy future.

3.3 Task Force Meetings

The Task Force was convened on the second Tuesday of the month from July 2022 to January 2023. These meetings were noticed with the Secretary of State and were open for public participation with a dedicated public comment section at the close of each meeting occurrence. Agendas, meeting minutes, slides, and recordings were publicly posted on the Connecticut Green Bank's Hydrogen Task Force website and meeting minutes were additionally translated into Spanish to promote transparency and accessibility.[21]

The objectives of the Task Force meetings were multifaceted. These meetings were intended to:

- **Educate** – Task Force members and the public were informed about leading scientific perspectives and market development related to clean hydrogen via presentations from industry experts such as the Green Hydrogen Coalition and national laboratories such as Sandia National Lab and the Lawrence Berkeley National Lab.
- **Engage** – Task Force members were offered opportunities to participate in showcase tours of hydrogen-related facilities around the state including the University of Connecticut's Innovation Partnership Building, FuelCell Energy, Nel Hydrogen, Dominion Millstone, and HyAxiom to see first-hand how Connecticut is contributing to the hydrogen economy.
- **Enable** – Task Force meetings provided Task Force members with the knowledge and collaborative atmosphere to develop findings and make recommendations for inclusion within the legislative report.
- **Emphasize Environmental Justice** – Critical voices from the Bridgeport Regional Energy Partnership and the Connecticut Roundtable on Climate and Jobs were elevated for Task Force attention to both inform the Task Force and empower critical stakeholders to enable the development of recommendations that considered community engagement.

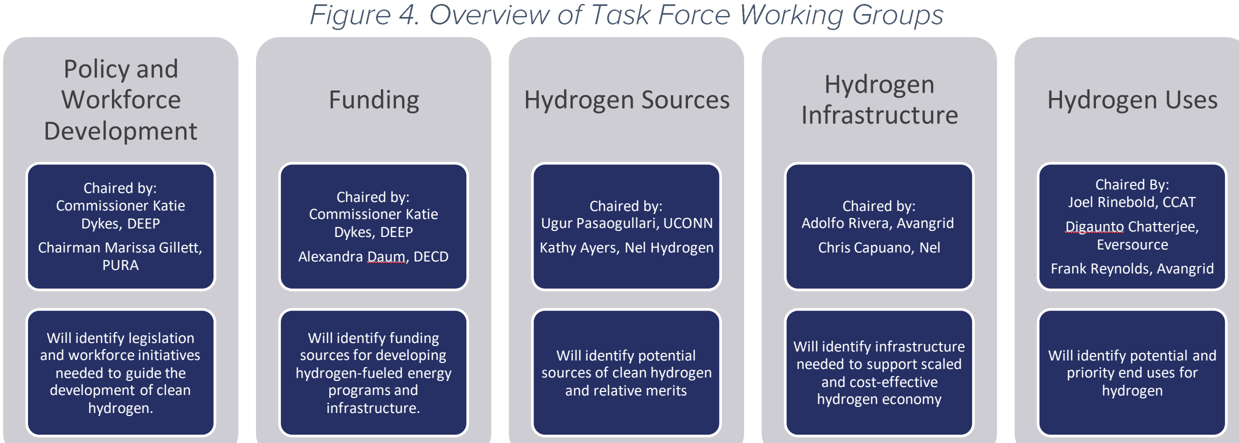
[21] Connecticut Green Bank (2022), Hydrogen Power Study Task Force.

<u>The University of Connecticut's Hydrogen Innovation and Research</u>
LOCATION
Storrs, Connecticut
FACILITY
The Innovation Partnership Building is a premier center for cutting edge research and industry collaboration and innovation. The IPB provides an ecosystem that inspires great ideas, pushing the envelope for next generation solutions. Cross-disciplinary research teams develop novel approaches to critical real-world problems in fields ranging from manufacturing and biomedical devices to cybersecurity and sustainable energy.
TYPE
Education and Research
FACULTY AND STAFF
8,646 Full-Time Faculty and Staff
STUDENTS
32,146 Students (i.e., 23,837 Undergraduate Students; 8,309 Graduate and Professional Students)
PARTNERSHIP
On October 20, 2022, UCONN initiated a partnership with the National Renewable Energy Laboratory (NREL) for research and innovation to leverage scientific collaboration to research new renewable energy technologies at the IPB. UCONN is one of five research universities including MIT, Princeton, Georgia Tech, and Carnegie Mellon to collaborate with NREL in the eastern United States.
FUN FACT
UCONN President Radenka Maric is the Connecticut Clean Energy Fund (predecessor to Connecticut Green Bank) Professor in Sustainable Energy with her expertise in proton exchange and alkaline fuel cells, and water-gas shift reforming reactions.

3.4 Working Group Process

The efforts of the Task Force were supported by five Working Groups – Sources, Uses, Infrastructure, Funding, and Policy and Workforce Development – whose objectives were to develop findings and recommendations to be brought before the Task Force in response to the Special Act 22-8 mandate. These Working Groups were led by Task Force appointed co-chairs and coordinated and supported by Strategen.

Figure 4. Overview of Task Force Working Groups



Working Group meetings were held monthly from September to December 2022. These meetings were open to the public and stakeholder participation was encouraged.[22]

3.4.1 Sources Working Group

The Sources Working Group was co-chaired by Kathy Ayers, the Vice President of Research and Development at Nel Hydrogen and Professor Ugur Pasaogullari from the University of Connecticut. The objective of the Hydrogen Sources Working Group was to examine the sources of potential clean hydrogen in Connecticut including, but not limited to, wind, solar, biogas and nuclear. This included an assessment of the maximum in-state clean hydrogen production that could be achieved using Connecticut's share of carbon-neutral feedstocks, while factoring in potential needs for these types of resources in other segments of a decarbonized economy. This analysis was also coordinated with forecasts of clean hydrogen demand developed by the Uses Working Group to assess any gaps in the state's clean hydrogen production capacity and its projected hydrogen use.

3.4.2 Uses Working Group

The Uses Working Group was co-chaired by Digaunto Chatterjee, the Vice President of System Planning at Eversource, Frank Reynolds, the President and CEO of Avangrid, and Joel Rinebold, the Director of Energy at CCAT. The objective of the Hydrogen Uses Working Group was to provide recommendations for potential end uses of hydrogen-fueled energy to promote achievement of Connecticut's decarbonization goals. This included a cross-sectoral assessment of the areas where clean hydrogen use will be most viable in the future, coupled with analysis of the potential demand from the identified end uses. In addition to a forecast for overall hydrogen demand, the Uses Working Group also considered the geographic location of end users and their proximity to potential sources of hydrogen production.

3.4.3 Infrastructure Working Group

The Infrastructure Working Group was co-chaired by Chris Capuano, the Director of Contract R&D Programs at Nel Hydrogen, and Adolfo Rivera, the Senior Director of Green Hydrogen at Avangrid. The Infrastructure Working Group developed insights into infrastructure requirements to meet projected clean hydrogen demand and assessed existing infrastructure that could be repurposed to meet this demand. This included developing an understanding of hydrogen transportation and storage needs and identifying opportunities and barriers to developing this infrastructure in Connecticut. The Infrastructure Working Group also considered the potential for strategic partnerships with neighboring states to enhance infrastructure development for a regional clean hydrogen ecosystem.

3.4.4 Funding Working Group

The Funding Working Group was co-chaired by Commissioner Alexandra Daum from DECD and Commissioner Katie Dykes from DEEP. The objective of the Funding Working Group was to review

[22] Connecticut Green Bank (2022), Hydrogen Power Study Task Force Working Groups.

existing hydrogen funding mechanisms and incentives, such as those in the Infrastructure Investment and Jobs Act (IIJA) and determine how Connecticut could be best positioned to participate in these programs and potentially develop new opportunities. The Funding Working Group also recommended additional funding sources for developing a hydrogen ecosystem with a focus on the Targeted Brownfield Development Loan Program.

3.4.5 Policy and Workforce Development Working Group

The Policy and Workforce Development Working Group was co-chaired by Commissioner Katie Dykes from DEEP and Chairwoman Marissa Gillett from PURA. The objective of the Policy and Workforce Development Working Group was to review the Connecticut policy and regulatory landscape to determine gaps that need to be addressed to promote development of a clean hydrogen ecosystem. The Policy and Workforce Development Working Group also worked with local industry experts to develop recommendations regarding workforce initiatives and policy developments based on best practices that can help support a hydrogen ecosystem.

3.5 Transparency, Engagement, and Outreach

The Task Force recognized the critical importance of process transparency and dedicated engagement and outreach efforts to enable robust public participation and ensure that diverse stakeholder perspectives are represented and reflected in the final legislative report to the Energy and Technology Committee.

To that end, all Task Force and Working Group meetings were noticed with the Secretary of State and were open for public participation with several opportunities for discussion and comments. Agendas, meeting minutes, slides, and recordings were publicly posted on the Connecticut Green Bank's Hydrogen Task Force website and meeting minutes were translated into Spanish to promote transparency and accessibility.[23] Further, dedicated marketing materials for each Task Force meeting were developed and Task Force members were encouraged to publicize meeting occurrences with their network.[24] In addition, the Green Bank and its consultant promoted the activities of the Task Force at DEEP's Comprehensive Energy Strategy Technical Session hosted on November 4, 2022.[25]

As findings and recommendations were being developed, the Green Bank issued a Request for Written Comment to publicly capture stakeholder feedback.[26] Stakeholder comments have been incorporated into this legislative report. Finally, the Green Bank and its consultant hosted a public listening session on December 8, 2022, to provide further opportunity for open stakeholder feedback to inform the activities of the Task Force.[27] In addition to an overview of Special Act 22-8, this webinar included a summary of the Task Force's process and key findings, as well as ample time to field public

[23] Connecticut Green Bank (2022), Hydrogen Power Study Task Force.
[24] For example, see the October 2022 Task Force meeting flyer.
[25] Connecticut DEEP (2022), CES Technical Meeting 6 Recording.
[26] Connecticut Green Bank (2022), Special Act 22-8 Public Request for Written Comments.
[27] Connecticut Green Bank (2022), Hydrogen Study Task Force Webinar and Listening Session.

comments. The Request for Written Comments and Notice of this public listening session were shared with the Green Bank's listserv to increase engagement.

It should be noted that the efforts of the Task Force and associated Working Groups are not intended to replace the stakeholder engagement process used to develop and vet updates to state policy; rather, these efforts are intended to surface new ideas for consideration regarding how to develop a clean hydrogen economy in Connecticut.

4 Findings and Recommendations

This section includes both the findings and recommendations developed during the Task Force process. For this report, findings were considered research, analysis, or other fact base critical to understanding opportunities and the best path forward for Connecticut. Recommendations are the interpretation and application of those findings to Connecticut, including specific actions that might be taken by various state organizations to achieve the objectives laid out by Special Act 22-8. Recommendations also represent areas of consensus from Task Force and Working Group participants, but additional perspective from the stakeholder process, including minority opinions, caveats, concerns, suggestions, or areas of interest, are represented in dedicated sections on stakeholder feedback.

4.1 Findings and Recommendations by Special Act Task

The following subsections align directly with the directives assigned from the Special Act 22-8 mandate and provide a description of key findings, recommendations, and stakeholder feedback.

4.1.1 A review of regulations and legislation needed to guide the development and achievement of economies of scale for the hydrogen ecosystem in the state.

4.1.1.1 Findings

Connecticut has existing policies intended to enable decarbonization, which provide ecosystem support for the development of clean hydrogen to contribute to the state's climate goals. For example, Connecticut General Statute 22a-200a. mandates statewide greenhouse gas emission reduction targets across all sectors,[28] while Public Act 22-5 also requires reductions specific to the electric sector, including a 100% zero emissions electric supply by 2040.[29] This is supported by Connecticut's Renewable Portfolio Standard (RPS), which sets annual targets for shares of electric generation from renewable energy sources, reaching 48% by 2030.[30] Additionally, Connecticut has set limits for NOx emissions from fuel-burning equipment at stationary sources[31] and is part of the multi-state zero emission medium- and heavy-duty vehicle (MHDV) memorandum of understanding, which sets goals for 30% of all new MHDV sales to be zero emissions by 2030 and 100% by 2050.[32]

[28] Connecticut General Assembly (2022), Connecticut General Statute 22a-200a.
[29] Connecticut General Assembly (2022), Connecticut Public Act No. 22-5.
[30] Separate portfolio standards are set for resources designated as Class I, Class II, and Class III as per the Renewable Portfolio Standard.
[31] Connecticut Agencies Regulations §22a-174-22f (2016).
[32] Multi-State Medium- and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding, (2020).

Connecticut also has several existing policies or programs that explicitly mention the inclusion of hydrogen and fuel cells, including, but not limited to:

- **Special Act 22-8 (2022)** establishes the Hydrogen Power Study Task Force. The express goal of the Special Act is to "study hydrogen-fueled energy in the state's economy and energy infrastructure."[33]
- **Conn. Gen. Stat. 16-244z (2022)** establishes procurement plans for electric distribution companies and implements a set of renewable energy tariffs.[34]
- **Conn. Gen. Stat. 31-53d (2021)** states that a developer of a 2 MW or greater Class I renewable energy project shall take all reasonable actions to ensure that a community benefits agreement is entered into and take appropriate actions to ensure a workforce development program is established.[35] In Connecticut, fuel cells are included as a Class I renewable resource.
- **Executive Order 21-3 (2021)** directs DEEP to include in the next Comprehensive Energy Strategy, a set of strategies to: (1) provide for more affordable heating and cooling; (2) achieve reductions in GHG emissions from residential buildings and industrial facilities; and (3) improve the resilience of the state's energy sector.[36]
- **Conn. Gen. Stat. 22a-202 (2020)** establishes the CT DEEP Connecticut Hydrogen and Electric Automobile Purchase Rebate (CHEAPR) program, which provides support for zero emissions vehicles and hydrogen refueling, including passenger vehicles.[37]
- **The 2020 Integrated Resource Plan (2020)** discusses clean hydrogen as a strategy to reduce electric system emissions.[38]
- **Conn. Gen. Stat. 16-244y (2018)** sets a competitive process for electric distribution companies (EDCs) to acquire new fuel cell electricity generation projects with preference given to projects that (1) use equipment manufactured in Connecticut; or (2) make use of existing sites and supply infrastructure.[39]
- **Conn. Gen. Stat. 16a-3f through h (2018)** states that the DEEP commissioner may solicit proposals from providers of Class I renewable resources, including fuel cells, to provide a certain percent of EDC load.[40]
- **Conn. Gen. Stat. 16-244x (2016)** establishes a pilot program to support the development of shared clean energy facilities.[41]
- **Conn. Gen. Stat. 13b-38dd (2009)** directs the development of a zero-emissions buses implementation plan.[42]

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[33] Connecticut General Assembly (2022), Special Act 22-8.
[34] Connecticut Gen. Stat. §16-244z.
[35] Connecticut Gen. Stat. §31-53d.
[36] Connecticut Government (2021), Executive Order 21-3.
[37] Connecticut Gen. Stat. § 22a-202.
[38] Connecticut DEEP (2021), 2020 Connecticut Integrated Resources Plan.
[39] Connecticut Gen. Stat. §16-244y.
[40] Connecticut Gen. Stat. §16a-3f through h.
[41] Connecticut Gen Stat §16-244x.
[42] Connecticut Gen. Stat. §13b-38dd.

While the policies and programs mentioned above demonstrate that Connecticut is working to create the ecosystem needed to support a robust clean hydrogen economy, there is opportunity for further policy development or strengthening of existing policy commitments.

4.1.1.2 Recommendations

Additional policies, programs, funding, and other policy instruments could be established to provide clearer guidance for Connecticut's hydrogen deployment and long-term vision. Best practices and lessons learned from other jurisdictions offer a portfolio of potential actions that could be modified and applied in Connecticut, as appropriate.

The Policy and Workforce Development Working Group developed a set of policy guiding principles to align research and recommendations with existing state policy and processes related to clean hydrogen. These guiding principles stipulate that all final recommendations should:

1. Be in compliance with relevant state statutes and regulations, or identify changes that would enable compliance;
2. Align with state policy and active regulatory proceedings;
3. Identify any fundamental underlying policy or regulatory challenges, and/or potential enablers;
4. Identify expected impacts to active policy proceedings; and
5. Identify or recommend relevant regulatory stakeholder proceedings that could be used to allow for additional review and vetting or identify the need for new procedural avenues.

The policy guiding principles informed the development of potential policy recommendations and could be employed to guide further policy development in the state.

To guide the development of and achievement of economies of scale for a hydrogen ecosystem in the state, Connecticut should evaluate the applicability of best practices and lessons learned from other jurisdictions for modification in the Connecticut context. Based on an analysis of national hydrogen policy, Connecticut should consider the following enabling policy actions that would support hydrogen development and deployment across all end use applications:

- **DEEP should conduct further investigation to ultimately establish a definition of clean hydrogen that would be most appropriate for Connecticut**. While hydrogen can be produced from fossil fuels via steam methane reformation, from electricity via electrolysis, or from organic sources, these sources have differing levels of GHG emissions associated with production. Many countries and states have established definitions of clean, green, renewable, or low-carbon hydrogen to differentiate hydrogen with lower GHG emissions intensity (as seen in Table 5) and the federal government has similarly suggested a definition based on life cycle emissions. Such definitions can provide clarity for hydrogen development within the state and will help to guide project and fuel eligibility for siting, funding, tariff regulation, and other actions and initiatives referenced in this report.

- **DEEP should clarify and work with relevant agencies and stakeholders to explore the acceleration of permitting for clean hydrogen infrastructure, while ensuring appropriate guardrails to avoid unintended adverse impacts.** To scale development at the speed needed to transition to a clean economy, it is important to ensure that permitting requirements are transparent and readily understood by all stakeholders. An example of work that supports this goal is the Governor's Office of Business and Economic Development in California, which published the "Hydrogen Station Permitting Guidebook" with the explicit goal of streamlining the permitting process.[43] In addition to permitting, statutory authorization to build infrastructure, including that of LDCs, should be addressed to ensure coordinated and regulated build-out.
- **DEEP should require feedback and guidance from the Connecticut Equity and Environmental Justice Advisory Council (CEEJAC) to advance community impact, environmental justice, and energy equity discussions on hydrogen and to support the development of a framework that outlines both a vision and goals for Connecticut's clean hydrogen policies.** In California, community impacts have been taken into account through the creation of advisory boards and other programs through state agencies, including the California Air Resources Board (CARB).[44,45] Engaging with communities, especially those that have been disadvantaged or underrepresented, is a critical step in ensuring the transition to a clean economy is one that is inclusive, just, and sustainable.
- **DEEP should lead interstate and interagency coordination to develop a hydrogen roadmap and strategy that identifies hydrogen supply and demand scenarios; approaches to a clean hydrogen backbone to enable cost-effective scaled transport; and other research and infrastructure investment opportunities to inform policy development and funding and RD&D strategy, in consultation with ecosystem stakeholders.** With the announcement of the DOE's Regional Clean Hydrogen Hubs program (H2Hubs), it will be essential for Connecticut to have interagency and regional collaboration to effectively compete for the $8 billion available for regional clean hydrogen hubs.[46] DEEP should work with other state agencies in Connecticut and in coordination with other states in the region. Connecticut can look to the DOE's National Clean Hydrogen Strategy and Roadmap as a guide, and then use a similar or adapted methodology at the state level. Similarly, Connecticut can consider state reports, like the Oregon Department of Energy's renewable hydrogen report that seeks to identify where renewable hydrogen can be most useful in its decarbonizing economy. Connecticut's vision can build on work done and input provided to the Task Force, and ideally would include an examination of the following factors:
    - Current technologies available for hydrogen transport
    - The role of hydrogen transport costs in overall delivered cost
    - Cost and funding mechanisms for any enabling infrastructure and clean hydrogen production

[43] California Governor's Office of Business and Economic Development (2020), Hydrogen Station Permitting Guidebook.
[44] California Air Resources Board, Environmental Justice Advisory Committee.
[45] California Public Utilities Commission, Disadvantaged Communities Advisory Group.
[46] United States Department of Energy Office of Clean Energy Demonstrations, Regional Clean Hydrogen Hubs.

- The cost and availability of zero-carbon renewable energy resources to produce clean hydrogen via electrolysis
- Alignment with state policies and goals
- Alignment with regional hub activities
- Stakeholder feedback, and especially community preferences

- **State agencies should identify appropriate leads to coordinate on hydrogen safety with local and federal organizations to allow for alignment and clear flow of best practices, policy developments, trainings, and certifications**. Connecticut can consider adopting and/or developing codes and standards to ensure safe operation, handling, and use of hydrogen and hydrogen systems. Jurisdictions could also consider (1) benchmarking existing testing for safe hydrogen sensors that detect leaks and monitor hydrogen purity and (2) developing codes and standards for buildings and equipment in commercial, industrial, and transport applications, if not already in place. To this end, Connecticut can look to the federal code and standards set by the DOE to inform processes.[47]

Further, Connecticut should consider the following enabling policy actions that would provide targeted support for the highest priority end use applications identified by the Uses Working Group, as discussed in Section 4.1.7.

- **DEEP should explore market-based approaches to incent reductions in the carbon intensity of fuels for mobility end use applications.** For example, the California Air Resources Board (CARB) has established a Low Carbon Fuels Standard (LCFS), which aims to lower the lifecycle intensity of the transportation sector using a carbon crediting system.[48] This program additionally includes a provision that covers Hydrogen Refueling Infrastructure.[49] In Connecticut, ensuring that fuel reduction measures are applicable to medium- and heavy-duty vehicles will be integral for supporting the use of hydrogen in this hard-to-decarbonize and high priority category.[50]
- **DEEP should identify and potentially expand clean transportation incentives to include on-site port handling equipment, harbor crafts, and ocean-going vessels, in collaboration with other state and federal agencies.** California, through CARB, lists a variety of funding opportunities for clean commercial harbor craft and equipment.[51] One notable funding opportunity, hosted by the California Energy Commission, awards up to $12.6 million for demonstration projects of hydrogen fuel cell systems and hydrogen fueling infrastructure for commercial harbor craft, with the goal of "advance[ing] technologies that can enable ports as high throughput clusters for low-cost and low-carbon hydrogen and achieve scaled demand across multiple

[47] United States Department of Energy, Hydrogen Program Codes and Standards.
[48] California Air Resources Board (2020), Low Carbon Fuel Standard.
[49] California Air Resources Board , LCFS ZEV Infrastructure Crediting.
[50] The medium- and heavy-duty category includes vehicles with various use-cases, some of which may be more appropriate for electrification, while others, such as long-haul heavy-duty trucking, are more difficult to electrify and are therefore more challenging to decarbonize.
[51] California Air Resources Board (2020), Funding Programs for Commercial Harbor Crafts.

applications."[52] Launching similar funding opportunities can help send strong market signals to ensure hydrogen can be integral to decarbonizing these hard-to-decarbonize sectors.

- **The Legislature should evaluate broader policies that would facilitate the decarbonization of hard-to-electrify sectors, including long-haul heavy-duty trucking, aviation, shipping, and industrial processes.** For example, in California the legislature has a net-zero GHG emissions mandate by 2045. To support the achievement of this mandate, California's legislature passed Assembly Bill 1322, which would require the CARB to develop and implement a plan to reduce GHG emissions associated with aviation, including a sustainable fuels target for the aviation sector of at least 20% by 2030.[53] Within this bill, hydrogen is included as a sustainable fuel. Although Bill 1322 was ultimately not signed by California's governor, it nonetheless provides an example of potential measures to establish sector-specific targets to help facilitate the decarbonization of hard-to-electrify sectors where hydrogen can play an integral role.
- **The Legislature should consider tax exemptions for hydrogen vehicles and critical facilities that produce or use clean hydrogen**. By making hydrogen or fuel cell vehicles exempt from state taxes, the price of these vehicles becomes more cost-competitive with other vehicle types and can thereby generate market momentum. For example, the State of Washington, via its Department of Revenue, implemented a sales and use tax exemption for fuel cell vehicles as of July 2022.[54] Connecticut could also explore implementing a similar tax exemption through its Department of Revenue Services. A recent, and unprecedented, example is the federal government's implementation of a hydrogen production tax credit (Section 45V) in the Inflation Reduction Act, which provides a credit of up to $3 per kilogram of hydrogen for qualified clean hydrogen that results in a lifecycle greenhouse gas emissions rate less than or equal to 4 kilograms of CO_2 emissions per kilogram of hydrogen.[55] While this is a federal tax provision and does not target critical facilities specifically, it could be considered as a guide for Connecticut. Use of market signals and incentives can make clean hydrogen production more cost-competitive with other fossil fuel sources.

4.1.1.3 Stakeholder Feedback

During the identification of existing Connecticut decarbonization policy, including hydrogen-related policies, stakeholders helped to determine potential gaps and areas for further action. They also provided feedback regarding identified policies that were deemed not to be relevant to the development of a hydrogen economy or programs that were no longer in existence.

Notably, PURA has provided clarity on the scope of its statutory authority regarding hydrogen. PURA noted that Title 16 does not directly address the production, sale, or distribution of hydrogen gas. However, the language in statutes related to gas companies and natural gas is fairly broad and could be interpreted as extending PURA's jurisdiction to include the distribution of hydrogen by local

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[52] California Energy Commission (2020), Hydrogen Fuel Cell Demonstrations in Rail and Marine Applications at Ports.
[53] California Legislature (2022), AB-1312: California Global Warming Solutions Act of 2006: aviation greenhouse gas emissions reduction plan.
[54] Washington State Department of Revenue, Tax Incentive Programs.
[55] United States Legislature (2022), H.R.5376 – Inflation Reduction Act of 2022.

distribution companies (LDCs) and by other entities. PURA further noted that relevant statutes may require revision to further clarify PURA's role in regulating hydrogen.[56]

Multiple stakeholders, including the Environmental Advocates[57] and the Connecticut Roundtable on Climate and Jobs, expressed concerns regarding the emissions impacts that may result from uncertainty around a definition of hydrogen and identified a policy framework as a potential tool to address these concerns.[58] However, discussion around a definition of clean hydrogen revealed a range of opinions among stakeholders on how to align a state definition with existing regional and federal approaches, which is further discussed in Section 4.2.1. Representatives from the Connecticut DEEP expressed the need for further investigation into what definition would be most valuable for Connecticut before recommending any specific definition and noted that such analysis will be undertaken throughout DEEP's Comprehensive Energy Strategy (CES) process.[59]

The Environmental Advocates also noted there is considerable ambiguity as to which existing regulations are applicable to hydrogen on the state and federal level and specifically noted a lack of regulation for hydrogen end uses.[60] Building on concerns about a lack of regulatory certainty, Eversource noted that a stable regulatory structure that enables the siting and development of clean hydrogen projects will be a key aspect in ensuring that projects can be developed within a reasonable timeline in response to the environmental, safety, and economic concerns voiced by disadvantaged communities.[61]

Eversource recommended that policies be instituted in a way that promotes the development of a clean hydrogen economy rather than attempting to pre-determine any particular end use. Further, Eversource noted that in order to implement hydrogen solutions and facilitate ecosystem development, the state may need to assess the need for modifications or amendments to existing laws and regulations, including those related to the natural gas industry and the role for LDCs. As an example, Eversource cited recent action taken by New York to amend its energy-related legislation to allow LDCs to participate in the alternative fuels sector and suggested that Connecticut may need to consider similar measures.[62]

Other stakeholders recommended specific policies and incentives that should be developed. CCAT recommended that relevant policies and incentives should include commitments to build a broad and complete energy supply chain, develop training and workforce resources, establish and support institutional centers to conduct world class research, provide leadership to demonstrate and deploy technologies for multiple user classes in critical markets, and provide in-kind and monetary cost

[56] Connecticut Public Utilities Regulatory Authority (2022), Comments to the Hydrogen Task Force, p.2.
[57] The Environmental Advocates include Conservation Law Foundation, Sierra Club, the Nature Conservancy in Connecticut, Acadia Center, Save the Sound, Eastern CT Green Action, and People's Action for Clean Energy.
[58] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Policy Working Group Meeting #2.
[59]Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Policy Working Group Meeting #3.
[60] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 13.
[61] Eversource (2022), Comments to the Hydrogen Task Force, p. 2-3.
[62] *Ibid.,* p. 6.

share for federal grant applications.[63] Bloom Energy recommended the addition of hydrogen generated from carbon free energy sources such as wind, solar, and nuclear to be Renewable Portfolio Standard Class I eligible under Connecticut statute and establishing protocols for hydrogen to be used in the energy sector, particularly in decarbonization of the existing natural gas system and long-term energy storage to aid in further electric grid decarbonization.[64] FuelCell Energy encouraged the consideration of methods to motivate investment within the state through incentives such as tax credits and/or carbon capture credits, both for the price of carbon captured per kilogram and for the price of carbon emissions reduced per ton as well as incentives or grants to expand in state manufacturing.[65]

The importance of community-based recommendations was emphasized by several stakeholders, including the Environmental Advocates, FuelCell Energy, Eversource, CCAT, and Bloom Energy, as discussed further in Section 4.2.3. In written comments, PURA also noted that Public Act 21-43 provides a policy framework for involving disadvantaged communities, as both participants and beneficiaries, through community benefit agreements, and suggested that the Task Force may consider recommendations that build upon Public Act 21-43, which currently applies only to hydrogen in its capacity to power fuel cell generation.[66]

Finally, several stakeholders provided comments regarding the creation of tax exemptions for hydrogen vehicles which is further discussed in Section 4.1.6.3.

4.1.2 Recommendations for workforce initiatives to prepare the state's workforce for hydrogen fueled energy-related jobs.

4.1.2.1 Findings

Hydrogen infrastructure has many similarities to fossil fuel infrastructure, and therefore presents a unique opportunity to repurpose and retrain the existing fossil fuel workforce to enable participation in the state's clean energy transition. Skillsets such as pipefitting, boiler making, and electrical wiring are relevant for hydrogen and existing training programs can be deployed or expanded to facilitate the development of a skilled hydrogen workforce in Connecticut. Through this lens, there is significant opportunity to repurpose, retrain, or upscale workers, while also leveraging the state's expertise in hydrogen technologies, fuel cell manufacturing, and insurance.

Existing training and apprenticeship programs and local labor unions in Connecticut provide a framework through which job training can potentially be expanded and leveraged as necessary to include new skillsets related to the development of hydrogen projects. The Connecticut State Building Trades (CSBT) Council and its affiliates provide 17 joint apprenticeship training programs to prepare workers in building and construction trades,[67] and the Connecticut Department of Labor's Office of

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[63] Connecticut Center for Advanced Technology (2022), Comments to the Hydrogen Task Force, p.7.
[64] Bloom Energy (2022), Comments to the Hydrogen Task Force, p. 4.
[65] FuelCell Energy (2022), Comments to the Hydrogen Task Force, p. 6.
[66] Connecticut Public Utilities Regulatory Authority (2022), Comments to the Hydrogen Task Force, p.3.
[67] Connecticut State Building Trades.

Apprenticeship Training facilitates registered apprenticeship programs across a variety of industries.[68] The Northwest Regional Workforce Investment Board additionally offers job training in manufacturing and engineering through the Apprenticeship Connecticut Initiative to develop a workforce pipeline in partnership with local community colleges, high schools, employers, and the Manufacturing Service Corporation.[69] These and other programs can be applied and expanded to accommodate future needs and aid in workforce transition.

Executive Order 21-3 established the Connecticut Clean Economy Council (CCEC) to advise on strategies and policies to strengthen the state's climate mitigation, clean energy, resilience, and sustainability programs to lower emissions and advance economic and environmental justice.[70] The CECC shall include leaders across several state agencies, including DECD, DEEP, the Office of Policy and Management, DOT, OWS, and the Office of the Governor, as well as the Connecticut Green Bank and Connecticut Innovations. Among other duties, the council is tasked with efforts to inform the needs for workforce training programs, identify approaches to deploy funding to scale economic opportunities, and support diverse and equitable participation in sectors within the fields of climate and sustainability. The CCEC provides a mechanism for advancing workforce development initiatives related to hydrogen through coordination and partnership from multiple state government and industry stakeholders.

[68] Connecticut Department of Labor Office of Apprenticeship Training, Work Schedules - Apprenticeable Trades.
[69] Northwest Regional Workforce Investment Board, Manufacturing Your Future with ACI.
[70] Connecticut Executive Order No. 21-3 (2021).

Ensuring a Just Transition – A Labor Perspective
Aziz Dehkan, Executive Director, Connecticut Roundtable on Climate and Jobs

How has the Roundtable been approaching the topics of equity, workforce development, and environmental justice related to energy?
The Roundtable led an effort to pass Public Act 21-43 "An Act Concerning a Just Transition to Climate-Protective Energy Production and Community Investment" to emphasize the importance of community investment and engagement. This legislation emerged from an experience with a project in East Windsor that did not include a community benefits agreement or prevailing wages, which does not create a level playing field for local labor. We attempted to engage with the developer but did not have success and realized that engaging on a project-by-project basis would not be sustainable. That experience led to Senate Bill 999 (eventually Public Act 21-43), which states that "the developer of a covered project shall (1) take all reasonable actions to ensure that a community benefits agreement is entered into with appropriate community organizations representing residents of the community in which the project is or will be located if the nameplate capacity of the project is five megawatts or more, and (2) take appropriate actions to ensure a workforce development program is established." A "covered project" means a renewable energy project that is situated on land in this state, commences construction on or after July 1, 2021, and has a total nameplate capacity of two megawatts or more. A "covered project" does not include any renewable energy project (A) selected in a competitive solicitation conducted by (i) the Department of Energy and Environmental Protection, or (ii) an electric distribution company, as defined in section 16-1 of the general statutes, and (B) approved by the Public Utilities Regulatory Authority prior to January 1, 2022.

How would you advise developers of hydrogen and fuel cell projects on the importance of community engagement and local workforce development?
The community needs to be heard and a clear process with transparency should be undertaken on the part of the developer. It is important to have an open dialogue because most communities want involvement, but this needs to be enforceable on the part of the developer.

Of note, transportation to and from job sites is not always available to local workers and underscores the importance of community engagement initiatives in workforce development. Community outreach and engagement are beneficial for developing local workforce capability and for understanding community needs and providing avenues to address these needs. Engagement with community leaders and groups provides additional pathways to connect local workers with training and upscaling efforts and presents an opportunity to reach populations that have traditionally been underrepresented in the energy workforce and the broader economy.

Community benefit agreements have been identified by environmental justice and just transition experts as a critical tool for creating local job opportunities. Key provisions can include commitments to use the local workforce, offer prevailing wages, and partner with existing apprenticeship and training programs. Public Act 21-43 includes requirements for community benefit agreements, prevailing wages, and workforce development plans for covered Class I renewable energy projects of 2 MW or greater and can potentially serve as a template for the expansion of policies to facilitate community engagement and local workforce development associated with hydrogen projects.

4.1.2.2 Recommendations

Recommendations related to workforce development were informed by Task Force and Working Group activities and conversations with local experts, including representatives from the CSBT Council, who gave a presentation during the October Policy & Workforce Development Working Group meeting in which they shared examples of successful workforce training programs in Connecticut and discussed offerings through the Connecticut State Building Trades Training Institute (BTTI).[71] Representatives from the CSBT also described plans for the BTTI to expand and provide training for careers in renewable energy.

Preparing Connecticut's hydrogen workforce can be advanced through development of a skilled labor pool, ideally converting existing fossil fuel jobs and creating opportunities to reach and involve traditionally underrepresented populations, while leveraging and building upon the state's existing expertise in hydrogen-related technologies and the insurance industry. The following actions should be considered for workforce development in Connecticut:

- **The OWS should lead coordination – in partnership with UCONN; community colleges; vocational high schools; regional comprehensive universities; Workforce Investment Boards; trades with expertise in hydrogen technologies and relevant skillsets; labor-led workforce development programs and training programs; LDCs, EDCs, and other employers; and any other relevant workforce or training programs – between existing entities such as the Governor's Workforce Council and DEEP to establish a comprehensive program for engagement with local experts to understand workforce development needs and potential specific to hydrogen and hydrogen technologies such as fuel cells and electrolyzers as well as upstream suppliers.** This engagement can occur through appropriate existing venues, such as the Clean Economy Council, established through Executive Order 21-3. Connecticut has extensive experience in hydrogen and related skillsets, and outreach and partnerships with the trades, academia, native hydrogen and fuel cell companies, electric and gas utilities, and local community groups can inform steps to prepare the state's workforce. This effort should:
    - Specifically identify areas of the workforce that are expected to be disproportionately impacted by the state's clean energy transformation and determine existing applicable roles and skillsets, including those that support LDC and EDC operations, to understand the opportunities to repurpose, retrain, or leverage members of the workforce to enable a just transition.
    - Leverage existing frameworks and expand programs to increase training of overlapping job skillsets that can be applied in a hydrogen economy. In addition, this process should explore opportunities to introduce dedicated hydrogen training into initiatives offered through the trades and the Connecticut State Building Trades Training Institute, along with other apprenticeship programs registered with the Department of Labor. Training efforts should include the identification and development of key competencies and the potential for trade certifications for the

[71] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Policy Working Group Meeting #2.

clean hydrogen industry. Increased emphasis should be placed on establishing or expanding programs to support the workforce in Connecticut's native fuel cell industry, which has a strong footprint within the state and offers a competitive advantage in regional, national, and global markets.

- Include workforce development in local engagement activities, and as part of a broader effort to develop a community impacts framework that outlines both a vision and goals to be incorporated into hydrogen policy development.
- Solicit guidance through the CECC, and from CEEJAC and other partners, to establish a working group of state and local government representatives, environmental justice groups, and community representatives to further address hydrogen related topics.
- For project-specific engagement with communities, groups, institutions, and other partners, outreach efforts should begin as early as possible and guarantee opportunities for involvement are accessible for local stakeholders at times and locations intended to enable participation.
- Continue to pursue workforce diversity to leverage targeted funding available for hydrogen-related training initiatives. For example, DOE's Hydrogen and Fuel Cell Technologies Office is providing $2 million in funding to build a talent pipeline for scientists and engineers from Historically Black Colleges and Universities and Other Minority Institutions to support hydrogen workforce development.[72]

- **The OWS should partner with relevant state agencies and UCONN; community colleges; vocational high schools; regional comprehensive universities; Workforce Investment Boards; trades with expertise in hydrogen technologies and relevant skillsets; labor-led workforce development programs and training programs; LDCs, EDCs, and other employers; and any other relevant workforce or training programs to further advance the development of a skilled hydrogen workforce and durable supply chain.** Through coordination with Connecticut's existing expertise, a pipeline of workers from universities, community colleges, and vocational schools could be created to support the design, engineering, marketing, coordination, and deployment of hydrogen and related assets in the state. Coordination across these groups, and with industry, is critical and a roadmap should be developed to connect these resources to ensure proactive planning.
- **UCONN, working in collaboration with community colleges; vocational high schools; regional comprehensive universities; Workforce Investment Boards; trades with expertise in hydrogen technologies and relevant skillsets; labor-led workforce development programs and training programs; LDCs, EDCs, and other employers; and any other relevant workforce or training programs, should identify opportunities to support development of the hydrogen workforce and advance research and development in hydrogen electrolyzers and hydrogen fuel cells, and should identify resources and funding needs to implement and contribute to the development of a hydrogen roadmap led by DEEP**. Such actions would build upon Connecticut's deep expertise and further position the state as a leader in these technologies for regional, national, and global market opportunities.

[72] U.S. Department of Energy National Energy Technology Laboratory (2022), NETL Announces Additional $2 Million to Prepare Tomorrow's Clean Energy Innovators.

- **The Legislature should consider amending requirements for community benefit agreements, through Public Act 21-43, to lower the minimum project size from 2 MW to 1 MW, explicitly note the inclusion of hydrogen, and consider the development of similar requirements for all hydrogen projects.** This would not only support alignment with and maximization of federal investment and production tax credits and associated prevailing wage and apprenticeship requirements, but would also provide additional avenues for creating job opportunities locally, by allowing for the expansion of eligible included projects. As part of this process, the Legislature should examine the benefits of including hydrogen specifically or the potential for further actions to develop more comprehensive requirements for community benefit agreements across a broader range of projects involving hydrogen.
- **The Legislature should provide funding to increase community engagement and decrease the burden of engagement on communities.** This may include compensation for community participation in hydrogen-related proceedings and funding for time, resources, and technical expertise for the development of community benefit agreements that provide opportunities for local jobs. Additional funding should be considered for overcoming transportation challenges in enabling community members to access and work at local job sites for projects involving or relevant for the state's hydrogen economy.
- **Eligible entities should pursue federal funding for manufacturing capabilities for electrolyzers and hydrogen fuel cells, to further advance development in the state**. These efforts would support Connecticut's strong native fuel cell industry and related workforce and offer an opportunity to build a competitive advantage for the state in regional, national, and global markets for hydrogen development. Entities should communicate with the Legislature regarding obstacles and barriers related to federal funding, and the Legislature should consider matching of federal dollars, as outlined in Section 4.1.3.2, and may consider exploring additional incentives to promote the expansion of manufacturing in Connecticut, benchmarked against actions taken in other states. Further coordination with existing training and apprenticeship programs will be critical to developing a hydrogen workforce.
- **With regard to hydrogen infrastructure insurance, steps should be taken to ensure clear rules and policies for hydrogen infrastructure to support insurance industry workforce opportunities**. Such actions would support insurance industry workforce opportunities and enable standardized hydrogen insurance products that can be marketed nationally. Hydrogen is still relatively new for the insurance industry, and efforts to support innovative and detailed approaches to risk assessment and underwriting would boost Connecticut's position as a leader in the insurance industry.

4.1.2.3 Stakeholder Feedback

Industry stakeholders such as Nel Hydrogen and FuelCell Energy have identified workforce development as a key area where the state can play an important role. FuelCell Energy noted the tight labor market and that skilled workers will be needed in the manufacturing facilities that make hydrogen production equipment, and in hydrogen production and distribution facilities and infrastructure.[73] Representatives from the Connecticut State Building and Construction Trades

[73] FuelCell Energy (2022), Comments to the Hydrogen Task Force, p. 6.

Council emphasized the importance of including fossil fuel workers in the clean energy transition. They suggested that some skillsets required for fossil fuel jobs, such as pipefitters and boilermakers, could be directly transferrable to hydrogen-related roles.[74]

PURA emphasized that the state should focus funding on building foundational workforce resources that will support the projects being funded with federal dollars. In particular, the state should work to address training and certification gaps that are either not provided or not available at the scale needed by private industry.[75]

Another common theme in stakeholder feedback has been the desire for a stronger equity component in workforce development recommendations. The Environmental Advocates stated that Connecticut should focus on creating targeted clean hydrogen workforce development opportunities for populations that face systemic discrimination or are underrepresented in the workforce, including women, minorities, people with English as a second language or limited English proficiency, and formerly incarcerated individuals. They also emphasized that hydrogen-related career pathways should also be made available to people who currently work in the fossil fuel industry.[76]

The Environmental Advocates also recommended that training and apprenticeship programs could be established at community colleges and technical high schools or training institutes. They noted that it may be most efficient for hydrogen workforce development initiatives to be integrated into broader clean energy training programs, rather than setting them up as standalone programs. This would limit the risk of new trainees having trouble finding employment in a particular field or sector, for example, if the deployment of a particular technology or approach does not occur as quickly as expected.[77]

Other key topics mentioned by stakeholders regarding workforce development included project labor agreements, prevailing wages, and ensuring a just transition. Representatives of the Greater Bridgeport Community Enterprises and the Connecticut Roundtable on Climate and Jobs advocated the importance of environmental justice and community engagement in economic development work, noting that a supportive community atmosphere can encourage local job growth.[78]

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[74] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Policy Working Group Meeting #2.
[75] Connecticut Public Utilities Regulatory Authority (2022), Comments to the Hydrogen Task Force, p. 6.
[76] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 6.
[77] *Ibid.*
[78] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Policy Working Group Meeting #2.

4.1.3 An examination of how to position the state to take advantage of competitive incentives and programs created by the federal Infrastructure Investment and Jobs Act.

4.1.3.1 Findings

The IIJA was passed in November 2021 with bipartisan support. The law contains $1.2 trillion to support a wide variety of investments including power grid modernization, low- and zero-emissions vehicle infrastructure, climate resiliency, port modernization, and water infrastructure.

The IIJA has substantial opportunities that can be applied to projects across the hydrogen value chain. The IIJA contains several hydrogen-specific provisions and funding opportunities. For example, the law includes $8 billion towards the development of regional clean hydrogen hubs,[79] $1 billion towards electrolysis research, development, and demonstration, and $500 million towards clean hydrogen technology manufacturing and recycling RD&D.[80] Further, this law includes additional provisions that can be applied towards deployment of equipment and infrastructure for the end-use of hydrogen. For example, it contains $2.5 billion for Charging and Fueling Infrastructure Grants that may support development of hydrogen fueling stations for mobility applications, $2.25 billion in Port Infrastructure Development Program Grants, and funding directed towards additional end uses.[81]

In an examination of how to position the state to take advantage of competitive incentives and programs in the IIJA, the Funding Working Group identified the following key areas of focus: (1) the importance of prioritizing community engagement and ensuring benefits to Disadvantaged Communities in adherence to the Justice40 Executive Order and (2) the need to identify and maximize sources of non-federal funding to meet grant match requirements.

Justice40 Coverage in the IIJA: Community Engagement and Disadvantaged Communities

Many programs within the IIJA are covered by the Biden Administration's Justice40 Executive Order (EO 14008), which directs 40% of the overall benefits of certain federal incentives to flow towards disadvantaged communities (DACs).[82] To be considered as a DAC, a census tract must rank in the 80th percentile of the cumulative sum of 36 burden indicators and have at least 30% of households classified as low income. Federally recognized tribal lands and U.S. territories are also categorized as disadvantaged.[83] The White House has published a list of all programs covered under Justice40.[84]

Figure 5. Disadvantaged Communities in Connecticut per U.S. Department of Energy's Definition

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[79] United States Department of Energy Office of Clean Energy Demonstrations, Regional Clean Hydrogen Hubs.

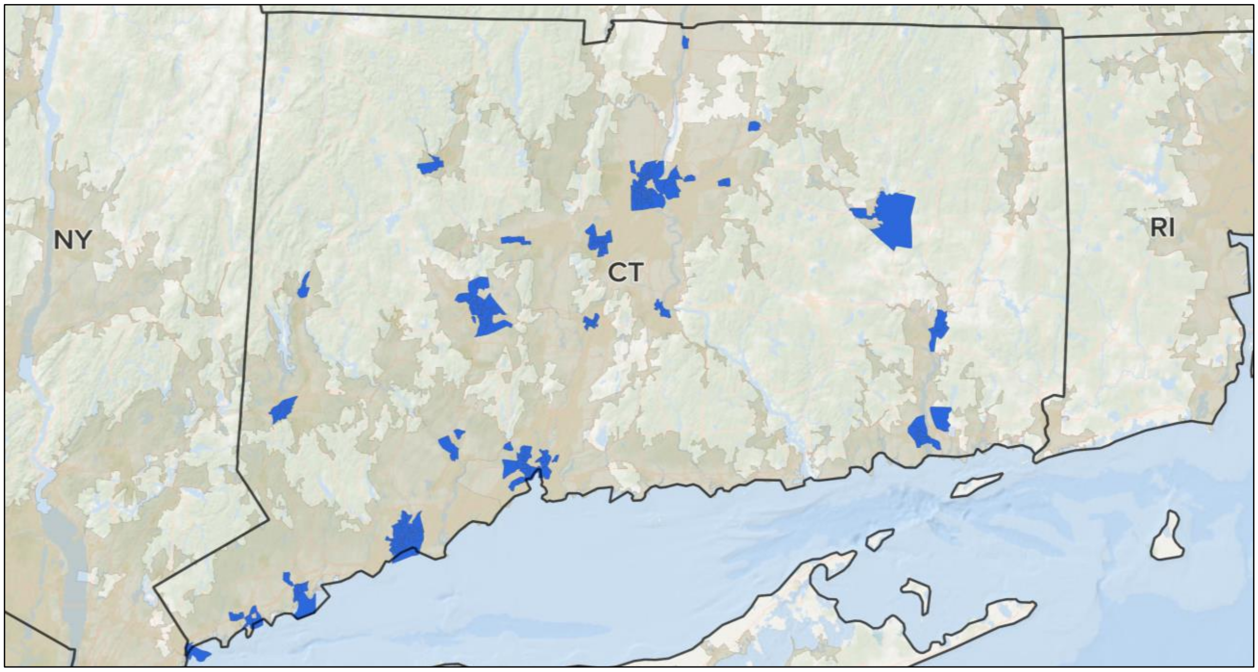
[80] Pillsbury Winthrop Shaw Pittman LLP (2021), Hydrogen Highlights in the Bipartisan Infrastructure Bill.

[81] For a thorough overview of opportunities that may be applied to hydrogen in the IIJA, please refer to Appendix D.

[82] Executive Office of the President, Office of Management and Budget (2021), Interim Implementation Guidance for the Justice40 Initiative.

[83] White House, Justice40.

[84] White House (2022), Justice40 Initiative Covered Programs List.



Source: White House Justice40 Initiative.

Justice40 is being implemented in federal programs to ensure DACs receive the benefits of federal investments under the covered categories. For example, the Funding Opportunity Announcement for H2Hubs includes a Community Benefits Plan accounting for 20% of the proposal scoring criteria, in which applicants must demonstrate how they will:

- Carry out meaningful community and labor engagement;
- Invest in the American workforce;
- Advance diversity, equity, inclusion, and accessibility; and
- Contribute to the Justice40 Initiative goal that 40% of the overall climate and clean energy investments flow to disadvantaged communities.[85]

These Community Benefits plans will be evaluated based upon a variety of factors, including their ability to measure and track impacts, the ability to specifically demonstrate how the H2Hub will provide societal benefit while minimizing negative impacts, support from Workforce and Community Agreements, the presence of communities as core partners, and more.

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[85] Latham and Watkins (2022), DOE Releases Draft Clean Hydrogen Production Standard, Draft Roadmap, and Hydrogen Hub Funding Opportunity.

Environmental Justice and Community Engagement – A Community Perspective
Adrienne Farrar Houl, the President and CEO of Greater Bridgeport Community Enterprises

Can you tell us about Bridgeport and its participation in the Department of Energy's Communities LEAP program?
As an old industrial city, Bridgeport has a long history of industrial abuse of our local environment. The Connecticut Department of Energy and Environmental Protection identifies Bridgeport as an Environmental Justice community and our Department of Economic Development has designated Bridgeport a Distressed Community. About 20% of households in Bridgeport are below the poverty level, leading to a significant energy burden at 6.2%. Over a year ago, the Bridgeport Regional Energy Partnership (BREP) was created to facilitate state and federal funding and investment in clean and renewable energy in our community. Working with Operation Fuel, Connecticut Green Bank, the City of Bridgeport, and the Bridgeport Regional Business Council, we recruited over 40 community organizations to form BREP. With founding organizations, we sought DOE technical assistance for community-driven, city-wide energy planning, and Bridgeport was selected as one of 24 cities across the country for the Communities Local Energy Action Plan (LEAP) pilot program. Three pathways were selected to pursue clean and renewable energy projects and programs:

- *1. Energy Efficiencies to Reduce Energy Burdens (in the built environment)*
- *2. Clean Energy Planning and Development including Resiliency and Transportation*
- *3. Advanced Manufacturing, Energy-Focused Workforce and Supply Chain Development*

BREP will develop community environmental benefit agreements to ensure community and producer/developer consensus as each project must satisfy criteria defined by our community.

How should the Task Force and the Northeast Regional Clean Hydrogen Hub be thinking about environmental justice and community engagement?
Communities in Connecticut understand the extent of their energy burdens but need support in developing comprehensive plans to address them. As a first step, criteria to identify the components of positive community impact must be determined. Therefore significant, planned community outreach is needed, which requires expansive skillsets and relevant messaging support. Funding will be needed for recruitment to engage and support skilled personnel in this area. It is important for the community to acquire a certain level of technical understanding so that they can generate a comprehensive plan that accurately expresses community needs and identifies the best solutions that meet defined criteria. Best practices from neighboring states may be leveraged since many are navigating similar issues, including initiating community environmental benefits.

Connecticut is well-positioned to be a first mover in bringing the vision of Justice40 to reality, with its strong existing commitments to a just energy transition. These existing relationships can provide a channel for strong collaboration with communities around IIJA activities. Examples of Connecticut's leadership in community engagement include:

- **S.B. 999 (Public Act 21-43): Ensuring Community Benefit Agreements for Energy Projects:** This landmark state legislation is the first of its kind, codifying the industry best practice for community engagement. It ensures that host communities for Class I renewable energy projects (including fuel cells) ≥2MW receive real benefits by requiring developers to negotiate community benefits agreements.[86]

- **Executive Order No. 21-3: DEEP Environmental Justice Advisory Council:** Connecticut established an avenue for meaningful and direct feedback on issues such as permitting, equitable program delivery, and more. "[T]he purpose and mission of the CEEJAC is to advise the Commissioner of DEEP on current and historic environmental injustice, pollution reduction, energy equity, climate change mitigation and resiliency, health disparities, and racial inequity."[87]
- **Bridgeport Selected to Participate in the Communities LEAP Program:** Bridgeport, CT was one of 24 selected communities that will work with U.S. DOE, national labs, and other experts, community-based organizations, utilities, environmental organizations, economic development organizations, equity organizations and others to develop roadmaps for clean energy economic development pathways.[88]

Match Funding Requirements in the IIJA and Sources of Non-Federal Matching

Many IIJA funding opportunities require applicants to commit varying levels of non-federal match funding. For example, the H2Hubs application requires a 50% non-federal cost share requirement, while many of the clean transportation grants and programs only require 10 – 20%.

Sources that are eligible for match funding include: [89]

- Third-party financing;
- State or local government funding or property donations;
- Project participant funding; and
- Donation of space or equipment.

Sources that cannot be used for cost sharing include:[90]

- Any partial donation of goods or services;
- Revenues or royalties from the prospective operation of an activity beyond the project period;
- Proceeds from the prospective sale of an asset of an activity;
- Federal funding or property (e.g., federal grants, equipment owned by the federal government); or
- Expenditures that were reimbursed under a separate federal program.

Thus, based on match funding guidance, state sources could include:

- Funding from existing hydrogen-related programs;
- Funding from newly established hydrogen-related programs;
- Funding from participating developers;

[86] Connecticut General Assembly (2021), Public Act 21-43.
[87] Connecticut DEEP, Connecticut Equity and Environmental Justice Advisory Council.
[88] United States Department of Energy, LEAP Communities.
[89] Department of Transportation (2022), Understanding Non-Federal Match Requirements.
[90] United States Legislature (2021), Infrastructure Investment and Jobs Act.

- Legislative appropriations;
- Local government funding;
- Donations of property from the government; and
- Donations of property or equipment from participating partners.

Connecticut has several eligible programs, which may be explored for potential eligibility to serve as non-federal matching funds needed for many grants in the IIJA. Existing programs for consideration include but are not limited to the following examples in Table 2.

Table 2: Connecticut Programs Potentially Eligible for IIJA Match Funding

Program	Administrator	Description
Smart-E Loans	CT Green Bank	Provides low-interest financing with flexible terms for home energy performance upgrades
C-PACE	CT Green Bank	Provides building owners access to affordable, long-term financing for qualifying clean energy and energy efficiency options
Capital Solutions	CT Green Bank	Seeks to provide access by project developers and capital providers or investors to Green Bank capital
Brownfield Remediation Grants and Loans	DECD	Provides loan financing or grants to eligible entities for costs associated with the investigation, assessment, remediation, and development of a brownfield
The Manufacturing Innovation Fund Apprenticeship Program	DECD	Supports a combination of on-the-job training and classroom instruction for apprentices in Connecticut's manufacturing industry
The Innovative Energy Solutions Program	PURA	Provides funding projects for developers and utilities to test and demonstrate technologies across the electric grid
Residential Renewable Energy Solutions	Electric Distribution Companies	Provides 20-year tariffs for residential projects (including affordable housing, providing tariff and Renewable Energy Certificate payments)
Non-Residential Renewable Energy Solutions Program	Electric Distribution Companies	Provides 20-year tariffs for commercial energy projects, providing tariff and Renewable Energy Certificate payments
Shared Clean Energy Facility Program	Electric Distribution Companies	Provides a 20-year tariff term for projects between 100kW and 4,000 kW; Credits are applied to bills of participating electric customers at no cost.
Microgrid Grants and Loans	DEEP	Helps to support local distributed energy generation for critical facilities

It is important to note that further legal analysis would be needed to understand the eligibility of these sources and different funding mechanisms to serve as match funding. For example, additional clarity is needed from relevant agencies to understand if state tax incentives and tariffs may qualify as match funding within the IIJA. As of this time, federal agencies are still working on this guidance.

4.1.3.2 Recommendations

To position the state to take advantage of competitive incentives and programs in the IIJA, Connecticut should consider the following actions:

- **DEEP should lead interstate and interagency coordination to develop a hydrogen roadmap and strategy that identifies hydrogen supply and demand scenarios; approaches to a clean hydrogen backbone to enable cost-effective scaled transport; and other research and infrastructure investment opportunities to inform policy development and funding and R&D strategy, in consultation with ecosystem stakeholders.** DEEP is supporting the Northeast's multi-state collaboration to develop a proposal to become one of the regional clean hydrogen hubs, coordinating with Connecticut entities across the hydrogen value chain. Their central role will allow them to coordinate parallel policy development and funding efforts, ensuring alignment with the regional vision.
- **The Legislature should create a transparent source for municipalities, cities, and other local applicants to access resources, such as match funding and/or application guidance.** This is being undertaken in other states to streamline the process of identifying match funding and project partners. For example, Colorado has established a Local Match Program, which allocates $80 million in state General Funds for the non-federal match requirements in the IIJA and a central webpage to inquire about funds.[91] California has a Grants Ombudsman that serves as an independent and confidential resource to help navigate the California Energy Commission grant programs.[92] A similar model could be adapted to serve as a resource for Connecticut entities on federal opportunities. Separately, California passed a state law, SB 1075, which established a California Clean Hydrogen Hub Fund within the State Treasury that could, upon appropriation, authorize match funding.[93]
- **The Legislature should consider appropriating grant funding to support federal match requirements.** This may apply to the entire value chain, including manufacturing, production facilities, and multi-sector enabling infrastructure, such as public access fueling stations for trucks, commuter buses, ports, and material handling equipment. End-uses may be prioritized based on:
    - High societal benefit and strong underlying economics for hydrogen (more information on end use prioritization can be found in the 4.1.7.2),
    - Significant federal grant opportunities with low requirements of match funding (more information can be found in Appendix D.),
    - Ability to be deployed near-term (e.g., high technology-readiness. More information on this assessment can be found in Appendix A.).

[91] Colorado Department of Local Affairs, Local Match Program.
[92] California Energy Commission, Grants Ombudsman.
[93] California Legislature (2022), Senate Bill 1075.

- **The Legislature should provide funding to increase community engagement and decrease the burden of engagement on communities.** Community benefit agreements and Justice40 requirements are important steps in creating a more inclusive and equitable energy transition, but they will require considerable time and resources from local stakeholders to engage effectively. The state can further demonstrate its support for communities by providing funding for time and resources (e.g., technical expertise and consulting services) to develop community benefits agreements.
- **DEEP and PURA should consider implementing an intervenor compensation program to increase community participation in hydrogen-related proceedings.** As an example, Minnesota, California, Idaho, Oregon, and Wisconsin all have implemented similar programs.[94]

4.1.3.3 Stakeholder Feedback

CCAT noted that continued interagency coordination and clear policy commitments will be key to obtain competitive federal funding and demonstrate Connecticut's commitment to hydrogen deployments.[95] Also noting the importance of cost sharing, stakeholders have shared ideas that include the potential of a future bond issuance from the legislature, which could provide matching grant funds to a project, if awarded, paid for through taxpayers.[96]

Stakeholders have also brought up the need for further community engagement, education, and outreach to ensure that equitable benefits are realized from a Connecticut hydrogen economy.

The Environmental Advocates have emphasized that, to increase transparency and public awareness of federal funding opportunities, the state should create a publicly accessible, searchable database with information on federal funding opportunities and the status of projects that have applied for or received funding. They highlighted that, by providing information about hydrogen funding opportunities and transparency around projects, stakeholders and the public can better engage in the development of clean hydrogen projects in Connecticut.[97] In discussing match funding opportunities in the Working Group, Sierra Club emphasized that key feedstocks should be prioritized and highlighted that further investigation is still required to learn more about environmentally appropriate uses of hydrogen.[98] Similarly, they noted that recommendations could be more specific about how the legislature can focus their efforts for match funding.

Conservation Law Foundation also noted that environmental justice advocates and allies have been concerned that Justice40 does not include race as a criterion to assess disadvantaged communities. They shared that race is one of the best predictors of which communities face disproportionate

[94] National Association of Regulatory Utility Commissioners (2021), State Approaches to Intervenor Compensation.
[95] Connecticut Center for Advanced Technology (2022), Comments to the Hydrogen Task Force, p.7.
[96] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Funding Working Group Meeting #3.
[97] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 14.
[98] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Funding Working Group #2.

environmental burdens.[99] The Conservation Law Foundation also inquired about the potential of a public-facing resource that shows the availability of federal funding and status of dispersed funding. DEEP noted that there may be interest in a resource like this, such as a web page, that compiles all the relevant information, including the initiatives of the ongoing work that organizations are doing and the related hydrogen funding opportunities.

Notably, the Regional Clean Hydrogen Hub initiative of the IIJA is unique in requiring a regional submission with many different participants. However, lessons can be learned from Connecticut stakeholders since they have experience applying to federal funding opportunities, which may be leveraged to inform applications to competitive opportunities in the IIJA. Many Connecticut stakeholders across the value chain have been active in the regional Clean Hydrogen Hub initiative by the U.S. Department of Energy (DOE), for which the first stage of applications are due in April. FuelCell Energy also noted that they also routinely apply for and receive federal funding to advance the development of their hydrogen production platforms.[100] They explained that the typical mechanism is a cost shared grant, awarded on a competitive basis. LuftCar also noted that they have been applying to DOD and DOT grants in addition to DOE grants.[101]

4.1.4 An examination of the sources of potential clean hydrogen, including, but not limited to, wind, solar, biogas and nuclear.

4.1.4.1 Findings

Strategen examined the production potential of clean hydrogen from five carbon-neutral resources – solar, onshore wind, offshore wind, biogas[102], and nuclear – that may be utilized to power water splitting technologies such as electrolysis. This analysis aimed (1) to set a ceiling for hydrogen production in Connecticut based on limitations imposed by land quantity, natural resource quality, system efficiency, and price forecasts and (2) to approximate production price points for hydrogen sourced from different types of clean energy, considering federal incentives from the IRA.

[99] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Funding Working Group Meeting #1.
[100] FuelCell Energy (2022), Comments to the Hydrogen Task Force, p. 6..
[101] LuftCar (2022), Comments to the Hydrogen Task Force, p. 2.
[102] Sierra Club and the Conservation Law Foundation have noted that the carbon intensity of biogas may differ depending on the feedstock and some feedstocks may not produce carbon neutral biogas.

Connecticut's Nuclear Resources – An Overview of Dominion's Millstone Power Station

LOCATION
Waterford, CT
EMPLOYEES
1,000
TYPE
Generator
TECHNOLOGY
Nuclear Power Plant – Pressurized Water Reactors
PRODUCTION
16,000-17,000 GWh of zero emission electricity annually with 9,000 GWh procured as a zero-carbon resource for Connecticut locking in low-cost (i.e., 4.999 cents) and long-term (i.e., 10 years) carbon-free energy
INSTALLATION
2,100 MW (863 MW from Unit 2 License through 2035; and 1,233 MW from Unit 3 License through 2045)
FUN FACT
Dominion Energy was an original investor in the second largest fuel cell project in the world in Bridgeport, Connecticut.

The siting potential of solar and onshore wind was defined using National Renewable Energy Laboratory (NREL) supply curves.[103] Offshore wind capacity potentials were also sourced from NREL,[104] and estimates for biogas supply were based on analysis by the American Gas Foundation (AGF).[105] In addition, Strategen assessed the potential to utilize curtailed electricity to produce hydrogen using levels of expected curtailment from the ISO-NE Pathways Study.[106]

Strategen developed three production scenarios for hydrogen that represented different levels of limiting assumptions for clean energy production, summarized in the table below. After assessing the total technical production potential in each scenario, Strategen subtracted the capacity that would be required to meet Connecticut's target of achieving 100% zero-carbon electricity established in

[103] NREL defines its supply scenarios as follows:
"NREL developed geospatial data showing solar and wind supply curves, which characterize the quantity and quality of such resources. The data is provided for three land access levels:
a) The **Open Access** supply curve data only applies land area exclusions based on physical constraints (e.g., wetlands, building footprints) or for protected lands.
b) The **Reference Access** supply curve data applies a wider range of exclusions and is used by default in NREL's capacity expansion modeling.
c) The **Limited Access** supply curve data applies the most restrictive land area exclusions, capturing potential increased setback requirements and difficulties deploying on federally managed lands."
More details available at https://www.nrel.gov/gis/solar-supply-curves.html
[104] Lopez, Anthony et al., National Renewable Energy Laboratory (2022), Offshore Wind Energy Technical Potential for the Contiguous United States.
[105] American Gas Foundation (2019), Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment.
[106] Schatzki, Todd, et al., ISO New England (2022), Pathways Study: Evaluation of a Pathways to a Future Grid.

Connecticut Public Act 22-5 (as outlined in DEEP's 2021 Decarbonization Integrated Resource Plan)[107] to arrive at an estimate of the total clean energy capacity that would be available for hydrogen production. More details of this analysis, including underlying inputs and assumptions, are provided in Appendix C.

Table 3: Hydrogen Production Cases

Production Case	Low Case	Mid Case	High Case
Siting restrictions for solar and onshore wind	NREL "Limited Access" Scenario	NREL "Reference Access" Scenario	NREL "Reference Access" Scenario
Offshore wind technologies allowed	Fixed bottom only	Fixed bottom only	Fixed-bottom and floating
Nuclear supply potential[108]	2.5% of Millstone's average capacity	5% of Millstone's average capacity	10% of Millstone's average capacity
Biogas supply potential	AGF "Low" Scenario	AGF "High" Scenario	AGF "High" Scenario
Curtailment forecast	In line with ISO-NE Pathways Study (Status Quo scenario)		

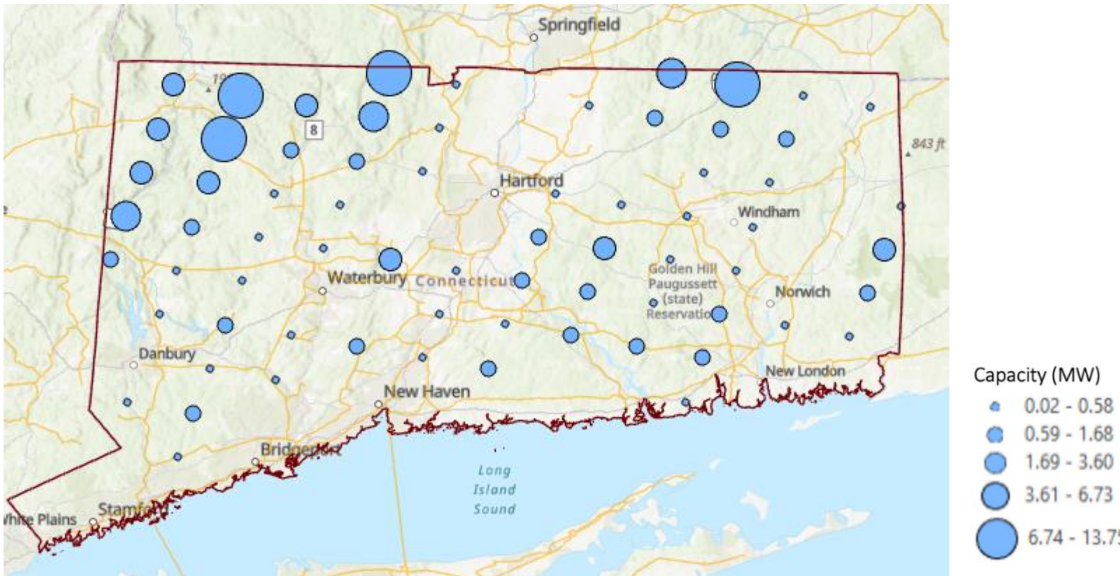
For land-based resources, the production potential for solar energy in Connecticut was determined to be the highest, significantly larger than the production potential from onshore wind. While having a much overall smaller capacity factor (16.7%) compared to onshore wind (40%), the total technical generation capacity for solar under the Low Case totaled around 30,000 MW, and around 119,000 MW under the Mid and High Cases. By contrast, the total capacity potential for onshore wind for the Low Case is around 112 MW, and 1,800 MW for the Mid/High Case. By comparison, in order to meet the state's zero-carbon electricity target, Connecticut is expected to add 2,300 MW of solar capacity and 400 MW of onshore wind capacity by 2040.

The production potential for these two resources is not evenly distributed across the state. For solar energy, the overall level of generation is highest on the east side of Connecticut, ranging from 1,443 MW to 2,544 MW in the Mid Case. The potential is the lowest in some parts of central-North and the Southwest coastal area of Connecticut, with a potential ranging from 26 MW to 466 MW. By contrast, most of potential wind capacity is in the northwest of the state, with an estimated potential around 60 MW under the Mid/High Case. The figures below provide a geographical representation of wind and solar production potential in Connecticut under the Low Production Case. Please note that the scales for each map are different, with more details provided by the key to the right of each map.

[107] Based on the DEEP Decarbonization Pathway IRP, Millstone Extension Scenario (as used in ISO-NE Pathways Study).

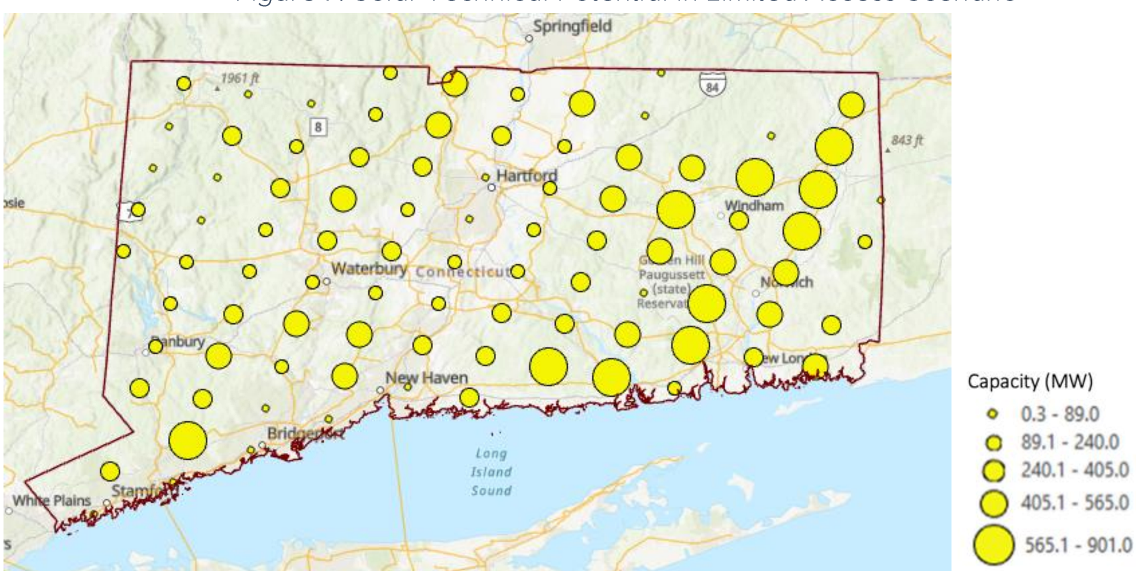
[108] Interviews with Dominion confirmed that some amount of Millstone's existing capacity could be allocated to hydrogen production in the future, but the exact amount would be dependent on future economic conditions that the company could not speak to at this time. Instead, it was recommended that this analysis present a range of possible scenarios for hydrogen production from nuclear power in the state. "Average capacity" here refers to Millstone's average capacity factor over the last 10 years (roughly 90.6%).

Figure 6: Onshore Wind Technical Potential in Limited Access Scenario



Source: Strategen Consulting

Figure 7: Solar Technical Potential in Limited Access Scenario



Source: Strategen Consulting

Under the Low Case scenario, after accounting for Connecticut's general decarbonization needs as stated in the DEEP Decarbonization Pathway IRP,[109] Strategen found that available clean energy capacity could produce 2.3 million metric tons (Mt) of hydrogen within the state's territory annually, roughly 6 times higher than what would be required to cover the energy consumption of all medium-

[109] Based on the DEEP Decarbonization Pathway IRP (as used in ISO-NE Pathways Study).

and heavy-duty trucks (Class 3-8) in Connecticut in 2020.[110] This could be increased to 4.9 Mt per year in the Mid Case and 8.1 per year Mt in the High Case, if less restrictive siting limitations and other technology improvements were assumed.

Solar and offshore wind provide the largest bulk hydrogen production opportunities for Connecticut, with biogas, nuclear, and curtailed energy providing relatively small levels of production. Onshore wind energy only contributed to hydrogen production in the Mid and High Cases, as in the Low Case, 100% of available onshore wind capacity was required to meet Connecticut's decarbonization targets. This technical potential only considered resources located within Connecticut or, in the case of offshore wind[111], resources located off the North Atlantic coast and allocated to Connecticut in proportion to its share of regional energy demand in 2021.[112]As such, these values represent the clean energy potential specific to Connecticut and not necessarily the most economic resources to be developed in the wider power system region.

Following the energy capacity assessment, Strategen used technology price forecasts from NREL,[113] local resource characteristics, and currently available information on tax credits in the Inflation Reduction Act (IRA) to calculate the levelized cost of energy (LCOE) for each clean energy source. These LCOE values were then modeled, along with IRA benefits and expected improvements on electrolyzer technology, to forecast the levelized cost of hydrogen (LCOH) from dedicated clean energy generators in the state. The resulting values represent the production cost of the fuel and do not include any transportation, compression, or storage costs.

Both the quantity and price of hydrogen that could be produced from each source of clean energy under the Mid Case in 2030 and 2040 are summarized in the following graphs. The Mid Case was selected as its parameters are meant to outline a "base case" for hydrogen production in Connecticut. Estimates for the Low and High Cases, as well as the inputs and assumptions that were used to calculate the LCOH values in each graph are provided in Appendix C. Because the technical potential for renewable energy production in Connecticut is static over time, the estimates for the volume of hydrogen that could be produced in 2030 and 2040 are roughly the same. The only difference is in estimates for hydrogen production from excess renewable energy, which are higher in 2040 due to higher forecasted curtailment levels in that year. Because estimates for renewable energy curtailment in 2050 aren't available at this time, a supply curve for 2050 wasn't constructed.

[110] Seamonds, David et al., M. J. Bradley & Associates (2021), Southern New England: An Analysis of the Impacts of Zero-Emission Medium- and Heavy-Duty Trucks on the Environment, Public Health, Industry, and the Economy.

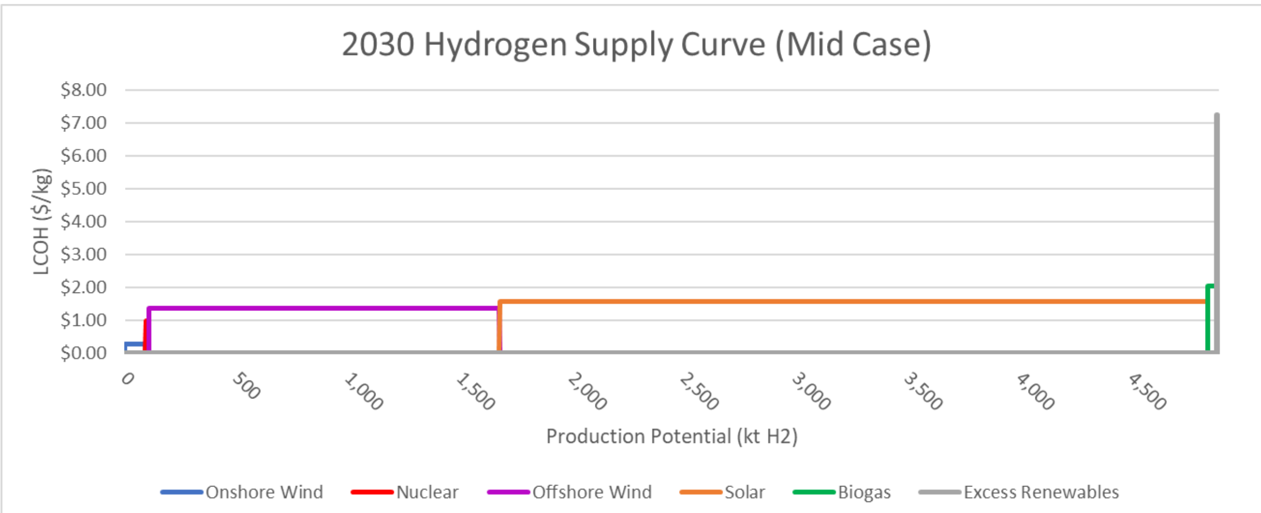
[111] Notably, Connecticut must procure offshore wind that interconnects within Connecticut to be comparable to the solar and onshore analysis; therefore, power supply should be viewed with a regional perspective. Further, onshore wind developments may require virtual connections via PPAs.

[112] In this case, "regional" refers to all U.S. states with access to the North Atlantic coastline, specifically: Connecticut, Massachusetts, Maine, New Hampshire, New Jersey, Rhode Island, and New York.

[113] NREL's Annual Technology Baseline 2022 provides consistent, freely available, technology-specific cost and performance parameters across a range of R&D advancements scenarios, resource characteristics, sites, and financial assumptions for electricity-generating and storage technologies, both at present and with projections through 2050. These values were adjusted for Connecticut using regional Capex parameter variations and adjustments of each technology.

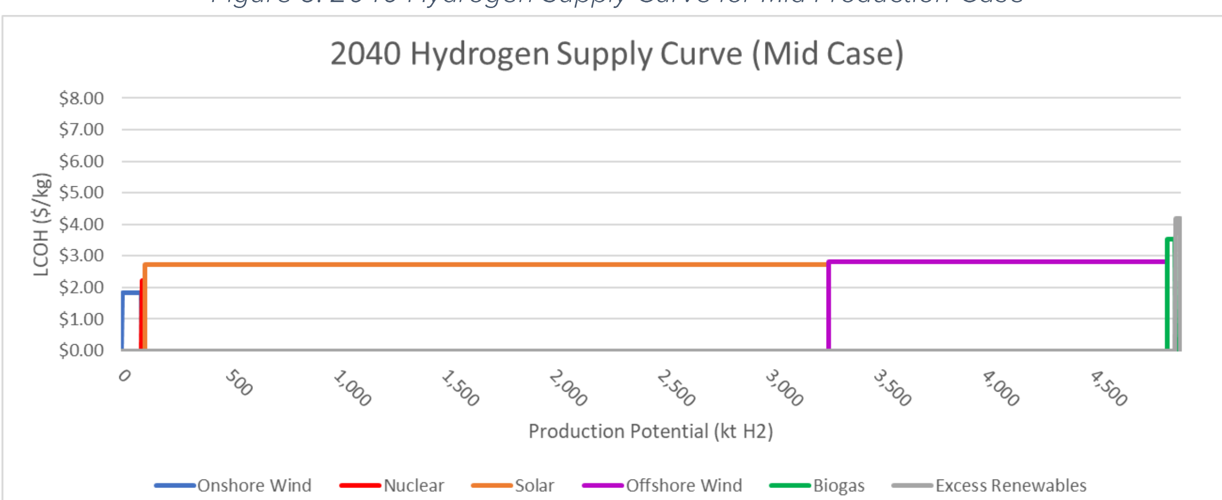
From a price perspective, the costs of hydrogen are generally higher in 2040 due to the expected phase-out of tax credits for clean energy and clean hydrogen production in 2032.[114] For reference, in order to reach price parity for diesel, hydrogen would need to fall under $5.13/kg delivered cost in 2030, inclusive of the costs associated with transportation, storage, and distribution (which aren't included in the LCOH estimates below). More information on hydrogen price parity points and infrastructure costs are provided in Section 4.1.7.

Figure 8. 2030 Hydrogen Supply Curve for Mid Production Case



Source: Strategen Consulting

Figure 9. 2040 Hydrogen Supply Curve for Mid Production Case



Source: Strategen Consulting

[114] Analysis assumes that hydrogen project developers are able to monetize the full value of the tax credit on tax equity markets.

The above analysis focused on wind, solar, nuclear, and biogas resources in Connecticut, as these were the potential resources considered that may be utilized to power water splitting technologies such as electrolysis to produce hydrogen as explicitly mentioned in the Task Force legislation. However, as Connecticut refines its hydrogen strategy in the future, there are a number of other potential production methods for hydrogen that could yield additional cost advantage, such as hybrid renewable installations, hydrogen imports, or direct grid connections.

Hybrid Renewable Installations: Tying hydrogen production to multiple renewable energy sources can improve electrolyzer capacity factors and further reduce hydrogen costs. For example, co-locating an electrolyzer with a solar plant while also tying production to an offshore wind installation (either through a direct interconnection or a PPA -type structure) would allow the electrolyzer to continue producing zero-carbon hydrogen when one of these resources isn't available. Similarly, electrolyzers co-located with solar could also connect to the electrical grid so that they can take advantage of excess wind capacity, which is likely to occur at night when the solar plant is idled.

Hydrogen Imports: Although Connecticut has substantial renewable energy resources on its own, regional hydrogen transport infrastructure could allow the state to access larger amounts of lower-cost hydrogen. For example, onshore wind provides one of the lowest-cost feedstocks for hydrogen production in the Northeast, but wind resources in Connecticut are extremely limited (and in the Low Case scenario, fully committed for decarbonization of the state's electricity sector). Importing hydrogen produced in states with more access to these lower cost wind resources (e.g., New York or Maine) could provide cost advantages if low-cost delivery is enabled via a regional pipeline network.

Direct Grid Connections: As Connecticut's electric sector decarbonizes in line with its climate targets, it may be possible to produce clean hydrogen with zero-carbon grid power (e.g., hydroelectric power). This would significantly increase electrolyzer capacity factors compared to systems tied to specific renewable energy installations, potentially allowing for the production of clean hydrogen under $2/kg in 2040. However, this is dependent on several conditions, including:

1. The ability for electrolyzers to access electricity tariffs close to wholesale prices, e.g., as a transmission service customer or other specialized rate plan.
2. The sufficiency of regional grid capacity to service electrolyzers without significant upgrades.
3. The ability to certify this hydrogen as "clean" given varying generation sources on the ISO-NE wholesale market.

Investigation into other potential production methods for hydrogen that could yield additional cost advantage could be considered based on Connecticut's state goals and decisions on how clean hydrogen in the state will ultimately be defined.

4.1.4.2 Recommendations

The findings outlined above suggest a number of steps that can be taken to support the development of a clean hydrogen supply for Connecticut and ensure that the hydrogen production does not conflict with the states existing climate goals. These are described in more detail below.

- **DEEP should continue to evaluate the sufficiency of zero-emission electricity sources to meet both electric sector decarbonization goals and hydrogen production targets.** These evaluations should be incorporated into both existing state planning processes, as well as regional coordination about strategic resources such as offshore wind.
- **DEEP should investigate accounting mechanisms that encourage hydrogen producers to certify the carbon intensity of produced hydrogen.** This is important to encourage hydrogen to be produced by renewable energy installations that may present collocation challenges, such as offshore wind and hydroelectric power. Without a mechanism that certifies that hydrogen is produced with zero-carbon electrons, it may be difficult for clean hydrogen production that is not directly connected to a renewable energy installation to qualify for federal tax credits (in addition to any other state incentives that may apply). If RECs are used at all as part of this accounting mechanism, steps should be taken to ensure that these RECs are retired directly by the hydrogen producer to avoid double counting.
- **PURA should consider whether existing renewable energy, flexible and/or interruptible load tariffs could be applied to electrolytic hydrogen production and determine if a specific electrolytic tariff would be required.** Today, the high cost of electrolyzer operation is a significant driver of end-user hydrogen costs. Retail electricity rates are often not economically feasible to use for hydrogen production with electrolyzers. By enabling the use of grid supplied electricity via tariff to increase electrolyzer capacity, specialized tariffs can lower the overall cost of production and could drive Connecticut hydrogen market development. Note that appropriate renewable energy certificate structures would be required to ensure the climate integrity of this hydrogen. Similar electrolytic hydrogen tariffs have been deployed to accelerate hydrogen adoption for mobility in Washington[115] and Arizona[116].

4.1.4.3 Stakeholder Feedback

Overall, there was broad support among stakeholders for an approach that assumed hydrogen production was in addition to other decarbonization needs. Environmental Advocates pointed out that, when possible, it is generally more efficient to use electricity from renewable energy directly to electrify buildings or transportation.[117] In addition, Bernard Pelletier expressed a preference for producing hydrogen from excess renewable energy to prevent clean energy from being "wasted." They noted that seasonal differences in clean energy production, as well as the large amount of offshore wind energy that's planned to be installed, would make curtailment a significant concern in the future.[118]

In addition, industry stakeholders weighed in on hydrogen production methodologies for Connecticut. FuelCell Energy noted that in-state hydrogen production is preferential from an economic development standpoint and also because transporting hydrogen adds costs and emission,

[115] City of Tacoma (2021), Resolution No. U-11206 Electrofuel Service Pilot (Schedule EF).
[116] Arizona Corporation Commission (2021), Docket E-01345A-20-0367 Decision No. 77893.
[117] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 7.
[118] Bernard Pelletier (2022), Comments to the Hydrogen Taskforce, p. 1.

so production as close as possible to end use is generally preferable. FuelCell Energy acknowledged that Connecticut may benefit from an open market that allows the state to import as well as export hydrogen.[119] Zone Flow also presented a technoeconomic analysis of their technology, stating that hydrogen produced from steam methane reformation with carbon capture and storage is the lowest-cost and nearest-term production method available for Connecticut.[120] Eversource advocated for the recommendation of direct legislative support for production, sale, and distribution of hydrogen.[121] Regarding the production of hydrogen via grid connected electrolyzers, Nel Hydrogen noted that the grid will become greener with time based on the number of states driving to carbon neutrality, and grid connected electrolysis projects will take time to develop and install, so the current grid mix should not be the only factor in determining the carbon intensity of hydrogen at a given location.[122]

Nel Hydrogen also provided feedback regarding hydrogen certification mechanisms. Nel noted that there are current efforts to implement hourly matching of renewable credits to certify hydrogen or require new committed installations of solar or wind for an electrolyzer project. They noted that hourly matching was deemed impractical in Europe and further explained that renewable projects do not follow the same timeline as hydrogen projects. Nel emphasized that these methods may slow hydrogen progress and highlighted that incentivizing early hydrogen with a plan to transition installations to lower carbon intensities over time is a preferred approach.[123]

Finally, several stakeholders weighed in on potential definitions of clean hydrogen, which is further discussed in Section 4.2.1.

4.1.5 Recommendations for funding and tax preferences for building hydrogen-fueled energy facilities at brownfield sites through the Targeted Brownfield Development Loan Program.

4.1.5.1 Findings

Connecticut offers a wide range of funding opportunities that may be applied to support the remediation and redevelopment of brownfield sites into hydrogen-fueled energy facilities and other hydrogen infrastructure. However, it is important to note that no current state-level tax preferences or tax credits are associated with brownfield remediation or redevelopment.

The Targeted Brownfield Development Loan Program, along with a suite of additional programs and resources, is administered by the Office of Brownfield Remediation and Development within the Connecticut Department of Economic and Community Development. To qualify for these programs, sites under consideration must match the C.G.S. Sec. 32-760 definition of a brownfield: "any abandoned or underutilized site where redevelopment, reuse or expansion has not occurred due to the presence or potential presence of pollution in the buildings, soil or groundwater that

[119] FuelCell Energy, Inc (2022), Comments to the Hydrogen Task Force, p. 5.
[120] Zone Flow (2022), Comments to Hydrogen Task Force, p. 2.
[121] Eversource (2022), Comments to the Hydrogen Task Force, p. 6.
[122] Based on discussion with Nel Hydrogen.
[123] Based on discussion with Nel Hydrogen.

requires investigation or remediation before or in conjunction with the redevelopment, reuse or expansion of the property."

Importantly, any applicants and potential development partners must have no direct or related liability for the conditions of the brownfield. The Targeted Brownfield Development Loan Program and the Brownfield Municipal Grant Program are both potential resources to support the remediation and redevelopment of brownfield sites to build hydrogen-related facilities and infrastructure.

The Targeted Brownfield Development Loan Program provides low-interest loan financing for the costs associated with the investigation, assessment, remediation, and development of a brownfield. Eligible entities for these loans include potential brownfield purchasers and current brownfield owners (including municipalities and economic development agencies, provided that a current owner did not contribute to any existing environmental contamination). The program has previously provided loans of up to $4 million with the following terms:

- 3% interest;
- Allowance for flexible deferred repayment to match projected cash flow with a maximum 30-year term; and
- A minimum developer equity of 10%.

The Brownfield Municipal Grant Program is a competitive grant program for municipalities, municipal entities, and land banks that provides funding to assist with brownfield redevelopment projects that will drive significant economic impact. The program has a focus on public-private partnerships; for example, partnerships between a developer and an eligible municipal recipient. Remediation grants are limited to $2 million and assessment-only grants are limited to $200,000. Projects must go through a competitive selection round where they are scored based on a rubric that is defined for each funding cycle. In the most recent funding cycles, renewable energy projects have been given additional scoring credit. Projects should also demonstrate that the land is being put to the highest and best end use.

The municipal grant program has received an average of $15 million annually over the last few years, and DECD will be requesting $50 million for fiscal year 2023 and 2024.[124]

Funding from brownfield loan and grant programs can be applied to the following costs associated with the investigation and redevelopment of a brownfield:

- Soil, groundwater, and infrastructure investigation
- Assessment
- Remediation
- Lead and asbestos abatement
- Demolition

[124] Connecticut Green Bank (2022), Hydrogen Power Study Taskforce: Funding Working Group Meeting #1.

- Hazardous materials or waste disposal
- Long-term groundwater or natural attenuation
- Other institutional controls
- Attorney fees for environmental consulting
- Planning, engineering, and environmental consulting
- Building and structural issues
- Environmental insurance

Developing Brownfields for Energy Projects

A required end use of remediated and repurposed land is not specified by the programs; therefore, hydrogen-fueled energy facilities are currently eligible for funding. In fact, the Municipal Grant Program has already been deployed successfully for hydrogen-fueled energy facility projects. For example, a 14.9-MW fuel cell project was deployed in Bridgeport, Connecticut by Dominion Energy and FuelCell Energy utilizing remediation funding and financing from the Connecticut Green Bank.[125] The project provides reliable, clean power to Connecticut Light & Power and generates tax revenue, while repurposing a previously vacant lot.

[125] Sonal Patel, Power Magazine (2018), Dominion Sells 14.9-MW Bridgeport Fuel Cell Facility.

Connecticut's World Leading Fuel Cell Manufacturing Industry: FuelCell Energy Spotlight

US LOCATIONS
Torrington, CT (Manufacturing)
Danbury, CT (Research)

EMPLOYEES
500+

TECHNOLOGY
Molten Carbonate Fuel Cells (MCFC) – Stationary Power Generation, Hydrogen and Carbon Capture Applications

Solid Oxide Fuel Cells (SOFC) – Stationary Power Generation, Electrolysis and Energy Storage Applications

PRODUCTION
100 MW annual production capacity in Connecticut

INSTALLATIONS
225 MW installed globally, including 45MW in Connecticut

APPLICATIONS
Combined heat and power, carbon capture, and hydrogen production for: Utilities, Universities, Hospitals, Hotels, Mixed Residential-Commercial, Industrial, Retail, Ports, Micro-grids, Data Centers

FUN FACT
FuelCell Energy has a first of its kind in the world hydrogen project at Toyota's Port of Long Beach, CA. Fuel cells running on biogas will produce 2.3 MW power, 1400 gallons/day of water and 1200 kg/day of hydrogen to support port operations, car washing and fuel cell electrical vehicle fueling. FuelCell Energy is also partnering with Exxon to develop the only technology that can capture carbon dioxide while producing power at the same time.

Currently, some of the eligible sites for brownfield programs can be identified in the Connecticut Brownfields Inventory.[126] This inventory is not a comprehensive list of all potential Brownfields in the state, as many are not registered. It includes those which have received funding for assessment and/or remediation on the state or federal level or have already been accepted into a liability relief program administered by DECD or DEEP.

[126] Connecticut DEEP, Connecticut Brownfields Inventory.

While brownfield remediation and redevelopment funds are not applicable to direct costs of developing hydrogen-related infrastructure and facilities, they may be applied to pre-construction costs such as demolition of previous facilities, providing net financial benefit to project developers. Further research may be considered to assess the applicability of brownfield remediation and redevelopment funding to contribute to any relevant match funding requirements in the IIJA (more information on match requirements can be found in Section 4.1.3.1).

The Brownfield Redevelopment Programs typically require the full funding stack to be established before providing funding. However, a letter can be awarded to conditionally approve a project, contingent upon receiving the full stack of funding. This may be considered if the project is contingent upon potential competitive federal funding grants, such as those in the IIJA.

Opportunity for Additional Funding Under the Inflation Reduction Act

Under the Inflation Reduction Act, several of the tax credit programs for clean energy projects provide additional credit for projects that are sited in an "energy community", which is defined as:

- "A brownfield site (as defined in… the Comprehensive Environmental Response, Compensation, and Liability Act of 1980).
- An area which has (or, at any time during the period beginning after December 31, 1999, had) significant employment related to the extraction, processing, transport, or storage of coal, oil, or natural gas (as determined by the Secretary).
- A census tract in which after December 31, 1999, a coal mine has closed, or after December 31, 2009, a coal-fired electric generating unit has been retired, or which is directly adjoining to any census tract described in subclause."[127]

However, it is important to note that the federal definition of a brownfield differs from the Connecticut definition, so it should not be assumed that all projects qualifying for the IRA brownfields energy communities tax credit would qualify for relevant Connecticut programs.

4.1.5.2 Recommendations

The Targeted Brownfield Development Loan Program and other brownfield programs represent an excellent source of funding to advance hydrogen-fueled energy facilities on remediated land, and the State could pursue specific steps to improve accessibility and use, including:

- **DEEP and DECD should continue maintaining the Connecticut Brownfields Inventory as a resource for potential developers to identify prospective project sites and should consider expansion of the list to include those potentially eligible as "energy communities" under the Inflation Reduction Act.** This inventory can serve as a useful tool for developers in evaluating potential land availability. By expanding the inventory to include sites which may qualify as Brownfield "energy communities" (regardless of their eligibility under the state definition of a brownfield), Connecticut can further encourage developers to look at sources of funding - in addition to and beyond the state's programs - that support remediation of brownfields and advance the state's clean energy needs.

[127] As defined in the Inflation Reduction Act Sec. 13101.

- **DEEP and DECD should continue supporting development of clean energy projects on brownfields and projects that have community support and/or have completed community benefit agreements.** For example, DECD can encourage the use of their programs for clean energy projects by continuing to include renewable energy within competitive selection criteria. In recognition of the IRA incentives for siting projects on brownfields, stakeholder feedback indicated the potential for an increase in project development in these "energy communities". These Task Force participants raised the importance of ensuring that communities are provided appropriate channels for engagement on prospective projects.
- **DECD should evaluate the need for additional funding for the Brownfield Loan and Grant programs to help meet the clean energy needs of the state and its subsequent land requirements.** The federal government has earmarked significant clean energy investment funding within the next decade, with some programs encouraging development in "energy communities", including brownfields. Connecticut's brownfield remediation and redevelopment programs may experience a significant increase in clean energy project proposals. The legislature may consider allocating additional funding to these programs that is specified for clean energy projects to ensure that local brownfield redevelopment projects may leverage federal opportunities without reducing other critical applications of the existing funding, such as affordable housing. The administrator of the brownfield programs, DECD, should consider this potential in upcoming budget requests.

4.1.5.3 Stakeholder Feedback

DECD, the brownfield program administrator, provided valuable feedback regarding the scope of the brownfield programs and informed stakeholders regarding project selection criteria and funding availability. DECD also noted that the brownfield programs require that selected projects demonstrate that they have a bankable business value proposition and are shovel ready. Notably, DECD also clarified that the brownfield programs are not applicable to direct costs of developing hydrogen-related infrastructure and facilities, but they may be applied to pre-construction costs.[128] The team from DECD also explained that because of the broad definition of a brownfield, it is impossible to create a comprehensive list.[129]

The Environmental Advocates brought up concern about hydrogen infrastructure developments on brownfield sites. They pointed out that many of Connecticut's brownfields are located in environmental justice communities and distressed municipalities where residents are burdened by environmental harms from former and existing uses and infrastructure. The Environmental Advocates also highlighted that there are size constraints on using brownfields for hydrogen projects, explaining that most of the state's brownfields are less than five acres, too small for siting most hydrogen infrastructure. They further emphasized that siting hydrogen production, transport, or storage infrastructure on brownfields is not recommended due to safety, cost, and remediation

[128] Connecticut Green Bank (2022), Hydrogen Power Study Taskforce: Funding Working Group Meeting #1.
[129] Ibid.

criteria.[130] Alternatively, DECD noted that, by definition, brownfield remediation can improve communities by cleaning up contamination in otherwise abandoned or underutilized sites.

An industry stakeholder, Nel Hydrogen, also recommended that DECD take a proactive approach in promoting brownfield sites as expansion opportunities for clean energy companies.

4.1.6 Recommendations regarding funding sources for developing hydrogen-fueled energy programs and infrastructure

4.1.6.1 Findings

Broadly, the Funding Working Group considered State and Federal sources of potential hydrogen funding. At the federal level, significant funding is available beyond the IIJA to support hydrogen infrastructure, renewable resources, manufacturing and supply chains, workforce development, and research and development. At the state level, in recognition of the limited nature of state resources, stakeholders identified focused funding opportunities in high-impact areas.

Federal Funding Opportunities

The most significant federal opportunity for hydrogen market development is the IRA, which passed in September 2022 and directs $379 billion in tax credits and grant opportunities towards clean energy and climate provisions.[131] The IRA includes tax credit opportunities that are significant sources of non-competitive funding to support hydrogen-fueled energy programs and infrastructure, some of which are detailed below.

The Clean Hydrogen Production Tax Credit provides a ten-year incentive to facilities that begin production by 2033, awarding up to $3/kg to produce clean hydrogen. Credits are determined based on carbon intensity of hydrogen production process on a life cycle basis (all qualifying hydrogen must be under 4 kg CO_2e/kg H_2). Importantly, to obtain full value of credit, the taxpayer must meet prevailing wage and apprenticeship requirements.

The Investment Tax Credit provides a tax credit to offset the capital expenses of a hydrogen production facilities, stationary fuel cells, and energy storage (including hydrogen storage). The tax credit's value can reach 30%, with a base of 6%. The full credit will be achieved through ensuring prevailing wage and apprenticeship requirements are satisfied (for all projects larger than 1 MW) and by achieving lower carbon intensity. Additional credits are available for meeting certain conditions, such as utilizing domestic content and siting projects within "energy communities". This credit is available until 2024, after which it will turn into a technology-neutral "Energy Investment Tax Credit" (available through 2033).

The Advanced Energy Project Tax Credit extends a 30% incentive for qualifying energy projects, including manufacturing projects of fuel cell electric vehicles and electrolyzers.

[130] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 6.
[131] 117th Congress (2021-2022), H.R.5376 Inflation Reduction Act of 2022.

The Alternative Refueling Property Tax Credit provides a 30% tax credit (capped at $100,000) for the cost of an alternative fuel vehicle refueling property placed in service before 2033 and can be applied to hydrogen refueling stations. These stations must be sited within a low-income or rural census tract area to be eligible.

In addition, the CHIPS and Science Act, passed in August 2022, may play an important role in creating opportunities for hydrogen in Connecticut. This law authorizes $174 billion for investment in science, technology, engineering, and math programs, workforce development, and research and development.

Programs in the CHIPS and Science Act with direct references to hydrogen include:

- $11.2 billion in funding for Department of Energy research, development, and demonstration activities is directed to support RD&D activities aligned with 10 technology areas in the energy offices, including hydrogen development.[132]
- $800 million in grants to support the research, development, and demonstration of advanced nuclear reactors and specifies the prioritization of projects that support hydrogen production. This program is called Fission for the Future.[133]

Additional grants, financing, and other sources of funding that may be applicable to hydrogen in the Inflation Reduction Act and other federal programs are detailed in Appendix D.

Potential Areas for State Funding Focus

In order to enable near-term progress, the Task Force identified end uses that are the highest priority for additional investigation (more information on end use prioritization can be found in Section 4.1.7). Priority end uses were selected on a variety of considerations, including their likeliness to use hydrogen due to underlying economics and their potential to have substantial societal benefits, such as pollution reduction. More information on end use evaluation can be found in 4.1.7

Funding also represents an opportunity to advance areas that are important to the state, as well as emphasize areas of strength which can support Connecticut's competitiveness for federal grant opportunities. Stakeholder feedback throughout the Task Force and Working Group processes identified many key areas of strength that can differentiate Connecticut in the national and global market, including:

- *A world-leading fuel cell and hydrogen equipment manufacturing industry:* Connecticut was named a "Top 3 State" for fuel cell development by the U.S. Department of Energy, ranking third in the nation in total fuel cell patents. The state estimates that at least 600 fuel

[132] Bipartisan Policy Center (2022), CHIPS and Science Act Summary: Energy, Climate, and Science Provisions.
[133] Pillsbury (2022), Chips and Science Act Offers Support to Advanced Nuclear and Fusion Industries..

cell and hydrogen supply chain companies are based in Connecticut, generating over $211 million in gross state product.[134]

- *Hydrogen leadership and innovation in academia:* In New England, UConn led the way as the first public R1 research university to sign onto the regional clean hydrogen hub effort.[135] This effort was led by UConn President Radenka Maric, who brings over three decades of hydrogen and fuel cell research, deep experience in supporting technology innovation, and a track record of securing significant grant funding from the U.S. DOE. As of 2020, she had secured over $40 million in research funding.[136] This institution has demonstrated its readiness to support research, innovation, and workforce development in the emerging hydrogen ecosystem.

Connecticut's World Leading Fuel Cell Manufacturing Industry: Nel Hydrogen Spotlight

LOCATION
Wallingford, CT (Manufacturing and Research)

EMPLOYEES
130

TECHNOLOGY
Proton Exchange Membrane (PEM) Water Electrolyzers

Alkaline Water Electrolyzers

Hydrogen Refueling Stations

PRODUCTION
75 MW currently, expanding to 500 MW by the end of 2024

INSTALLATIONS
3,000+

APPLICATIONS
Transportation, Industrial Chemicals, Green Steel, Power, Refining

FUN FACT
Nel has a 20 MW solar to hydrogen PEM plant installation with Iberdrola (parent company to Avangrid) in Spain for green-ammonia production.

[134] Connecticut Department of Economic and Community Development, Green Energy Overview.
[135] Matt Engelhardt, UConn Today (2022), UConn Applies Clean Energy Expertise to Multi-State Hydrogen Hub.
[136] Jessica McBride, UConn Today (2019), UConn Researcher Radenka Maric Named AAAS Fellow.

4.1.6.2 Recommendations

To best align with requirements of federal funding sources, such as the IRA:

- **Consider amending requirements for community benefit agreements, through Public Act 21-43, to lower the minimum project size from 2 MW to 1 MW, explicitly note the inclusion of hydrogen, and consider the development of similar requirements for all hydrogen projects.** Amending requirements in this way would align state requirements with those in the Inflation Reduction Act, ensuring that state projects are more likely to be eligible for federal benefits. This shift would also ensure that a broader range of clean energy projects would require agreements, leading to greater community alignment on projects. This recommendation is detailed further in Section 4.1.2.2.

To further support high-priority hydrogen end uses with state funding:

- **DEEP and PURA may wish to consider promoting hydrogen end uses that are currently commercially viable through the existing clean energy programs including projects developed by both third parties and affiliates of the EDCs and LDCs. PURA's consideration should include how any changes would affect the programs' existing objectives and cost-effectiveness.** Connecticut has a strong history of climate action, with many existing policies and programs that support their decarbonization goals. To integrate hydrogen most efficiently into the state's energy system toolkit, stakeholders recommend evaluating the existing structures that can be expanded to include hydrogen and its related infrastructure.
- **The Legislature should consider tax exemptions for hydrogen vehicles and critical facilities that produce or use clean hydrogen.** A tax exemption for hydrogen vehicles and critical facilities would provide support for high-priority end uses, such as heavy-duty vehicles, while supporting the state's existing decarbonization policy objectives. For example, the recently enacted Clean Air Act in Connecticut authorizes the DEEP commissioner to adopt regulations implementing California's medium- and heavy-duty motor vehicle standards.[137] This recommended tax exemption would support this end use transition.
- **DEEP should identify and potentially expand clean transportation incentives to include on-site port handling equipment, harbor crafts, and ocean-going vessels, in collaboration with other state and federal agencies.** These end-uses are typically located in a cluster around ports, supporting the potential for shared infrastructure.

To further support Connecticut's areas of strength and competitive advantages:

- **UCONN, working in collaboration with community colleges; vocational high schools; regional comprehensive universities; Workforce Investment Boards; trades with expertise in hydrogen technologies and relevant skillsets; labor-led workforce development programs and training programs; LDCs, EDCs, and other employers; and any other relevant workforce or training programs, should identify opportunities to support development of the hydrogen workforce and advance research and development in hydrogen electrolyzers and hydrogen fuel cells, and should identify resources and funding needs to implement and contribute to the development of a hydrogen roadmap led by DEEP.** Stakeholders noted the importance of

[137] Abigail Brone, CT Insider (2022), CT Enacts Clean Air Law to Shift State Vehicles to Electric.

UCONN's deep capabilities in hydrogen fuel cell and electrolytic technology research and innovation to support Connecticut's hydrogen economy. These recommended actions would build upon Connecticut's deep expertise and further position the state as a leader in clean hydrogen technologies for regional, national, and global market opportunities.

- **UCONN should host a "learning laboratory" funded by the state which would include facilities (e.g., hydrogen production, hydrogen stations), and capabilities (e.g., fuel cell buses, stationary fuel cells) to host integrated technology demonstration projects, with the primary objective of addressing technical barriers to the deployment of fuel cells, hydrogen and other clean energy technologies.** The learning laboratory may be modeled from the example of the National Research Council of Canada which partners with industry to advance innovative research solutions from the lab to the marketplace.[138] This facility would work with industry, government, community colleges and local universities, and other partners to leverage resources and advance clean energy technologies to commercialization, while providing education and awareness of these technologies to Connecticut families and businesses.
- **DECD should establish a Strategic Innovation Fund with bond funds to encourage RD&D that will accelerate technology transfer and commercialization of innovative products, processes, and services related to hydrogen with guidance from an Industry Advisory Board.** This program could provide funding to support clean hydrogen and fuel cell economic development in Connecticut and facilitate the growth and expansion of local businesses and industries. Further, this initiative would support the advancement of industrial research, development, and technology demonstration through collaboration between the private sector, researchers, and nonprofit organizations and support workforce development for high value green jobs modelled after the Manufacturing Innovation Fund. The Strategic Innovation Fund Industry Advisory Board should leverage existing industry groups such as the Manufacturing Innovation Fund's advisory board or the Connecticut Hydrogen Fuel Cell Coalition.
- **DECD and OPM should identify opportunities for tax incentives or programs to retain Connecticut's leadership in the electrolyzer and hydrogen fuel cell manufacturing industry and prevent offshoring of manufacturing in line with federal policy.** Given the global momentum for hydrogen, hydrogen fuel cell manufacturing can be a significant area for Connecticut's economic development and job creation. Further, the IRA provides additional tax credit for projects that utilize domestically manufactured goods, which may drive a significant demand for Connecticut's fuel cell products.[139]

4.1.6.3 Stakeholder Feedback

Several stakeholders have identified key incentives or funding needs that the legislature or state agencies could consider to encourage the growth of a Connecticut hydrogen economy. Eversource identified that financial incentives to develop and supply hydrogen within disadvantaged communities would encourage developers to prioritize the development of projects in these areas. Further, Eversource commented that financial incentives could be implemented to enable

[138] Government of Canada, About the NRC.
[139] David E. Bond, White & Case (2022), New US Climate Bill Seeks to Promote Domestic Content in Clean Energy Projects.

community acceptance, including tax credits, grants, and PILOT agreements, along with other mechanisms that have supported the deployment of various technologies in Connecticut.[140]

UCONN noted that supporting early-stage developments that are at a low technology readiness level would benefit the state and lead to the creation of new companies. Additionally, UCONN has noticed a funding gap for early-stage projects. They noted that in some cases, academic institutions have funds that are restricted and cannot be used on early-stage projects. Connecticut Green Bank also recommended that early-stage pre-commercial demonstrations of technology should be considered from an economic development perspective. Further, the Connecticut Green Bank and the University of Connecticut have emphasized UCONN's capabilities regarding fuel cell and electrolytic technology research and workforce development which may be leveraged for future research and investigation related to hydrogen in the state.[141]

Stakeholders had divergent perspectives regarding the recommendation for the Legislature to consider tax exemptions for hydrogen vehicles and critical facilities that produce or use clean hydrogen. Sierra Club, the Conservation Law Foundation, and the Acadia Center expressed that only high priority mobility end uses, such as heavy-duty trucking, should be included within this policy and there should not be tax exemptions for light-duty hydrogen vehicles.[142] In contrast, FuelCell Energy and Toyota have expressed that light duty vehicles should not be excluded from a tax credit.[143] FuelCell Energy noted that as progress is made to build out hydrogen infrastructure, light-duty hydrogen vehicles may become a viable approach to decarbonization.

Further, stakeholders commented on the significant support from the federal government but noted key gaps that the state could address. Specifically, Eversource noted that as most federal funding would support the production of clean hydrogen, the State could focus on removing barriers to customer adoption such as workforce training. The state could also focus on fostering the end use of clean hydrogen in low-income and EJ communities, which would help to further drive the development of clean hydrogen production in the state by ensuring a broad-based demand.[144] FuelCell Energy noted that the state should consider how it can support manufacturing of hydrogen generating technologies up to and including incentives to expand in-state manufacturing, transport, fueling and storage infrastructure, and how to incentivize end users.[145]

Some stakeholders also suggested considering increases in caps on existing clean energy programs, which already support fuel cell projects, as these changes could enable deployment to meet decarbonization policy objectives.[146] For example, PURA and the Program Administrator Utilities,

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[140] Eversource (2022), Comments to the Hydrogen Task Force, p. 2.
[141] *Ibid*.
[142] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Sources and Uses Working Group Meeting #4 Meeting Minutes.
[143] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Policy and Workforce Development Working Group Meeting #4. and based on discussion with FuelCell Energy.
[144] *Ibid*., p. 7.
[145] FuelCell Energy (2022), Comments to the Hydrogen Task Force, p. 6.
[146] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Funding Working Group Meeting #3.

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Eversource Energy and United Illuminating, may consider increasing their 10 MW cap on the Non-Residential Renewable Energy Solutions Program. This program increases the business value proposition for hydrogen fuel cells to support critical facilities and would support market development.

Stakeholders have brought Connecticut's key competitive advantages to the forefront. Industry stakeholders including Nel Hydrogen, FuelCell Energy, HyAxiom, and Infinity have noted that Connecticut's fuel cell manufacturing capabilities uniquely position Connecticut in the hydrogen industry. They have noted that the fuel cell manufacturing industry will be an opportunity for job growth and can be leveraged as the hydrogen industry grows globally.[147] The Conservation Law Foundation has indicated hesitancy to support the hydrogen fuel cell manufacturing industry with taxpayer dollars as it is already a mature and thriving industry.[148] HyAxiom and Nel Hydrogen noted that although the Connecticut fuel cell industry is impressive, it is important to have legislative support to help the industry grow as competition also increases.[149] Alternatively, Sierra Club noted that the fuel cell industry is already subsidized by ratepayers, and recommended clarity in manufacturing recommendations to ensure that investments will go towards clean hydrogen.[150][151]

Environmental stakeholders noted that although additional tax credits are available for siting facilities in "energy communities" and low-income communities to create economic opportunity and enable adoption of clean energy, Connecticut should ensure robust community engagement to ensure input on whether communities would like to host these facilities.[152] Sierra Club also generally cautioned the Task Force to not incentivize hydrogen uses that increase greenhouse gases and NO_x emissions.[153] Finally, Sierra Club noted that since the information from Public Act 21-43 is relatively new, it is important to see how communities respond and if it strengthens community engagement. As an example, they noted that although all the developers are required to publicize the public meetings for the community, there is not currently decision making coming from the community.

UCONN noted the potential challenges for community engagement as envisioned and emphasized that implementation of engagement structures needs to be easy for towns so that they do not become a burden. They noted the need to work on great implementation policies at the local level, especially given that most development decisions in Connecticut are done at the local level by parties such as towns' planning and zoning committees.

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[147] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Funding Working Group Meeting #4.
[148] Based on conversations with the Conservation Law Foundation.
[149] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Sources and Uses Working Group Meeting #4 .

[151] *Ibid.*
[152] Connecticut Green Bank (2022), Hydrogen Power Study Taskforce: Funding Working Group Meeting #3.
[153] Connecticut Green Bank (2022), Hydrogen Power Study Task Force: Funding Working Group Meeting #2.

4.1.7 Recommendations for potential end uses of hydrogen-fueled energy.

4.1.7.1 Findings

Hydrogen has the potential to be used as a tool to reduce carbon emissions across many difficult to decarbonize sectors. In evaluating potential end uses for hydrogen, Strategen analysis considered the viability of hydrogen use in Connecticut across eight different criteria:

- Cost-competitiveness compared to alternative decarbonization options[154];
- Potential to reduce in-state greenhouse gas emissions;
- Timeline for commercial deployment;
- Need to build out additional supporting infrastructure;
- Ability to reduce pollution impact to disadvantaged and frontline communities;
- Impact on local workforce needs; and
- Value of improving resilience via a diversified fuel supply.

[154] In the discussion of alternative methods of decarbonization compared to fuel cells, the term electrification is used to refer to battery electric vehicles,

A robust literature review focused on cost-competitiveness revealed that hydrogen represents a cost-effective zero-carbon fuel for many end uses that have not yet decarbonized. This cost-competitiveness assessment is described in greater detail in Appendix A. Some of these end uses can economically convert to hydrogen fuel today, while others will likely become economic as delivered costs of hydrogen decline due to state and federal infrastructure investment. Some end uses will likely not be commercially ready in the near-term (i.e., before 2030), but are important to consider as hydrogen-based fuels currently present the most technically feasible approach to decarbonization.

Connecticut's World Leading Fuel Cell Manufacturing Industry: HyAxiom Spotlight

LOCATION
South Windsor, CT (Manufacturing)

EMPLOYEES
Approx. 300

TECHNOLOGY
Phosphoric Acid Fuel Cell (PAFC) – Stationary Applications

Proton Exchange Membrane Fuel Cells (PEMFC) – Investing for Transportation Applications

Polymer Electrolyte Membrane Electrolysis Cells (PEMEC) – Researching for Electrolyzers

PRODUCTION
200 MW annually with 30% in Connecticut and 70% in South Korea

INSTALLATION
568 MW with 90% in South Korea and 10% in USA (with 22 MW in CT)

APPLICATIONS
Utilities, Universities, Hospitals, Hotels, Mixed Residential-Commercial, Industrial, Retail and Data Centers

FUN FACT
HyAxiom was formed by combining technology from UTC Power and the commercialization capability of Doosan.

Based on a review of latest research, as well as insights and feedback from stakeholders, Strategen developed a qualitative assessment of each end use across the identified criteria, which was used to inform further recommendations. In general, hydrogen was found to be a particularly cost-effective option for transportation applications that required long periods of use and had limited refueling time. It could also provide significant value in stationary applications where power was needed on-demand and for prolonged periods of time. A list of and description of each end use that was considered is provided below, with more details provided in Appendix A.

Table 4: Summary of End Uses Considered in Analysis

End Use	End Use Description	Justification for Consideration
Aviation	The use of hydrogen directly on airplanes in fuel cells, or to produce synthetic kerosene from clean hydrogen and carbon-neutral CO_2 sources.	Outside of biofuels (which have supply limitations when used at scale), hydrogen-based fuels offer the only technically viable decarbonization solution.
Maritime	Liquified or gaseous hydrogen use on ships in fuel cells, or hydrogen converted to methanol or ammonia.	The majority of carbon-free shipping will need to employ one of these three options, as electrification of transoceanic shipping is technically infeasible.
Heavy-Duty Trucks	The use of hydrogen in fuel cells on any vehicle over 26,000 lbs.	Due to their irregular scheduling, low down times, and heavy loads, hydrogen presents a wide range of benefits for this end use compared to electrification.
Light-Duty Vehicles	The use of hydrogen in passenger vehicles and pick-up trucks.	Hydrogen has been proposed by some industry stakeholders as a pathway to decarbonize light-duty transport, and several passenger fuel cell vehicle models exist today.
Buses	The use of hydrogen in fuel cells on buses.	Hydrogen provides similar benefits for buses as for heavy-duty trucks, with highest benefits for buses that travel long distances (e.g., >400 miles per day).
Material Handling Equipment	The use of hydrogen fuel cells in forklifts and similar equipment. Applications exist within warehouses, stores, ports, and other facilities.	Fuel cells in forklifts realize benefits such as fast refueling, increased performance, and reduced space needs for refueling infrastructure.
Industrial Heat	Hydrogen combusted to provide heat for industrial processes.	In addition to biofuels, hydrogen is one of the primary options considered for heat applications that cannot be economically electrified.
Residential / Commercial Heat	The use of hydrogen to provide space heating for residential and commercial buildings.	Hydrogen can be combusted for heat like natural gas, although 100% hydrogen use would require large-scale retrofits of pipelines and equipment.
Hydrogen Blending	Hydrogen blending into existing natural gas feedstocks for industrial processes, or in the general pipeline network.	If blend levels are kept low, equipment retrofits can be avoided. (See *Note on Hydrogen Blending* below)

Dispatchable Power Generation	Using hydrogen to produce electricity for peak power applications, either via a fuel cell or combustion turbine.	Dispatchable carbon-free generation is valuable on grids with high penetrations of renewables. This use case also allows hydrogen to serve as "seasonal storage" and produced from renewable energy that would otherwise have been curtailed.
Critical Facilities	The use of hydrogen fuel cells to provide back-up power at hospitals, data centers, and other facilities that require long-duration back-up power (i.e., 24+ hours).	Power is required on-demand and for durations that are difficult to achieve with solar plus battery storage solutions.
Rail	The use of hydrogen on locomotives in fuel cells.	Hydrogen can provide an attractive alternative to battery electrification for rail cars that travel long distances.
Harbor Craft	Using hydrogen in fuel cells to power regional ferries and other localized port vessels.	Dedicated refueling locations provide the possibility of convenient hydrogen refueling.
Specialty Vehicle Fleets	Special-purpose vehicles that have long uptimes and dedicated refueling infrastructure, like police cruisers or ambulances	Charging limitations from long uptimes may make electrification challenging for these applications.

Note on Hydrogen Blending:

Hydrogen can be blended directly into natural gas feedstocks at industrial facilities or blended into the gas network for delivery to all customers connected to that network. Testing conducted in Europe has found that hydrogen blends up to 15 or 20% by volume (5-7% by energy content) are possible without requiring substantial retrofits of existing infrastructure or equipment.[155] However, capacity for hydrogen blending can vary based on local grid conditions, and state-specific testing is recommended to ensure compatibility with existing infrastructure. For example, a recent study in California was only able to verify the safety of 5% hydrogen blends by volume in the state's gas distribution system, noting that additional demonstration projects would be required to ensure at-scale viability.[156]

Hydrogen blending for non-core customers (e.g., industrial or power generation customers) could be done at the facility level due to the large, concentrated demand for natural gas that exists at these facilities. This would require an assessment of the customers' facility to determine that hydrogen can be blended directly into their fuel feedstock without affecting operation or increasing pollutant emissions from their facility. However, because this use case focuses blending at individual customer facilities, this assessment would likely not need to assess the impact of hydrogen blending on the wider gas network.

[155] Raju, Arun SK and Alfredo Martinez-Morales (2022), University of California, Riverside, Hydrogen Blending Impacts Study.
[156] *Ibid.*

Even blending hydrogen only at non-core customer facilities would create significant demand for hydrogen in the short term. For reference, blending hydrogen into the natural gas feedstocks for two gas plants located in Bridgeport (i.e. Bridgeport Energy and Bridgeport Harbor Station) at a ratio of 10% hydrogen by volume in 2030 could use close to 7.6 kt of hydrogen.[157] This would require around 410 GWh of electricity to produce, or roughly the amount renewable energy that would otherwise be curtailed by the state in that year.[158] As hydrogen production increases, these facilities could be fully decarbonized by retrofitting them with turbines that can burn 100% hydrogen or replaced with fuel cells that can operate on 100% hydrogen.

Hydrogen can also be delivered to non-core customers by blending it into the main gas network. However, this would also deliver hydrogen to all customers connected to the gas network, including residential and commercial customers. This approach would require a broader assessment to understand how hydrogen would interact with the gas distribution system in Connecticut, which would likely take longer than facility-level assessments. As a result, in this report, "hydrogen blending for non-core customers" refers primarily to blending done at the facility level, as this is a more directed and less technically demanding approach to supplying hydrogen to these end users.

Hydrogen Demand Analysis:
To better understand the potential demand for hydrogen in Connecticut, Strategen assessed the scale of hydrogen use that could be expected in the highest priority end uses (see Recommendations section for more details on end use prioritization). Similar to the hydrogen supply analysis, this assessment was designed to reflect maximum potential demand estimates, identifying the largest possible hydrogen demand that could feasibly be required by highest priority end uses over the next three decades. The rationale for focusing on maximum potential demand was twofold:

1. To determine if state-specific clean energy resources could fully cover demand in ambitious adoption scenarios.
2. To understand what economies of scale Connecticut could potentially realize in the development of hydrogen infrastructure.

Using this approach, this assessment found that hydrogen demand could scale up from 25.2 kilotonnes (kt) per year in 2030 to 200.5 kt/year in 2040 and 335.5 kt/year per year in 2050. The annual production in 2050 would require around 18.1 TWh of electricity, which represents slightly less than 10% of the technical production capacity of state-specific clean energy resources identified in the Hydrogen Mid Production Case, indicating that state-specific clean energy resources could feasibly meet all priority hydrogen demand. This demand could drive around 12.8 GW of additional

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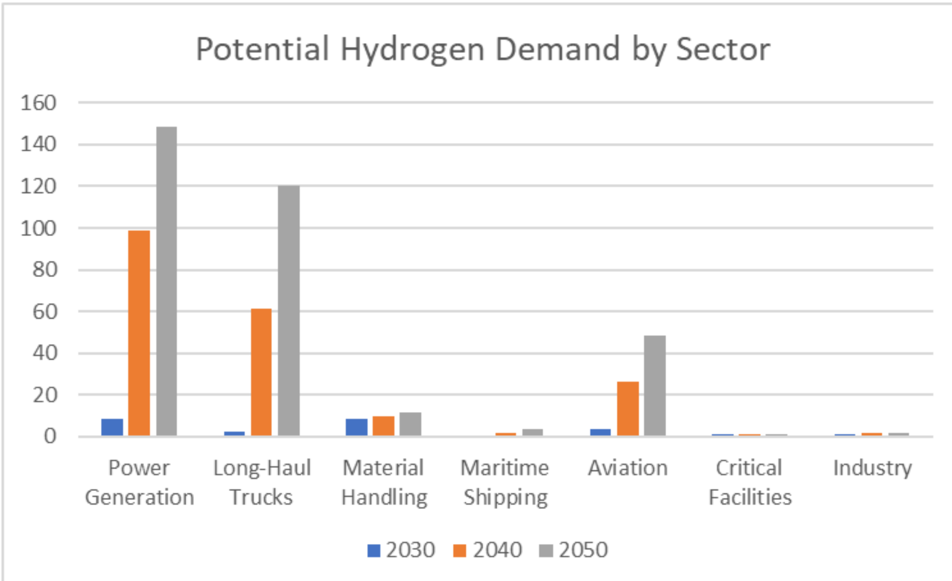
[157] S&P Capital IQ (2022), Screening and Analytics: Gas power plant net generation in Connecticut in 2021" StadAnd Connecticut Department of Energy and Environmental Protection (2021), 2020 Integrated Resources Plan: Appendix 3 Results.

[158] Based on curtailed electricity estimates provided in ISO-NE's Pathways Report. See Appendix C for more details.

fuel cell capacity in the state by 2050, driven primarily by demand for fuel cells in long-haul trucking and power generation.

Figure 10. Potential Annual Hydrogen Demand by Sector

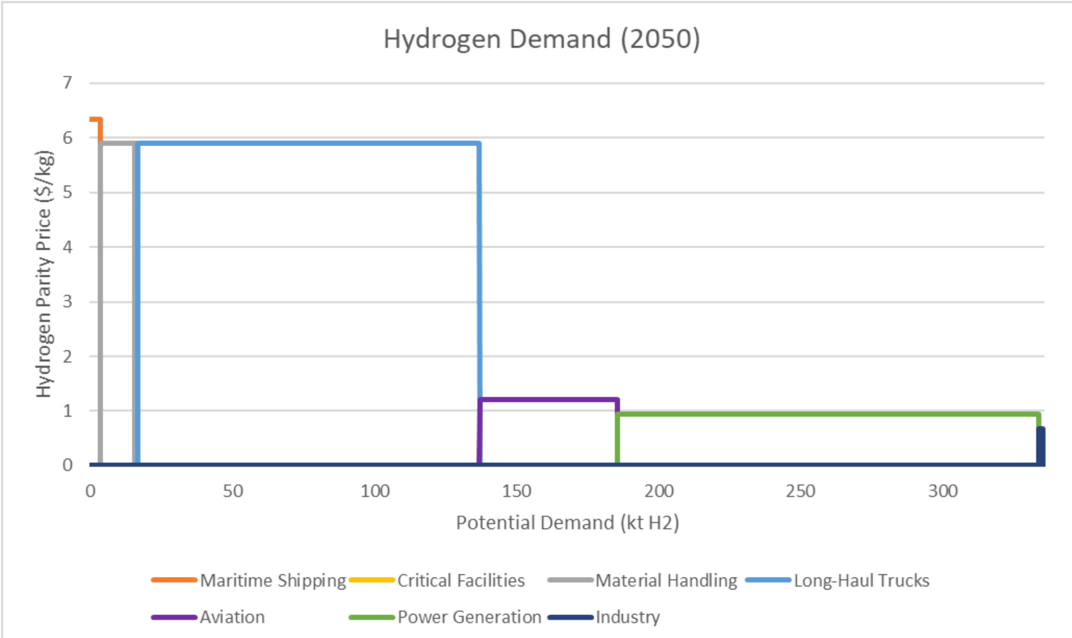


Source: Strategen Consulting

Additionally, to assess the economic conditions under which different industries would be most likely to transition to hydrogen, price points were calculated at which hydrogen would reach cost parity with the traditional fuel choice in each end use. The price levels were determined by identifying the volume of the traditional fuel that would deliver the same amount of energy as a kilogram of hydrogen in a specific application, taking into account the efficiency of fossil fuel equipment (e.g., internal combustion engines) relative to hydrogen technology (e.g., fuel cells). In other words, if hydrogen were priced underneath levels described in this chart, then it would cost end users less to purchase hydrogen than the fossil fuel alternative.

Although ultimate end user decisions will be determined by a number of considerations not accounted for in this analysis (such as the capital costs of underlying equipment and policy pressures to adopt carbon-neutral solutions), these prices serve as a proxy for the point where different sectors may begin to transition their operations to hydrogen. The prices represent the final delivered cost of hydrogen, inclusive of all transportation and storage costs, which can vary across end uses. In stationary applications, they typically include the cost of hydrogen pipelines, compression stations, and storage. For distributed transportation applications like long-haul trucking or material handling, the costs of liquefaction and truck delivery may also be included in the final cost of hydrogen. More details around the infrastructure costs are provided in subsequent sections.

Figure 11. Hydrogen Demand Curve for 2050



Source: Strategen Consulting

4.1.7.2 Recommendations

Based on the above analysis, several end uses were identified as high priority opportunities to leverage hydrogen to reduce greenhouse gas and local pollutant emissions while simultaneously stimulating economic development within Connecticut. Additional consideration of these end uses by the legislature would be valuable from both an environmental and economic development standpoint, with higher-priority end uses providing an opportunity for supportive policy to play a role in developing local and regional markets.

The recommendations in this section are divided across three prioritization tranches for end uses, which are described in more detail below:

- **DEEP should consider further investigation and the possibility of focused policy and market development support for hydrogen use in highest priority end uses.** The highest priority end uses includes those where (1) technical considerations make it highly likely that hydrogen will be used, (2) hydrogen use is particularly economic and (3) hydrogen use could create significant societal benefits due to the scale of the industry (via GHG emission reductions, workforce development, etc.). As a result, these applications present "least regrets" opportunities for policy support, and state-level or regional policy coordination has the potential to play a catalytic role in scaling up hydrogen use across several of these sectors. The highest priority end uses are as follows:
    - Aviation (long- and medium-haul)
    - Cargo ships
    - Critical facilities (24-hour backup need)
    - High heat industrial processes

    - Hydrogen fuel cells for peak power generation
    - Long-haul heavy-duty trucks
    - Material handling equipment with long uptimes and charging space constraints
- **DEEP should consider further investigation into high priority hydrogen end uses and the possibility of coordinating support measures with other hydrogen efforts.** This includes smaller-scale end uses where hydrogen could be an economic decarbonization solution depending on the local needs and conditions. Hydrogen transitions for these end uses can be a good option to consider on a case-by-case basis, particularly if there are opportunities for these end uses to share hydrogen infrastructure that is developed for other applications.
    - Long-distance buses
    - Localized harbor craft (e.g., ferries)
    - Freight rail
    - Hydrogen blending for non-core customer[159] (i.e., power generation and industrial heat)
    - Specialty fleet vehicles with long uptimes and specific refueling locations
    - Heavy-duty vehicles with charging constraints[160] (e.g., drayage trucks, some commuter buses)
- **PURA should evaluate the role of stationary hydrogen fuel cells for critical backup power and peak power generation and identify approaches to incorporate recommendations into appropriate planning venues.** Fuel cells for backup power are already in place today and can potentially be incorporated into demand response programs and specialized tariffs that encourage transition to 100% hydrogen systems. Fuel cells in for power generation can be incorporated into system planning to service load pockets facing grid constraints, with eventual incorporation into system planning to provide seasonal storage on a fully decarbonized grid.

4.1.7.3 Stakeholder Feedback

Working Group participants were particularly engaged on topics related to hydrogen end uses, and the diverse range of stakeholder feedback was instrumental in the development of this analysis and recommendations.

Stakeholders provided support for the concept of end use prioritization. The Nature Conservancy stated that the need to move rapidly towards sector-wide decarbonization, electrification, and energy efficiency does not allow any potential energy options to be ignored. They noted that there is a need to establish the right priorities for hydrogen use.[161] PURA also noted their support for the

[159] Refers primarily to blending hydrogen into natural gas feedstocks at industrial facilities. Delivery to non-core customers could also be achieved by blending hydrogen into the broader gas system, but this would deliver equivalent levels of hydrogen to all customers on the system (including residential and commercial customers).
[160] Refers to buses or other heavy-duty vehicles where electrification would require costly upgrades to local electricity infrastructure, or where space constraints or other obstacles may hinder the use of battery vehicle charging (e.g., at ports or densely urbanized areas).
[161] The Nature Conservancy (2022), Comments to the Hydrogen Task Force, p. 2.

draft prioritization framework established by the Uses Working Group as presented at the November 8, 2022 Task Force meeting.[162]

A number of stakeholders also weighed in on criteria that should be considered in this prioritization. FuelCell Energy recommended consideration for how quickly each end use can grow in size as a source of hydrogen demand, and how effectively the end use supports decarbonization, as well as other air quality (e.g., criteria pollutants) and environmental justice goals. PURA recommended prioritizing end-uses that are difficult to decarbonize and provide meaningful societal benefits.[163] The Nature Conservancy also noted several criteria for end use prioritization – cost, safety, efficiency, and environmental preservation.[164] Additionally, the Environmental Advocates detailed a set of criteria developed by EarthJustice to guide end use prioritization.[165]

There was significant stakeholder feedback on which end uses should be placed in which priority buckets. CCAT recommended that applications that that have multiple values to Connecticut communities, industry, energy reliability, and workforce should be considered for prioritization.[166] Eversource noted that the building sector and portions of the transportation sector could be near-term focus areas for hydrogen use, and FuelCell Energy noted that light-duty hydrogen fuel cell vehicles can be a significant source of hydrogen demand.[167] By contrast, the Environmental Advocates stated that hydrogen does not make economic sense as a decarbonization strategy for light-duty vehicles or buildings and affirmed that the deployment of clean hydrogen should be limited to hard-to-decarbonize applications that cannot easily or cost-effectively be electrified.[168] They identified that hydrogen potentially makes sense as a road transport fuel in the limited context of heavy-duty long-haul trucking.

Eversource identified that technology and market factors have set the conditions necessary to begin electrification of a large portion of transportation applications, including the expected mass adoption of passenger electric vehicles, last mile/local delivery vehicles, transit and school buses, and fixed route industrial applications like refuse trucks, but there remains a group of transportation applications that are considered difficult to electrify, including long-haul trucking, aviation and maritime shipping which may be appropriate for hydrogen.[169] FuelCell Energy identified blending as a near term hydrogen end use as it decarbonizes multiple sectors that require high Btu/ high grade heat in their process of making products and/or delivering services.[170] FuelCell Energy also noted that Connecticut should support other end uses which have potential benefits, such as hydrogen power generation, material handling, and light- and heavy-duty vehicles.[171]

[162] Connecticut Public Utilities Regulatory Authority (2022), Comments to the Hydrogen Task Force, p. 5.
[163] Ibid., p. 4.
[164] The Nature Conservancy (2022), Comments to the Hydrogen Task Force, p. 4.
[165] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 9.
[166] Connecticut Center for Advanced Technology (2022), Comments to the Hydrogen Task Force, p. 5.
[167] FuelCell Energy Inc (2022), Comments to the Hydrogen Task Force, p. 4.
[168] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 7.
[169] Eversource (2022), Comments to the Hydrogen Task Force, p. 4.
[170] FuelCell Energy Inc (2022), Comments to the Hydrogen Task Force, p. 4.
[171] *Ibid.*, p. 4.

Stakeholders also noted the omission of hydrogen as a long duration energy storage (LDES) solution.[172][173] This spoke to a lack of clarity in the initial presentation of end uses because the use of fuel cells for peak power generation represents a LDES application, as hydrogen's function as LDES is typically accomplished by producing hydrogen from excess renewable energy and then converting it pack to electricity (via fuel cells or combustion turbines) to meet peak power demand when renewable energy is not available.

There was also significant discussion of the appropriate end uses to prioritize within working group meetings. CCAT expressed concern that some end uses identified as "highest priority" would be particularly difficult for Connecticut to address. This included hydrogen use for long-haul trucks, maritime shipping, and aviation, which are integrated into regional transportation networks and so are challenging to address with state-specific policy. Toyota also stated that customer use patterns for passenger vehicles might make them difficult to address with electrification alone. Other stakeholders, such as the Acadia Center and Conservation Law Foundation, stated that hydrogen use should be concentrated on sectors that are hardest to electrify.

In general, there were two end uses that solicited a particularly large volume of stakeholder comments in working groups: commuter buses and hydrogen blending. The feedback on these two end uses is outlined in more detail below:

Buses

There was substantial discussion in Uses Working Group meetings and follow-up communications about the value of hydrogen for use in buses, including municipal transit buses and other commuter buses that travel shorter routes (as well as other heavy-duty vehicles with shorter ranges). Stakeholders across several sectors supported the consideration of hydrogen for this end use, noting (for example) that battery electric buses are far heavier than fuel cell buses. This included representatives from DEEP, CCAT, and Avangrid.[174]

By contrast, Acadia Center opposed the uniform use of hydrogen in buses, noting in an email that some energy experts have concluded that electrification can be particularly cost-effective for buses with shorter driving ranges.[175] Overall, the diversity of this feedback illustrated that "buses" is not a monolithic end use, and that the usage profiles and local conditions are important to consider when deciding how to decarbonize this particular area of the economy. This feedback prompted the division of buses into several sub-categories, including long-distance buses and buses that operate in areas where local conditions may limit the feasibility of battery charging.

Hydrogen Blending

The blending of hydrogen into existing natural gas pipelines and feedstocks was an area of focus for many stakeholders. Sierra Club pointed out that the technical limits of hydrogen blending meant that

[172] Bloom Energy (2022), Comments to the Hydrogen Task Force, p. 2.
[173] Bernard Pelletier (2022), Comments to the Hydrogen Task Force, p. 1.
[174] Connecticut Green Bank (2022), Hydrogen Power Study Taskforce: Uses Working Group Meeting #3.
[175] Based on conversations with the Acadia Center.

it could not completely decarbonize gas use,[176] and Acadia Center stated that hydrogen blending can't reduce gas system emissions to zero and so shouldn't be considered as a one-to-one comparison to options that fully eliminate users' on-site emissions (e.g., electrification).[177]

However, other stakeholders expressed support for testing hydrogen blending in the natural gas system. CCAT advocated for it as a way "store" hydrogen that is produced from renewable energy that would otherwise have been curtailed, allowing otherwise "wasted" renewable energy to reduce greenhouse gas emissions from gas networks. They also noted that this could provide a way to avoid "stranding" existing infrastructure, stating that investigating the use of hydrogen in energy infrastructure was a primary goal of the Task Force set out in Special Act 22-8.[178]

Finally, there was concern that the distinction between hydrogen blending for core and non-core customers was overly nuanced and confusing. Acadia Center stated that applications where hydrogen is blended at individual customer facilities, such as those that use high heat processes, is fundamentally different than those where it is blended into the entire gas system for all customers, and that these two applications should be treated separately.[179]

4.2 Additional Findings and Recommendations

In addition to the statutorily mandated areas of research, the Task Force also investigated further foundational topics – defining clean hydrogen, understanding infrastructure needs, and identifying stakeholder engagement strategies – that must be understood to develop a clean hydrogen ecosystem in Connecticut.

4.2.1 Identification of how to define clean hydrogen in Connecticut.

4.2.1.1 Findings

Federal guidance from the proposed Clean Hydrogen Production Standard has established "clean hydrogen" as that with less than 4 kg of CO_2e/kg H_2 on a lifecycle basis (well-to-gate). The use of a lifecycle or carbon intensity-based definition of clean hydrogen removes ambiguity associated with the "colors of hydrogen" and provides a standardized methodology to assess hydrogen on a technology-neutral basis. A carbon intensity framework can adopt a threshold and certification scheme to rigorously account for greenhouse gas emissions arising both at the site of production and upstream of production.

While designations of clean, green, and renewable hydrogen are not necessarily interchangeable, it is helpful to understand how different jurisdictions have defined each of these terms to inform the development of a Connecticut specific definition of clean hydrogen. Prior to the U.S. Federal guidance

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176 Connecticut Green Bank (2022), Hydrogen Power Study Task Force Infrastructure Working Group #3 .
177 Connecticut Green Bank (2022), Hydrogen Power Study Task Force Uses Working Group #1.
178 Connecticut Green Bank (2022), Hydrogen Power Study Trask Force Uses Working Group #3 Meeting Minutes..
179 *Ibid.*

on defining clean hydrogen, three U.S. states – Oregon, Washington, and Montana – defined clean hydrogen in statute.

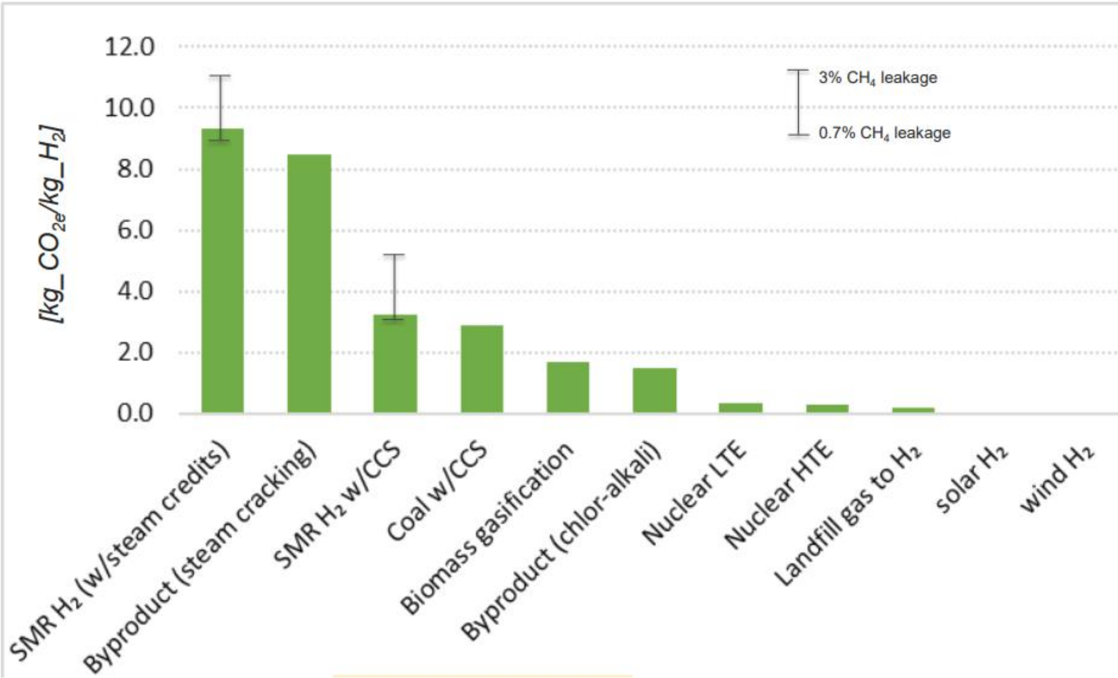
Table 5. Survey of National and International Definitions of Clean, Renewable, or Green Hydrogen

	Hydrogen Type (e.g., clean, renewable, green)	Based on a carbon intensity calculation	Technology agnostic (e.g., includes biomass, biogas, electrolysis, nuclear)	Electrolysis with renewables only	Excludes use of fossil fuels
US DOE	Clean	X	X		
Montana	Green		X		X
Washington State	Renewable		X		
Oregon	Renewable		X		X
Australia	Clean		X		
Canada	Green			X	X
Canada	Low Carbon Intensity	X	X		
Chile	Green			X	X
France	Renewable	X		X	X
France	Low Carbon	X	X		
Germany	Green			X	X
Sweden	Renewable/Clean		X		
CertifHy	Green	X	X		X
CertifHy	Low Carbon	X	X		

Varying approaches have been taken for defining hydrogen based on a region's climate goals, technology development activities, and geographic considerations. Notably, federal guidance from the IIJA and Proposed Clean Hydrogen Standard provides a minimum standard that clean hydrogen must meet to access federal incentives, set at 2 kg CO_2e/kg H_2 at the point of production and 4 kg CO_2e/kg H_2 on a lifecycle basis.

The federal definition of clean hydrogen in the IIJA and Clean Hydrogen Production Standard enables production of clean hydrogen from a diversity of feedstocks. A study using the GREET model from Argonne National Laboratory identified the lifecycle carbon intensity associated with hydrogen production pathways and demonstrated that clean hydrogen as defined by the Clean Hydrogen Production Standard can be produced by diverse feedstocks, including nuclear, solar, wind, landfill gas, and even potentially fossil fuels with carbon capture and sequestration assuming minimal methane leakage.

Figure 12. Well-to-Gate GHG Emissions of Hydrogen Production Pathways



Source: Argonne National Laboratory: GREET Model for Hydrogen Life Cycle GHG Emissions (June 15, 2022)

4.2.1.2 Recommendations

The development of a statewide definition of clean hydrogen would provide clarity for hydrogen development within Connecticut.

- **DEEP should conduct further investigation to ultimately establish a definition of clean hydrogen that would be most appropriate for Connecticut**. While hydrogen can be produced from fossil fuels via steam methane reformation, from electricity via electrolysis, or from organic sources, these sources have differing levels of GHG emissions associated with production. Many countries and U.S. states have established definitions of clean, green, renewable, or low-carbon hydrogen to differentiate hydrogen with lower GHG emissions intensity (as shown in Table 5) and the federal government has similarly suggested a definition based on lifecycle emissions. Such definitions can provide clarity for hydrogen development within the state and will help to guide project and fuel eligibility for siting, funding, tariff regulation, and other actions and initiatives referenced in this report.

4.2.1.3 Stakeholder Feedback

Discussion regarding a definition of clean hydrogen revealed a range of opinions among stakeholders. Eversource, Bloom Energy, FuelCell Energy, and CCAT recommended alignment of the Connecticut definition for clean hydrogen with federal guidance.[180] Bloom Energy stated that consistent definitions are essential to ensure clarity in this developing sector and will enable more participation in federal tax incentives and innovation programs benefiting Connecticut ratepayers.[181] FuelCell Energy noted that Connecticut has several clean energy technology companies that serve broader national and global markets and stated that a definition consistent with the federal definition will enable broader economic development.[182]

The Environmental Advocates stated that Connecticut should pursue a more stringent definition for clean hydrogen than the one established by the federal government. They proposed that an appropriate state definition of clean hydrogen should include only hydrogen produced with zero-carbon renewable energy. The Environmental Advocates clarified that zero-carbon resources must be additional to prevent any double counting of their clean energy attributes. With a clean hydrogen definition that includes only non-fossil fuel, 100% zero-carbon feedstock, they also noted that having more stringent state requirements would not preclude Connecticut projects from obtaining federal funding, unless that funding is specifically for production methods or sources that would not qualify as clean hydrogen under a more stringent definition in Connecticut.[183]

Representatives from DEEP expressed the need for further investigation into which definition would be most valuable for Connecticut before recommending any specific definition and noted that such analysis will be undertaken throughout DEEP's Comprehensive Energy Strategy (CES) process.[184]

4.2.2 An examination of the infrastructure needed for a clean hydrogen ecosystem.

4.2.2.1 Findings

Various types of infrastructure are required to enable the effective delivery of hydrogen to end users, including compression, storage, transportation, and in some cases, liquefaction. Hydrogen is produced at low pressures, between 20 and 30 bar, and must be compressed to between 200 and 500 bar to be economically transported.[185] Once compressed, hydrogen can be transported through pipelines or on trucks, as well as via more specialized transport methods like barges or rail. Hydrogen can also be liquefied for transportation on trucks, which allows for higher energy density by volume than gaseous hydrogen.

Another key piece of hydrogen infrastructure is storage. At small volumes, hydrogen can be held in smaller storage tanks at production or end-use sites. At large volumes, geologic storage sites provide the most economic means for hydrogen storage and can be used for long-term storage to balance any seasonal variation in hydrogen production from renewable energy. Salt caverns are the lowest-cost

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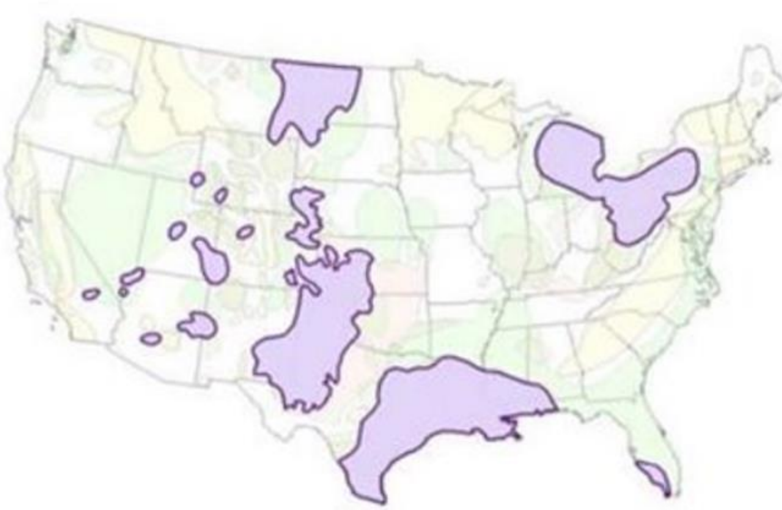
180 Eversource (2022), Comments to the Hydrogen Task Force, p. 1; Bloom Energy (2022), Comments to the Hydrogen Task Force, p. 1; FuelCell Energy Inc. (2022) Comments to the Hydrogen Task Force, p. 2; and CCAT (2022), Comments to the Hydrogen Task Force, p. 4.
181 Bloom Energy (2022), Comments to the Hydrogen Task Force, p. 1.
182 FuelCell Energy Inc. (2022), Comments to the Hydrogen Task Force, p. 2.
183 Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 3-4.
184 Connecticut Green Bank (2022), Hydrogen Power Study Task Force Policy Working Group #3..
185 U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office, Gaseous Hydrogen Compression.

and commercially available form of geologic storage, but are only present in specific locations. The map below shows the locations of known salt cavern storage in the US;[186] the closest sites to Connecticut are in Upstate New York and Pennsylvania, approximately 150 to 200 miles from Bridgeport, and would likely require a pipeline connection to access.

Figure 13. Known Salt Deposits in the Continental U.S.



Source: Geologic storage of hydrogen: Scaling up to meet city transportation demands (September 23, 2014)

The cost-effectiveness of hydrogen transportation infrastructure varies according to both the volume of hydrogen and the distance over which the hydrogen is being transported. Figure 14 shows approximate costs for different forms of transportation.[187] Transmission pipelines are generally the lowest-cost alternative for transporting large quantities of hydrogen over long distances. When transporting volumes over 100 kilograms per day, the average costs for transmission pipelines are between $0.05 to $0.10 per kilogram of hydrogen for distances up to 100 kilometers (or around 60 miles), and $0.10 to $0.58 per kilogram for inter-city distances on the scale of hundreds of miles.[188] These estimates include the cost of associated compression and storage.

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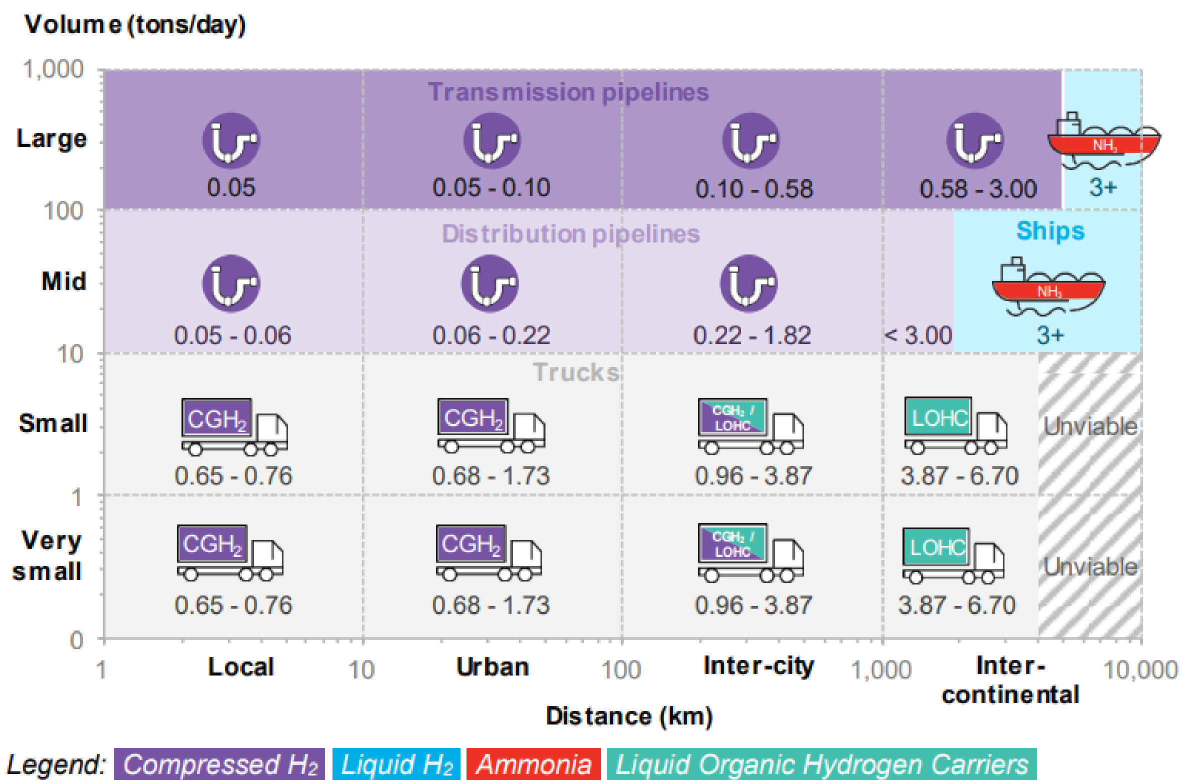
[186] Lord et al., Sandia National Laboratories (2014), Geologic storage of hydrogen: Scaling up to meet city transportation demands.

[187] "Liquid Organic Hydrogen Carriers" refers to a novel way of transporting hydrogen via organic compounds that can absorb and release hydrogen through chemical reactions. They are yet commercialized at scale, to this report has focused on liquid hydrogen as the most likely transport option for truck delivery over long distances.

[188]BloombergNEF (2020), Hydrogen Economy Outlook.

Figure 14. Hydrogen Transportation Costs by Distance and Volume ($/kg)



Source: Bloomberg NEF: Hydrogen Economy Outlook (March 30, 2020)

There are approximately 1,600 miles of hydrogen pipelines currently operating in the United States, located in areas with high concentrations of large hydrogen users (historically petroleum refineries and chemical plants), such as the Gulf Coast.[189] Pipelines for hydrogen are similar to those used for natural gas transmission. However, hydrogen has a stricter set of material standards for pipelines than natural gas, due to the potential for embrittlement, leading to higher labor and material costs for hydrogen transmission.[190]

While pipelines are a cost-effective method for transporting hydrogen at high volumes (i.e., over 150 metric tons per day), initial capital costs for development are high. Estimated costs vary based on the size and location of the pipeline, but research on hydrogen pipelines estimates capital costs of approximately $1 million to $3 million per mile, depending on diameter.[191,192] While the capital cost increases with diameter, the increased volume offsets the increased costs, so that the average cost per kilogram tends to decrease for larger diameter pipelines.[193]

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189 U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office, Hydrogen Pipelines.
190 DeSantis, Daniel et al. (2021), Cost of long-distance energy transmission by different carriers.
191 *Ibid.*
192 Saadi, Fadl H. et al. (2018), Relative costs of transporting electrical and chemical energy.
193 DeSantis, Daniel et al. (2021), Cost of long-distance energy transmission by different carriers

However, while hydrogen pipelines have higher material and labor costs than their natural gas equivalents, capital costs for compression stations located along hydrogen pipelines are generally lower. As gases flow through the pipeline, they require additional compression to counteract pressure drops, which occur more quickly for natural gas than for hydrogen.[194] As a result, the amount of compression required is higher in natural gas pipelines, contributing to an estimated $660,000 per mile versus $308,000 per mile for hydrogen pipelines.[195] Work by DeSantis et al. (2021) suggests that, when compression costs are taken into account, capital costs for hydrogen pipelines can be lower than that for natural gas, coming in at $1.38 million per mile versus $1.69 million per mile for natural gas (assuming 36" pipeline).[196]

It is also important to consider that the geographic location of the pipeline can impact the costs associated with pipeline development. The Brooklyn Union Gas Company and KeySpan Gas East Corporation, both subsidiaries of National Grid, filed their Leak Prone Pipe (LPP) Prioritization Report in March of 2022, in which they estimated average costs of $8.7 million per mile and $2.2 million per mile, respectively, to replace natural gas distribution pipelines.[197] Similar documents filed by Niagara Mohawk Power Corporation, another subsidiary of National Grid, give estimates of $1.3 million per mile,[198] which is more closely in line with estimates found in the literature. The difference in cost is likely a function of the location, as Brooklyn Union operates in densely populated areas within New York City, KeySpan operates in the suburbs of New York City, and Niagara Mohawk operates in less densely populated areas in Upstate New York.

The primary alternative to pipeline transmission of hydrogen is transportation via trucks. Trucks can transport hydrogen in both liquid and gaseous forms, but truck delivery of liquid hydrogen is generally more cost-effective than that of gaseous hydrogen when transported over long distances (i.e., over 400 miles[199]) due in part to the increased energy density of liquid hydrogen. Other methods of transportation for hydrogen that could be investigated further for Connecticut's particular needs include rail and shipping on barges.

Shipping hydrogen over very long distances (e.g., between countries) typically requires conversion to a hydrogen carrier, such as Liquid Organic Hydrogen Carriers (LOHC) or ammonia. Ammonia is particularly promising as a hydrogen carrier because it is easier to store and transport than hydrogen, has a relatively high density, and already has widespread global infrastructure.[200]

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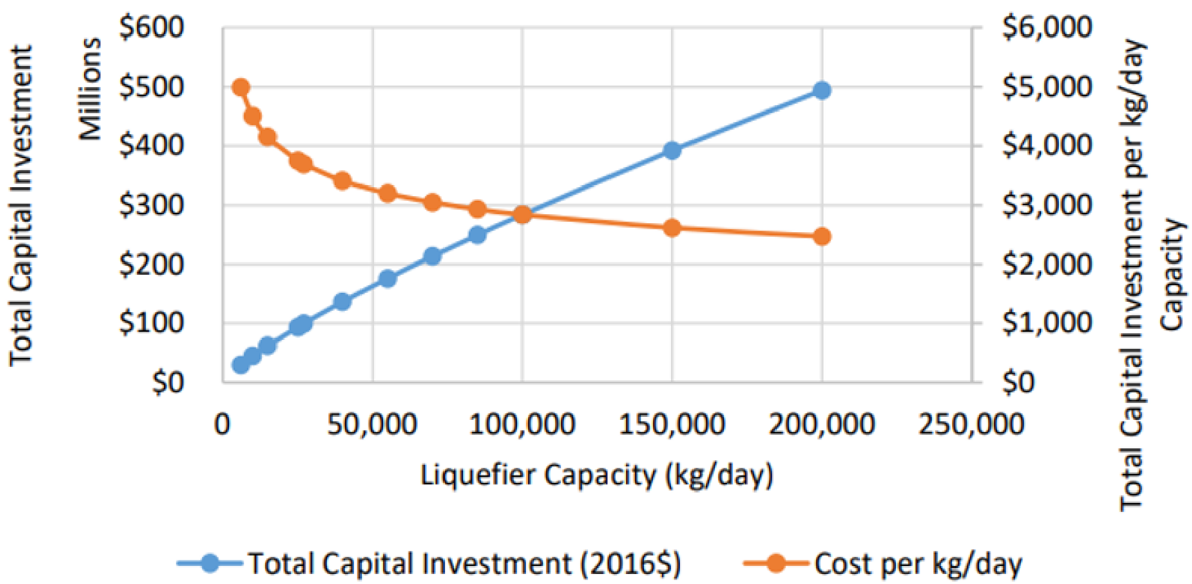
194 *Ibid*.
195 *Ibid*.
196 *Ibid*.
197 National Grid. *"Annual Leak Prone Pipe (LPP) Prioritization, Type 3 Leak, and Capital Report."* Case 19-G 0309 – Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of The Brooklyn Union Gas Company d/b/a National Grid NY for Gas Service *and* Case 19-G-0310 – Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of KeySpan Gas East Corporation d/b/a National Grid for Gas Service, 30 March 2022.
198 National Grid. *"Annual LPP Prioritization, Type 3 Leak, and Capital Plan Report."* Case 20-G-0381 – Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Niagara Mohawk Power Corporation d/b/a National Grid for Gas Service, 30 March 2022.
199 Connelly, Elizabeth et al., Department of Energy (2019), Current Status of Hydrogen Liquefaction Costs.
200 Argus Media (2020), Green shift to create 1 billion tonne 'green ammonia market?

However, there are additional costs and facilities required to convert hydrogen to and from carriers, some of which involve significant process emissions.[201] These alternative transport methods require additional research and evaluation to determine their cost-effectiveness and suitability.

Although LOHCs and ammonia could be used for regional truck transport of hydrogen as well, this report assumes liquid hydrogen to be the primary method of increasing hydrogen energy density for long-distance truck delivery given its greater commercial use today. Research on the costs of hydrogen liquefaction suggests that capacities of 6,000 to 200,000 kilograms per day could be technically feasible, and the associated range of capital investment would be $30 million to $490 million.[202] For context, a typical commercial liquefier currently operates at a capacity of around 27,000 kilograms per day and has a capital contribution of about $1.40 per kilogram to the levelized cost of hydrogen, not including operating costs of electricity.[203] Liquefiers benefit from economies of scale, as the capital investment per kilogram of hydrogen decreases with higher volumes of throughput. However, these reductions are steepest at lower capacities (see Figure 15).

Figure 15. Capital Investment for Liquefiers at Different Capacities



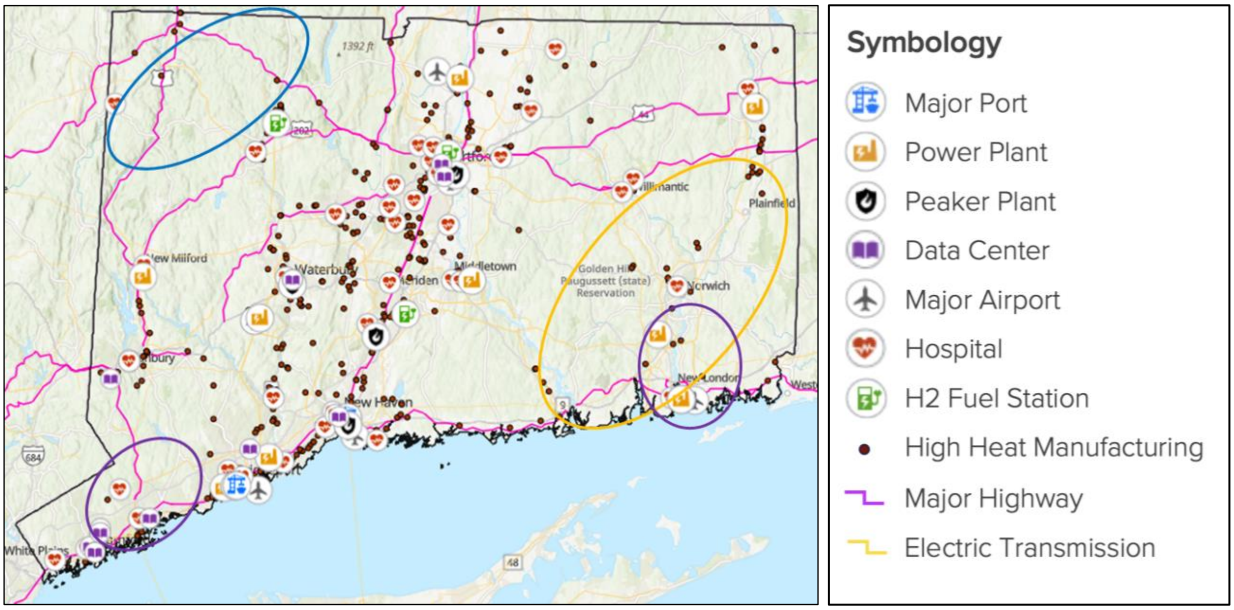
Source: DOE: Current Status of Hydrogen Liquefaction Costs (August 6, 2019)

Based on the likely locations of hydrogen production and use in Connecticut, investment in hydrogen infrastructure is necessary to connect clean hydrogen production sources with end uses at scale. The map below shows the relative locations of major potential hydrogen offtakers compared to the most promising renewable energy production sites. The blue circle indicates areas with the highest onshore wind production capacity, while the orange circle marks areas with substantial solar

[201] IRENA (2022), Global Hydrogen Trade to Meet the 1.5C Climate Goal: Technology Review of Hydrogen Carriers.
[202] *Ibid.*
[203] *Ibid.*

production capacity. The purple circles represent areas where offshore wind could be interconnected with Connecticut in the future, although it's possible that interconnection limitations will require "virtual" connections between electrolyzers and offshore wind installations via PPA agreements.

Figure 16: Locations of Hydrogen Offtakers and Renewable Energy Potential in Connecticut



Source: Strategen Consulting

4.2.2.2 Recommendations

Based on the probable locations for hydrogen production and consumption in Connecticut, it's likely that additional infrastructure will be required to transport, store, and distribute hydrogen across the state. The following recommendations provide some steps that Connecticut could take to enable the development of this infrastructure:

- **DEEP should lead interstate and interagency coordination to develop a hydrogen roadmap and strategy that identifies hydrogen supply and demand scenarios; approaches to a clean hydrogen backbone to enable cost-effective scaled transport; and other research and infrastructure investment opportunities to inform policy development and funding and RD&D strategy, in consultation with ecosystem stakeholders.** Connecticut can look to the DOE's National Clean Hydrogen Strategy and Roadmap[204] as a guide, and then use a similar or adapted methodology at the state level. Similarly, Connecticut can consider state reports, like the Oregon Department of Energy's renewable hydrogen report that seeks to identify where renewable hydrogen can be most useful in its decarbonizing economy.[205] In addition, existing hydrogen infrastructure should be studied to determine the value of refurbishing or

[204] United States Department of Energy (2022), DOE National Clean Hydrogen Strategy and Roadmap.
[205] Oregon Department of Energy (2022), Renewable Hydrogen In Oregon: Opportunities And Challenges.

completing partially installed or non-functional assets compared to installing new dedicated infrastructure. Connecticut's vision can build on work done and input provided to the Task Force, and ideally would include an examination of the following factors:

a. Current technologies available for hydrogen transport;
b. The role of hydrogen transport costs in overall delivered cost;
c. Cost and funding mechanisms for any enabling infrastructure and clean hydrogen production;
d. Alignment with state policies and goals;
e. Alignment with regional hub activities; and
f. Stakeholder feedback, and especially community preferences.

- **DEEP should investigate the need for hydrogen fueling stations to support multi-sectoral mobility applications, and as appropriate, coordinate with the Connecticut Department of Transportation to develop more specific strategies for optimizing siting and funding.** This could include an assessment of major transit routes to determine refueling locations that would best serve regional transit needs.
- **DEEP should clarify and work with relevant agencies and stakeholders to explore the acceleration of permitting for clean hydrogen infrastructure, while ensuring appropriate guardrails to avoid unintended adverse impacts.** To scale development at the speed needed to transition to a clean economy, it is important to ensure that permitting requirements are transparent and readily understood by all stakeholders. An example of work that supports this goal is the Governor's Office of Business and Economic Development in California, which published the Hydrogen Station Permitting Guidebook with the explicit goal of streamlining the permitting process.[206] In addition to permitting, statutory authorization to build infrastructure, including that of LDCs, should be addressed to ensure coordinated and regulated build-out.

4.2.2.3 Stakeholder Feedback

Stakeholders have highlighted the need for hydrogen transportation and storage infrastructure although there is not consensus regarding the type of infrastructure that will be needed. FuelCell Energy noted that to scale the hydrogen supply and demand sectors, both distributed hydrogen and hydrogen pipeline transport will be needed.[207] PURA encouraged the consideration of which distribution technologies will be most beneficial to end users and the state. PURA noted that given the wide variety of potential end uses, they are not yet convinced that natural gas pipelines are the optimal option, as existing pipelines may not reach all potential end use sites or serve all necessary end uses.[208]

Eversource stated that Connecticut should consider all forms of infrastructure, starting with pipelines, and understanding and planning for the roles of other delivery systems. They noted that

[206] California Governor's Office of Business and Economic Development (2020), Hydrogen Station Permitting Guidebook.
[207] FuelCell Energy Inc. (2022), Comments to Hydrogen Task Force, p. 5.
[208] PURA (2022), Comments to Hydrogen Task Force, p. 2.

the state should not prioritize certain infrastructure unless and until market signals clearly indicate that the infrastructure is needed and not otherwise being developed.[209] The Environmental Advocates stated that Connecticut should not invest in infrastructure to distribute hydrogen to buildings through the gas distribution system and any build out of infrastructure should focus on deployment of clean hydrogen for hard-to-decarbonize applications that cannot easily or cost-effectively be electrified.[210]

Regarding statutory authority, PURA explained that if existing natural gas distribution or transmission infrastructure is used to transport hydrogen, it will be subject to state and federal safety regulations and requirements overseen by PURA. They noted that these regulations mandate that LDCs maintain gas lines up to and including the gas meter while maintenance beyond the gas meter (i.e., the gas line that extends from the meter into a building) is normally the responsibility of the gas user or property owner. PURA acknowledged that current requirements are designed to accommodate the chemical properties of natural gas and may need to be modified to account for hydrogen.[211]

Several parties also discussed the topic of safety associated with hydrogen transportation. The Environmental Advocates noted that best practices for the production, transport, delivery, storage, and use of clean hydrogen are still in development. They explained that the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) has recognized that there are major research gaps for safely using existing pipelines for potential hydrogen transport. Given the safety concerns associated with hydrogen transport and use, following best practices and establishing stringent regulatory requirements will be critical to minimize the chances of explosions and other risks. The Environmental Advocates recommended that safety requirements should be established and regularly updated in accordance with the best available science and regulators should provide a robust public engagement process to ensure that community concerns are taken into account.[212]

Bloom Energy noted that, with any gas, safety is always a concern, but modern engineering principles, material design, building codes, and safety trainings can mitigate much of the concern hydrogen presents, just as society has adapted to the inherent risks of more commonly used fuels such as natural gas, propane, gasoline, and diesel. They explained that codes organizations such as the National Fire Protection Association (NFPA), American Society of Mechanical Engineers (ASME), and American Society of Testing Materials (ASTM) already have regulations regarding hydrogen operations and should be looked to as technical resources for safe implementation and through a variety of efforts at National Labs, DOE also is providing substantial scientific research to support community and climate goals in the hydrogen sector.[213]

[209] Eversource (2022), Comments to Hydrogen Task Force, p. 7.
[210] Environmental Advocates (2022), Comments to Hydrogen Task Force, p. 12.
[211] PURA (2022), Comments to the Hydrogen Task Force, p. 4.
[212] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 11.
[213] Bloom Energy (2022), Comments to the Hydrogen Task Force p. 3.

Eversource also pointed out that outside industry groups such as the American Institute of Chemical Engineers also have detailed knowledge on hydrogen systems and could be leveraged to provide additional input on safety topics. Eversource recognized that operational and safety concerns around blending will require the appropriate scientific inquiry that pipeline and local distribution companies are best positioned to perform.[214] In addition, Eversource advocated for the recommendation of direct legislative support of appropriate state regulatory oversight for hydrogen.[215] They also suggested legislative support could be leveraged to aid the deployment of hydrogen infrastructure, as well as the production, sale, and distribution of hydrogen.

The Environmental Advocates also raised concerns with the costs and inefficiencies associated with hydrogen infrastructure.[216] PURA noted their concern with rate-basing infrastructure to deliver hydrogen for purposes other than heat and power, which may not be the most beneficial, fair, or equitable option for ratepayers with gas service.[217] The Environmental Advocates noted that while estimates may vary by distribution system, hydrogen cannot be blended into the gas distribution system at high volumes. They explained that in Connecticut, over 50% of gas mains are made of steel or iron, which cannot be used to transport a high level of hydrogen.[218] The Environmental Advocates stated that utilization of current natural gas infrastructure for hydrogen transport would not be sufficient and thus large capital investments in new infrastructure for hydrogen transport through pipelines would be necessary as well as large capital investments in hydrogen storage systems.[219] They also stated that truck or rail transport would also be expensive because hydrogen must be highly compressed, making these options realistic only for smaller volumes of hydrogen.[220]

Stakeholders provided several recommendations for activities that may be needed regarding hydrogen infrastructure. Eversource advocated for the recommendation of direct legislative support for deployment of hydrogen infrastructure in Connecticut.[221] FuelCell Energy stated that Connecticut should work with neighboring states and the federal government on codes and standards for pipelines and other infrastructure, thus speeding up permitting for pipeline and vehicle fueling infrastructure. They also noted that for pipeline and fueling infrastructure, a Siting Council type approach that expedites approval, while attending to energy justice concerns, should be considered.[222] The Environmental Advocates noted that policies that will accelerate a transition to clean trucks, most notably California's Advanced Clean Trucks rule, will be critical to speed up the adoption of both electric and hydrogen fuel cell trucks in Connecticut. They recommended that Connecticut should coordinate with neighboring states and others in the region on developing the

[214] Eversource (2022), Comments to the Hydrogen Task Force" p. 6.
[215] *Ibid.*, p. 6.
[216] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 2.
[217] PURA (2022), Comments to the Hydrogen Task Force, p. 2-3.
[218] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 12.
[219] *Ibid.*, p. 2.
[220] *Ibid.*, p. 12.
[221] Eversource (2022), Comments to the Hydrogen Task Force" p. 6.
[222] FuelCell Energy Inc. (2022), Comments to the Hydrogen Task Force, p. 5.

infrastructure needed to accommodate increasing numbers of electric trucks and hydrogen fuel cell trucks.[223]

4.2.3 An identification of strategies for community engagement, outreach, and education related to hydrogen.

4.2.3.1 Findings

The Task Force found that clean hydrogen can provide an important tool to address economy-wide deep decarbonization and to address many issues related to energy equity, energy justice, and enabling a just and sustainable clean energy transition. As a low or zero-carbon fuel, hydrogen can help to reduce reliance on existing fossil fuel end uses that contribute to both global pollutants such as greenhouse gases, as well as local pollutants such as NO_X, SO_2, and $PM_{2.5}$ that increase adverse health impacts, up to and including premature death.

Notably, as the topic of hydrogen development advances, stakeholder concerns have been growing in response to topics that include hydrogen safety, infrastructure, workforce impacts, public health impacts, greenhouse gas emissions, and end use prioritization. As the clean hydrogen economy develops, it is critical to ensure that resultant benefits are equitably distributed and stakeholder concerns are addressed.

Further, the Biden Administration's Justice40 Initiative requires that 40 percent of the overall benefits of certain Federal investments be allocated to marginalized communities that are underserved and overburdened by pollution, and in many cases has placed increased focus on direct engagement and participation from these communities in the infrastructure planning and deployment process. Thus, it will be critical for Connecticut to prioritize community engagement, outreach, and education as it pursues hydrogen-related federal funding opportunities.

Effective community engagement aims to actively involve the community to achieve more cohesive long-term sustainable outcomes, processes, relationships, discourse, decision-making, and implementation. These efforts must be inclusive and intentional to build long-term relationships and develop meaningful solutions to complex issues. The activities of the Task Force have provided a starting point for community engagement with local experts including the Bridgeport Regional Energy Partnership, but these conversations will need to continue to ensure that the perspectives of all stakeholders are considered, and the public is educated and aware of hydrogen activity in the state.

4.2.3.2 Recommendations

The following recommendations will enable the state to increase community engagement and education related to hydrogen.

[223] Environmental Advocates (2022), Written Comments to the Hydrogen Task Force, p. 12.

- **The Legislature should create a transparent source for municipalities, cities, and other local applicants to access resources, such as match funding and/or application guidance.** This is being undertaken in other states to streamline the process of identifying match funding and project partners. For example, Colorado has established a Local Match Program, which allocates $80 million in state General Funds for the non-federal match requirements in the IIJA.[224] California passed a state law, SB 1075, which established a California Clean Hydrogen Hub Fund within the State Treasury that could authorize funding upon appropriation to be utilized to match federal funds.[225]
- **The Legislature should provide funding to increase community engagement and decrease the burden of engagement on communities.** While community benefit agreements and Justice40 requirements are important steps in creating a more inclusive and equitable energy transition, they will require considerable time and resources from local stakeholders to engage effectively. The state can further demonstrate its support for communities by providing funding for time and resources, such as technical expertise and consulting services, to develop community benefits agreements.
- **DEEP should require feedback and guidance from the Connecticut Equity and Environmental Justice Advisory Council (CEEJAC) to advance community impact, environmental justice, and energy equity discussions on hydrogen and to support the development of a framework that outlines both a vision and goals for Connecticut's clean hydrogen policies**. In California, community impacts have been taken into account through the creation of advisory boards and other programs through state agencies, including the California Air Resources Board (CARB).[226,227] Engaging the community – especially communities that are disadvantaged – is a critical step in ensuring the transition to a clean economy is one that is as inclusive, just, and sustainable as possible.

4.2.3.3 Stakeholder Feedback

Many stakeholders emphasized the importance of community outreach and education. FuelCell Energy emphasized that Connecticut is fortunate to have a significant representation of the nascent clean hydrogen industry in-state already, and some facilities like FuelCell Energy's Torrington manufacturing operations, are in DECD distressed communities. They acknowledged that as these companies expand and as new companies enter the market, Connecticut should continue robust economic development outreach to attract these companies to the state and to environmental justice and distressed communities.[228] Both FuelCell Energy and Bloom Energy encouraged building a foundation of clear scientific education for the public and establishing transparent project development processes directly involving local communities.[229]

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[224] Colorado Department of Local Affairs, Local Match Program.
[225] California Legislature (2022), Senate Bill 1075.
[226] California Air Resources Board, Environmental Justice Advisory Committee.
[227] California Public Utilities Commission, Disadvantaged Communities Advisory Group.
[228] FuelCell Energy Inc. (2022), Written Comments to the Hydrogen Task Force, p. 3.
[229] FuelCell Energy Inc. (2022), Comments to the Hydrogen Task Force, p. 3 and Bloom Energy (2022), Comments to the Hydrogen Task Force, p. 2.

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Bloom Energy and CCAT noted that understanding community needs will require robust, direct engagement with impacted communities.[230] Eversource also identified that forums such as those used in developing the Comprehensive Energy Strategy and Integrated Resource Plan provide valuable opportunities for stakeholder participation.[231]

Stakeholders had robust recommendations regarding community outreach planning, defining community impacts, and public education. FuelCell Energy recommended that Connecticut should create a task force that works with developers to define, communicate, and mitigate local impacts in partnership with environmental justice and disadvantaged communities. They also recommended that Connecticut could prioritize, through a variety of incentives, projects that displace legacy systems that have negative local impacts with clean hydrogen alternatives. FuelCell Energy also noted that Connecticut should also work with the federal government to ensure alignment with federal and state definitions of distressed communities as not all DECD distressed communities are recognized in the DOE's Justice40 model as Disadvantaged Communities. They also highlighted that stringent standards on air pollution would incentivize the development of truly clean hydrogen production.[232] Eversource noted that the strong, existing relationships that local distribution companies have with environmental justice and disadvantaged communities should be leveraged.[233]

The Environmental Advocates stated that Connecticut should develop an outreach plan to educate the public about the state's clean hydrogen planning and development process. As a starting point, state officials should reach out to regional councils of government, municipal officials, Energy Task Force members and the CT Energy Network, environmental and environmental justice groups, business and/or industry associations and groups, and community groups. They noted that as a first step, the Connecticut Equity and Environmental Justice Advisory Council (CEEJAC) should be consulted and should participate in creating equity and EJ-focused components of the state's hydrogen outreach plan.

The Environmental Advocates explained that for any hydrogen siting decisions that may impact EJ or disadvantaged communities, early and meaningful stakeholder engagement will be critical, as will consideration of cumulative impacts. They recommended that state and local siting authorities and project proponents should make it a priority to identify and engage with potentially affected communities early in the siting process, while there is still an opportunity for local residents to influence the location and suggest measures, such as community benefits agreements, to mitigate any negative impacts associated with the hydrogen project. They also highlighted that best practices in public outreach should be utilized, such as meeting communities where they are (e.g. by holding local meetings at places of worship, schools, community centers, etc.), holding meetings on the weekend or during evenings when more working people can attend, providing outreach materials in accessible

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230 Bloom Energy (2022), Comments to the Hydrogen Task Force, p. 2 and CCAT (2022), Comments to the Hydrogen Task Force, p. 4.
231 Eversource (2022), Comments to the Hydrogen Task Force, p. 5.
232 FuelCell Energy Inc. (2022), Comments to the Hydrogen Task Force, p. 3.
233 Eversource (2022), Comments to the Hydrogen Task Force, p. 2.

languages spoken in the community, providing options for in-person and remote meetings, recording and transcribing meetings for later viewing online, and providing free food, childcare, and compensation for people who participate in community meetings.[234]

5 Conclusion

Connecticut is well-positioned to capitalize on hydrogen-related federal funding opportunities given its many competitive strengths, including its participation in the Northeast Regional Hub application effort, its strategic positioning along high-volume transit corridors, its presence of a robust and nation-leading fuel cell and electrolyzer industry, and its existing efforts to support community engagement, particularly within disadvantaged communities. However, given federal match funding requirements and the imminent timing of funding applications, Connecticut must urgently consider its resources and funding strategy if the state wishes to capture significant federal funding.

At the direction of the Connecticut Legislature, the Task Force developed findings and recommendations based on in-depth analyses and research, expert input, and stakeholder feedback to establish the opportunity for a clean hydrogen economy in Connecticut. The Task Force also identified actions required to enable an equitable and just clean energy transition that includes clean hydrogen.

The Connecticut Green Bank would like to thank the Energy and Technology Committee for the opportunity to convene the Task Force to study hydrogen-fueled energy in Connecticut's economy and energy infrastructure. We would also like to thank the Task Force members, designees, and participants who contributed their time and resources to a robust study of hydrogen and its potential impact on Connecticut as reflected in this report. We look forward to supporting the future processes and actions that are initiated within the state based on the findings and recommendations presented by the Task Force.

[234] Environmental Advocates (2022), Comments to the Hydrogen Task Force, p. 11.

A. Appendix A: Hydrogen End Uses Evaluation

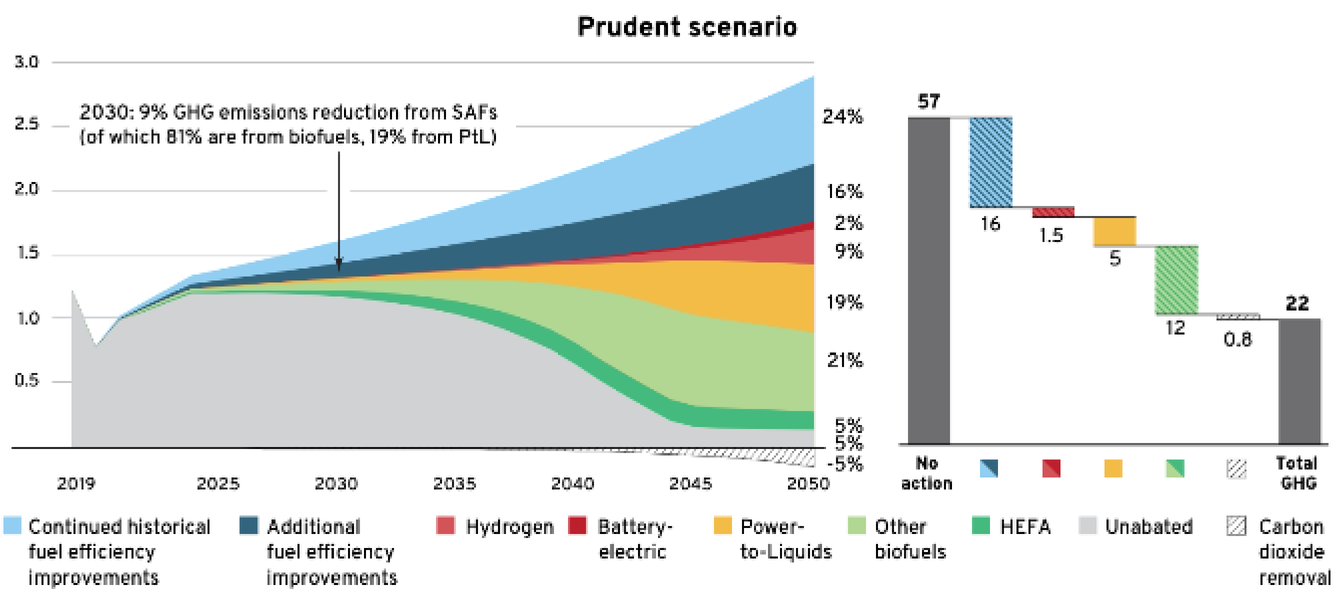
Appendix A provides a discussion of the methodology and sources utilized by Strategen to evaluate the prioritization of hydrogen end uses. The end uses discussed in this section include aviation, maritime shipping, industrial heat, residential and commercial heat, the power sector, heavy-duty vehicles, buses, passenger cars, material handling equipment, ferries, critical facilities, rail, and hydrogen blending. A systems level analysis of hydrogen use is also discussed.

A.1. Aviation

The aviation industry is responsible for emitting 1.24 gigatons of CO_2e every year, equivalent to 2% of the global anthropogenic GHG emissions and 3.5% of the overall climate impact, due to net effective radiative forcing. By 2050, this impact could potentially double or triple in the absence of meaningful policy and technology deployment advances (Mission Possible Partnership 2022). The aviation industry currently relies on jet fuel, a heavy-oil fuel that is refined from crude oil nationwide. Depending on the size of the airport, jet fuel is typically delivered by truck or through direct pipelines.

In 2022, the Mission Impossible Partnership (MPP) assessed two potential pathways to decarbonize aviation: a prudent and an optimistic scenario. Both pathways analyzed by MMP project a mix of incremental efficiency gains, biofuels, hydrogen, and batteries as potential alternatives to current jet fuels but assume different market shares and timing for these alternatives depending on the speed of renewable electricity cost reductions.

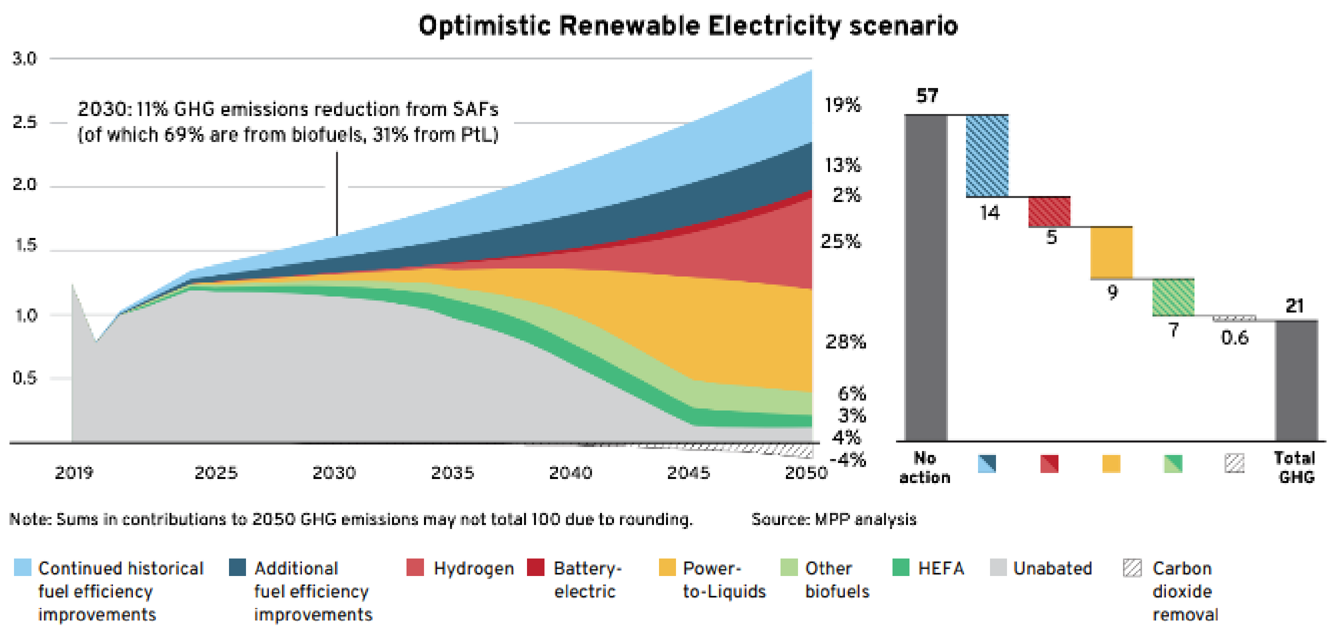
Figure 17. Prudent Deployment Scenario for the Aviation Sector



Source: Mission Possible Partnership. "Making Net-Zero Aviation Possible. An industry-backed, 1.5°C-aligned transition strategy." July 2022.

In the prudent scenario, the assumed cost of renewable electricity does not allow for scaled, economic deployment of clean hydrogen and derivative fuels until the 2040s. Hence, biofuels are identified as the most promising alternative to decarbonize aviation in this scenario. In the optimistic scenario, the cost of renewable electricity declines at a rate that allows hydrogen to be cost competitive by 2030 and to scale up over the following decade. However, even in the prudent scenario, hydrogen and hydrogen-derived fuels demonstrate the fastest gains in market share post-2045, indicating that these hydrogen fuels will ultimately be the most cost-effective for sectoral decarbonization over the long term compared to other potential solutions (Mission Possible Partnership 2022).

Figure 18. *Optimistic Deployment Scenario for the Aviation Sector*



Source: Mission Possible Partnership. "Making Net-Zero Aviation Possible. An industry-backed, 1.5°C-aligned transition strategy." July 2022.

Biofuels are the only sustainable aviation fuel (SAF) available today and are expected to represent the majority of the aviation fuel market in 2050 if costs for hydrogen remain high. However, biofuel use will also depend on whether sufficient volumes of sustainable biomass, which is subject to global resource constraints, can be directed to the aviation sector. Hydrogen Power to Liquid (PtL) fuels are projected to enter the market in the late 2020s and are expected to decline in cost by the mid-2030s. In future scenarios where low electricity costs push down the cost of clean hydrogen production, PtL fuels are likely to outcompete biofuels sooner than would otherwise be the case (Mission Possible Partnership 2022).

Hydrogen and battery electric aircraft will require further investments in technology development and production. Aircraft powered directly by hydrogen fuel cells could become commercially available in the 2030s and scale up through 2050 to reach as much as a third of aviation's final energy demand. Without substantial changes to aircraft design, however, the range of these aircraft could be limited to about 2,500 km due to the additional space requirements for storing hydrogen onboard. If new airframe designs and storage technologies are developed, these advances could increase the range of hydrogen fuel cell aircraft and allow them to further increase their market share (Mission Possible Partnership 2022). Battery-electric aircraft would likely require breakthroughs in battery chemistry, but even with such advances, battery-electric aircraft likely could only power regional flights up to about 1,000 km by mid-century. Designated "green corridors" could support deployment of both hydrogen and battery-electric aircraft by providing refueling or recharging infrastructure at dedicated airports that are connected by regular flight routes (Mission Possible Partnership 2022).

A study by the Clean Air Task Force (CATF) reached a similar conclusion to that of the MPP study. Namely, that a combination of aviation biofuels, scalable zero-emission fuels, and low-carbon electricity is needed to displace conventional jet fuel. The CATF study has a focus on biofuels and highlights that ramping up aviation biofuel production is a worrisome prospect given that bioenergy already faces several sustainability and supply chain challenges (Clean Air Task Force 2022).

Supporting Research

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- National Bureau of Economic Research. "Airports, Air pollution and Health." *The Digest*: no. 5, May 2012. https://www.nber.org/digest/may12/airports-air-pollution-and-health

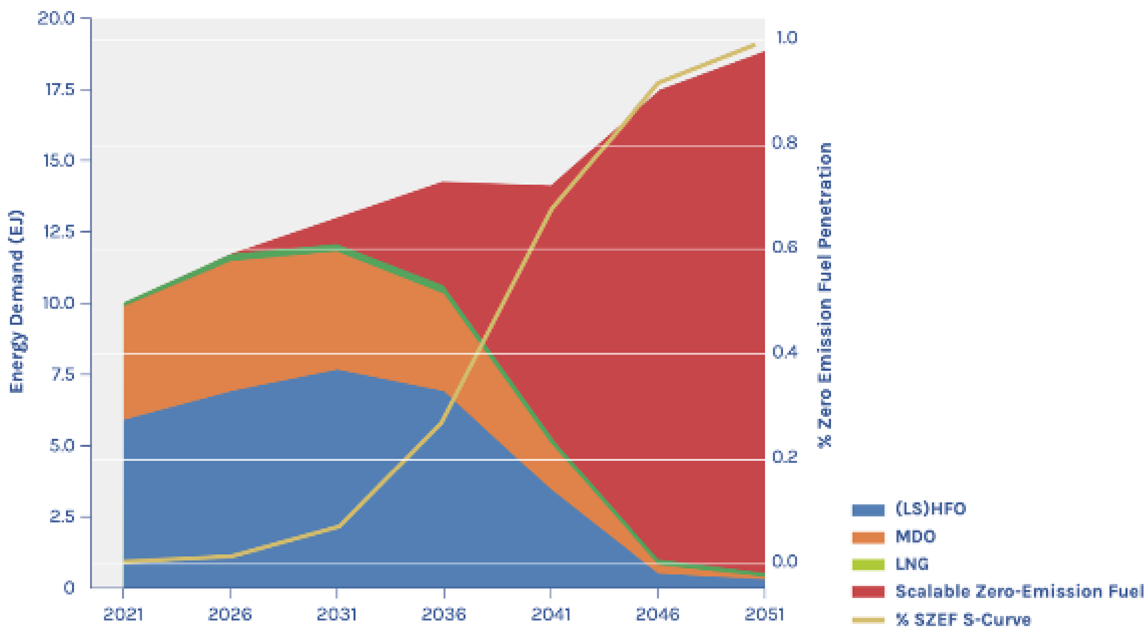
A.2. Maritime Shipping

Currently, marine ships are fueled by bunker fuel, a generic name for different types of heavy fuel oil (HFO) with diverse quality classifications. HFO is the most common fuel for large ships because it is inexpensive and energy dense. As fuel represents 30-35% of total operating costs for the maritime shipping industry, the majority of the global shipping fleet relies on cheap diesel Bunker C fuel oil (a low-quality HFO) which contributes significant amounts of GHGs, sulfur, and other emissions that contribute to climate change and cause adverse environmental and human health impacts. In places where the emissions of ships are regulated, Marine Gas Oil (MGO, a low-sulfur fuel oil) is one of the most prominently used fuels.

In 2021, the G7 nations made a clear commitment to align international shipping with the goal to maintain global warming under 1.5ºC degrees, a pathway that requires a 45% emission reduction from 2010 levels by 2030 and net-zero emissions by 2050. A report commissioned by the MPP in

2021 put forward a pathway to achieve this decarbonization goal within the maritime sector. The MPP analysis projected that liquified natural gas (LNG) use would expand out to 2030 but would still compose a relatively small share of the overall fuel mix. The MPP determined that the bulk of maritime decarbonization could be achieved by rapidly increasing the use of scalable zero-emission fuels (SZEFs), which will be introduced in 2026 and rapidly scaled up around 2031, according to the analysis. The MPP projected that the use of all other fossil fuels would decline rapidly as SZEFs enter the market (Mission Possible Partnership 2021).

Figure 19. *Projection of Maritime Energy Mix*



Source: Mission Possible Partnership. "A Strategy for the Transition to Zero-Emission Shipping: An analysis of transition pathways, scenarios, and levers for change." 2021.

Multiple fuels are being considered as potential SZEFs for the maritime sector, namely biofuels and hydrogen-based fuels like ammonia and e-methanol. The MPP report portrays ammonia as the most cost-effective SZEF after 2030. The study assumes that given underlying supply constraints, growing demand for biomass-based fuels will increase their prices, but growing demand for hydrogen will help lower hydrogen and hydrogen-based fuel costs by driving economies of scale in production once potential supply chain bottlenecks are overcome (Mission Possible Partnership 2021).

Figure 20. *Projection of the Total Cost of Ownership of Different Fuels and Production Pathways*

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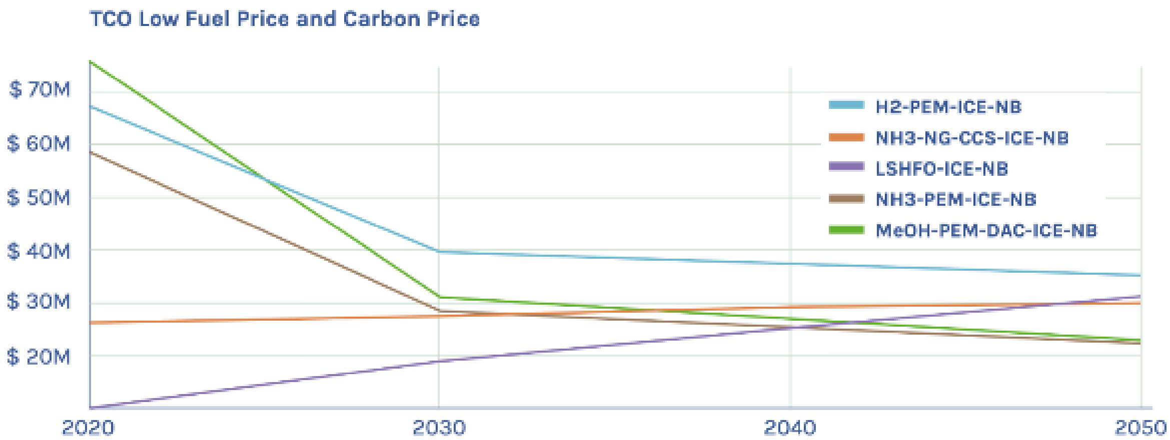

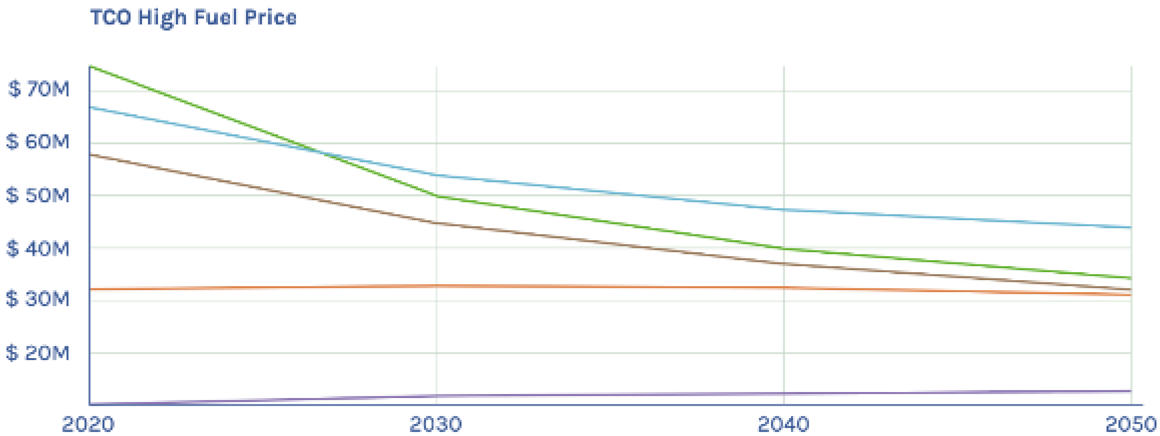

Source: Mission Possible Partnership. "A Strategy for the Transition to Zero-Emission Shipping: An analysis of transition pathways, scenarios, and levers for change." 2021.

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A.3. Industrial Heat

The United States industrial sector utilizes heat for an array of applications including washing, cooking, sterilizing, drying, and the generation of process heating. These processes occur at different scales and temperatures, and the viability of heating alternatives depends on these factors. Today, the majority of industrial process heat demand relies on the combustion of fossil fuels. Most low-temperature heating needs could be served by energy efficiency and renewable energy, but hydrogen and other zero-carbon fuels provide potential alternatives to decarbonize higher-temperature needs.

According to a study of industrial heating in European countries, 30% of industrial heating applications require heat below 410°C, another 27% can be met with heat between 410 and 1,380°C, and the remaining 43% require heat above 1,380°C. Many renewable heating resources can easily meet lower temperature requirements (i.e., under 1,380°C), and even if renewable sources cannot support the entire heating load, they can still provide pre-heating to supplement a conventional heating process. As it takes a relatively large amount of energy to raise the temperature of water (compared with heating air, for example), even a modest amount of pre-heating can reduce a facility's dependence on fossil fuels while also reducing costs in the process (Vannoni 2008).

However, many industrial processes require significant amounts of thermal energy at very high temperatures that exceed what can be economically provided by direct electrification. For example, conventional steel blast furnaces require temperatures of about 1,100°C, and cement kilns require about 1,400°C. In addition, many industrial facilities require continuous operation, or need to be able to be operated on demand (Friedmann 2019). Low-carbon fuels like hydrogen and biogas are economically viable solutions that exist today to reduce CO_2 emissions at scale for high temperature industrial processes (see Figure 18).

Figure 21. Temperature Requirement of Selected Industries and Temperature of Low Carbon Replacement Fuels

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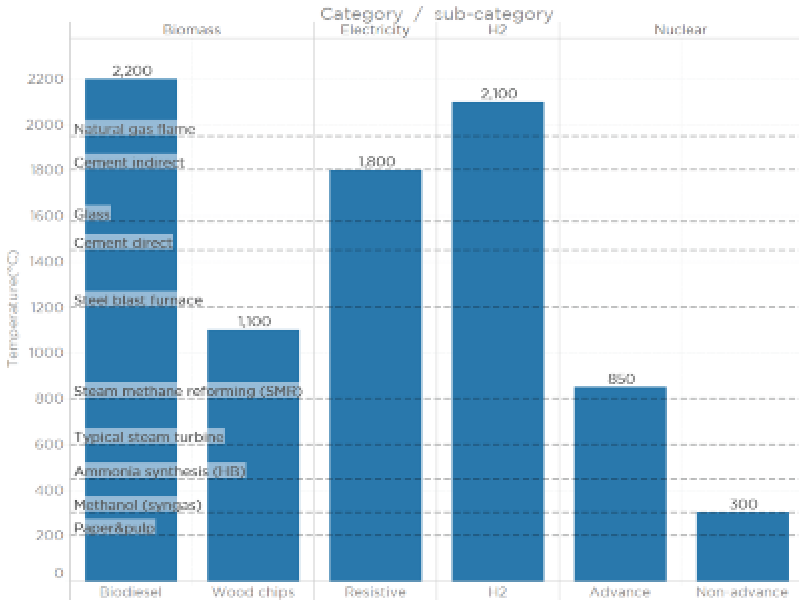

Source: Friedmann, Julio, Zhiyuan Fan and Ke Tang. "Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today." Columbia University, Center on Global Energy Policy, 7 October 2019.

The U.S. Department of Energy's "Industrial Decarbonization Roadmap" identifies four key technological pillars to significantly reduce emissions for the five subsectors studied (*Chemicals, Refining, Iron & Steel, Food & Beverages, and Cement & Lime*): energy efficiency; industrial electrification; low-carbon fuels, feedstocks, and energy sources (LCFFES); carbon capture, utilization, and storage (CCUS). Hydrogen, along with biofuels, falls under the "LCFFES" category and can provide a means to reduce combustion emissions for industrial processes with heat demands that are difficult to satisfy with electrified solutions (U.S. Department of Energy 2022).

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- Friedmann, Julio, Zhiyuan Fan and Ke Tang. *"Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today."* Columbia University, Center on Global Energy Policy, 7 October 2019. https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today
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https://archive.iea-shc.org/data/sites/1/publications/task33-Potential_for_Solar_Heat_in_Industrial_Processes.pdf

A.4. Residential/Commercial Heat

Hydrogen may be used to provide space heating for residential and commercial buildings, similar to the way natural gas provides heat to these buildings today. However, utilizing 100% hydrogen in the current natural gas distribution network, rather than low-level blends with natural gas, would require significant retrofits of the existing pipeline network, as well as upgrades to customer furnaces to effectively combust hydrogen for heat. A meta-analysis of 32 independent studies considering the use of hydrogen-based heating systems for residential customers found that hydrogen was more expensive than electrification regardless of the climate or region studied (Rosenow 2022).

A key reason for the relatively high cost of hydrogen-powered heating systems compared to heat pumps is the efficiency loss associated with hydrogen heating. Electrolyzers and hydrogen boilers can typically only convert electricity to heat at a total pathway efficiency of around 70%, whereas heat pumps can often achieve electricity-to-heat conversion efficiencies of 300% or higher (Baldino 2021). As a result, electrification pathways for space heat require significantly less build-out of renewable energy capacity than hydrogen-based pathways, with corresponding lower costs. The cost of renewable capacity build-out as well as the additional costs of retrofitting the gas distribution network for 100% hydrogen blends makes hydrogen use for residential and commercial heat unreasonable outside of niche applications.

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- Baldino, Chelsea et al. "Hydrogen for heating? Decarbonization options for households in Germany in 2050." International Council on Clean Transportation, 28 April 2021. https://theicct.org/wp-content/uploads/2021/06/Hydrogen-heating-germany-EN-apr2021.pdf
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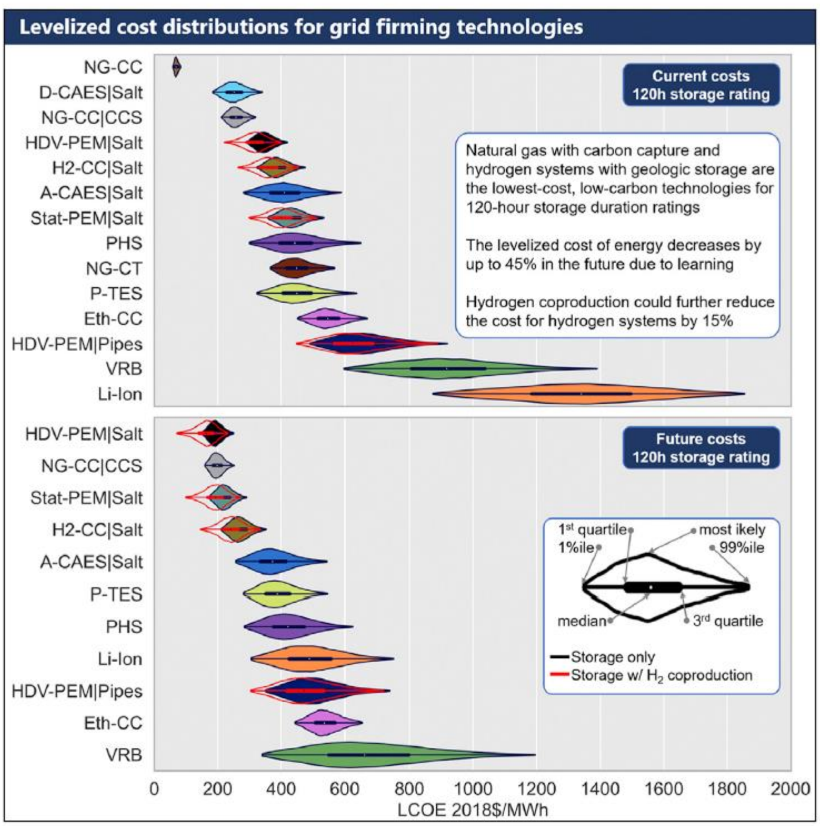
- Rosenow, Jan. "Is heating homes with hydrogen all but a pipe dream? An evidence review." *Joule*, 2022. https:// doi.org/10.1016/j.joule.2022.08.015

A.5. Power Sector

In the power sector, hydrogen could be used as a carbon-free fuel in turbines and fuel cells, which could enable high penetration of renewables on the grid by providing dispatchability and long-duration storage capabilities. Notably, as renewables become cheaper, they will replace fossil fuel generation but will also create a need for flexibility (dispatchable energy) during low-renewable periods to manage seasonal fluctuations in the availability of renewable energy sources like wind or solar. Turbines capable of burning 100% hydrogen blends are in development today and could be commercially available by 2030 (Power Magazine 2019).

There are several potential technologies that could serve long-duration storage needs, including gas turbines with carbon capture and long-duration batteries like vanadium flow systems. However, the cost advantages of hydrogen, particularly when coupled with low-cost underground storage, make it one of the most economic options as electrolyzer costs fall over time. Figure 22 compares the projected costs of different technologies capable of providing 120 hours of grid storage, using learning curve assumptions to estimate both current and future costs (Hunter 2021). Based on expected cost declines, hydrogen used in both combustion turbines and fuel cells are expected to be the most economic long-duration storage option that doesn't require carbon capture.

Figure 22. Relative Costs of Long-Duration Storage Technologies



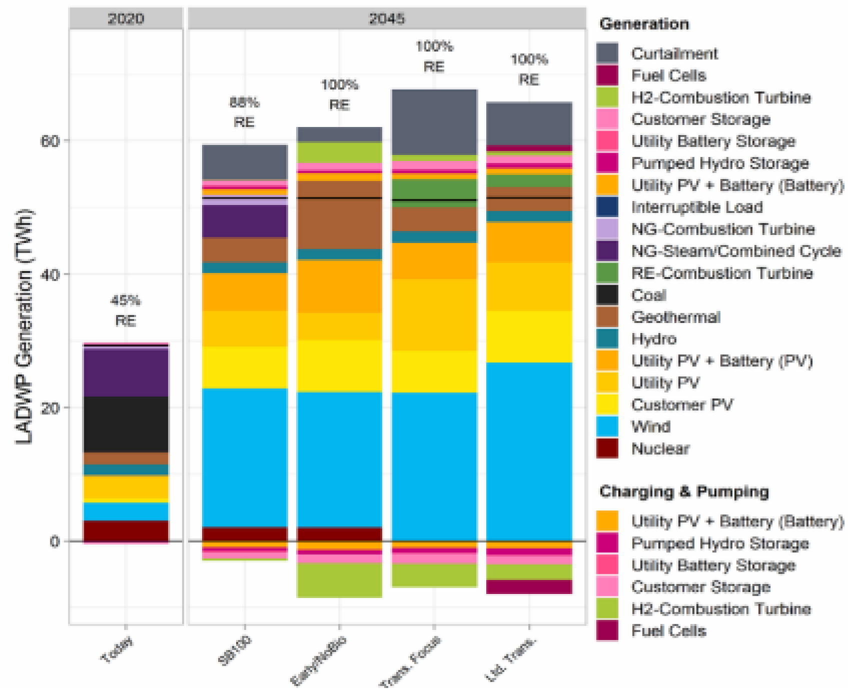
Acronym	Technology description
PHS	pumped hydropower storage
D-CAES | Salt	diabatic compressed air energy storage in a salt cavern that relies on natural gas combustion to reheat the air
A-CAES | Salt	adiabatic compressed air energy storage in a salt cavern that relies on thermal energy storage to reheat the air
P-TES	pumped thermal energy storage
VRB	vanadium redox flow batteries
LI-Ion	lithium-ion batteries
NG-CT	natural gas combustion turbine
NG-CC	natural gas combined cycle
NG-CC | CCS	natural gas combined cycle with 90% carbon capture and sequestration
Eth-CC	ethanol-fueled combined cycle
H_2-CC | Salt	hydrogen production via PEM electrolysis, power generation via combined cycle, and hydrogen storage in a salt cavern
Stat-PEM | Salt	hydrogen production via PEM electrolysis, power generation via a stationary PEM fuel cell, and hydrogen storage in a salt cavern
HDV-PEM | Salt	hydrogen production via PEM electrolysis, power generation via heavy-duty vehicle fuel cells, and hydrogen storage in a salt cavern
HDV-PEM | Pipes	hydrogen production via PEM electrolysis, power generation via heavy-duty vehicle fuel cells, and hydrogen storage in underground pipes

Source: Hunter, Chad A. et al. "Techno-economic analysis of long-duration energy storage and flexible power generation technologies to support high-variable renewable energy grids." Joule, 5, 8, 2021.

Burning hydrogen in combustion turbines could be done by retrofitting existing turbines or using hydrogen-ready turbines, but risks of high NOx emissions need to be mitigated with specialized technology. The Clean Energy Group (CEG) has warned that burning hydrogen for power generation can produce dangerously high levels of nitrogen oxides (Milford 2021), however, research by the DOE has indicated that NOx from hydrogen combustion can be effectively controlled by technological or operational changes, leading to a conclusion that "hydrogen turbines of the future will have comparable performance and emissions of NOx compared to today's natural gas-fueled turbines" (U.S. Department of Energy 2022). It is, however, important that regulation shifts to ensure hydrogen-based turbines are held to the same emission standards as natural gas turbines.

In 2021, the Los Angeles Department of Water and Power (LADWP), in partnership with the National Renewable Energy Laboratory, conducted a detailed study of the resources needed to transition the Los Angeles power system to 100% renewable energy by 2045. The study results indicated that hydrogen for power generation, both in combustion turbines and (in some scenarios) in fuel cells, would be required to effectively balance a system with high renewable energy penetration (National Renewable Energy Laboratory 2021).

Figure 23. The Role of Hydrogen in the LADWP Planned Energy Mix



Source: National Renewable Energy Laboratory. "LA100: The Los Angeles 100% Renewable Energy Study and Equity Strategies." March 2021.

In addition to being combusted in retrofitted gas turbines, hydrogen can also be used to generate clean power directly in fuel cells. This has both efficiency and air quality benefits, as fuel cells can have higher conversion efficiencies than gas turbines – particularly turbines that are not combined cycle models – and produce no NO_x emissions. However, fuel cells of this size have limited commercial deployment and still face higher costs today, although these costs are expected to fall as fuel cell manufacturing picks up globally.

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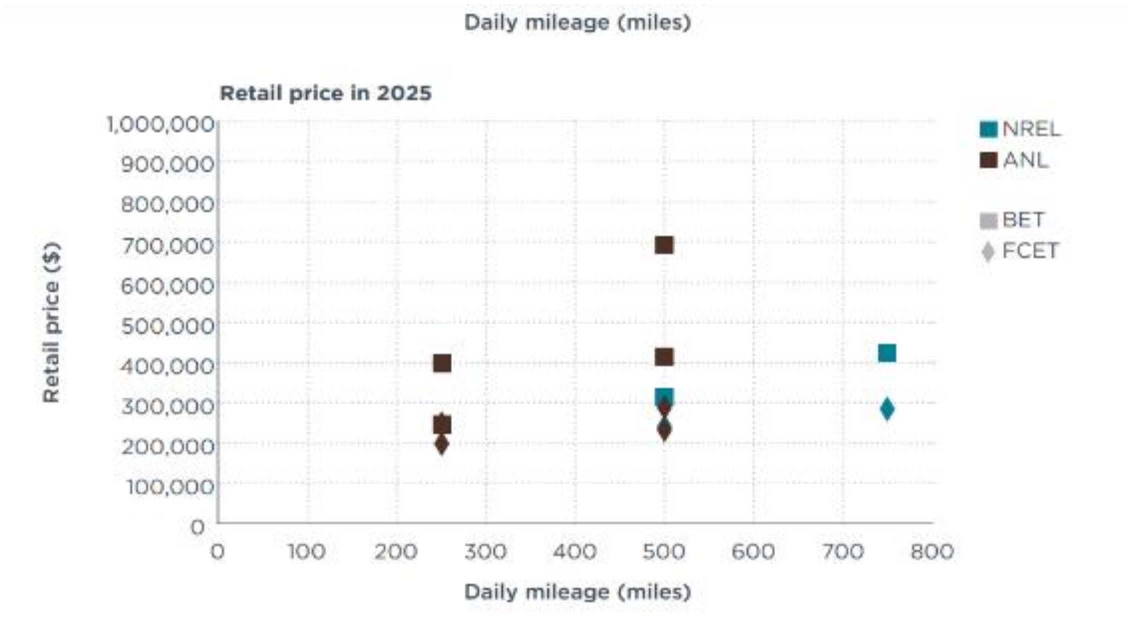
A.6. Heavy-Duty Vehicles

Heavy-duty vehicles are defined as any truck over 26,000 lbs. which includes both class 7 and 8 U.S gross vehicle weight rating (GVWR) truck classifications. Due to their irregular scheduling, low downtimes, heavy loads, and long distances of travel, hydrogen is a promising decarbonization solution for heavy-duty vehicles.

The International Council on Clean Transportation estimated that upfront costs for battery-electric and hydrogen fuel cell tractor trucks can vary by up to a factor of four. Battery-electric truck (BET) up-front costs range from about $200,000 to $800,000, with fuel cell electric trucks (FCET) in the same studies ranging from $200,000 to $600,000. Capital costs are a function of total battery capacity and increase with increased range. Currently, electric propulsion systems for zero-emission tractor trucks make up upwards of 90% of total truck costs, but according to the ICCT, this value is expected to fall to as low as 75% in the next decade due to an expected decrease in battery pack and fuel cell systems costs (Sharpe and Basma 2022).

Figure 24 illustrates the relative costs of battery electric trucks and fuel cell trucks in 2025, as forecasted by Argonne National Laboratory (ANL), and the National Renewable Energy Laboratory (NREL). This graph highlights that the price of battery electric trucks is a function of expected daily mileage, due to increasing costs associated with larger battery capacity. As a result, within both the NREL and ANL analysis, the retail price gap between fuel cell and battery electric trucks increases as daily mileage increases. ANL’s analysis considered both Class 8 day cabs, as well as Class 8 sleeper cabs. For daily mileage values with two reported prices for the same technology type, the higher value represents the sleeper cab variation (Sharpe and Basma 2022).

Figure 24. Comparative Costs of Battery Electric Trucks and Fuel Cell Trucks, 2025



Source: Sharpe, Ben and Hussein Basma. "A meta-study of purchase costs for zero emission trucks (Working Paper 2022-09)." International Council on Clean Transportation, February 2022.

NREL's Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks provides a total cost of ownership analysis beyond procurement costs. This report includes dwell and payload costs which cause fuel cell electric vehicles (FCEVs) to reach cost parity with battery electric vehicles (BEVs) much sooner due to the additional costs related to BEV trucks' higher weights and longer charging times (Hunter et al. 2021).

Figure 25. *Total Cost of Ownership for Class 8 Long Haul Tractors by Fuel Type*

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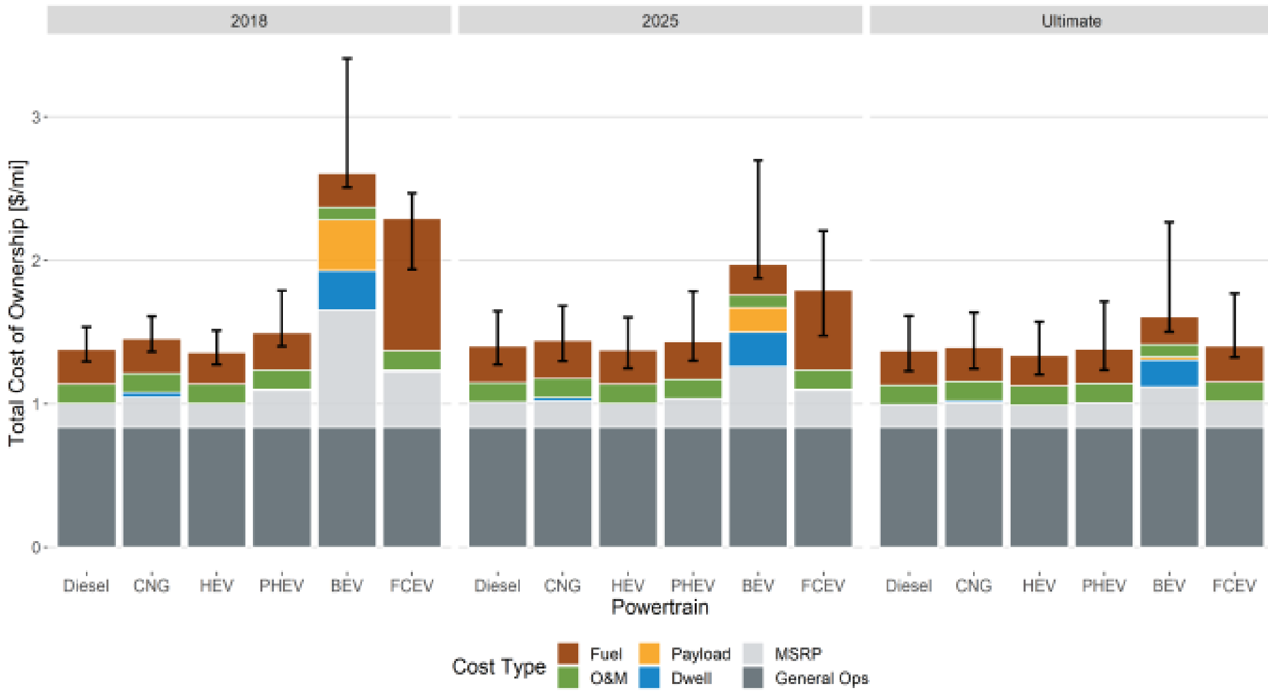

Source: Hunter, Chad, et al. "Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks". National Renewable Laboratory, NREL/TP-5400-71796, September 2021.

Another NREL report on decarbonizing heavy-duty vehicles published in March of 2022 found that zero-emission vehicle (ZEV) use in the medium and heavy-duty trucking sectors would likely see the deployment of both FCEVs and BEVs, with FCEVs predominating in long-haul applications. It also identified that changes in the speed of cost declines for both underlying energy sources (i.e., electricity, hydrogen) and technology (i.e., batteries, fuel cells) could have a significant impact on which technology is ultimately deployed (Ledna et al. 2022).

Figure 26. Cost Parity Points of ZEVs

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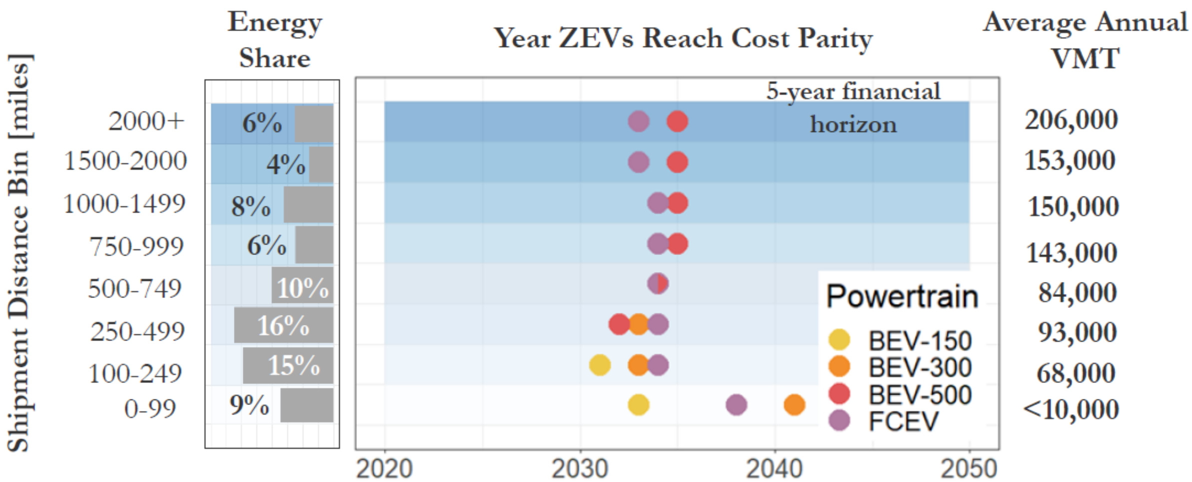

Source: Ledna, Catherine et al. "Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis." National Renewable Energy Laboratory, March 2022.

Development for both FCEVs and BEVs is advancing quickly. FCEVs manufactured by Hyundai have been deployed in Germany and Switzerland in the past few years, and a coalition of vehicle manufacturers (including Daimler, Honda, and Hyundai) have committed to deploying 10,000 FCEVs in Europe by 2030 (Kurmayer 2021). According to Hyundai Motor Group, production has also started for the U.S. market as well, with 30 of Hyundai's Xcient Fuel Cell truck set to hit streets in a pilot deployment in California in 2023. Given the relative similarities between truck markets across the U.S., it's expected that the successful operation of FCEV trucks on the West Coast would support early uptake in other parts of the country as well (HMG Newsroom 2022).

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A.7. Buses

The Strategen analysis of hydrogen use in buses was broken into two separate segments:

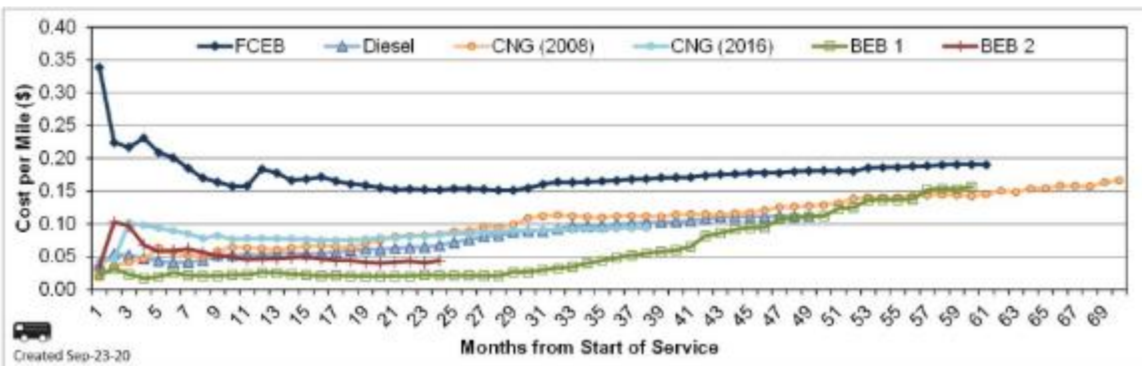
1. Long-distance transport (e.g., coach buses)
2. Commuter transport (e.g., transit and school buses)

Factors such as changes in elevation, route speed, necessary acceleration and deceleration related to traffic, weather, and even the way a specific driver operates the vehicle, all influence the preferred technology of a bus. Fuel cell electric buses perform similarly to conventional diesel and gasoline vehicles both in operation and in their ability to be fueled quickly. The most effective applications for fuel cell buses and battery alternatives will be highly dependent upon the site and operational characteristics of where it will be used.

According to an NREL study, the fuel economy for newly designed fuel cell buses averages 7.95 mi/kg, which equates to 8.99 miles per diesel gallon equivalent and results in an estimated maximum range of 350 miles. Due to the aforementioned factors effecting efficiencies, results will be different for similar busses operated under different conditions. The highest efficiency levels and lowest variability are achieved with highway driving (Eudy and Post 2021).

Commuter buses like transit fleet and school buses incur higher costs per mile when fueled by hydrogen due to maintenance costs on propulsion systems. Ultimately, the cost-effectiveness of hydrogen in buses is largely connected to the mileage and downtime availability of a particular application; for commuter transport, which involves frequent stops over small distances and long periods of non-use, these factors tend to favor electric battery options. The graph below demonstrates the relative cost per mile for fuel cell electric buses (FCEB) compared to battery electric buses (BEB) for commuter-style travel.

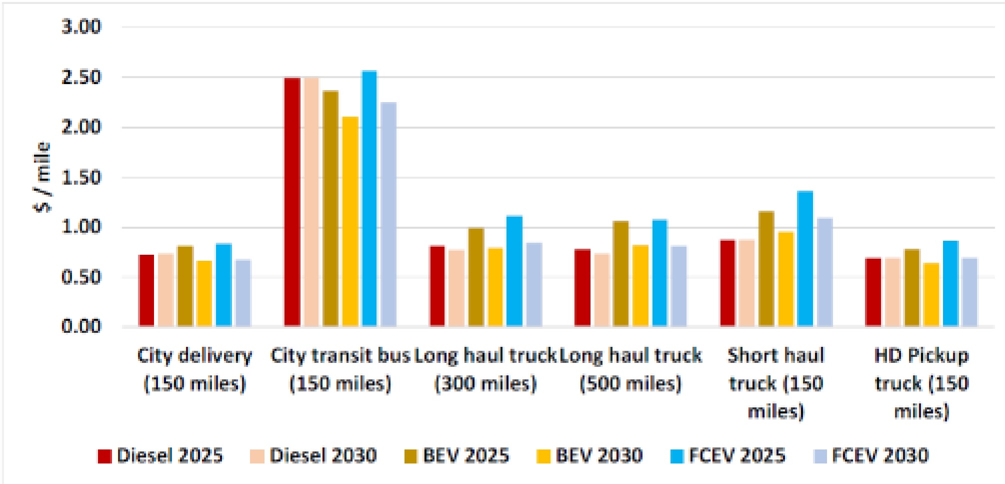
Figure 27. Cumulative Maintenance Costs per Mile by Technology Type



Source: Eudy, Leslie and Matthew Post. "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2020." National Renewable Energy Laboratory, NREL/TP-5400-75583, March 2021.

However, studies suggest that the total cost of ownership for zero-carbon transit buses, while generally favoring electric versions, is still close enough that hydrogen can still be considered cost competitive. A 2022 study by the UC Davis Institute of Transportation Studies indicated that 15-year total cost of ownership between battery electric and fuel cell buses was similar for both city delivery and city transit applications. In addition, fuel cell buses have been commercially deployed at several transit agencies in California (Eudy 2021). As a result, although this report assumes that the majority of transit bus needs will likely be served by battery electric vehicles, it does not rule out the possibility that fuel cell buses could be considered in situations where bus routes, re-fueling profiles, and local grid constraints create a better match for fuel cell technology.

Figure 28. Total Cost of Ownership by Vehicle Type and Year



Source: Burke, Andrew et al. "Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses: Methods, Issues, and Results." UC Davis Institute of Transportation Studies, 1 August 2022.

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A.8. Passenger Cars

Currently, there are three hydrogen fuel-cell passenger cars on the consumer market in North America: the Toyota Mirai, the Hyundai Nexo, and the Honda Clarity. These cars are all priced above $50,000, out-pricing widely available electric vehicle options from Tesla, Polestar, Chevrolet, and others. The cost to fully charge a market leading Tesla Model 3 averages under $10, lower than the price of a single kilogram of hydrogen at the pump in California ($13.14) as of May 2021, forcing existing manufacturers to offer incentives for consumers, in some cases up to $15,000 worth of hydrogen fuel (Energy Sage News 2022).

In addition to being more expensive in terms of both upfront purchase and fueling costs, hydrogen fuel cell cars require the build-out of a statewide (and ultimately nationwide) network of fueling stations to adequately serve the passenger car market. Although Connecticut does have some hydrogen fueling stations installed already, its network of electric vehicle charging stations is significantly more extensive, creating a strong incentive for customers to choose electric cars over fuel cell versions (Nigro 2016). In addition, electric vehicles have the added benefit of requiring no additional infrastructure for charging at home, which is convenient for typical usage patterns.

Although fuel cell vehicles do have an advantage in driving range and fast refueling, electric vehicle technology is also quickly improving in both range and charging speed for electric vehicles, leading to the rapid growth of the EV market in Connecticut (Connecticut Department of Transportation 2022). This echoes developments in global auto markets, where major manufacturers have been increasingly switching market strategies to target electric vehicles. Beginning in March 2020, three major auto manufacturers—Daimler AG, Volkswagen, and General Motors (GM)—followed the move by Honda to reduce their strategic focus on the hydrogen-powered passenger car market (Palmer 2020).

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A.9. Material Handling Equipment

More than 20,000 hydrogen fuel cell forklifts are now in warehouses, stores, and manufacturing facilities throughout the United States. Hydrogen-powered forklifts offer refueling in minutes, increased performance, and zero emissions. Hydrogen-powered vehicles are like their internal combustion engine counterparts in that they can be refilled quickly and easily at a fueling station.

They also require less maintenance because they don't need the watering, equalizing, charging, or cleaning that is required with lead-acid batteries, according to the Hydrogen and Fuel Cells Technology Office. In addition, compared to battery-powered forklifts, fuel cell forklifts perform better on speed, charging time, and space requirements for charging infrastructure (U.S. Department of Energy 2018).

Battery-powered lift trucks lose approximately 14% of their speed over the last half of the battery charge, while fuel cells maintain constant forklift power at all times, even in freezer applications. Compact hydrogen fueling stations are more space-efficient than battery charging rooms, freeing up approximately 7% more valuable warehouse space for other inventory and revenue-generating operations. Battery charging also requires 15 minutes per shift, compared to two minutes for hydrogen refueling. Over a year, that 13 minutes saved per shift represents more than 234 hours of lost productivity per forklift truck in a three-shift operation (Plug Power 2022).

Analysis by the Connecticut Center for Advanced Technology demonstrated that, when considering costs related to forklift downtime and charging space requirements, costs for fuel cell forklifts were roughly $6,400 lower per year than battery-powered forklifts (Rinebold et al. 2018). In recognition of this economic advantage, deployment of fuel-cell forklifts continues to grow globally, particularly in foreign markets (Hydrogen and Fuel Cell Technologies Office 2018). Larger companies with the capital to invest in fuel cell forklifts have found that the lower ongoing costs and improved performance make them a more cost-effective option; it's expected that as fuel cell costs decrease with expanded manufacturing, market share will increase as smaller businesses are also able to access this technology. There is also opportunity for fuel cells to make inroads into markets for other types of material handling equipment, including those used at maritime ports.

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A.10. Ferries

There are few direct cost comparisons of battery-powered electric ferries and hydrogen fuel cell ferries but there are several studies that compare hydrogen fuel cell ferries to conventional diesel ferries. The level of cost-competitiveness for zero-emissions ferry technologies varies by region, location, and application due to factors like existing infrastructure, fuel costs for both hydrogen and electricity, and operational factors such as distance and sailing schedule.

The most competitive applications for hydrogen passenger ferries are those where short docking times may not allow for a battery electric ship to charge because in these cases, an operator would need a larger fleet of electric ferries in order to maintain the same level of service, greatly increasing the total cost of ownership (Hydrogen Council 2020). Another scenario where hydrogen could be a competitive low-carbon alternative is in the case of larger ferries with a motor power of up to 4 MW due to the high size, weight, and cost a battery alternative.

For regional ferries that travel approximately 8 nautical miles roundtrip and have 500 kW motor power, estimates show that hydrogen fuel cell ferries could become cost competitive with battery electric ferries before 2030, and competitive with conventional diesel ferries shortly after 2030 (Hydrogen Council 2020). For a large passenger and cargo ferry that travels approximately 10 nautical miles roundtrip and has a 4 MW engine, the most competitive low-carbon alternative is biodiesel. The fuel cell RoPax is expected to economically compete with biodiesel in 2030, and with conventional diesel by 2035 (Hydrogen Council 2020).

The current estimated TCO for small passenger and cargo ferry boats with engine power of 430 kW is $1.06 per passenger, assuming hydrogen fuel costs of $5/kg. If the hydrogen fuel cost reached $3.50/kg, the estimated TCO may reach as low as $0.67 per passenger, compared to an estimated $0.65 per passenger for a comparable diesel ferry. In the case of small high-speed ferries with an engine power of approximately 1600 kW, the current estimated TCO per passenger is $2.66. With a reduction in hydrogen fuel costs to $3.50/kg, the TCO could decrease to $1.56, compared to $1.53 for a conventional diesel alternative. Further, by decreasing the amount of onboard hydrogen storage, the TCO could further decrease to $1.40 per passenger (Ahluwalia et al. 2021).

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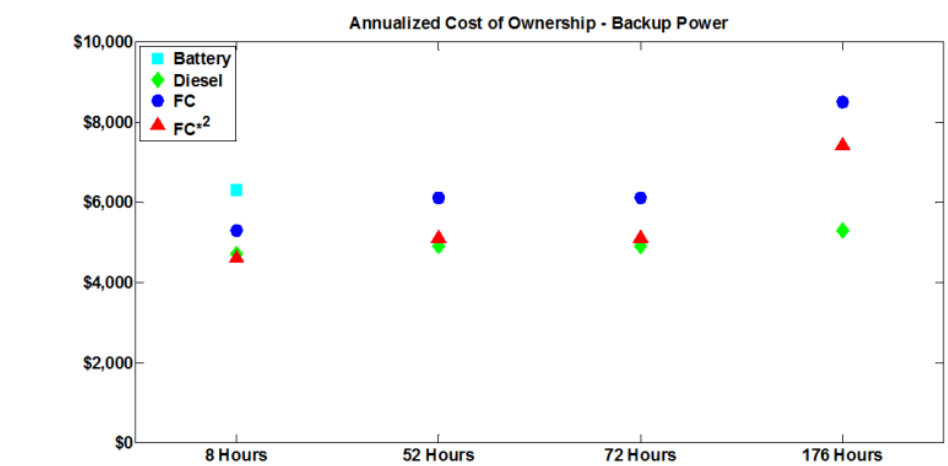
A.11. Critical Facilities

According to the Federal Emergency Management Agency (FEMA), typical critical facilities include hospitals, fire stations, police stations, storage of critical records, and similar facilities (Federal Emergency Management Agency 2023). Traditionally, critical facilities have relied on back-up generators, typically diesel generators, to ensure power availability. For example, hospitals in Connecticut are required to have enough on-site backup power to cover load for 24 hours, regardless of how often outages of this length occur (Clean Energy Group 2015). However, backup generators can frequently fail when called upon. For example, during Superstorm Sandy, the New York University Langone Medical Center was forced to evacuate its patients due to the failure of backup generators (Olinsky-Paul 2013). Backup diesel generators also have high emissions of both carbon dioxide and local pollutants.

Fuel cells have and batteries have been identified as a potential carbon-free alternative to diesel generators. Analysis by NREL has found that for longer-term outages (i.e., 52 hours or more), fuel cells provide a more cost-effective back-up power solution than batteries (Kurtz et al. 2014). The results of this analysis are shown in Figure 29.

Figure 29. Fuel Cell Backup Power Cost of Ownership



	8 Hours	52 Hours	72 Hours	176 Hours
Battery	$6300	$24800	$31300	$67200
Diesel	$4700	$4900	$4900	$5300
FC	$5300	$6100	$6100	$8500
FC*2	$4600	$5100	$5100	$7400

NREL cdp_bu_30
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1) Refer to the report for complete analysis details and assumptions (http://www.nrel.gov/docs/fy14osti/60732.pdf).
2) Fuel cell system with incentives (FC*), calculated as 30% of expenditures and capped at $3,000/kW of system capacity.

Fuel Cell* includes incentives

Source: Kurtz, J. et al. "Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison National Renewable Energy Laboratory, NREL/TP-5400-60732, September 2014.

Market research by Battelle has identified telecom towers as a potential early market for fuel cell back-up technology, given the needs to weather longer-term outages and relative insensitivity to upfront capital costs (Mehadevan et al. 2007). Data centers are also a potential market for fuel cell backup power, given their need for continuous 24/7 power (requiring back-up power run times of up to 48 to 72 hours) and the carbon emission reduction commitments of many players in this space (Saur et al. 2019). Since the first deployment of fuel cell in at least 100 telecommunications towers as backup power in 2011, more and more states have started investing in fuel cell systems for critical facilities. New York State, for example, invested $15 million in 2018. Additionally, Connecticut already has fuel cells deployed at several hospitals throughout the state, indicating their fit for applications with long back-up power requirements (Clean Energy Group 2015).

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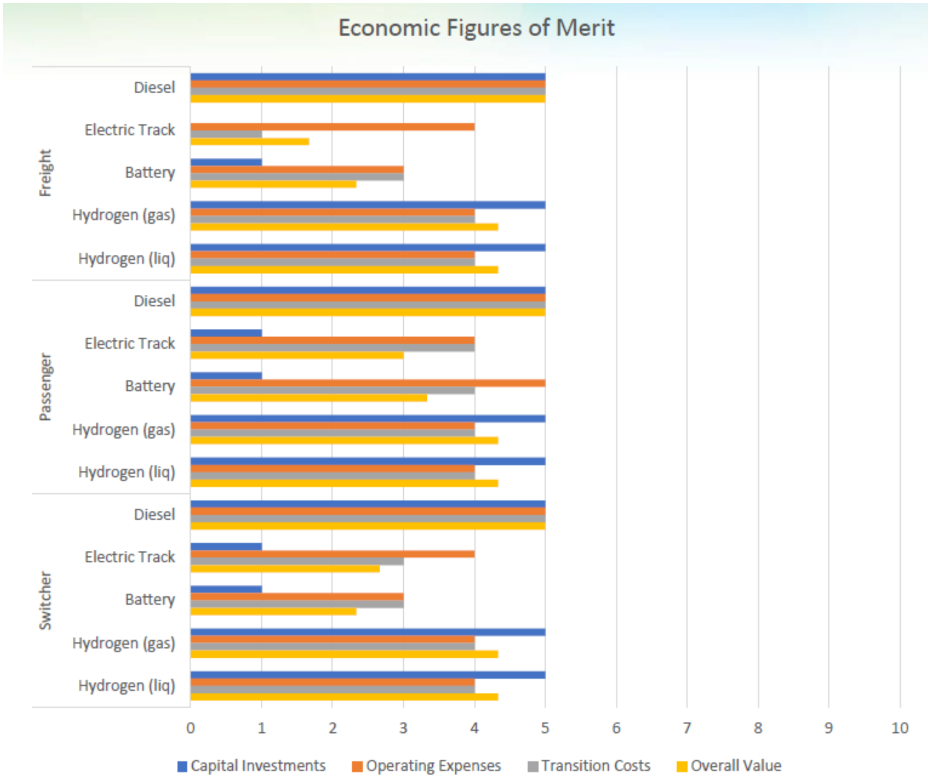
A.12. Rail

Hydrogen can provide many benefits to rail locomotive power operations, specifically offering interoperability, scalability, fast-refueling, and lightweight energy storage at scale. Hydrogen fuel cell powered locomotives can run on existing tracks, so while the purchase of new hydrogen locomotives may be expensive, they avoid the need for expensive electrification of the track itself. Moreover, hydrogen fuel cells offer a longer range and faster fueling than electric alternatives, making them a competitive low-cost option (Burgess 2021).

A review by Barbosa distinguishes the advantages of different types of fuel cells for different rail types. Polymer electrolyte membrane fuel cells (PEMFC), which operate at moderate temperatures (80 °C) and is best fitted to non-permanent demand cycles, has been proposed for applications like light rail and trams, commuter and regional trains, shunt/switch locomotives, and underground mine locomotives. Meanwhile, solid oxide fuel cells (SOFC), which have higher efficiency than other types of fuel cells but need to work at a high operating temperature (1,000 °C) could be a promising technology for freight or heavy haul locomotives, given their steady duty cycles (Barbosa 2019).

Regarding the life-cycle cost of light rail vehicles, an analysis by Sun et al. predicts that as the cost of hydrogen and fuel cells fall, fuel cell hybrid trams will become progressively more competitive. Similarly, a techno-economic analysis by Zenith et al. 0 also suggests that there is potential for fuel cell and battery technologies to replace diesel on railways with low traffic volumes. Further, analysis by Sandia National Laboratory assessed hydrogen trains against electric solutions, developing a comparison across several systems of merit, including economic cost-competitiveness. Their system ranked each metric on a scale of 1 to 10, with 10 being the best. The Sandia's assessment demonstrates that hydrogen-powered rail can provide significant economic benefits compared to battery-electric rail, particularly for freight or switcher rail lines (Erhart 2019). However, other studies show that the economics for hydrogen-fueled and electric power trains are close for many use cases (Ruf et al. 2019), or, in some cases, battery-powered rail cars have been demonstrated to be more cost effective (Cuenca 2020).

Figure 30. *Sandia Assessment of Hydrogen Merit for Rail Applications*



Source: Erhart, Brian et al. "Impact of Hydrogen for Rail Applications." Sandia National Laboratory. Presentation in Lansing, Michigan, 27 March 2019.

Electrified train systems continue to be deployed in many regions, including in Connecticut, where it was recently announced the state would replace diesel trains with electric trains on the Shore Line East route that provides daily service from New Haven to New London (Lewis 2022).

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A.13. Hydrogen Blending

Hydrogen can be blended into most existing natural gas pipelines at low percentages. Demonstration projects in Europe have found that 15-20% blends by volume are possible before major retrofits are required (Raju 2022). Due to the lower volumetric energy density of hydrogen, a 20% blend by volume would equate to about a 7% blend by energy content. This means that the maximum blend limit can only reduce emissions from the gas system by around 7%, making it an incomplete climate mitigation solution. For core gas customers (i.e., residential and commercial customers), falling costs in heat pump technologies make heat electrification a more cost-effective method for reducing gas use when compared on a per-MMBtu reduction basis[235].

NREL's Electrification Futures Study (2016) forecasted that heat pump technology improvements would make air source heat pumps the most cost-effective heating technology for residential and commercial in the 2040-2050 timeframe. Since Connecticut currently has a target for 100% zero-carbon electricity in 2040, it follows that heat electrification will ultimately be the most cost-effective option for reducing carbon emissions for core customers, even assuming hydrogen blends are kept at a level that avoids infrastructure upgrades. This is supported by a review of systems-level decarbonization modeling studies, all but one of which did not incorporate hydrogen in final energy delivery for building heat.

However, existing analysis does support hydrogen blending for non-core customers (e.g., industrial and power sector customers). In these cases, blending hydrogen with biogas can provide a lower-

[235] Developed from calculations based on cost data from Jadun 2017. High installation rates of air source heat pumps will likely require upgrades to electrical infrastructure, adding additional costs. However, these costs are highly location-specific and are beyond the scope of this project to assess.

cost solution decarbonization solution than electrification, which is much more expensive for high-heat processes. Analysis by Oberg et al. (2022) found that gas turbines running a blend of 30% hydrogen by volume were a cost-effective method of providing seasonal storage in grids with high penetration of renewables. This blended rate was chosen even when the model had the option to include higher-hydrogen blends, including up to 100% hydrogen. In addition, three out of four systems-level decarbonization studies reviewed had some level of hydrogen blending in industrial and/or power sector gas feedstocks (Larson 2021; Williams 2014; Sustainable Development Solutions Network 2020).

Hydrogen blending for non-core customers could be achieved by blending hydrogen directly at the non-core customers' facilities. This would require an assessment of the customer's facility to determine that hydrogen can be blended directly into their fuel feedstock without affecting operation or increasing pollutant emissions from their facility. However, because this customer would be the only facility using hydrogen in this case, this assessment would only need to take into account the impact of hydrogen blending on equipment at that customer's premises.

Hydrogen can also be delivered to non-core customers by blending it into the main gas network. However, this would deliver hydrogen to all customers connected to the gas network, including residential and commercial customers. This would require a broader assessment to understand how hydrogen would interact with the gas distribution system in Connecticut, which would likely take longer than facility-level assessments. For example, California recently completed an assessment of hydrogen blending in the state's gas distribution system that concluded hydrogen could likely be safely blended into the gas distribution system at a ratio of 5% by volume, but that additional demonstration projects would be required to ensure at-scale viability (Raju 2022).

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A.14. Systems-Level Analysis

Four modeling studies looking at national or global decarbonization pathways were referenced to assess how hydrogen was most cost-effectively allocated when considered in the context of an optimized economy-wide model. Although these studies did not engage with all end uses discussed above (e.g., forklifts, critical facilities), their results broadly supported the assessment above. Across all four studies, hydrogen was most consistently deployed in power generation, heavy-duty vehicles, maritime shipping, aviation, industrial heat, and blending for non-core customers. The graph below summarizes where hydrogen use is proposed for each study referenced. Green-colored squared indicating where hydrogen plays a significant role, while white-colored squared indicating where hydrogen is not used significantly or otherwise not mentioned.

- Study 1: International Energy Agency 2021, "Net Zero by 2050"
- Study 2: Larson 2021: "Net-Zero America: Potential Pathways, Infrastructure, and Impacts Final Report"
- Study 3: William 2014, "Pathways to deep decarbonization in the United States"
- Study 4: Sustainable Development Solutions Network 2020, "Zero Carbon Action Plan"

Table 6: Systems-Level Analysis of Hydrogen Applications

	Study 1	Study 2	Study 3	Study 4

Aviation				
Blending for Core Customers				
Blending for Non-Core Customers				
Buses				
Heavy-Duty Vehicles				
Industrial Heat				
Light-Duty Vehicles				
Maritime Shipping				
Power Generation				
Residential/Commercial Heat (100% H2)				

Supporting Research:

- International Energy Agency. *"Net Zero by 2050."* October 2021, https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf
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B. Appendix B: Hydrogen Demand Analysis

Appendix B provides an overview of the methodology and sources utilized by Strategen Consulting to assess the scale of hydrogen use that could be expected from the highest priority end uses in Connecticut. The highest priority end uses for hydrogen as determined by the Task Force include aviation, maritime shipping, critical facilities, material handling, long-haul trucking, power generation, and high heat industrial uses. Based on expected changes in energy use in Connecticut over the next few decades, Strategen's assessment found that hydrogen demand could scale from 25.2 kilotonnes (kt) per year in 2030 to 200.5 kt per year in 2040 and 335.5 kt per year in 2050. The majority of this demand is expected to be driven by power generation and long-haul heavy-duty vehicles.

Table 7. Overview of Demand Methodology and Supporting Research by Hydrogen End Use

End Use	Description of Methodology
Aviation	Assumed that hydrogen use at scale would be required for sectoral decarbonization in Mission Possible Project's "Optimistic" scenarios.
Critical Facilities	Assumed fuel cell backup capacity at data centers, hospitals, telecom towers, and facilities with behind-the-meter generation assets greater than 100 kW.
High-Heat Industry	Based on high-heat industrial processes' share of 2020 industrial gas demand, scaled up according to the industrial energy growth rate from 2010-2019.
Long-Haul Trucking	Assumed sales of long-haul fuel cell trucks begin in 2028 and scale up to reach 90% of sales over 10 years. Also assumed a truck lifespan of 10 years.
Maritime Shipping	Assumed hydrogen use at scale forecasted by the American Bureau of shipping's "Zero Carbon Outlook" report.
Material Handling	Assumed fuel cell forklift sales in Connecticut began in 2020 and scale up to reach 40% of all forklift sales in 10 years. Also assumed a forklift lifespan of 4 years.
Power Generation	Assumed thermal generation in 2050 in line with E3's "Net Zero New England" report, with Connecticut's generation consistent with its share of ISO-NE fossil fuel generation in 2021.

The sources utilized to calculate hydrogen demand in priority end uses are listed below.**Aviation**

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High-Heat Industry

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C. Appendix C: Hydrogen Supply Analysis

Appendix C provides an overview of the methodology, data and assumptions utilized by Strategen to quantify the technical potential of clean hydrogen produced from different sources in the state of Connecticut. The technical potential was assessed for three supply cases (low, medium, and high) defined in Section 4.1.4. The production sources discussed in this section include solar, onshore wind, offshore wind, biogas, and nuclear energy. This appendix also includes an overview of the assumptions utilized regarding the energy and hydrogen production technologies, such as forecasted costs, lifetimes, and efficiency of the assets, as well as the applicable tax credits from the Inflation Reduction Act passed by the U.S. Congress in 2022. This appendix concludes with projected levelized costs of hydrogen (LCOH) and accompanying supply curves for each production technology and supply scenario.[236]

Table 8**Error! Reference source not found.**, below, identifies the technical production potential for each clean energy source located within Connecticut state boundaries or, in the case of offshore wind, within an accessible distance from Connecticut. These technical potentials include resources that are already built, planned, or contracted for as part of the total estimate of available capacity. The "IRP Add." column provides the amount of incremental capacity for each clean energy source that is expected to be required to meet Connecticut's 100% zero-carbon electricity target (Schatzki 2022).

[236] LCOH values provide the levelized cost of hydrogen at point of production and don't include costs for compression, transportation, storage, or distribution infrastructure.

Table 8. Clean Energy Technical Production Potential in Connecticut

Clean Energy Source	IRP Add.	Technical Production Potential			Sources for Technical Production Potentials
		Low Case	Mid Case	High Case	
Total solar generation capacity (MW)	2,300	27,854	119,153	119,153	NREL Wind Supply Curves
Total onshore wind generation capacity (MW)	400	112	1,794	1,794	NREL Solar Supply Curves
Total offshore wind generation capacity (MW)	4,700	24,809	24,809	66,344	Lopez (2022)
Biogas production potential (Trillion Btu)	0	3.2	5.7	5.7	American Gas Foundation (2019)
Nuclear production capacity (MW)	0	47.7	95.4	190.8	Assumptions developed from communications with Dominion

All renewable energy LCOE's were calculated using the NREL Annual Technology Baseline (ATB) model and include tax credits provided by the Inflation Reduction Act. Capacity factors for onshore wind and solar are the average capacity factors in the state according to the NREL supply curves referenced in **Error! Reference source not found.**. Capacity factors for offshore wind were chosen based on the highest capacity factor available for fixed-bottom offshore wind in NREL's Annual Technology Baseline model that did not exceed the capacity factor used by DEEP in its 2021 Deep Decarbonization Integrated Resource Plan (Connecticut Department of Energy and Environmental Protection 2021).

Table 9: Renewable Energy Inputs

Input	Value	Unit	Source
Solar Capacity Factor	16.7%	%	NREL Solar Supply Curve
Onshore Wind Capacity Factor	40%	%	NREL Wind Supply Curve
Offshore Wind Capacity Factor	48%	%	NREL ATB
Solar LCOE (2030)	$25.80	$/MWh	NREL ATB
Solar LCOE (2040)	$30.40	$/MWh	NREL ATB
Onshore Wind LCOE (2030)	$19.10	$/MWh	NREL ATB
Onshore Wind LCOE (2040)	$24.90	$/MWh	NREL ATB
Offshore Wind LCOE (2030)	$43.60	$/MWh	NREL ATB

Offshore Wind LCOE (2040)	$44.30	$/MWh	NREL ATB

Cost estimates for electrolyzer capital expenditures were sourced from the International Council on Clean Transportation (Christensen 2020), which reported several different forecasts for various electrolyzer technologies across time intervals (e.g., 2025, 2030, 2050). Strategen analysis utilized an average of the International Council on Clean Transportation forecasts and assumed linear cost reductions between intervals. The feasibility of these forecasts and other inputs were confirmed in direct communication with representatives from Nel Hydrogen. Alkaline electrolyzers were assumed as the default technology in all cases, although representatives from Nel confirmed that costs for proton exchange membrane (PEM) electrolyzers would likely be within the same range by 2030.

Table 10: LCOH Calculation Inputs - Electrolysis

Input	Value	Unit	Source
Electrolyzer CapEx (2030)	442	$/kW	Christensen (2020)
Electrolyzer CapEx (2040)	293	$/kW	Christensen (2020)
Stack Life	80,000	Hours	Christensen (2020)
Stack Rebuild Cost	50%	% Of Initial Capex	Christensen (2020)
Annual Fixed O&M	2%	% Of Initial CapEx	Christensen (2020)
Plant Electrical Efficiency	0.0185	H_2 kg/kWh	Bloom Energy
Cell Degradation Rate	0.15%	% Per 1,000 Hours	Ginsberg (2022)
Plant Economic Life	20	Years	Nel (Interview)
Production Tax Credit	$.03	$/kg H_2	Inflation Reduction Act
Cost of Capital	6%	%	Assumption

Error! Reference source not found. provides the inputs that, in addition to the underlying cost of electricity, were used to assess the cost of producing hydrogen from electrolysis. **Error! Reference source not found.** provides the inputs that were used to estimate the cost of producing hydrogen from steam methane reformation of biogas.

Table 11: LCOH Calculation Inputs – Steam Methane Reformation

Input	Value	Unit	Source
LCOH w/ Fossil Gas Reformation	$1.06	$/kg H_2	Lewis (2022)
Fuel Portion of SMR LCOH	$0.77	$/kg H_2	Lewis (2022)
Estimated Natural Gas Price	$4.42	$/MMBtu	Lewis (2022)
Estimated RNG Price	$18.55	$/MMBtu	American Gas Foundation 2019

Figure 28 shows the LCOH, in $/kg, of hydrogen in 2030 and 2040 in the low and high production scenarios. These values represent the price at point of production, and do not include cost of hydrogen infrastructure (e.g., pipelines compressors, storage). Estimates assume hydrogen producers meet the labor requirements needed to receive full production tax credit.

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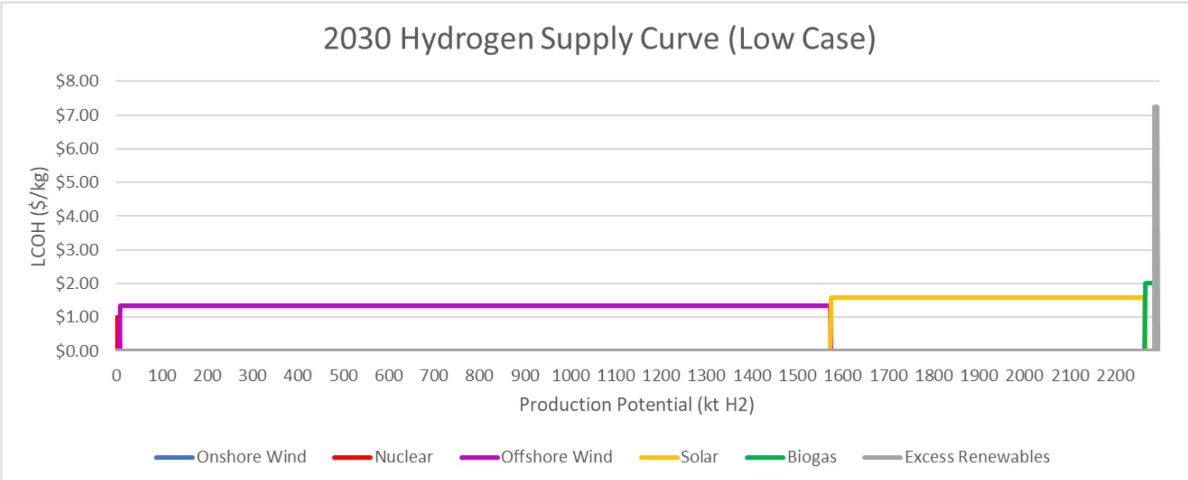
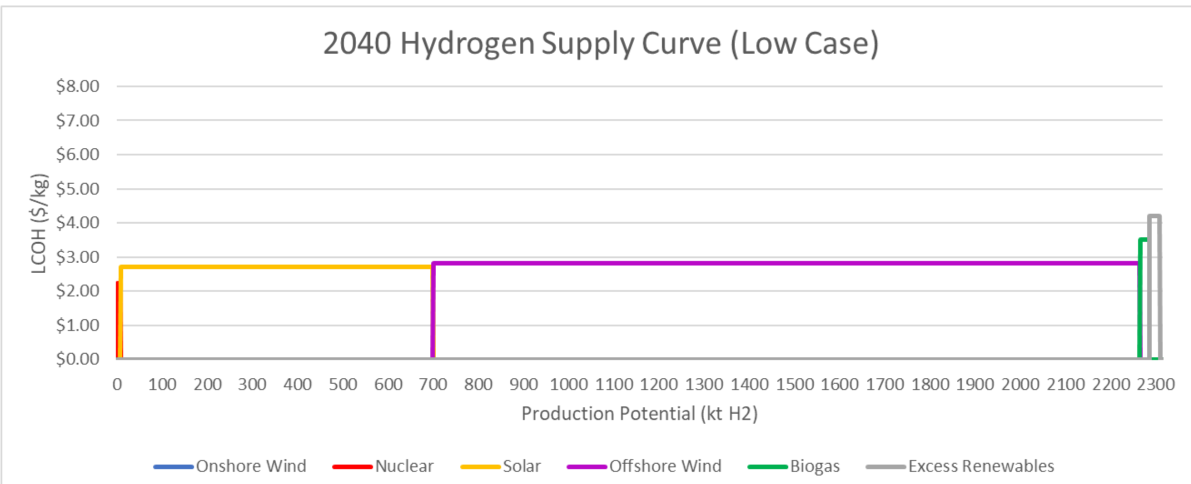
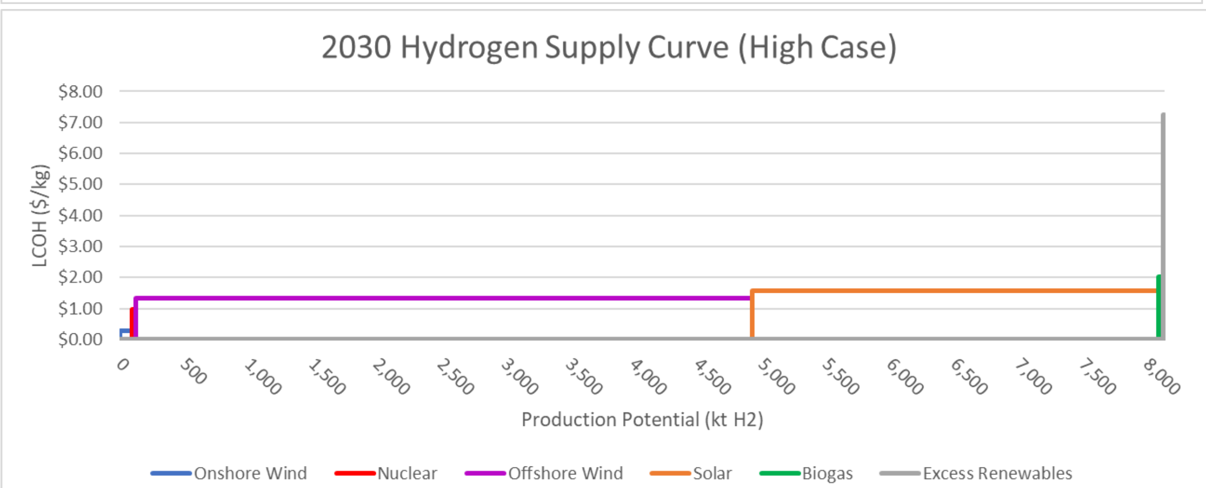
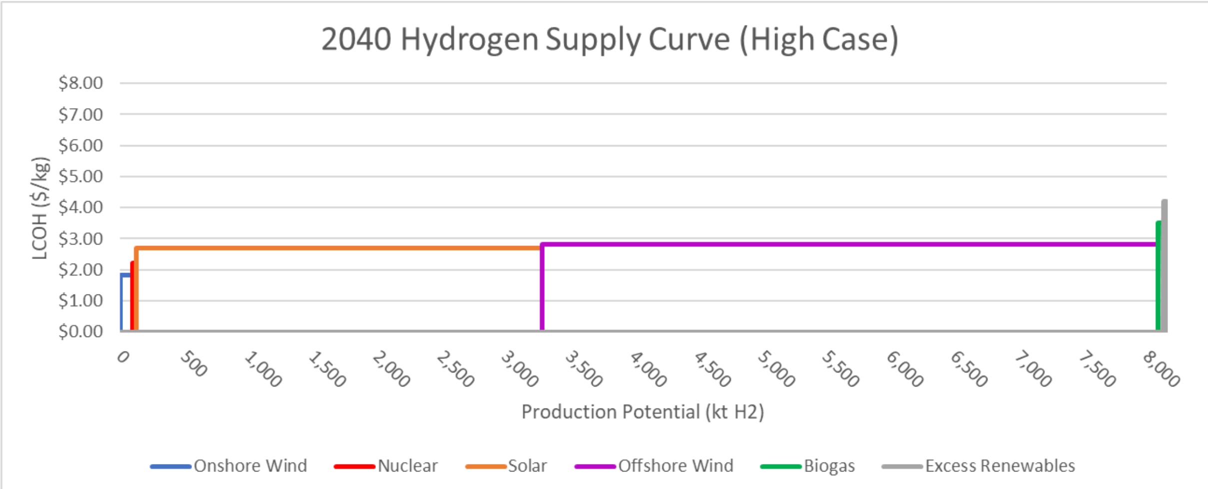
Figure 28: Hydrogen Supply Curves – Low and High Cases









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D. Appendix D: Funding Opportunities Summary

Table 12 was compiled by the Funding Working Group to provide an overview of potential federal funding sources that may be applied to hydrogen-related projects and infrastructure. This resource should be used for informational purposes only and may not encapsulate all potentially applicable federal funding opportunities. This resource reflects information available as of December 2022 and details may be subject to change. Readers should review these programs and form their own conclusions of its applicability.

Table 12. Overview of Federal Funding Opportunities for Hydrogen

Category	Federal Funding Component/Program	IIJA/IRA/Other?	Administrator	Total Funding	Description	Funding Type	Non-Federal Match Requirement	Notes
Aviation	Airport Infrastructure Grant Program	IIJA	DOT - FAA	$15 billion	Grants for airport infrastructure projects that increase safety and expand capacity, including sustainability projects.	Formula Grants	None	Program Overview Available through 2026
Aviation	Airport Terminal Program	IIJA	DOT - FAA	$5 billion	Grants will fund safe, sustainable, and accessible airport terminals, on-airport rail access projects and airport-owned airport traffic control towers.	Competitive Grants	20% for large and medium hub airports; 5% for remainder of eligible airports	Program Overview $1 billion available annually through 2026
Aviation	Alternative Fuel and Low-Emission Aviation Technology Program	IRA	DOT - FAA	$291.1 million	A portion will support projects related to production, transportation, blending, or storage of SAF ($244.5 million). Another portion will go to projects related to low-emission aviation technologies, a broadly defined term that encompasses any technologies that improve fuel efficiency, increase the utilization of SAF, or reduce aircraft emissions ($46.5 million).	Competitive Grants	25%; 10% for small hub airport or non-hub airport	Program Summary (Webpage Not Yet Available) Available through 2027
Aviation Heavy Duty Trucks	Strengthening Mobility and Revolutionizing Transportation (SMART) Grants	IIJA	DOT	$500 million	Provide grants to eligible public sector agencies to conduct demonstration projects focused on advanced smart community technologies and systems in order to improve transportation efficiency and safety.	Competitive Grants	None	Program Overview $100 million annually through 2026

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Buses	Clean School Bus Program	IIJA	EPA	$5 billion	Supports the purchase or lease of zero-emission and alternative fuel transit buses and to purchase, construct, or lease bus related facilities.	Grants and Rebates	None	Program Overview Available through 2026
Buses	Low or No Emission Bus and Bus Facilities Grants	IIJA	DOT - FTA	$5.6 billion	Supports the purchase or lease of zero-emission and low-emission transit buses and to purchase, construct, or lease bus related facilities.	Competitive Grants	15% for buses, 10% for infrastructur e	Program Overview Available through 2025
Cargo Ships Materials Handling	America's Marine Highway Program Grants	IIJA	DOT - MARAD	$25 million	Develop and expand marine highway service options and facilitate their further integration into the current U.S. surface transportation system.	Competitive Grants	20%	Program Overview
Cargo Ships Materials Handling	Port Infrastructure Development Program Grants	IIJA	DOT - MARAD	$2.25 billion	Supports port electrification, microgrids, and hydrogen refueling infrastructure for medium or heavy-duty trucks that service the port. $400 million specifically for reducing idling truck emissions.	Competitive Grants	20%	Program Overview
Critical Facilities	Building Resilient Infrastructure and Communities	IIJA	DHS - FEMA	$1 billion	Pre-disaster mitigation program supporting states, local communities, tribes, and territories undertaking hazard mitigation projects to reduce the risks they face from disasters and natural hazards.	Competitive Grants	25% typically, 10% for small and impoverished communities	Program Overview
Critical Facilities Microgrids	Preventing Outages and Enhancing the Resilience of the Electric Grid Grants	IIJA	DOE - GDO	$5 billion	Prevent outages and enhance the resilience of the electric grid. Eligible uses include activities that reduce the likelihood and consequences of disruptive events.	Grant	Unknown	Program Overview Available until expended
Critical Facilities Microgrids	Program Upgrading Our Electric Grid and Ensuring Reliability and Resiliency	CHIPS	DOE	$5 billion	To coordinate and collaborate with electric sector owners and operators—(A) to demonstrate innovative approaches to transmission, storage, and distribution infrastructure to harden and enhance resilience and reliability; and (B) to demonstrate new approaches to enhance regional grid resilience, implemented through States by public and rural electric cooperative entities on a cost-shared basis.	Grant, Cooperative Agreement, or Other	20% for R&D, 50% for commercial	Program Overview $1 billion annually through 2026

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Harbor Craft	Construction of Ferry Boats and Ferry Terminal Facilities	IIJA	DOT - FHWA	$912 million	Increases funding for the ferry boat program, which funds the construction of ferry boats and ferry terminal facilities.	Competitive Grants	20%	Program Overview
Harbor Craft	Electric or Low Emitting Ferry Program	IIJA	DOT - FTA	$250 million	Supports the purchase of electric and low-emission ferries.	Competitive Grants	20%	Program Overview $50 million annually through 2026
Rail	Consolidated Rail Infrastructure and Safety Improvement Grants	IIJA	DOT - FRA	$5 billion	Funds projects that improve the safety, efficiency, and reliability of intercity passenger and freight rail.	Competitive Grants	20%	Program Overview
Heavy Duty Trucks	Carbon Reduction Program	IIJA	DOT - FHWA	$6.4 billion	Supports the development of alternative fuel vehicles, including: publicly accessible H2 fueling and zero-emission construction equipment and vehicles (incl. supporting facilities).	Formula Grants	20% typically, 10% for interstate	Program Overview ~$1.3 billion available annually through 2026
Heavy Duty Trucks	Clean Heavy-Duty Vehicles	IRA	EPA	$1 billion	Supports the replacement of existing Class 6 and Class 7 trucks (buses, garbage trucks, and other similarly sized vehicles) with zero-emission vehicles, as well as the construction and operation of associated charging or fueling infrastructure. 40% must go to non-attainment areas.	Grants and Rebates	Unknown	Program Overview Available through 2031
Heavy Duty Trucks	Reduction of Truck Emissions at Port Facilities	IIJA	DOT – FHWA	$400 million	Funding to study and provide grants to reduce idling at port facilities, including through the electrification of port operations.	Grant - Unknown	20%	Program Overview $80 million available annually through 2026
Heavy Duty Trucks Buses	Alternative Fuel Refueling Property Tax Credit	IRA	USDT - IRS	6% base, 30% with added requirements	Tax credits for the cost of an alternative fuel vehicle refueling property. Property must be sited within a low-income or rural census tract area.	Tax Credits	None	Program Overview Valid for any property placed in service before 2033; includes direct payment

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Heavy Duty Trucks Buses	Commercial Clean Vehicle Credit	IRA	USDT - IRS	Tax credit equal to the lesser of the following: -30% vehicle purchase price -Incremental cost compared to equivalent ICE vehicle	Tax credits for the purchase of clean vehicles for commercial use.	Tax Credits	None	Program Overview Maximum per recipient: $7,500 for < 14,000 lbs. $40,000 for > 14,000 lbs. No domestic or assembly requirements
Heavy Duty Trucks Buses Materials Handling	Congestion Mitigation and Air Quality Improvement Program	IIJA	DOT - FHWA	$13.2 billion	Added eligibility for the purchase of medium-and heavy-duty zero-emission vehicles, nonroad vehicles from construction or port-related freight, and related charging/fueling equipment.	Formula Grants	20% typically, 10% for interstate	Program Overview ~2.6 billion available annually through 2026
Heavy Duty Trucks Light Duty Vehicles	Charging and Fueling Infrastructure Grants	IIJA	DOT	$2.5 billion	Support development of alternative fueled infrastructure, including hydrogen fueling stations.	Competitive Grants	Unknown	Program Overview
Industrial	Industrial Emission Demonstration Projects	IIJA	DOE - OCED	$500 million	To fund demonstration projects that test and validate technologies that reduce industrial emissions.	Competitive Grants	TBD	Program Overview Available until expended
Infrastructure	Natural Gas Distribution Infrastructure Safety and Modernization Grants	IIJA	DOT-PHMSA	$1 billion	Grants to repair, rehabilitate, or replace its natural gas distribution pipeline systems or portions thereof or to acquire equipment to (1) reduce incidents and fatalities and (2) to avoid economic losses.	Competitive Grants	None	Program Overview $200 million available annually through 2026
Manufacturing	Advanced Energy Project Tax Credit	IRA	USDT - IRS	$10 million available, 30% of amount invested	Tax credits for the cost of new or upgraded factories to build specified renewable energy components (fuel cells qualify).	Tax Credits (competitive application)		Program guidance anticipated in 2023
Manufacturing	Advanced Technology Vehicle Manufacturing Loan Program	IRA	DOE - LPO	$3 billion	Expands authorities to lend under this program, which aims to produce advanced technology for medium and heavy-duty vehicles, trains or locomotives, maritime vessels, aircraft, or hyperloop technology.	Loans	None	Program Overview Available through 2028

Manufacturing	Clean Hydrogen Manufacturing Recycling Research, Development, and Demonstration Program	IIJA	DOE - EERE	$500 million	Advance new clean hydrogen production, processing, delivery, storage and use equipment manufacturing technologies and techniques.	Grants - Unknown	Unknown	Program Overview Available until expended
Manufacturing	Domestic Manufacturing Conversion Grants	IRA	DOE	$2 billion	Provides grants for domestic production of plug-in electric hybrid, plug-in electric drive, and hydrogen fuel cell electric vehicles and components of such vehicles.	Competitive Grants	50%	Program Overview Available through 2031; priority given to the refurbishment or retooling of manufacturing facilities that have recently ceased operation or will cease operation in the near future.
Manufacturing Production	Defense Production Act Funding	IRA	DOE	$500 million	Provides the DOE with the authority to utilize the Defense Production Act (DPA) to accelerate domestic production of key energy technologies, including electrolyzers, fuel cells, and platinum group metals.	Unknown	Unknown	Guidance in development
Materials Handling	Grants to Reduce Air Pollution at Ports	IRA	EPA	$3 billion	Grants are directed to purchase and install zero-emission equipment and technology at ports, as well as the development of climate action plans at ports. $750M to be directed at ports in nonattainment areas.	Competitive Grants	None	Program in development Available through 2027
Microgrids Electric Sector	Energy Improvement in Rural and Remote Areas	IIJA	DOE - OCED	$1 billion	Provide financial assistance to improve, in rural or remote areas of the United States, the resilience, safety, reliability, and availability of energy. This program includes funding of microgrids.	Grant, Cooperative Agreement, or Other	Unknown	Program Overview $200 million available annually through 2026
Production	Clean Hydrogen Electrolysis Program	IIJA	DOE - EERE	$1 billion	Demonstrate technologies that produce clean hydrogen using electrolyzers and validate information on the cost, efficiency, durability, and feasibility of commercial deployment.	Competitive Grants	Unknown	Program Overview Available until expended

Production	Clean Hydrogen Production Tax Credit	IRA	USDT - IRS	$0.60/kg - $3/kg	Tax credit for clean hydrogen production with 4 tiers based on lifecycle GHG emissions.	Tax Credits	None	Program Overview Available through 2033, eligible for direct payment
Production	Investment Tax Credit	IRA	USDT - IRS	6% base, 30% with added requirements	Tax credits for investment in clean energy technology. 10% bonuses for domestic content conditions and siting in an energy community.	Tax Credits	None	Program Overview Available through 2033
R&D	Department of Energy Research, Development, and Demonstration Activities	CHIPS	DOE	$11.2 billion	Support RD&D activities aligned with 10 technology areas in the energy offices (incl. hydrogen, sustainable transportation, advanced manufacturing, industrial emissions reduction, & more).	Unknown	Unknown	Program in development Available through 2026
R&D	Fission for the Future	CHIPS	DOE	$800 million	Support the research, development, and demonstration of advanced nuclear reactors; specifies prioritization of H2 projects.	Competitive Grants	Unknown	Program in development
R&D	Industrial Research and Assessment Centers	IIJA	DOE - MESC	$150 million	Provide funding for institutions of higher education, community colleges, trade schools, and union training programs to identify opportunities for optimizing energy efficiency and environmental performance at manufacturing and other industrial facilities.	Cooperative agreements	Unknown	Program Overview Available until expended
R&D	Long-Duration Energy Storage Demonstration Initiative and Joint Program	IIJA	DOE - OCED	$150 million	Establish a demonstration initiative composed of demonstration projects focused on the development of long-duration energy storage technologies.	Grant, Cooperative Agreement, or Other	50%	Program Overview Available until expended
Renewable Energy Development	Energy Efficiency and Conservation Block Grant	IIJA	DOE - SCEP	$550 million	Includes development, implementation, and installation of fuel cells as a renewable energy technology on or in government buildings and financing for zero-emission transport/infrastructure.	Formula & Competitive Grant	None	Program Overview Available until expended

Workforce Development	Building, Training, And Assessment Centers	IIJA	DOE - SCEP	$10 million	Grants to institutions of higher education to establish building training and assessment centers to educate and train building technicians and engineers on implementing modern building technologies.	Grants - Unknown	Unknown	Program Overview Available until expended
Microgrids Critical Facilities Renewable Energy Development Production	Greenhouse Gas Reduction Fund	IRA	EPA	$27 billion	Establishes a clean energy deployment clean bank. Includes: $7.0 billion deployment of zero-emission technologies in low income and disadvantaged communities. $11.9 billion in funds is available for grants for financial assistance and technical assistance, with $8 billion of additional funds available specifically for low-income and disadvantaged communities.	Competitive Grants	Unknown	Program Overview Available until September 30, 2024
All	Regional Clean Hydrogen Hubs	IIJA	DOE – OCED	$8 billion	Create networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the use of hydrogen as a clean energy carrier that can deliver or store tremendous amounts of energy.	Grant, Cooperative Agreement, or Other	50%	Program Overview

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