Hydrogen and Fuel Cell Technology Towards Clean Energy Goals

Recommendations for the State of New Jersey

New Jersey Fuel Cell Task Force 6/8/23

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Report and recommendations for the State of New Jersey

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MONTCLAIR STATE UNIVERSITY

Clean Energy and Sustainability Analytics Center (CESAC)

New Jersey Board of Public Utilities BPU

FOREWORD

On June 19, 2020, Governor Murphy signed P.L. 2020, c. 38 into law and created the New Jersey Fuel Cell Task Force (Task Force). The purpose of the Task Force is to develop a plan to increase the usage of fuel cells in New Jersey. The Task Force has five statutory obligations to this effect:

(1) To serve as a resource to State departments and local governments on fuel cell issues;
(2) To assist in the growth of fuel cell businesses in the State;
(3) To increase the use of fuel cells throughout State government departments and agencies;
(4) To develop a strategy for the development of infrastructure to support the use of fuel cells; and
(5) To provide information and educational materials to the public, government, and industry about the use and benefits of fuel cells.

The Task Force membership consists of experts from both private industry and the government of New Jersey who are working towards this common goal. The Task Force has developed many recommendations to increase the use of fuel cells in New Jersey and has spent several months working in conjunction with Montclair State University to produce a report on the subject. This report is intended to serve as both an introduction to fuel cell technology to policymakers and the general public and to provide a narrative for why the recommendations are important.

The Task Force consists of the following members:

Nick Barilo – Center for Hydrogen Safety
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Executive Summary

Fuel cell systems can play a critical role in achieving New Jersey's 2019 Energy Master Plan (EMP) goals and Pathway to 2050 objectives, and in implementing the Climate Resilience Strategy, filling the gap where other technologies may have technical limitations and/or harmful emissions. With the State's initiative to become an innovation hub for technology, New Jersey can benefit from the unique and timely opportunity offered by the *2021 Infrastructure Investment and Jobs Act* (*Bipartisan Infrastructure Bill; H.R.3684*) that provides a total of $9.5 billion for clean hydrogen programs. Those funds include $8 billion to support the development of regional hydrogen hubs across the United States.

This report explores and identifies the ways in which New Jersey is well positioned to adopt fuel cell systems for stationary and mobile applications and green or carbon-neutral hydrogen (i.e., hydrogen produced without upstream or downstream carbon emissions) as a zero-emission fuel source. Further, the report identifies areas where action can be taken to further hydrogen and fuel cell technologies and provides recommendations for statutory, policy, and regulatory modifications. In doing this, the Task Force aims to develop an equitable framework that includes innovation, infrastructure, safety, education and workforce development.

Fuel Cells

A fuel cell uses the chemical energy of hydrogen or other fuels to cleanly and efficiently produce electricity. If hydrogen is the fuel, the only byproducts of this process are electricity, water, and heat. Fuel cells are used today in a range of applications, from providing power to homes and businesses; keeping critical facilities like hospitals, grocery stores, and data centers up and running; and moving a variety of vehicles including cars, buses, trucks, forklifts, trains, and more. Unlike combustion engines, hydrogen fuel cell systems emit no greenhouse gases or criteria air pollutants, enabling improved local air quality. Fuel cells work similarly to batteries; however, their reactants are continuously fed rather than being completely contained, meaning they do not run down or need recharging like batteries. The fuel cell system will continue to produce energy as long as the initial fuel source (natural gas, biogas, hydrogen, etc.) is supplied. This enables, for example, a fuel cell electric vehicle (FCEV) to be refilled in 3-5 minutes, similar to a gasoline vehicle, while it can take hours to recharge a battery electric vehicle (BEV).

Northeast Regional Hydrogen Hub

In June 2022, the United States Department of Energy (US DOE) released a Notice of Intent (NOI) to fund the Bipartisan Infrastructure Law's Regional Clean Hydrogen Hubs program (H2Hubs). Recognizing the immense potential for renewable hydrogen in the Northeast, a coalition of Northeast states led by New York and including New Jersey, Connecticut, Maine, Massachusetts, Rhode Island and Vermont have come together to propose a regional clean hydrogen hub in collaboration with hydrogen and fuel cell ecosystem partners. As noted by New Jersey Governor Murphy and documented in the EMP, clean hydrogen has the potential to reduce greenhouse gas emissions and harmful air pollutants and expand the State's diverse clean energy portfolio.

Several factors make New Jersey an ideal partner in a regional hydrogen hub. The State is widely considered a logistics and transportation hub, with more than 2,800 miles of interstate highways, state highways, and the highest railroad density in the US. The Port of New York and New Jersey, the largest port on the East Coast, is the gateway to one of the most concentrated consumer markets in the US. Additionally, New Jersey is building the country's first port dedicated to assembling offshore wind turbines that will be installed across the Eastern Seaboard. New Jersey also holds five foreign trade zones along with an infrastructure that offers unsurpassed market access.

New Jersey's Position

In terms of workforce and research and development capacity, New Jersey hosts the highest concentration of engineers and scientists in the US, has a well-established manufacturing base and workforce, and has numerous industrial and chemical plants that could be used to generate hydrogen. New Jersey is home to seven research universities among its more than 60 established universities, colleges, and community colleges. New Jersey is well-positioned to continue to educate a growing body of scientists, engineers, and other workforce members critical to the development of a clean energy economy. Additionally, several existing State policies and incentives support clean energy technology adoption, with several new programs in development.

Opportunities and Applications

In 2018, the Northeast Electrochemical Energy Storage Cluster (NEESC), funded by the US Small Business Administration, published an economic analysis and roadmap identifying numerous opportunities for early deployment of hydrogen and fuel cell systems in New Jersey.[2] The analysis indicated that New Jersey's nascent hydrogen and fuel cell supply chain contributed to the region's economy by providing approximately $54 million in revenue and investment, more than 200 indirect and induced jobs, over $2.7 million in state and local tax revenue, and labor income of approximately $20 million in 2016. These supply chain companies are involved in manufacturing, parts distribution, fuel processing, industrial gas supply, engineering research and development, coating applications, and venture capital management.

The NEESC roadmap identified substantial opportunities for further growth. In the near term, existing businesses and institutions in New Jersey have the potential to install up to 214 megawatts (MW) of electric generation using fuel cell technology, which would have an annual output of approximately 1.8 million megawatt hours (MWhs). This fuel cell generation capacity would reduce emissions of nitrogen oxides (NOx) by approximately 240 metric tons annually. FCEVs could replace existing conventional vehicles in New Jersey starting with more than 3,300 fleet vehicles, which could reduce annual emissions of carbon dioxide (CO_2) by approximately 27,500 metric tons and NOx emissions by approximately 11 metric tons.

New Jersey's projected environmental and economic benefits from emerging fuel cell and hydrogen markets will be significantly increased by the Federal Government's investment in a Northeast Regional Hydrogen Hub and the corresponding industry investment.

Clean Transportation

New Jersey's EMP urges the State to aggressively pursue today's available decarbonization technologies, including BEVs, hybrid, and FCEVs to achieve the State's mandated goal of 80% emission reductions by 2050 (80x50) relative to 2006 levels. The EMP supports the deployment of 330,000 electric vehicles on the road by 2025, per the Multi-State Zero-Emission Vehicle (ZEV) Programs Memorandum of Understanding. The EMP analysis indicates that the near-term increase in costs, as the State rolls out new electric cars and associated infrastructure, will be more than offset later with many economy-wide financial benefits, leading to a thriving innovation-based economy in the State. While the early focus in New Jersey has been on BEVs and plug-in hybrids to meet the ZEV mandate, Federal funding provided through a regional hydrogen hub could be used to include FCEVs.

While BEVs are the most common EVs today, FCEVs are also gaining momentum in US and global markets. More than 15,000 FCEVs have been sold or leased in the US, most of them in California, which has a network of 57 hydrogen refueling stations.[3] FCEVs have numerous benefits for all transportation segments that provide customers options for ZEVs based on their needs. For medium- and heavy-duty vehicles (M/HDVs) including trucks, buses, rail, marine vessels, and material handling equipment, FCEVs are a particularly competitive option because the weight, limited range and/or long recharge time of a battery can be cost-prohibitive, reduce the amount of cargo that can be transported, and take the vehicles out of service for too long during recharging. There are 66 hydrogen fuel cell buses on the road in California alone, with over 100 more on order for future delivery.[3] Fuel cell technology powered by hydrogen produced from renewable sources can play a larger role in commercializing zero-emission trucks and displacing highly polluting diesel engines. The need for an electrified M/HDV transition is seen especially in disadvantaged environmental justice communities, where the effects of transportation-related emissions is more prevalent. The State is also home to many large warehouses where fuel cell-powered material handling equipment offers significant advantages over diesel or battery power in terms of emissions, productivity, and lifecycle costs.

Clean, Reliable and Resilient Electric Power

Primary Power

The EMP defines 100% clean energy by 2050 as 100% carbon-neutral electricity generation. Achieving 100% carbon neutral generation will require that New Jersey rely on offshore wind and solar to meet an increasing percentage of the State's electric demand, which is expected to double by 2050. Relying on a non–dispatchable source[i] for electric generation during peak load poses challenges. As New Jersey relies on more intermittent sources such as solar and wind for its primary power needs there will be an increased need to enable those non-dispatchable renewables to be supported by sufficient dispatchable capacity to ensure grid reliability.

Hydrogen fuel cells are one potential source of dispatchable electric supply and peak shaving. Electricity supplied from fuel cells can be used to respond to peak demand and reduce the reliance on higher carbon-emitting combustion turbines or diesel engines that can be called upon during peak demand. Providing grid services in the wholesale market, as well as normal "blue sky"[ii] services, can increase the value of fuel cell electric generation systems and increase their market advantage by decreasing the installation payback time. Fuel cells using a decarbonized fuel stock for power production are eligible for net metering under EDECA, which defines them as a Class I at N.J.S.A 48:3-51 and under NJBPU regulations at N.J.A.C. 14:8-1.2.

Load-following fuel cell systems are capable of demand response and addressing capacity shortfalls as they can be called upon to ramp up and provide peak power as needed. For example, some New Jersey consumers utilize local generation to address peak load issues, including, in some cases, by relying on diesel engines. Fuel cell systems are replacing diesel generators for both primary and backup power around the US, including in New Jersey. Diesel generators have a disproportionate impact in non-attainment zones and overburdened communities. Replacing diesel emergency generators with fuel cells will result in avoided CO_2 emissions and reduced criteria pollutants (PM, NOx and VOC). The revenue that fuel cells receive for their value to the grid could be used as an incentive to promote their use as a replacement for diesel-powered emergency generators. Areas with high electric demand and electric distribution system congestion can result in less efficient, higher emitting and costly electric generating sources being called upon to meet local demand. The less efficient peak load serving units create what is known as locational marginal emissions during peak load events; fuel cells directly offset these marginal emissions. Fuel cells could be deployed as a demand response resource and potentially lessen the need for peaking dispatch. If fuel cells meet some of the peaking load demand, that load would not need to be served from high emitting and high-cost marginal peaking units. Additionally, there is potential for value stacking the revenue received for being available as a demand response resource with other incentives for fuel cells.

Backup Power

Backup power will always be necessary to preserve reliability and resilience. The more practical the backup power source, the more widespread the power source will become, thus dropping system costs over time. Geographically sensitive regions with a high cost of electricity, low grid reliability, more frequent natural disasters, utility rate structures that reward grid service, remote areas that need high electricity availability, and densely populated areas sensitive to pollutant emissions can benefit from clean DERs. Sensitive regions that need backup power systems most can provide resilience through clean local generation during "gray sky"[iii] islanded operation. Providing grid services in the wholesale market during normal "blue sky" grid-tied operation can increase the functional utility of the fuel cell backup systems and reduce adoption barriers by decreasing the installation payback time.

Many energy systems are greatly enhanced by the introduction of energy storage capabilities, although the current cost of these technologies remains relatively high. There are several applications where hydrogen-based energy systems may present a near term advantage over battery-based storage. Examples of fuel cells and hydrogen for backup power include small scale backup power (<100 kW), long duration energy storage, microgrids, and utilities.

The New Jersey EMP states that, starting in 2045, firm dispatchable power from carbon-neutral fuels will account for approximately 6% of total generation and may rely on existing fleets of gas turbines powered by biofuels or hydrogen. Fuel cells are a non-combustion approach that can complement future carbon-neutral combustion turbines for large-scale power generation. Resilient behind-the-meter fuel cell systems operate as DERs and can offset the demand on the electric grid, thereby increasing grid reliability through possible resource aggregation and coordination (FERC Order No. 2222).

Summary of Recommendations

The Task Force has generated a series of recommendations for the State's consideration. These recommendations will create momentum in advancing fuel cells and hydrogen within the State and strengthen New Jersey's hub proposal. The numbering of these recommendations is based on where the reader can find additional detail within the report. As per legislative mandate, the Task Force members can be available as needed to clarify any recommendations or provide additional information.

		Recommendation
*	1.1	Participate in a regional hydrogen hub
*	1.2	Explore incentivizing fuel cell technology to improve local air quality
*	1.3	Explore fuel cells as a non-combustion option for demand response programs
*	2.1	Establish an H2Biz function to assist emerging hydrogen and fuel cell industry
**	2.2	Consider options for state tax credits on investments or production of low-carbon hydrogen
**	2.3	Encourage revisions in PJM's open access wholesale tariff to include electrolytic fuel (green hydrogen) production
**	2.4	Consider requiring electric distribution companies to propose State electricity resiliency tariffs
**	2.5	Focus BPU's grid modernization program on valuing desired environmental attributes for distributed energy resources
*	2.6	Spur fuel cell electric vehicle adoption through incentives, bills, programs, and tax credits.
*	2.7	Explore the implementation of hydrogen infrastructure for appropriate alternate fuel corridors
*	2.8	Collaborate with New York for hydrogen/fuel cell technology development at the Port Authority of New York and New Jersey
*	2.9	Explore a pathway allowing fuel cell electric vehicles to access NYC from New Jersey
**	2.10	Utilize fuel cell systems to implement New Jersey's Climate Change Resilience Strategy
**	2.11	Explore the inclusion of fuel cells systems operating on hydrogen for a multiple-technology net metering protocol
*	2.12	Establish an incentive for fuel decarbonization programs using low-carbon hydrogen
*	2.13	Allocate and/or apply for federal funds to support fuel cell systems and hydrogen fuel cell electric vehicles
*	2.14	Engage private sector industry partners to develop fuel cell and hydrogen related pilot projects in New Jersey
**	2.15	Address supply barriers to clean transportation, including more permissive authorization for Buy American waivers
*	2.16	Develop online resources for hydrogen and fuel cell project developers
**	3.1	Incorporate requirements for safety planning/reviews for hydrogen projects
*	4.1	Engage a broad hydrogen and fuel cell technology education, training, and workforce development program

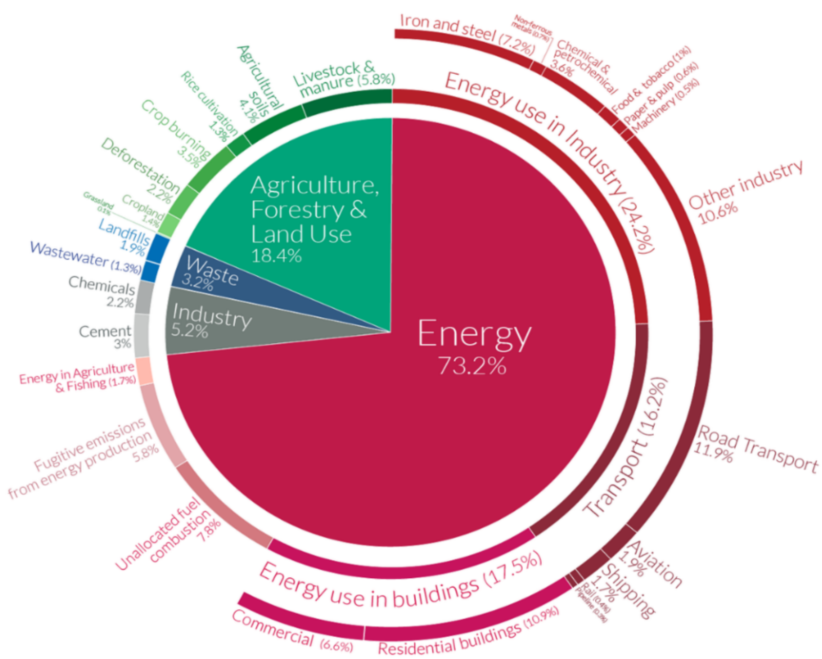
*Note: *Denotes immediate action items; **denotes next steps (1-5 years)*

1. Overview of fuel cells and hydrogen

Why fuel cells and hydrogen?

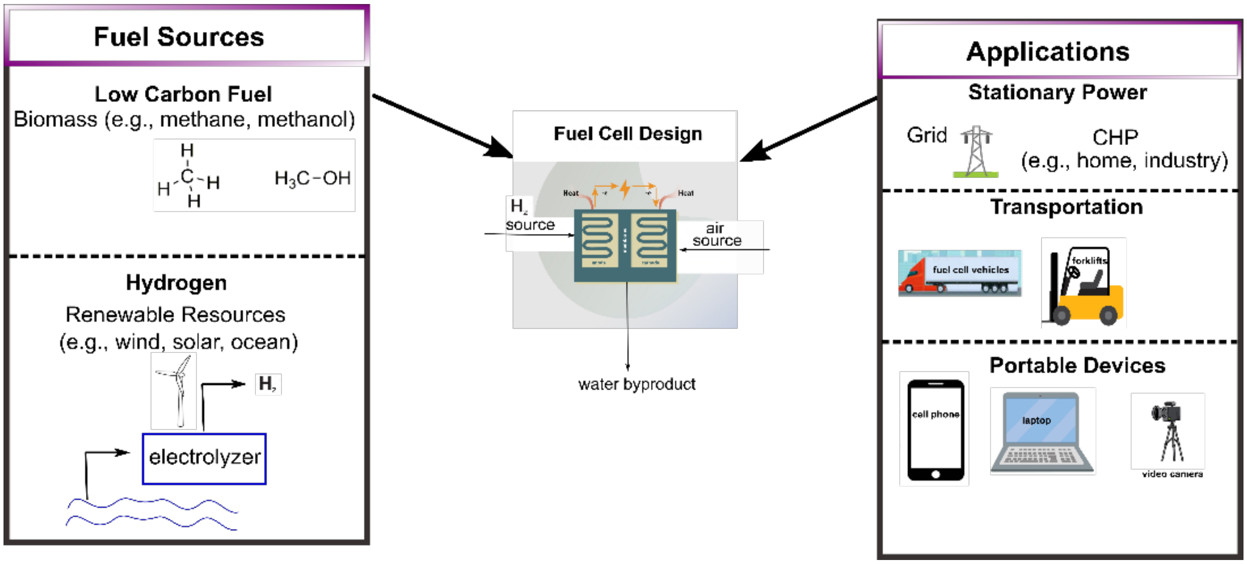
Due to economic and population growth, the demand for energy is increasing, averaging a net growth of 1.3% per year globally. Most of this energy demand is currently being met by carbon-based fossil fuels (e.g., coal, oil and natural gas), which drives large amounts of greenhouse gas (GHG) emissions (approximately 43.8 billion metrics tons of carbon dioxide equivalent (CO_2 eq)) and has a deep and negative impact on global climate change.[4] The energy sector currently accounts for approximately 73.2% of global GHG emissions (**Figure 1.1**). Without mitigation, this trend creates energy-related CO_2 and NO_x emissions that are expected to double by 2050.[4] Apart from environmental impact, this reliance on fossil fuels leads to various economic and social risks.[5, 6] To mitigate these negative impacts, the World Energy Outlook 2020 aims for net-zero emissions by 2050, pursuing a clean, secure, and affordable clean energy policy that includes use of low-carbon fuel and hydrogen.

Figure 1. 1 Global greenhouse gas emissions by sector[7]



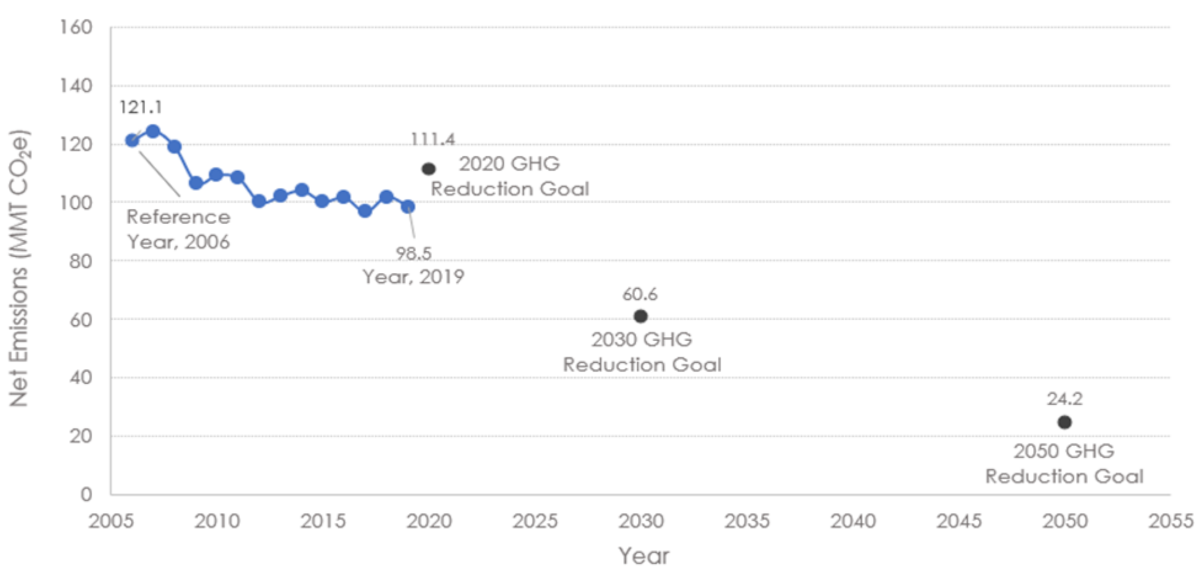
Hydrogen fuel can be produced from a number of fossil and non-fossil sources such as methane, biomass, and water via electrolysis. The electricity used to generate hydrogen fuel therefore presents the GHG emissions associated with the source from which it was produced. New Jersey's policy preference is to rely on clean hydrogen, which includes hydrogen derived from renewable energy sources or nuclear energy production. Fuel cells are an energy efficient technology that, when powered by hydrogen from carbon-neutral sources, can help to meet energy demands without producing harmful GHG emissions (**Figure 1.2**). Fuel cells can also operate on methane, methanol, and other fuels, producing fewer carbon emissions than traditional combustion technologies and no criteria pollutants at the point of use. That's because fuel cell systems generate electricity through an electrochemical reaction, which is more efficient than combustion. Unlike batteries, which become depleted during use and must be recharged with electricity, fuel cells are not discharged during operation if a steady supply of hydrogen fuel is provided. When the hydrogen storage system is depleted, it can be refilled more quickly than a battery can be recharged.

Figure 1. 2 Fuel cells: A clean, carbon-free energy source[6]



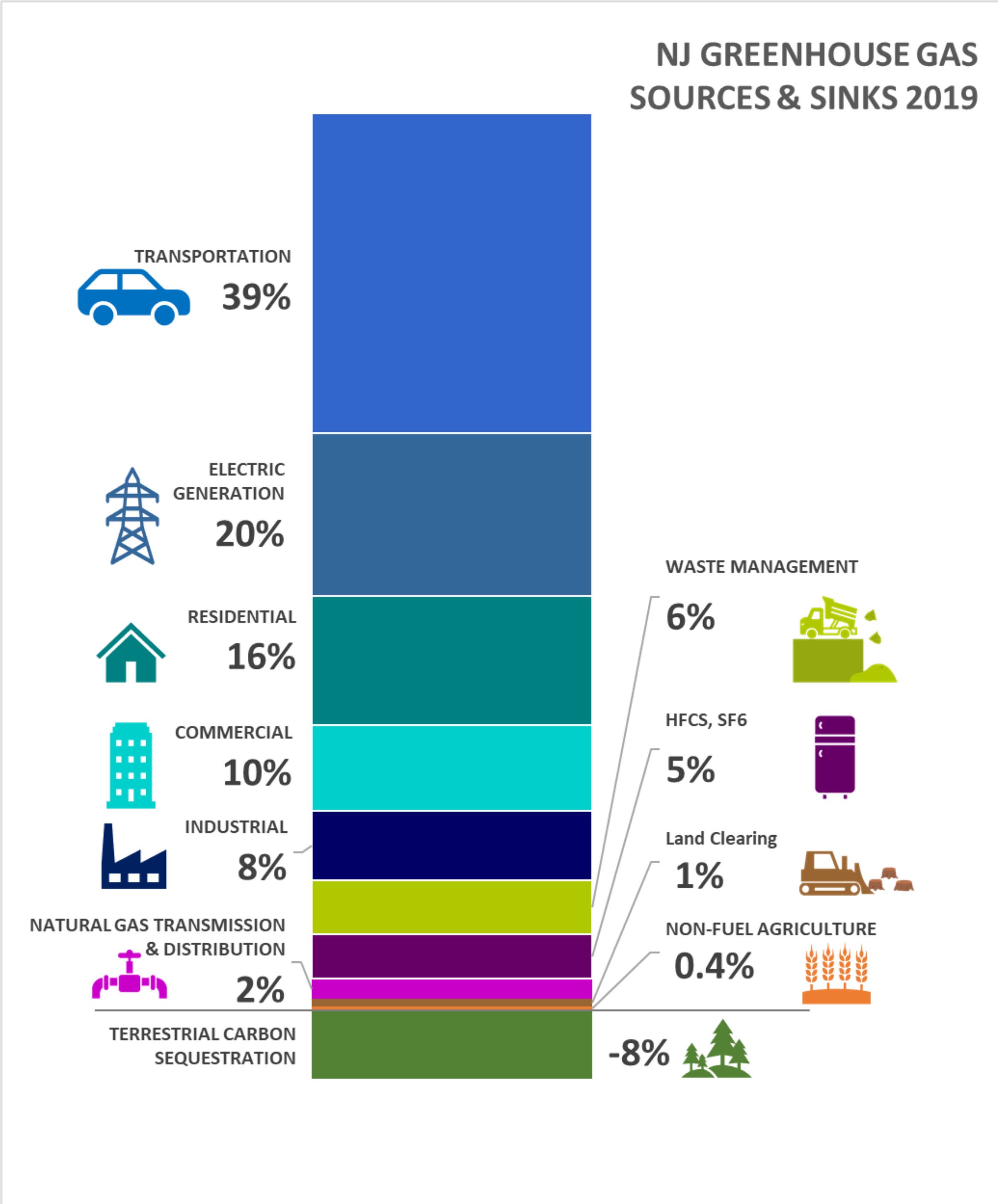
Fuel cell systems can help New Jersey achieve its emissions reduction and clean energy goals. The New Jersey Energy Master Plan (EMP) identifies hydrogen as a viable alternate fuel candidate; hydrogen can be produced locally and regionally from renewable or carbon-free energy sources, including electrolysis using wind, solar or nuclear power.

Figure 1. 3 New Jersey's greenhouse gas emissions and reduction goal by 2050[8]



To date, New Jersey has reduced its GHG emissions by over 20% since 2006 (**Figure 1.3**). This GHG reduction, however, happened primarily by transitioning grid power from coal to natural gas, a cleaner energy source. While the emissions decrease is substantial, natural gas combustion will only go so far and cannot result in full decarbonization of the power grid. Also, it does not address the emissions from the transportation sector, which accounts for about 40 million metric tons of GHG emissions (approximately 39% of total State emissions) (**Figure 1.4**). Electricity generation, residential and commercial sectors are other key areas that contribute significantly to GHG emissions with 20%, 16% and 10% of total state emissions, respectively. As will be discussed below, fuel cells can be applied in all these different areas and help to mitigate emissions from those sectors.

Figure 1. 4 New Jersey greenhouse gas sources and sinks[8]



Recommendation 1.1

Participate in a Regional Hydrogen Hub. The State of New Jersey should identify and convene appropriate stakeholders, collaborate with neighboring states, and determine necessary elements for a strong proposal to the DOE, including identifying State cost-sharing sources. In addition, further opportunities to finance clean transportation projects, new power generation, transmission, and distribution underpinnings with federal funds and supports should be identified.

The US Department of Energy (DOE), through the 2021 Infrastructure Investment and Jobs Act (IIJA) (commonly called the Bipartisan Infrastructure Law or BIL), plans to establish Regional Clean Hydrogen Hubs to reduce costs of hydrogen produced from clean electricity as well as support equipment manufacturing and strengthen domestic supply chains (**See Recommendation 1.1.**). On March 24, 2022, the Governors of New Jersey, New York, Massachusetts, and Connecticut announced a multi-state partnership to propose a regional clean hydrogen hub in collaboration with hydrogen and fuel cell ecosystem partners. In announcing the state's participation, Governor Murphy stated, "Clean hydrogen has the promise to expand New Jersey's diverse clean energy portfolio. Clean hydrogen technology also has the potential to improve net GHG emissions and harmful air pollutant impacts. Joining together with our regional partners will allow us to build a strong coalition for the development of clean hydrogen technology and cultivate economic growth and opportunity for New Jersey." Since this announcement, Maine, Rhode Island, Vermont have joined this partnership. The combination of these collaborative efforts, supporting policy, and hydrogen and fuel cell supply chain development makes these technologies an attractive and viable means towards reaching the state's energy goals.

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>
> \- Governor Phil Murphy

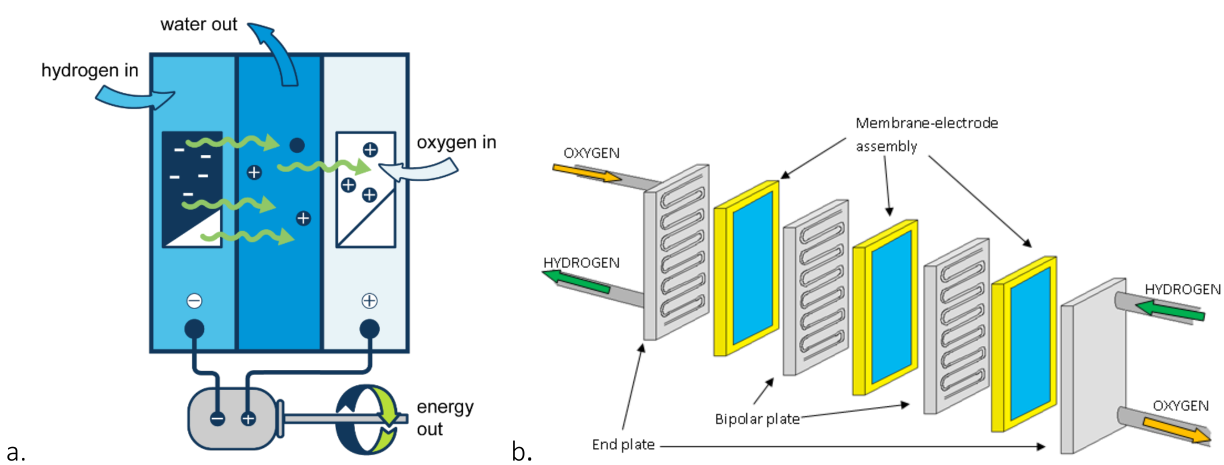
Currently, hydrogen is not widely used as a fuel. However, it has the potential for greater use in the future. The global fuel cell market is anticipated to reach $20.2 billion by 2026. Currently, the United States accounts for 24.3% of the global fuel cell market.[9] The Fuel Cell and Hydrogen Energy Association (FCHEA) *Road Map to a US Hydrogen Economy*[10] estimates that hydrogen could meet about 14% of energy demand by 2050 and support up to 3.4 million jobs in the US, providing approximately $750 billion per year in revenue. Additionally, use of hydrogen can reduce CO_2 emissions by 16% by 2050, and NO_x emissions by 36%. The hydrogen community is moving away from subjective color classification schemes and focusing on the carbon intensity of different hydrogen productions methods. The recent federal IIJA and Inflation Reduction Act call for a measurement of carbon intensity rather than a color scheme, to maintain an objective and technically based measurement.

The Inflation Reduction Act of 2022, which includes multiple tax benefits for hydrogen production, storage and use, establishes a lifecycle greenhouse gas emissions limit of 4 kilograms CO_2 equivalent per kilogram (kg) of hydrogen (H_2) produced as the definition of clean hydrogen eligible for the credit.[11] The full tax credit of $0.60/kg hydrogen is available for lifecycle emissions of less than 0.45 kg CO_2 eq/kg H_2. For emissions between 0.45 and 4 kg CO_2 eq/kg H_2, a lower tax credit rate is available.[11, 12] The BIL had established a preliminary carbon intensity standard of 2 kg CO_2 eq/kg H_2 for clean hydrogen and requires that US DOE develop a definitive clean hydrogen production carbon intensity standard. This remains a topic of discussion, particularly as climate leader states favor carbon-free and/or carbon-neutral energy policies.

How a fuel cell works

A fuel cell is an electrochemical device that converts the chemical energy of a fuel (e.g., hydrogen) and an oxidizing agent (oxygen) into electricity (**Figure 1.5a**). Typical components of a fuel cell are (1) positive electrode (cathode), (2) negative electrode (anode) and (3) electrolyte. In a typical fuel cell, hydrogen is fed to the anode and air/oxygen is provided to the cathode. Hydrogen molecules are ionized into electrons and protons at the anode. The electrons create a flow of electricity while passing through an external circuit, whereas the protons diffuse through the electrolyte membrane, combine with oxygen, and produce water and heat. More detailed information on fuel cell working principles is provided in **Appendix II.** Individual cells, or membrane-electrode assemblies (MEAs), are combined into stacks, which are sized to produce anywhere from kilowatt (kW) to megawatt (MW) capacity (**Figure 1.5b**). This makes fuel cells scalable from small to large applications.

Figure 1. 5 (a) Hydrogen fuel cell: A schematic diagram.[13]; (b) Hydrogen fuel cell stack diagram.[14]



Fuel cells can be powered by several different fuels and can be used in a number of applications including stationary uses (e.g., electricity generation), mobile uses (e.g., vehicles), and portable uses (e.g., laptops). Where hydrogen fuel is used in these applications, compressed hydrogen gas feeds into the fuel cell stack. Rather than burning the gas as a combustion engine does, the fuel cell stack converts the chemical energy of hydrogen into electrical energy that serves a resistive or inductive load or charges a battery. Hydrogen fuel can be available as a continuous stream of fuel or it can be stored in a refillable container. Depending on the fuel cell application, the hydrogen storage tank can be scaled to an appropriate size. Additional information on the applications of various fuel cells is found in **Appendix II**.

Benefits of fuel cells

Fuel cells offer benefits similar to batteries when compared to combustion systems, and they provide some advantages over batteries in certain applications. These benefits and advantages are described below.

(1) **Emissions reduction:** Fuel cell systems have reduced carbon emissions (zero point-source emissions when operating on hydrogen) compared to combustion systems and have virtually no criteria pollutant emissions, especially when the hydrogen and biogas are produced from renewable energy sources. Some types of fuel cells also eliminate the costs associated with handling hazardous toxic byproducts like battery waste and diesel fuel. The health effects related to waste and diesel emissions are of increasing concern in communities located adjacent to goods-movement infrastructure (i.e., ports, warehouses). These communities, often referred to as disadvantaged communities (DAC), environmental justice (EJ) communities, or overburdened communities, also have higher proportions of vulnerable or disadvantaged residents, making these regions the highest priority for adopting more affordable clean energy technology, like fuel cells (**See Recommendation 1.2**.)

Recommendation 1.2

Fuel Cells to Improve Local Air Quality. Explore incentivizing fuel cell technology for the purpose of improving local air quality. Replacement of diesel emergency generators, particularly in overburdened communities, will build a more resilient power infrastructure and have an immediate improvement on air quality.

(2) **Energy density**: To increase driving range, hydrogen fuel cell electric vehicles (FCEVs) need only to add more hydrogen storage, whereas battery electric vehicles (BEVs) need to add more batteries. This enables fuel cells to occupy less space at lower weight in some applications, particularly for longer ranges. Fuel cells are also ideal for emergency generators; their high energy density allows for a smaller footprint than diesel generators. Moreover, fuel cells do not require frequent charging like batteries or capacitors, which suffer capacity losses even while not in use.

(3) **Lower operational costs**: Installation and operational flexibility, easier serviceability, and faster fueling time make fuel cells cost-effective compared to lead acid batteries in material handling equipment, as the time for charging – or labor and space for battery swapping – are greatly reduced. Fuel cell vehicles can be refueled in just 3-5 minutes, similar to refueling a gasoline

vehicle. Senator Andrew Zwicker (a Princeton physicist) has stated, "Hydrogen-powered vehicles will change how we think about electric cars. Instead of slowly charging a battery, a hydrogen car can be filled at your local station in the same amount of time that it takes to fill up your gasoline-powered car. I can think of more than 1.00784[iv] reasons why we must make New Jersey a national leader when it comes to hydrogen-powered transportation. I look forward to working with my colleagues in the legislature to implement the recommendations in the taskforce report."

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-Senator Andrew Zwicker

(4) **Noise reduction**: Fuel cell systems and powertrains are quiet during operation, and electric powertrains are smooth compared to traditional combustion engines. This makes fuel cells attractive for several applications, including emergency power generation, vehicles and mobile power packs.

(5) **Energy efficiency**: Fuel cells are more energy efficient compared to internal combustion engines and can operate at efficiencies exceeding 60%.[15] In addition to producing power, fuel cells produce heat[16] to provide combined heat and power (CHP) for homes and building spaces, achieving a total efficiency as of more than 90% in some cases. Thus, depending on the relative economics of the underlying fuels, fuel cell CHP systems can help to save money and energy in stationary power applications.

(6) **Reliability:** Fuel cells also work efficiently independent of the grid in various harsh environmental conditions, such as extremely cold and hot weather, and during hurricanes and winter storms.

(7) **Flexibility:** Fuel cell technology can be used in combination with other energy generation sources, allowing for synergy and increased resilience. For example, hydrogen fuel cells can be used as range extenders in BEVs that require longer driving range than BEVs typically provide. In microgrids, fuel cells can serve as the baseload power source combined with lower capacity factor solar generation and battery energy storage.

(8) **Water Use**: Fuel cells produce water as a byproduct of operation. A 400-kW fuel cell system can potentially save one million gallons of water as compared to generating electricity from a combined cycle power plant.

Fuel cell use in different sectors: an overview

When available grid power exceeds the demand, the source either needs to be reduced or the excess power can be stored for future use. As the use of wind and solar power increases, the need for energy storage also increases to avoid wasting these intermittent clean sources. The International Energy Association (IEA) estimates a total energy storage requirement of 266 gigawatts (GW) by 2030 to limit the global temperature increase to 3.6˚F.[17] Bloomberg's New Energy Finance predicts the development of a cumulative 1,095 GW energy storage market by 2040, with $662 billion of investment.[18, 19] As awareness of their environmental benefits increases, several sectors and industries have adopted fuel cell technologies.

Fuel Cells Systems for Power Generation

The 2019 EMP describes a particular clean energy mix as the least cost pathway to achieve the Global Warming Response Act (GWRA) mandate for an 80% GHG reduction from the 2006 baseline by 2050 (80x50). Governor Murphy's Executive Order (EO) No. 274 established a commitment to achieve 50% clean energy by 2030. The subsequent EO 315 accelerated this target to 100% clean energy by 2035, achieved through a Clean Energy Standard establishing a market mechanism that accelerates the shift from fossil electric generation to renewable energy sources.

The EMP defines clean energy as carbon-neutral electricity generation. Achieving 100% carbon-neutral generation will require that New Jersey rely on offshore wind and solar to meet an increasing percentage of the state's electricity demand. Relying on a non–dispatchable source for electric generation poses challenges. A dispatchable electric generating source is a source that can be called upon in real time to respond to increased electric demand. As New Jersey relies more on solar and wind for its primary power needs, there will be an increased need to ensure those non-dispatchable renewables are supported by sufficient dispatchable capacity to ensure grid reliability.

Utilities

Electricity generators may use hydrogen to continue production during times of source shortages or high prices. Distribution companies may use the hydrogen fuel byproduct to continue supplying electricity when transmission failures occur from generating sources as well as keeping their own substations and facilities running during times of outage.

Hydrogen fuel cells can play a role in providing dispatchable electric supply and peak shaving. Electricity supplied from fuel cells can be used to respond to peak demand and reduce the reliance on higher emitting simple cycle turbines or diesel engines that can be called upon during peak demand. Load-following fuel cell systems are capable of demand response and addressing capacity shortfalls. They can be called on to ramp up and provide peak power as needed. The revenue stream for hydrogen fuel cells would level cost.

Distributed energy resource (DER) generation is relied upon to respond to peak load demand in some areas. Fuel cell systems are replacing diesel generators that serve this role as a DER for both primary and backup power around the US, including in New Jersey. This presents an opportunity for air quality benefits as diesel generators are among the highest emitting stationary combustion sources and have a disproportionate impact in non-attainment zones and overburdened communities. Higher locational marginal emissions occur during peak load events. Fuel cells can be used to respond to peak demand, reducing these periods of higher locational marginal emissions.

Regions with high electric cost, low grid reliability, more frequent natural disasters, utility rate structures that reward grid service, remote areas that need high electricity availability, and densely populated areas sensitive to pollutant emissions can especially benefit from DER. By identifying these sensitive regions that need backup power systems most, and deploying fuel cells there, New Jersey could provide additional grid services beyond emission reductions. Providing grid services may increase the value of the fuel cell backup system and decrease the installation payback time. **See Recommendation 1.3.**

Recommendation 1.3.

Fuel Cells for Demand Response. Explore fuel cells as a non-combustion option for demand response programs, which will provide additional grid reliability and stability.

Microgrids

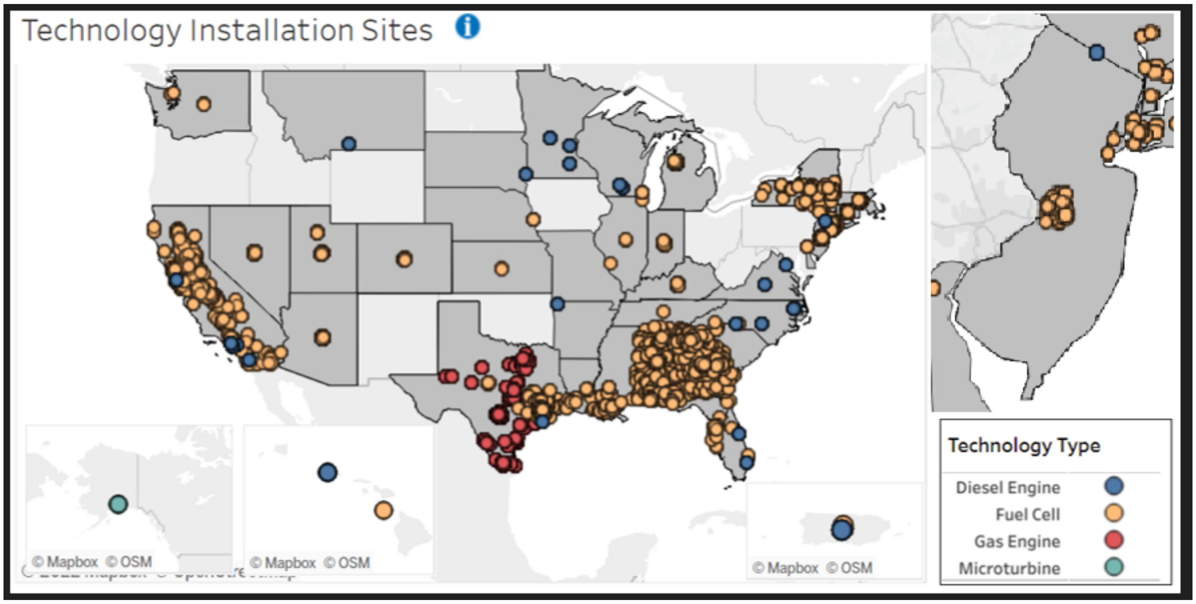
Microgrids operate from a variety of sources, mainly natural gas and solar power. However, both methods contained within the microgrid can produce hydrogen to be used as fuel, creating a third source. It should also be noted that microgrids can serve as a primary source of power,[20] especially with their own backup source of readily available renewable fuel.

Various companies integrate large scale fuel cell systems into other onsite renewable generation solutions (sometimes within microgrid configurations) as a dispatch able complement for the intermittencies of solar and wind and to displace the operational need for more costly grid power. This can be through direct owner-operator role or power purchase agreements with third party developers. As noted above, hydrogen can be used to continue supplying electricity during times of source shortage or when transmission failures occur, enabling facilities to keep running during times of outage. Fuel cell systems are providing this type of resilient power to major telecommunication facilities across the country, including in New Jersey.

Backup Power Fuel Cell Systems

Fuel cells generate direct current (DC) electricity that can be connected to the several telecom systems ranging from 12V to 48V. Since 2007, around 3,000 fuel cell powered backup systems have been installed in US by many telecom companies including Verizon, AT&T and Sprint.[21] A large portion of these fuel cell backup power systems are installed in the Northeast and Southwest areas of the US (**Figure 1.6**). Around 122 backup power fuel cell stations were also installed at Federal Emergency Management Agency (FEMA) sites.

Figure 1. 6 Commercial emergency backup power locations in the US and New Jersey, adapted from California Air Resources Board.[22]

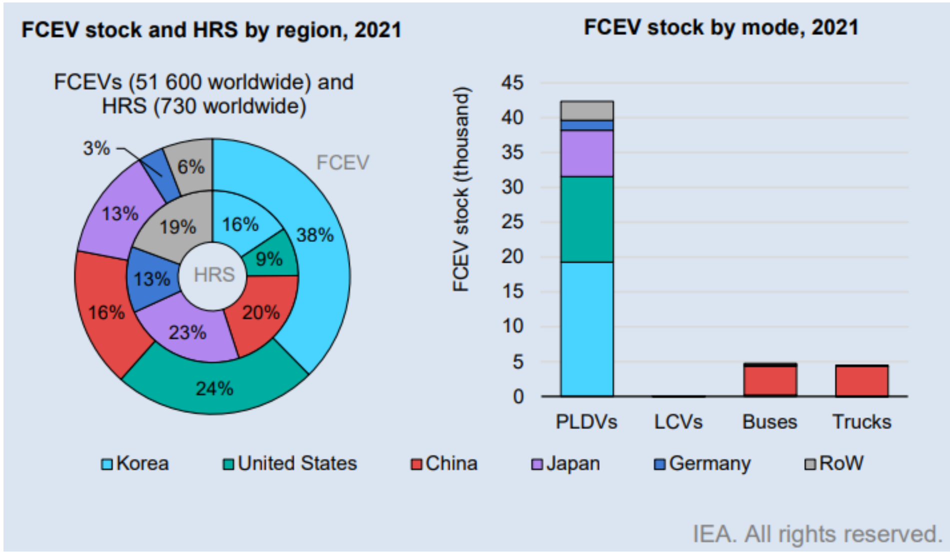


There are also 126 fuel cells configured for CHP operation in the US, accounting for 67 MW of capacity, primarily utilized in commercial and institutional buildings (i.e., hospitals, hotels, universities).[16] Numerous residential fuel cell applications also exist. These are stationary fuel cells built at a smaller scale for residential primary or backup power and are on the cusp of introduction into US markets. Residential fuel cells are the largest market for micro-CHP systems, with >225,000 installed globally.[23] Japan has installed numerous residential fuel cells and has plans to deploy 5.3 million units by 2030.

Transportation

Hydrogen-powered FCEVs complement BEVs as a zero-emission transportation option, sharing the benefits of high torque and smooth, quiet driving while differing in several ways that make it a better option for some customers. For instance, a longer range and faster, centralized refueling appeal to users that drive long distances, do not have or want downtime, and do not have a private, designated parking space to install an electric vehicle charging station. A diagram showing how hydrogen fuel cells work in a FCEV can be found in **Appendix III**. Global automobile manufacturers BMW, Honda, Hyundai, and Toyota have already introduced FCEVs, while Audi and Mercedes-Benz and others are expected to do the same.[24] Some automotive executives have identified FCEVs as “the game-changer” by 2025, expecting FCEV sales to reach 8 million by 2030 in developed nations.[25] To date, over 15,000 light-duty FCEVs have been sold or leased in California, the only major market in the US at this time. Two vehicles are publicly available for purchase or lease in select US markets: the Toyota Mirai and the Hyundai Nexo. As of 2020, 31,225 passenger FCEVs powered by hydrogen have been sold globally.[26] In 2021, there were approximately 51,600 total FCEVs reported worldwide among all classes (**Figure 1.7**).

Figure 1.7 Fuel Cell Electric Vehicles and Hydrogen Refueling Station stock statistics, 2021[27]



FCEVs= fuel cell electric vehicle (outer ring, left image); HRS hydrogen refueling station (inner ring, left image). PLDVs = passenger light-duty vehicles; LCVs = light commercial vehicles; RoW = rest of world.

The benefits of rapid refueling and weight savings for long ranges are even more pronounced for zero-emission medium- and heavy-duty vehicles due to their higher energy density relative to batteries in those applications. Several manufacturers are developing fuel cell trucks and buses. Fuel cells are being deployed in fleet delivery trucks – FedEx, DHL, and UPS, for example – either as the sole power source or in combination with batteries to extend the range of battery-powered delivery vehicles. Several prototype fuel cell trucks have been deployed for short range drayage operations at Southern California port facilities, and development is underway for long haul cross-country trips. Currently, 87 fuel cell buses are deployed in the US, predominantly operated by four California fleets – AC Transit in the Bay Area, Foothill Transit in Los Angeles County, Orange County Transit, and Sunline Transit in the Palm Springs area – and one fleet in Ohio by the Stark Area Regional Transit Authority (SARTA). The Southeastern Pennsylvania Transit Authority has approved purchase on 10 New Flyer hydrogen fuel cell buses.[28] Fuel cells are also being demonstrated in other transportation applications. Currently, China hosts the highest global market share of FCEV trucks (95%) and buses (90%), with a combined stock of more than 8,400 vehicles. While the market in Europe and the US is small, Hyundai, Toyota, Nikola and Hyzon Motors have announced their launch of FCEV truck trials.[26] Cummins and Toyota have announced that they will offer heavy-duty fuel cell powertrains for integration into trucks or potentially numerous other applications.[29]

Fuel cells are also being demonstrated in other transportation applications. At airports, fuel cells can power a variety of logistics and services, including baggage movers, meal-service trucks, passenger shuttles, and forklifts (see Material Handling section below).[30, 31] Fuel cells in these transportation applications, in addition to stationary applications (i.e., communication networks), have been deployed at Memphis International Airport, Los Angeles International Airport, and Kansai International Airport.[32] A fuel cell powered train by Alstom using roof-mounted hydrogen tanks with a range of 500 miles has begun testing in Germany,[6] and fuel cell powered trams are being demonstrated in China.[33] Stadler, the California State Transportation Agency (CalSTA) and the California Department of Transportation

(Caltrans) have signed a Memorandum of Understanding (MoU) for the design and delivery of four zero-emission HFC (hydrogen fuel cell) four-car FLIRT H2 trainsets for California at InnoTrans on Sept. 20, with an option to order an additional 25 trains to replace diesel-powered locomotives. The train fuel cell systems will be supplied by Ballard Power.[34] Marine vessels are also testing fuel cells; *Sea Change*, a 70-foot passenger ferry has been delivered to San Francisco Bay Ferry in San Francisco and is expected to enter service by late spring 2023.[35] Fuel cells are also being considered for off-road vehicles – tractors, wheel loaders, and excavators, for example.[36]

As of 2021, more than 730 hydrogen refueling stations were reported to be operating globally[27] - around 168 in Japan, 146 in China, 116 in Korea, 95 in Germany, and 138 spread across other non-US countries. Approximately 75 hydrogen stations are reported to be in North America, largely located in California, which has 54 stations.[37] Industry has stated plans to install around 3,000 hydrogen refueling stations globally, to provide fuel to about 2 million FCEVs by 2025.[31] Target estimates for FCEVs and hydrogen stations in six different countries is presented in **Table 1.1**.

Table 1. 1 Hydrogen fueling stations and fuel cell electric vehicle targets for 2025-2040[38-40]

Country	Fuel Cell Cars	Refueling Stations
USA (2025)	3.3 million	110[a]
UK (2040)	100% [b]	150
Japan (2030)	800,000	900
China (2030)	1 million	1,000
Germany (2040)	100% [b]	400
South Korea (2030)	630,000	520

Note: [a]California only, [b]100% of new sales to be zero emission vehicles (ZEV) by 2040.

Material handling equipment

Fuel cell-powered material handling equipment produces zero emissions and provides longer runtimes, constant power supply (no voltage sag), lower operational costs, and increased worker productivity relative to battery-powered equipment in some applications. As of 2018, there were more than 20,000 fuel cell powered forklifts in operation in the US.[41] FedEx Freight, Amazon, Central Grocers, Sysco Foods, and Walmart are using or planning to use fuel cell-powered material handling equipment such as narrow aisle lift trucks, pallet jacks and stock pickers.[42] Companies including CVS, Kroger, Ace Hardware, Lowe's, Unified Natural Foods, Wegmans, Carter's, Kimberly Clark, and Uline have also acquired fuel cell-powered handling equipment fleets in some capacity. Fuel cells are also ideal for moving large cargo in shipping ports, which operate 24 hours a day and are a key part of New Jersey's economic supply chain. Currently, the heavy trucks and machinery used to move and store cargo in port areas run on diesel, which emits carbon dioxide and criteria pollutants such as NOx and particulates.

Other industries/applications

Fuel cells are also widely used in other industries such as packaging, oilfield service, analog and mixed signal integrated circuit manufacturing, and defense and aerospace facilities. Some of the representative companies are Baker Hughes, Bridgestone-Firestone, Maxim Integrated, Owens Corning, TaylorMade-Adidas Golf Company, Aerojet Rocketdyne, Amgraph Packaging, LeGrand North America, Pratt & Whitney, and SC Johnson. Fuel cells are mostly installed in these companies in the states of California, Connecticut, and South Carolina to supply power to their offices, laboratories, workshop centers, and vehicle maintenance equipment. Many financial service companies and banks including Bank of America, Franklin Templeton, JPMorgan Chase, Morgan Stanley, and the First National Bank of Omaha have also installed fuel cells to generate high quality, sustainable, reliable power for their data centers and headquarters in California, Delaware, New York, and Nebraska.[43, 44]

2. New Jersey is well positioned for fuel cell and hydrogen market development

New Jersey is broadly considered a logistics and transportation hub. The state hosts the highest concentration of engineers and scientists in the US, has a well-established manufacturing base and workforce, and has numerous industrial and chemical plants that could potentially be used to generate hydrogen. Home to seven research universities among its 60+ established universities, colleges, and community colleges, New Jersey is staged to educate a growing body of scientists, engineers, and other workforce members critical to the development of a clean energy economy. Further, the state has the highest roadway density in the US, including over 2,800 miles of interstates and highways. New Jersey also holds five foreign trade zones whose goods movement infrastructure offers unsurpassed market access. In addition to the many federal policies and programs supporting hydrogen and fuel cell technology development, there are several existing state policies that support clean energy technology adoption.

New Jersey has several supporters of hydrogen and fuel cells, including Governor Phil Murphy who has promoted clean energy policies, programs, and initiatives. To that end, Governor Murphy recently joined the Governors of New York, Massachusetts, and Connecticut in signing a memorandum of understanding to create a regional clean hydrogen hub, to include a partnership of industry, educational, and non-profit collaborators. **See Recommendation 1.1.** Since the announcement, Rhode Island, Vermont and Maine have joined the Northeast Regional Hydrogen Hub partnership, demonstrating a shared regional vision of increasing the use of hydrogen energy to help achieve each State's carbon and criteria pollutant emissions reduction goals.[45] The seven-state hub collaborative will develop and submit a proposal for US DOE funding made available through the Federal Infrastructure Investment and Jobs Act. Coalition partners will work together to advance clean hydrogen projects to participate in the hub proposal, consistent with the core principles of greenhouse gas reduction, economic development, resilience, and environmental justice. This collaborative effort will advance a vision that enables a long-term sustainable clean hydrogen industry in the northeast region, as well as strategic connections to other clean hydrogen hubs across the country and around the globe.

Fuel cell and hydrogen industry in New Jersey and the Northeast

New Jersey is well positioned in relation to the fuel cell and hydrogen industries, with three major fuel cell developers in the Northeast as well as many hydrogen providers. Fuel cell manufacturers include Plug Power, Inc. (Latham, New York), FuelCell Energy (Danbury, Connecticut), and HyAxiom (formerly Doosan

Fuel Cell America - South Windsor, Connecticut). Another developer - Bloom Energy - has installed fuel cells in many New Jersey businesses. Hyzon Motors Inc. (Mendon, New York) is a startup with plans to introduce fuel cell trucks in 2023. Suppliers of hydrogen and hydrogen equipment in the Northeast include Air Liquide, Linde, Air Products, Chart Industries, Bethlehem Hydrogen, and Nel Hydrogen among others. Information on these companies and other key fuel cell developers and hydrogen suppliers can be found in **Appendix IV**. Discussion on the value chain of FCEVs and BEVs can be found in **Appendix V**.

Recommendation 2.1.

H2Biz to Assist Emerging Industry. Establish an "H2Biz" function in the New Jersey Business Action Center to support development of hydrogen and fuel cell businesses within the State.

Within New Jersey, US DOE identifies 15 companies as being involved in the hydrogen and fuel cell supply chain. These are identified in **Table 2.1** and mapped in **Figure 2.1** along with higher education institutions. With growing demand and resources, New Jersey can support existing and future businesses and academic institutions to strengthen the State's hydrogen and fuel cell supply chain. **Recommendation 2.1** suggests an approach to support emerging hydrogen and fuel cell industries in New Jersey that has worked well for clean energy stakeholders in California – a State-operated "H2Biz" function modelled after California's GoBiz office.[46]

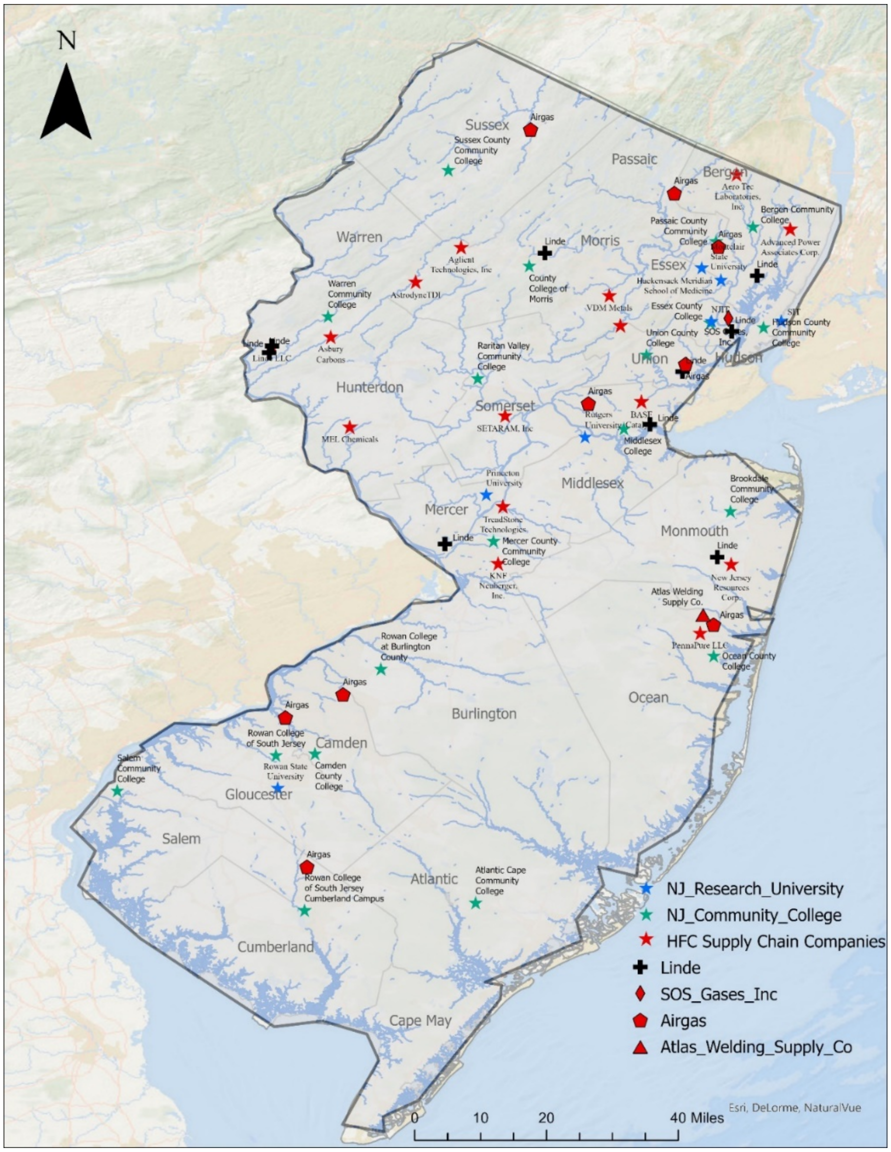
Table 2. 1 Overview of hydrogen and fuel cell supply chain companies in or around New Jersey (Information gathered from the Hydrogen and Fuel Cell Nexus)[47]

Company Name	Location	Products
Aero Tec Laboratories Inc.	Ramsey	Flexible composite materials, including crash-resistant fuel cells and bladders, fuel cell system accessories, and refueling equipment
Advanced Power Associates Corp.	New Milford	Converters that are used in fuel cell powered cars and buses
Agilent Technologies, Inc.	Distributor offices in the NYC metro area	Analytical instruments, including hydrogen purity testing equipment for safety and quality assurance
Airgas	Multiple locations	Air Liquide company, welding supply store and distributor of specialty gases including hydrogen
Asbury Carbons	Asbury	Graphite and carbon-based products including MEA-plates for fuel cells
AstrodyneTDI	Engineering and manufacturing center in Hackettstown	EMI filters and custom power conversion systems
Atlas Welding Supply Co	Lakewood	Welding supply store and distributor of specialty gases including hydrogen
BASF Catalysts	Iselin	Alkaline fuel cells and hydrogen storage systems

Hosokawa Nano Particle Technology	Summit	Solid oxide fuel cells (SOFCs) and SOFC components for stationary power generation
KNF Neuberger, Inc.	Trenton	Air, gas, and liquid diaphragm pumps for a variety of fuel cell types
Linde LLC	Multiple locations	Hydrogen and hydrogen production systems
MEL Chemicals	Flemington	Zirconia powders for use as electrolytes and anodes in SOFCs
New Jersey Resources Corp. Hydrogen Pilot	Howell	Green hydrogen pilot project which sources electricity from adjacent solar facility
New Jersey Resources Corp.	Wall	Hydrogen for hydrogen/natural gas blends in utility distribution pipelines
Perma Pure, LLC	Lakewood Township	Tubular membrane humidifiers for fuel cells
SETARAM, Inc.	Hillsborough Township	Thermal analyzers and other laboratory equipment
SOS Gases, Inc.	Kearny	Specialty gas distributor including hydrogen
TreadStone Technologies	Princeton	Coating technologies for fuel cell components
VDM Metals	Florham Park	MEA-plates for fuel cells

Note: Data in this table was compiled from a number of sources, though may not include all supply chain companies.

Figure 2. 1 Map of New Jersey hydrogen and fuel cell supply chain and higher education institutions



Source: Clean Energy and Sustainability Analytics Center, Montclair State University

Hydrogen Fuel Production and Distribution

Currently, FCEVs are not available to the general public in New Jersey and, therefore, there are no public hydrogen fueling stations in the state. However, hydrogen dispensers have been installed in warehouses in New Jersey to provide fuel for fuel cell-powered forklifts, and a few public utility companies are beginning to produce hydrogen for distribution to customers.

The New Jersey Resources Corporation launched the state's first green hydrogen pilot project in Howell, which has been operational since October 2021.[48] The project uses electricity generated from a nearby solar facility to power a 175kW electrolyzer that produces 65 kg of hydrogen per day, which is then blended into the utility's distribution pipeline to heat customer homes and businesses. The system offsets 180 tons of CO2 per year, equivalent to emissions 18,456 gallons of gasoline, or 90 tons of burned coal.

JERA Americas also recently announced a plan to reduce CO_2 emissions by blending hydrogen at two plants.[49] Linden Cogeneration recently signed an agreement to take the Bayway Refinery's hydrogen-containing fuel gas and blend it with natural gas to fuel its 172 MW gas turbine. This modification will enable a fuel blend of up to 40% hydrogen, leading to an anticipated reduction in CO_2 emissions of 10%.

Also in 2021, South Jersey Industries Inc. announced its collaboration with Atlantic Shores Offshore Wind LLC for a green hydrogen pilot project.[50] Atlantic Shores was awarded a contract to develop 1510 MW of offshore wind energy, 10 MW of which will be used to power an electrolyzer and compressor for the pilot project. The hydrogen will be used in hydrogen/natural gas blends to reduce the carbon footprint of power generation and in fuel cell applications.

As demand for hydrogen grows in New Jersey, state incentives would spur private investment in hydrogen production. **See Recommendations 2.2, 2.3, and 2.4.**

Recommendation 2.2

In-State Fuel Production Investment Incentives. To encourage private investment in in-state hydrogen production, and consider options for state tax credit on investments or production of low-carbon hydrogen.

Recommendation 2.3

Promotion of Existing Incentives: Efforts should be made to: educate operators of hydrogen production facilities on the ability to participate in demand response programs; educate project developers on the economic benefits of hydrogen as a peak shaving and demand response resource, and; work with PJM and FERC to eliminate barriers to entry.

Recommendation 2.4

NJ Resiliency Tariff (Retail): BPU should consider requiring electric distribution companies to propose electricity tariffs that recognize the system, environmental, and resilience benefits created through behind-the-meter resources, including fuel cell systems and electrolyzers.

Fuel Cell and Hydrogen Opportunities in New Jersey

Renewable/Grid Energy Storage

While renewable energy generation in New Jersey is currently minimal (nearly 8% as of 2020),[51] the state's planned expansion of solar and offshore wind projects will provide opportunities for hydrogen energy production and storage and for fuel cell applications. The New Jersey EMP calls for 17,000 MW solar energy and 2,000 MW energy storage by 2035; additionally, Governor Murphy has committed the state to building 7,500 MW of offshore wind by 2035 and 11,000 MW by 2040.[52] This renewable energy generation expansion along with Federal and State incentives for hydrogen and fuel cell development will provide opportunities for many New Jersey industries, particularly for those adjacent to existing and developing solar and wind energy generation projects.

Stationary Fuel Cells

Primary power and heat: Fuel cells can be used as stand-alone, grid-independent primary power sources or in combination with other primary power sources. There are four electric utility providers serving New Jersey: Atlantic City Electric, Jersey Central Power & Light (JCP&L), Public Service Electric and Gas (PSE&G), and Rockland Electric. There are also four major natural gas providers serving the state: Elizabethtown Gas, New Jersey Natural Gas, PSE&G, and South Jersey Gas. Fuel cells are compatible with both conventional and renewable primary power sources and can be used by both/either utility suppliers and utility customers. As in the Howell pilot project described above, fuel cell systems can be co-located with clean energy resources to generate and use green hydrogen. There are several potential applications for CHP blending hydrogen, including industrial parks, office parks, institutions, pharmaceutical facilities, higher education facilities, hospital and health care facilities, large retail centers, port facilities, and petroleum refining and chemical industries. In 2020, the New Jersey Board of Public Utilities (BPU) in collaboration with New Jersey Transit was awarded $400 million in US DOE funding to support a microgrid study that will incorporate solar, wind, and hydrogen fuel cell technology in addition to battery storage.[53]

> **Recommendation 2.5**
>
> **Distributed Energy Resources.** Focus BPU's grid modernization program on valuing/compensating desired operational attributes, such as air quality improvement, carbon reduction, and grid flexibility and resilience.

Backup power: With the increased frequency and severity of extreme weather events, access to emergency backup power is critical to public safety. This is particularly true for buildings and organizations that cannot afford to lose power, such as hospitals, schools, and telecommunications infrastructure. There are 113 hospitals in the state, 72 of which are acute care.[54] There are 2,493 K-12 public schools, enrolling over 1.3 million children, and 1,362 private K-12 schools, enrolling over 200,000 students.[55] The state is home to more than 60 higher education institutions, including public research universities, public colleges and universities, private colleges and universities, county colleges, and religious study institutions. During Hurricane Sandy in 2012, fuel cells were a key source of resilient emergency backup power to New Jersey telecommunications towers which operated for hundreds of hours as some areas of the state lost power for upwards of two weeks. There are over 1,300 telecommunication towers in the state, impacting companies including AT&T, Sprint, Verizon, and T-Mobile.[56] (**See Recommendation 2.5)**

Mobile Fuel Cells

Public transit: New Jersey operates numerous buses, trains, and light rails from many fleets including New Jersey Transit, Amtrak, Metropolitan Transportation-MTA, PATH, SEPTA, PATCO, New Jersey Riverline, Hudson-Bergen Light Rail, and Port Authority of New York and New Jersey, all of which are exploring zero-emission transit options (**See Recommendation 2.6**). The NEESC report estimates that the introduction of 139 ZEV fuel cell electric buses (FCEBs) replacing existing transit vehicles in New Jersey could reduce annual CO_2 emissions by 12,400 metric tons, and NOx emissions by 3 metric tons.[2, 57] See **Appendix VI**. These emissions reductions and associated improved air quality could prove particularly significant in overburdened environmental justice communities. The DOT Low- and No-Emission Bus and Bus Facilities grants could act as a major opportunity for New Jersey public transit; in 2022, the program supported 150 projects with $1.66B in funding. New Jersey Transit has received $44.7M in funding to renovate its Union City bus garage for battery electric buses. New Jersey Transit and other public transportation leaders should consider incorporating zero-emission fuel cell electric buses in areas that would benefit from their longer driving ranges and quicker refueling times compared to battery-electric buses. Fuel cell buses in the US are deployed mostly in California and Ohio; there are none in New Jersey. However, two New York companies - Plug Power and BAE Systems – recently partnered to develop a fuel cell electric bus (FCEB) fleet.[58] 595959595956565554

Recommendation 2.6

Spur Fuel Cell Electric Vehicle Adoption through the following:

- Identify and support candidates for FCEV clean fleet transition.
- Renew state clean vehicle purchase incentives to include hydrogen fuel cell electric vehicles.
- Consider drafting a bill, like the EV law, to add fuel cell vehicles and hydrogen infrastructure to the scope of existing targets for the state.
- Advocate for and expand upon the New Jersey Zero-Emission Incentive Program (NJ-ZIP).
- Advocate for Federal Tax Credits for fuel cell technology and hydrogen infrastructure.

Heavy- and medium-duty trucks: New Jersey DOT reported (2020) that of the 66.3 million miles travelled on public roadways, 25% of those miles are from vehicles with two or more axles (includes buses, trucks, and trailer trucks).[60] To help accelerate the adoption and use of zero-emission medium- and heavy-duty vehicles within the state, particularly in overburdened environmental justice communities, the NJEDA's Zero-emission Incentive Program (NJ ZIP) provides funding to qualifying businesses to purchase medium- and heavy-duty zero emission vehicles. Air Products and Cummins recently announced a partnership to develop a fleet of FCEVs, including over 2,000 trucks.[61] Nikola and Bosch are partnering to begin production of heavy-duty FCEVs in 2023.[62] [6363636363606059] Hexagon Purus and Ballard Power Systems are also collaborating on Class 6 and 7 trucks with plans for deployment in 2022. Hyundai plans to deploy over 30 Class 8 trucks in California; their Xcient Fuel Cell trucks debuted in Switzerland in 2020.[64] In just 11 months, the fleet reduced CO2 emissions by more than 630 tons compared to the diesel vehicles they replaced. UPS and the Center for Transportation and the Environment (CTE) have recently partnered to develop a prototype ZEV delivery van using hydrogen fuel cell technology, funded by US DOE, retrofitting and testing delivery vans across UPS distribution facilities in California, including routes in disadvantaged communities.[65]

Passenger vehicles: New Jersey has an estimated 6 million registered vehicles in the state; in 2019, the New Jersey CAR economic impact report stated that the average dealership sold 1,065 new and 810 used vehicles.[66] Under the Multi-State Zero Emission Vehicle MOU, the several states have set a non-binding target to place 3.3 million ZEVs (BEVs, FCEVs, PHEVs) total by 2025; New Jersey's portion of this is about 330,000. New Jersey has also begun to consider adopting the Advanced Clean Cars II (ACCII) regulation, a 10-year extension of the ZEV regulations that mandate automakers to sell increasing proportions of ZEVs, ending with 100% sales in 2035. This would drastically increase the number of ZEVs in the state. (**See New Jersey State Policy and Programs in Chapter 2).**

Recommendation 2.7

Hydrogen in Alternative Fuel Corridor. Revisit current Federal Alternative Fuel Corridor designations in New Jersey and explore the implementation of hydrogen infrastructure for appropriately designed corridors.

In the US, fuel cell vehicles are available albeit limited to California and Hawaii. Due to the need to install an extensive infrastructure network to support public sales, expansion to additional states outside California must be done strategically and judiciously based on potential market size and presence of supportive policies and incentives. In some states, certain factors actively discourage the introduction of fuel cell vehicles. For instance, there are currently regulations prohibiting FCEVs in tunnels between New Jersey and New York, as well as some other states, that make public introduction of FCEVs impossible, an issue noted in the New Jersey EMP.[52] **(See Recommendation 2.7)** The Toyota Mirai (LE, Limited, and XLE) large sedan has a range of 330-402 miles; the Hyundai Nexo (standard and Blue) SUV has a range of 354-380 miles.[67] Both can be refueled within 5 minutes.

Material handling equipment: Fuel cell material handling equipment was one of the earliest fuel cell technology markets in the US, and includes forklifts, narrow aisle lift trucks, pallet jacks, stock pickers, and cranes. Currently eligible for a federal tax credit of up to $3000/kW or 26% of total costs, fuel cell powered material handling equipment is financially attractive and provides benefits over incumbent technologies (diesel and batteries) in some applications.[68] The NEESC report estimates that choosing fuel cell powered material handling equipment over battery powered would result in 80% lower refueling/recharging labor costs and 75% less space required for refueling. The top fuel cell powered material handling equipment manufacturers include Toyota, Hyster-Yale, Linde, STILL GmbH, and Oorja Protonics. Several fuel cell manufacturers, like Plug Power, are working with equipment manufacturers to manufacture fuel cells that meet the equipment's specific needs. Many businesses in New Jersey use this equipment, including companies with retail outlets, warehouse storage facilities, and shipment centers. One example is FreezPak Logistics (Carteret, New Jersey), which uses forklifts powered by Plug Power fuel cells. Other material handling customers and/or potential customers include Central Grocers, Fedex, Sysco Foods, Amazon, and Walmart.[69]

Other fleet vehicles: Several opportunities exist for other specialty fleet vehicles, including passenger vehicles and industrial equipment needed for various industries including warehouse management, airports, manufacturing, construction, mining, agriculture, retailers, and wholesalers. Compared to BEVs that may serve the same function, FCEVs allow for longer run times and quicker refueling times. Fleet vehicles are ideally suited for fuel cell and hydrogen applications, as those vehicles can be refueled at a central hydrogen fueling facility. Fleet vehicle applications have often been proposed as an effective approach to building out the early hydrogen fueling infrastructure.

Drones and aircraft: Unmanned aircraft systems, more commonly called drones, are legal for personal, public and commercial use in New Jersey. The New Jersey Department of Transportation (DOT) has provided licenses for approximately 400 aeronautical facilities using drones, including airports, heliports, balloon ports and seaplane bases.[70] Fuel cell drones are an attractive option as they provide higher energy-to-mass ratio than batteries, enabling longer flight endurance. There are over 50 drone manufacturers in the US, with BFD Systems being the only fuel cell drone manufacturer located in New Jersey.[71] Airbus has identified hydrogen technology as an approach to achieving their goal of bringing zero-emission commercial aircraft to the market by 2035.[72] Pratt & Whitney was recently awarded a DOE project to develop hydrogen propulsion technology as part of the company's strategy to support the aviation industry's goal of zero-carbon aircraft emissions by 2050.[73] Several fuel cell manufacturers and drone/aircraft companies are working together to create innovate technologies, including Doosan, Micromulticopter Aero Technology (MMC), Plug Power, Protonex, AeroVironment Inc., and Elbit Systems Ltd.

Ferries and boats: New Jersey has several ferry terminals, serving transit routes on: (1) the Hudson River leading to New York City; (2) Sandy Hook Bay leading to New York City; (3) the Delaware River leading to Philadelphia; (4) Delaware Bay leading to Delaware; and (5) several leisure/tourist ferries along the Atlantic Coast. The world's first fuel cell powered ferry, *Sea Change*, developed by All American Marine, Inc. and SWITCH Maritime, using Cummins fuel cells and Hexagon hydrogen storage tanks, was deployed in the San Francisco Bay in 2021, and will be operational in 2022.[74] With a range of 300 nautical miles, this technology could be applied to any of New Jersey's ferry routes. There are numerous companies exploring fuel cell boats as well, including Toyota, Yanmar, ABB in partnership with Ballard, and Kisen.[75] Supportive policies and incentives would accelerate adoption of the diversity of mobile applications for fuel cells and a clean hydrogen fuel infrastructure.

Potential near-term employment impacts

Analyses conducted by NEESC in 2018 indicated that fuel cell investments in New Jersey can provide up to 1,673 direct impact jobs between by 2030, and as many as 4,199 indirect and induced impact jobs.[2] The corresponding value addition to the economy would be $138 million. It should be noted that this analysis was based on the hydrogen and fuel cell landscape in the US in 2018. The planned $10 billion BIL funding from the US Government for projects beginning in 2023, along with the 50 percent cost share contributed by industry and State governments for those projects and the anticipated tax incentives for clean hydrogen production under the Inflation Reduction Act, will significantly increase investments in hydrogen and fuel cell systems and the resulting economic impacts.

Direct employment related to manufacturing is only a small part of overall employment impacts. Additional employment in operations and maintenance are expected even when based on conservative estimates. The non-production jobs, including those in sales, site maintenance, planning, and management, for such applications as transportation, are a magnitude greater.[76] Employment impacts are likely to be the highest in relation to hydrogen refueling stations and is likely to peak during the build-up of the infrastructure, then level off and possibly stabilize at lower levels in later years once the infrastructure has been put in place. Policy aimed at realizing these economic impacts should take an integrated and possibly phased approach. This would help to address the interdependencies between various applications and the non-linear nature of their development over time. By actively encouraging investment in hydrogen and fuel cell systems and providing a supportive policy environment that fosters this investment, New Jersey can reap the economic and job creation benefits.

Recommendation 2.8

Collaboration with New York. Collaborate with the State of New York to propose end uses and seek federal funding for hydrogen/fuel cell technologies at the Port Authority of New York and New Jersey, which recently issued a Request for Information (RFI) for Zero-Emission Technology. The goals of the RFI can dovetail with the plans to create a regional hydrogen hub.

Public and Private Sector Stakeholders

Potential Government Adopters in New Jersey

Public Transportation

Port Authority of New York and New Jersey (PANYNJ) oversees most of the regional transportation infrastructure in the two states - including bridges, tunnels, public transit including bus terminals and PATH railway, airports, and seaports. They have committed to achieving net zero carbon emissions by 2050 across the Port Authority, establishing interim targets to reduce direct emissions to 35% of 2018 levels by 2025 and 50% by 2030. Their goals will be met by using energy efficient technologies and solar energy generation. In partnership with Bloom Energy, PANYNJ will install a fuel cell system at One World Trade Center, providing approximately one third of the building's energy demand.[77] The Northeast Hydrogen Hub proposed by New York, New Jersey and other states will provide a unique opportunity for the states to collaborate in reducing carbon and criteria pollutant emissions on interstate highways and in ports. **See Recommendations 2.8 and 1.1.**

South Jersey Port Corporation oversees the seaports and warehouses in the South Jersey Port District and aims to systematically replace fossil-fuel equipment, such as vehicles and cargo movers, with zero-carbon alternatives.[78] [7878787878757574] Proximity to the developing offshore wind farms places the Port Corporation in an opportune position to benefit from accessibility to clean energy generation, including fuel cells and hydrogen.

New Jersey Transit is a state-owned rail and bus public transportation system serving New Jersey, Pennsylvania, and New York. New Jersey Transit's strategic plan includes the goal of converting to 100% clean energy by 2050.[79] To reach this goal, they are assessing electric buses and alternative fuel technologies to enable a zero-emissions fleet. In addition, the **Low Emission or Alternative Fuel Bus Acquisition Requirement** mandates that all buses purchased by New Jersey Transit meet emissions standards or be powered by a fuel source other than conventional diesel, such as compressed natural gas, hybrid electric, hydrogen, biodiesel or ultra-low sulfur fuel. The agency has deployed eight electric buses and charging infrastructure at their Camden depot and plans to add more EVs to their fleet and install charging stations at other depots. In February 2022, New Jersey Transit ordered eight battery-electric Xcelsior CHARGE NJ™ buses from NFI Group, Inc., an electric bus and coach manufacturer, with options to purchase up to 75 more within the next five years.[80]

Municipalities

There are 564 municipalities in New Jersey, most of which have multiple operating facilities and equipment support (i.e., vehicles). Many opportunities to electrify municipalities exist given the wide-ranging applications, from resilient power for critical municipal buildings to zero-emission vehicle fleets. One example of an innovative project is the **New Jersey Clean Cities Coalition's** collaboration with **Atlantic County Utilities Authority** and South Jersey Industries to produce renewable hydrogen via electrolysis using power generated by the wind turbines in Atlantic City. In this US DOE funded project, the hydrogen will be used in natural gas blends and in transportation fuel cell applications. The oxygen from electrolysis will be used in ACUA's wastewater treatment plant. This project is expected to provide data and lessons learned to inform hydrogen projects using New Jersey's offshore wind power resources when they come online in the near future. It is also the first hydrogen fuel cell project in south New Jersey, which could benefit from the economic opportunities, jobs, etc. provided by the emerging hydrogen and fuel cell industries in the state.

Department of Defense

New Jersey is home to six military bases: McGuire-Dix-Lakehurst Air Force Base (Air Force), Fort Monmouth (Army), Picatinny Arsenal (Army), Loran Support Unit (Coast Guard), Training Center Cape May (Coast Guard), and the National Weapons Stations Earle (Navy). The US Department of Defense (DoD) has demonstrated fuel cell technologies in a number of military and service applications. In 2019, a fuel cell powered emergency relief truck was deployed by the US Army's Ground Vehicle Systems Center and the US Army Corps of Engineers.[81] The Corps of Engineers has also installed 18 fuel cell backup power systems at various locations, including Picatinny Arsenal. DoD has also funded several fuel cell projects led by the Center for Transportation and the Environment (CTE), including hydrogen-powered forklifts, electrolysis hydrogen generation, fuel cell shuttle buses, and fuel cells range-extenders in utility EVs at the Defense Depot San Joaquin in California, US Army's Forces Command at Joint Base Lewis-McChord in Tacoma, Washington, and Defense Logistics Agency (DLA) facilities.[82] Advent Technologies recently (2021) signed a contract with DoD to create a wearable fuel cell power system (portable generator, 'Honey Badger').[83] New Jersey's military bases could provide opportunities for collaborating with DoD on hydrogen and fuel cell projects to achieve mutual clean energy goals.

Recommendation 2.9

Fuel Cell Electric Vehicle Access. Discussions with the Port Authority of New York and representatives from New York and New Jersey should explore a pathway to allowing fuel cell electric vehicle access to New York City from New Jersey via public transportation and personal vehicles.

US General Services Administration (GSA)

In 2021, GSA awarded funds to five firms including three small businesses, to develop and deploy 10 models of electric transit buses equipped with fuel cells and battery technologies to advance the Biden-Harris Administration's goal of achieving 100% ZEVs by 2035.[84] These electric buses seat 34 to 46 passengers and are available for federal agencies to lease through GSA or purchase directly through GSA's AutoChoice ordering portal.

Federal Aviation Administration (FAA) Sites

New Jersey has a number of airports and FAA sites, e.g., WJ Hughes Technical Center outside Atlantic City, that could benefit from adoption of fuel cell technology for ground transport, utility vehicles, material handling, and telecom and facility backup power. In 2020, the US DOE held a workshop, in collaboration with US DOT and DoD (FAA), covering the progress and benefits of fuel cell systems in airport and aviation applications.[85] Argonne National Laboratory compiled a summary report of the workshop describing early fuel cell aviation and airport projects, technology gaps, research opportunities, and potential actions.

New Jersey State Policy and Programs

Fuel cell and hydrogen technologies are included in **New Jersey's Energy Master Plan (EMP)** as strategies to reaching the goal of 100% clean energy by 2050.[86] FCEVs are aligned with Goal 1.1: Decarbonize the Transportation Sector, including deploying 330,000 light-duty EVs by 2025 through the Multi-State ZEV

Task Force addressing EV incentives, fleet transitions, infrastructure development, and education and outreach. The EMP cites the potential of hydrogen fuel cells to improve New Jersey Transit's environmental footprint and recommends that State agencies partner with industry to develop incentives to electrify the medium- and heavy-duty vehicle fleet with fuel cell technology. The EMP notes that a key challenge is the Port Authority regulation prohibiting FCEVs from traversing its bridges and tunnels and recommends collaborating with the Port Authority to address the safety issues. **See Recommendation 2.9.** In EMP Strategy 7 Expand the Clean Energy Innovation Economy, clean vehicles, including FCEVs, are also acknowledged as a key player in New Jersey employment opportunities, providing a foundation upon which to build and expand the clean energy economy.

Fuel cells for stationary power generation can help New Jersey meet EMP Goal 5.1: Plan for and Implement the Necessary Distribution System Upgrades to handle increased electrification and integration of distributed energy resources. The EMP specifically notes the potential for fuel cell technology as a zero-emitting source of energy for both mobile and non-mobile (e.g., DER, storage) purposes, and the potential for New Jersey to generate vast amounts of offshore wind energy (which can be used to produce renewable hydrogen). The EMP also notes that fuel cells are included as a Class I Renewable in the State's Electric Discount and Energy Competition Act (EDECA), which enables market competition for electricity generation and established New Jersey's first RPS. Bolstering the grid's reliability and resilience is a key objective of Goal 5.1, calling for the addition of decentralized carbon-neutral electricity generation to the system mix to increase energy diversity, particularly where those decentralized resources are co-located with critical facilities, such as hospitals and first responders, and are configured to operate even when the larger grid fails. The EMP cites several steps to foster local renewable energy generation, including the need to properly value resilience and fuel security; compensate DER, including storage, for its resilience, low carbon, and transmission and distribution system benefits; and removing existing structural impediments and policies that limit potential growth in this market. Fuel cells and hydrogen can play a significant role in achieving the power generation and energy storage objectives of EMP Goal 5.1.

In the context of government as leader and early adopter, on May 12, 2021 New Jersey Governor Murphy signed into law **P.L. 2021, c.91** which "requires State agencies in awarding contracts for purchase of items that require power to consider items powered by fuel cells." This applies to any power consuming device, including motor vehicles, material handling equipment, electricity generators, telecommunication equipment, microgrids, and other fuel cell applications.[87]

The **New Jersey Global Warming Response Act** (updated 2019) (P.L. 2007, c.112; P.L. 2018,c.197) requires the state to adopt measures to reduce GHG emissions by 80% by 2050.[88] In response to this mandate, the **80x50 Report** was written to build upon the state's ongoing efforts and recommends that 100% of car sales be battery or fuel cell electric by 2035.

New Jersey's **Climate Change Resilience Strategy,** as directed by Executive Order No. 89, includes recommendations to promote the long-term mitigation, adaption, and resilience of the state's economy,

> *With climate change making drastic changes to our weather patterns and sea levels, it is imperative we begin the switch to alternative clean energy sources in New Jersey. Fuel cells are a highly efficient and reliable alternative to fossil fuels. Many businesses are already reaping the benefits of hydrogen fuel cells from a sustainability, cost and resiliency perspective. Investments in clean energy results in jobs for New Jerseyans. I urge Governor Murphy and the legislature to make this transition a priority to support our environment, our economy and jobs."*
>
> -Assemblyman Herb Conaway

communities, infrastructure, and natural resources. Assemblyman Herb Conaway has urged, "With climate change making drastic changes to our weather patterns and sea levels, it is imperative we begin the switch to alternative clean energy sources in New Jersey. Fuel cells are a highly efficient and reliable alternative to fossil fuels. Many businesses are already reaping the benefits of hydrogen fuel cells from a sustainability, cost and resiliency perspective. Investments in clean energy results in jobs for New Jerseyans. I urge Governor Murphy and the legislature to make this transition a priority to support our environment, our economy and jobs." Fuel cell and hydrogen systems can contribute to several of the Strategy's overarching goals including building resilient and healthy communities, strengthening the resilience of New Jersey's ecosystems, and promoting climate-informed investments and innovative financing. **See Recommendation 2.10.** In 2014, New Jersey created the Energy Resilience Bank, which received $200 million from the US Department of Housing and Urban Development (HUD) to support projects focusing on energy resilience. The ERB supported the development of distributed energy resources at critical facilities throughout the state that will enable them to remain operational during future outages.

New Jersey Clean Energy Program (NJCEP) offers financial incentives, programs, and services for New Jersey residents, businesses, and local municipalities to promote energy efficiency and clean energy. The NJCEP also manages the

Recommendation 2.10

Climate Change Resilience. Take action to implement New Jersey's Climate Change Resilience Plan Strategy utilizing fuel cell systems in areas such as grid hardening, emergency power, 'green bank style' funding and investments.

Recommendation 2.11

Fuel Cells in Net Metering. The BPU's net metering rules set forth net metering requirements that apply to electric power suppliers, basic generation service providers, and electric distribution companies, which have customers who generate Class I renewable energy on the customer's side of the meter. Exploring the inclusion of fuel cell systems operating on hydrogen for a multiple-technology net metering protocol can incentivize customers who operate a combination of net energy metering (NEM) and non-NEM renewable generation behind the same meter.

state's program for net metering, a billing mechanism that allows consumers to use electricity they generate (e.g., through rooftop solar panels) at any time, and compensates them at full retail value when their renewable energy system produces more electricity than they need. Fuel cell systems, given their benefits, should be encouraged and explored. New Jersey should explore compensation for hybrid DER resources that include both renewable and fuel cell components that provide benefits to the grid, including resilient power. **See Recommendation 2.11.**

Recommendation 2.12

Fuel Decarbonization Programs. Establish an incentive for displacing existing fossil-based fuels with low-carbon equivalent in hydrogen. Establishing a Low Carbon Fuels Standard for the state, and engaging with the US Environmental Protection Agency to approve pathways for hydrogen within the existing Renewable Fuels Standard Program are two means to achieve this.

New Jersey is one of nine states using a provision in the Clean Air Act to adopt California's **Zero Emission Vehicle (ZEV) Regulations** as their own. In recent years, several additional states have announced plans to become ZEV States to take effect in the near future. This regulation[89] requires auto manufacturers to sell increasing numbers of zero-emission vehicles including BEVs, FCEVs, and PHEVs in their state through the 2025 model year. In August 2022, California's Air Resources Board adopted ZEV requirements extending to 2035, at which time 100% of new car sales must be FCEVs, BEVs, or PHEVs.

DEP has begun stakeholdering the ACCII regulation that was recently adopted by the California Air Resources Board. The rule sets credit requirements for automobile manufacturers between 2026 and 2035, and the auto manufacturers generate credits by directly selling ZEVs in the applicable state or using one of the flexibilities built into the rule. By setting "credit" requirements, the California rule drives the sales of ZEVs including battery electric vehicles, hydrogen fuel cell electric vehicles, and plug-in hybrid-electric vehicles, while reducing smog-forming emissions from new internal combustion engine vehicles. New Jersey's current ZEV program ends in 2025 with a 22% credit requirement. If adopted this year, ACCII would take effect in NJ with Model Year 2027. Credit requirements would begin at 43% in 2027 and increase to 100% in 2035.

In 2018, New Jersey signed onto the 2013 **Multi-State ZEV Memorandum of Understanding (MOU)**, which signals their intention to support the mandatory vehicle sales requirements with voluntary government actions. The goals of the MOU are for the government agencies in each state to: 1) Create ZEV Implementation Task Force which will produce a more detailed Action Plan; 2) place 3.3 million ZEVs (BEVs, FCEVs, PHEVs) total among all the states by 2025 (New Jersey's portion of this is about 330,000), 3) coordinate activity among the states; 4) "lead by example" and establish purchase and infrastructure targets for themselves and report annually on their progress; 5) evaluate the need for various incentives, 6) work with their legislatures to develop shared standards for signage, preferential parking, HOV lane access, and reciprocity of these benefits between states; 7) establish public-private partnerships to encourage market growth; 8) conduct coordinated research, education, and outreach campaigns highlighting the benefits of ZEVs; 9) assess potential for H2 and FCEVs to fulfill their goals.[90] **See Recommendation 2.12.**

The **ZEV Program Implementation Task Force,** formed by the MOU, is managed by the Northeast States for Coordinated Air Use Management (NESCAUM), a non-profit association of state environmental agencies. The Task Force aims to raise consumer awareness and promotes growth of ZEV infrastructure purchase and non-financial incentives, public and private sector ZEV fleet adoption, and dealership efforts to increase ZEV sales. Their latest recommendations are in the 2018 Action Plan.[91]

New Jersey has recently adopted California's **Clean Trucks Rule** – from model year 2025, truck manufacturers must sell an increasing percentage of their total volume of class 2b-8 trucks are ZEVs. By 2035, this rule will require 55% of class 2b-8, 75% of class 4-8, and 40% of truck tractor sales to be plug-in FCEVs, BEVs, of PHEVs.

In 2021, New Jersey signed the **Multi-State Medium- and Heavy-Duty Memorandum of Understanding (MOU)** in which they target 1) working with Multi-State ZEV Task Force to develop an action plan published in July 2022[92], 2) setting targets of 100% new sales of medium- and heavy-duty ZEVs by 2050 with an interim goal of 30% by 2030, and 3) proceeding towards electrification of government and agency fleets. As with the Light-Duty ZEV MOU and Action Plan these targets and recommended actions are voluntary.[90]

The **New Jersey Zero Emission Incentive Program (NJ ZIP)**, funded by the Regional Greenhouse Gas Initiative (RGGI) and administered by the New Jersey Economic Development Authority, is a pilot voucher program with $90 million (as of March 2023) allocated towards supporting the purchase of new medium- and heavy-duty zero-emission vehicles.[93] The Program provides vouchers from $20,000-$175,000 based on the vehicle class (see **Table 2.2**) and provides bonus funding for specific groups including women-, minority-, or veteran-owned businesses; small businesses; businesses that drive 50% or more vehicle miles in NJ overburdened communities; businesses that demonstrate that 25% or more of the cost of the vehicle is spent in NJ on labor for vehicle design, assembly, or manufacturing; and for applicants purchasing a school bus. Those eligible for the program include commercial, industrial, and institutional organizations registered in New Jersey See **Appendix III** for definitions of vehicle classifications.

Table 2. 2 NJ ZIP base voucher values[93]

Voucher GVWR	Vehicle Class	Voucher Amount
8,501 – 10,000 lbs.	Class 2B	$20,000
10,001 – 14,000 lbs.	Class 3	$50,000
14,001 - $16,000 lbs.	Class 4	$65,000
16,001 – 19,500 lbs.	Class 5	$75,000
19,501 – 26,000 lbs.	Class 6	$90,000
26,001 – 33,000 lbs.	Class 7	$135,000
33,001+ lbs.	Class 8	$175,000

New Jersey has made substantial investments in clean transportation with funds provided by the Federal Government as part of Volkswagen's settlement with USEPA to resolve violations of the Clean Air Act. During 2009-2016, the auto manufacturer sold diesel motor vehicles equipped with software designed to cheat on federal emissions tests, which resulted in higher levels of NOx than allowed. Under the terms of the federal settlement, the Volkswagen trust fund is providing funds to all 50 States for projects that reduce NOx. The Volkswagen Partial Consent Decrees (Settlements) provided approximately $72 million for New Jersey transportation projects, especially wide-scale deployment of EVs. For more information on the program, see https://www.state.nj.us/dep/vw/index.html.[42]

Federal Investments, Programs and Policy

As noted, New Jersey has an opportunity to collaborate with the Federal Government through cost-shared demonstration and deployment projects to accelerate adoption of fuel cells and hydrogen systems and realize the energy, environmental and economic benefits they offer. **See Recommendation 2.13.** The US DOE has invested in hydrogen and fuel cell R&D for decades, partnering with industry, universities, national laboratories, and small businesses to improve the performance and reduce the cost of the technologies. As the technologies have become more competitive with incumbent energy technologies, demonstration and deployment investments have increased. Other significant investments have been made by the US DOT and DoD. These and other programs are described briefly in this section, along with other relevant Federal investments and policies.

Recommendation 2.14

Fuel Cell Demonstration Projects. Engage private sector industry partners to develop pilot/demonstration projects in New Jersey that help strengthen the ecosystem for fuel cell technology and next generation hydrogen production methods to showcase their benefits for various industries, and create the demand required to grow the manufacturing base and supply chain in the State.

US Department of Energy

The US DOE **Hydrogen and Fuel Cells Technologies Office** researches, develops, and validates transformational hydrogen and related technologies including fuel cells and turbines, and addresses institutional and market barriers to enable adoption in multiple applications.[94] The guiding framework, **H2@Scale**, supports stakeholder collaboration to advance affordable hydrogen production, transport, storage, and use across multiple sectors.[95] As part of its **Energy Earthshots™** initiative, DOE announced the **Hydrogen Shot™** on June 7, 2021, to reduce the cost of clean hydrogen to $1 per kilogram by 2031.[96] This corresponds to an 80% reduction from today's cost of approximately $5 per kilogram. Hydrogen Shot™ establishes a framework for clean hydrogen deployment, including support for demonstration projects through the American Jobs Plan. **See Recommendation 2.14.** Achieving the Hydrogen Shot™ goal is expected to reduce CO_2 emissions by 16% by 2050, yield $140 billion in revenues and create 700,000 jobs by 2030.

Recommendation 2.13

Funding for Fuel Cells. Allocate and/or apply for federal funds to support the development and deployment of resilient fuel cell systems and hydrogen fuel cell electric vehicles.

On top of DOE's investment of more than $600 million in 2021 and 2022, the 2021 **Infrastructure Investment and Jobs Act (Bipartisan Infrastructure Bill H.R.3684**) adds a total of $9.5 billion for clean hydrogen hubs and other projects (Section 813-816, 822) and includes the following definitions, programs and directives:[97]

(1) Definition of "clean hydrogen" – Hydrogen produced with a carbon intensity equal to or less than 2 kilograms of CO_2-equivalent produced at the site of production per kilogram of hydrogen produced. Sec. 822(b)(1)(B).
(2) Regional Hydrogen Hubs - $8 billion to develop at least 4 large-scale hydrogen production and utilization projects in diverse geographies with diverse feedstocks and multi-sector end uses of hydrogen. (Note: DOE has stated the possibility of a phased approach in which they fund 8 to 12 regional hydrogen hubs initially, which would be downsized to 4 to 8 in subsequent phases.)[98]
(3) Clean Hydrogen Electrolysis Program - $1 billion for research, development, demonstration, commercialization, and deployment program for commercialization to improve efficiency, durability, and reduce cost of producing clean hydrogen using electrolyzers, including hybrid storage.
(4) Clean Hydrogen Manufacturing and Recycling - $500 million to support a clean hydrogen domestic supply chain.
(5) Clean School Bus Program - $1 billion for adoption of clean school buses and zero-emission school buses.
(6) Grants for Charging and Fueling Infrastructure - $7.5 billion for grant program to award grants to install publicly accessible EV charging infrastructure, hydrogen fueling infrastructure, propane fueling, or natural gas fueling infrastructure directly related to the charging or fueling of a vehicle.
(7) Electric of Low-emitting Ferry Pilot Program - $50 million to provide grants for the purchase of electric or low-emitting ferries and the electrification of or other reduction of emissions from existing ferries.
(8) Port Infrastructure Development Program - $2.25 billion for projects that improve the resiliency of ports to address sea-level rise, flooding, extreme weather events, earthquakes, tsunamis, and projects that reduce or eliminate port-related criteria pollutant or GHG emissions. This includes workforce training and development.
(9) Clean Hydrogen Research and Development Program – to advance research and development to demonstrate and commercialize the use and storage of clean hydrogen in the transportation, utility, industrial, commercial, and residential sectors. Incorporates fossil fuels with carbon capture, utilization, and sequestration, renewable fuels, biofuels, and nuclear energy.
(10) National Clean Hydrogen Strategy and Roadmap – directs the development of the first US national strategy to facilitate a clean hydrogen economy.
(11) Clean Hydrogen Production Qualifications – directs the development of a Clean Hydrogen Production Carbon Intensity Standard.
(12) Plan for the National Energy Modeling System – a plan to identify any need or opportunity to update or further the capacities of the National Energy Modeling System for hydrogen production, storage, and transport.

US Department of Transportation

The US Department of Transportation (DOT) supports the development of fuel cell buses through the Federal Transit Administration (FTA) **Low- and No-Emission Vehicle Deployment Program**, which provides funding to state and local governmental authorities for the purchase or lease of zero-emission and low-emission transit buses as well as acquisition, construction, and leasing of required supporting facilities.[99] Fuel cell electric buses (FCEBs) have been deployed in several US locations through this program and a previous FTA program - the National Fuel Cell Bus Program (NFCBP)**,** including fleets in California and Ohio.[100] The [1011011011011019898]National Renewable Energy Laboratory (NREL) [97] works with fuel cell manufacturers, fleet operators, fuel providers and other government and industry groups to evaluate the performance and cost of fuel cell technologies in both light and heavy-duty vehicles, including FCEBs. [94,102] Currently, the Lab is evaluating the performance of approximately 60 fuel cell buses operating in California and Ohio.[103]

Several other federal incentives, laws and regulations, and programs can be found at https://afdc.energy.gov/laws/fed_summary?technologies=HY and are detailed in **Appendix VII**.

Recommendation 2.15

Address Supply Barriers to Clean Transportation. Request a temporary waiver of the Buy America requirements that is phased out over time in order to facilitate the acceleration of domestic manufacturing capacity while allowing an adequate supply of ZEV's and refueling infrastructure.

A Federal Policy with Implications for Hydrogen and Fuel Cell Technology Adoption

The **Buy American Act** (P.L. 72-428) requires the US government and third-party purchasers that use federal funds to purchase US-made goods at certain value thresholds, which vary depending on the agency making the purchase. To be considered US-made, goods must be manufactured in the US with at least 50% of the cost of their components coming from US sources. In some cases, this requirement may be waived if the domestic product is: (1) 25% or more expensive than an identical foreign product, or (2) if the product is not available domestically in sufficient quality or quantity. These requirements set the highest bar for the transportation sector. Federal Transit Administration, Federal Highway Administration, Federal Railroad Administration, Amtrak-National Railroad Passenger Corporation, and Federal Aviation Administration are all largely affected by the Act.

While high-volume models selling millions of vehicles worldwide are often produced in multiple regional production plants near their location of sale, lower-volume models are often produced in only one manufacturing plant and distributed globally. BEVs and FCEVs are currently very low-volume production vehicles and are often produced in the home country of the automaker. Building a new plant or repurposing a line in an existing plant in the U.S. is no small task, and often takes many years and significant investment. Domestic production requirements such as Buy American and Inflation Reduction Act will impact the availability and cost of eligible vehicles for a number of years to come.

Given the relatively small hydrogen and fuel cell supply chain in the US currently, limiting government purchases to US-made products may impact the speed of adoption of this emerging clean energy technology. **Recommendation 2.15** is aimed at addressing this barrier to the emerging fuel cell and hydrogen markets in the US.

Public and Private Resources

In addition to the US DOE, which provides a wealth of information and assistance to support hydrogen and fuel cell projects,[15, 104, 105] New Jersey has access to a number of resources within the State. The New Jersey Fuel Cell Task Force (Task Force), which generated this report (See Foreword), is a resource legislated by the State of New Jersey (S762/A741). The Task Force bill was sponsored by several members of the State legislature, including Senator Gordon M. Johnson, "Green sustainable energy is the future and New Jersey should lead the way. I have long championed investments in hydrogen fuel cells, not only as a green alternative in the fight against climate change but for a domestic alternative that would lessen our dependence on foreign energy producers. I am grateful to Governor Murphy and the entire New Jersey Fuel Cell Task Force for all the work they are doing to bring this exciting but underutilized energy source to the Garden State." The Task Force plans to create a website containing information and resources for government, industry, academia and small businesses. **See Recommendation 2.16.** In addition to government and industry experts, the Task Force includes a representative from the **Fuel Cell and Hydrogen Energy Association (FCHEA)**, the national industry association for the expansive and growing hydrogen and fuel cell sector, representing more than 80 leading companies and organizations that are advancing innovative, clean, safe, and reliable energy technologies. FCHEA provides a consistent industry voice to regulators and

Recommendation 2.16

Online Resources. The New Jersey Fuel Cell Task Force will create a website that provides information to businesses and to the public on state and federal resources for hydrogen and fuel cell systems, including incentive programs and funding opportunities, and will include distributable information such as hydrogen safety and best practices.

policymakers, as well as information on fuel cell and hydrogen energy markets and their environmental and economic benefits.

The **New Jersey Clean Cities Coalition (NJCCC)**, established by the US DOE, promotes the use of domestic fuels and advanced vehicle technologies by collaborating with vehicle fleet operators, fuel providers, and other stakeholders to help achieve the State's clean energy goals.[106] NJCC has for the past two decades been responsible for compiling and reporting petroleum reduction to the US DOE as traditional combustion engines are transitioning to alternative fueled vehicles. This information is gathered from

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>
> -Senator Gordon M. Johnson

both public and private fleets across the state. NJCCC is also leading a USDOE project in collaboration with the Atlantic County Utilities Authority and South Jersey Industries to produce renewable hydrogen via electrolysis using power generated by the wind turbines in Atlantic City. The hydrogen will be used in natural gas blends and in fuel cell applications. The oxygen from electrolysis will be used in ACUA's wastewater treatment plant. The NJCCC also collaborates with the **New Jersey Fuel Cell Coalition** (see below) to inform policymakers and other stakeholders about the economic, environmental, and energy potential of fuel cells and hydrogen, as well as its production, distribution, and use in the State.[107]

The **New Jersey Fuel Cell Coalition (NJFCC)** works to accelerate adoption of fuel cell and hydrogen technologies through education and outreach efforts that inform policymakers, project developers, and the public, and bring stakeholders together in collaborative efforts, and coordinating with other together federal and inter-state related actions.[108] The NJFCC collaborates with other stakeholder groups, including New Jersey Clean Cities, Connecticut Center for Advanced Technology, Stationary Fuel Cell Collaborative, Massachusetts Hydrogen Coalition, California Fuel Cell Partnership, Ohio Fuel Cell Coalition, and Hydrogen House Project to coordinate fuel cell and hydrogen activities in the Northeast and share lessons learned from other states. The NJFCC also supports fellowship and internships for students wishing to pursue careers in hydrogen and fuel cell technologies.

The State of California leads the Nation in fuel cell and hydrogen adoption, particularly in the transportation sector. In partnership with industry, the State has made considerable progress in building out the early hydrogen fueling infrastructure to support more than 7,000 FCEVs and FCEBs on its roads. The **California Air Resources Board** (CARB), the California Hydrogen Business Council and the **Hydrogen**

Fuel Cell Partnership continue to share lessons learned, best practices and other resources to other stakeholders.[44, 109, 110]

3. Safety, Codes & Standards

Hydrogen has been used safely in industrial settings for nearly a century. Like other fuels or forms of stored energy it can be hazardous if handled improperly. Hydrogen is non-toxic and dissipates rapidly which makes it safer in some settings compared to other fuels. However, it is flammable over a wide range of concentrations and is easily ignited. Intentional engineering, safety guidelines, and compliance with codes and safety standards for both mobile and stationary applications are essential for hydrogen's safe use and realizing its potential benefit.

The USDOE supports comprehensive research, development, demonstration, and deployment efforts to enable safe and reliable materials for hydrogen pipelines, compression and liquefaction, storage and delivery, as well as methods to ensure the safety and the long-term viability of hydrogen in mobile and stationary applications. FCEVs, stationary fuel cells, and hydrogen fueling stations are designed according to established safety guidelines. DOE efforts are focused on reducing the cost and the footprint, and improving the reliability, of fuel cells and hydrogen production, storage, transport and dispensing equipment.[111]

Hydrogen fueling stations have some of the same safety features as gasoline stations and added features for handling a gaseous fuel. As with gasoline refueling, consumers may not smoke, keep the engine on, or use a cell phone while filling up at a hydrogen fueling station.[112] Because hydrogen is a gaseous fuel, the dispensing nozzle that connects to the FCEV is specially designed to create a tight seal and stays locked as long as there is hydrogen pressure in the hose.[112, 113] Another safety feature prevents the vehicle from being driven while the fill hose is attached, preventing drive offs and damage to the hydrogen dispenser.

Fuel cell vehicles are designed with several built-in safety systems to prevent hydrogen leaks should an accident occur. A leak detection system shuts down the flow of hydrogen if a leak is detected, and, in case of a collision, the hydrogen is isolated in the storage cylinders so that only a small amount of residual hydrogen escapes from damaged fuel lines. In addition, FCEVs are robustly crash tested to ensure the safety of the vehicle and fuel systems. Toyota affirms that fuel cell electric cars are as safe as conventional vehicles.[114] For decades, the company has developed and tested FCEVs in a variety of extreme conditions and temperatures to validate their safety and reliability. The Hyundai Nexo is also considered one of the safest vehicles available, winning the top safety pick for three years by the Insurance Institute of Highway Safety, a nonprofit that researches the crashworthiness of vehicles.[115] The Nexo includes several common safety features, such as Forward Collision Avoidance technology.

The National Fire Protection Association updated standards for hydrogen fuel in 2023; the US DOE, NREL and other organizations have produced resources derived from those standards to clarify and elaborate further.[116, 117] DOE has also worked with domestic and international organizations to help improve building and fire code requirements for hydrogen systems,[118] develop procedures for safe handling and use of hydrogen, and ensure that hydrogen storage and transfer systems have distinct recognizable codes for safety inspectors and code officials. All DOE hydrogen projects are required to develop a safety plan that undergoes a rigorous review by hydrogen safety experts. The **Hydrogen Safety Panel (HSP)**, a neutral, expert resource with more than 600 years of experience, was created by DOE and its Pacific Northwest National Laboratory (PNNL) and works with hydrogen and fuel cell project developers to identify vulnerabilities in the design and operation of equipment and provides insights and options for modifications to ensure safety.[119, 120] The HSP has reviewed more than 400 projects since 2003 and is easily accessible through the **Center for Hydrogen Safety** (see below) for any hydrogen project that seeks its assistance. **See Recommendation 3.1.**

Recommendation 3.1.

Safety Reviews. Incorporate requirements for safety planning/reviews for hydrogen projects that include NJ state dollars.

The **Center for Hydrogen Safety** (CHS) is also an important resource for hydrogen and fuel cell projects. CHS is a non-profit and neutral international membership organization that promotes the safe operation, handling, and use of hydrogen and hydrogen systems across all installations and applications. CHS identifies and addresses concerns regarding the safe use of hydrogen as a sustainable energy carrier, in commercial and industrial applications, and hydrogen and fuel cell technologies. Its resources include eLearning courses, educational webinars, workshops, conferences and working groups to collaborate on safety topics. CHS works with PNNL to broadly disseminate hydrogen safety information through the Hydrogen Tools portal (https://h2tools.org). **H2 Tools** includes an online national hydrogen safety training program created specifically for emergency responders.[121] **H2 Tools' National Hydrogen and Fuel Cell Emergency Response Training** resource enables government and private training organizations throughout the country to develop their own training programs. A web-based course called **Hydrogen Safety for First Responders** introduces hydrogen's basic properties and a comparison to other fuels.[122] This course also describes hydrogen's use in fuel cells for stationary and mobile power, potential hazards, initial provocative actions in an incident, and further resources like videos, documents, and links to relevant hydrogen safety protocols. CHS also has four free video-based courses in addition to the materials described above.[123] The CHS also offers a new Fundamental Hydrogen Safety Credential online program.[124] Other safety resources include UL, LLC (formerly Underwriters Laboratories), a global safety listing/approval organization that offers a certification program for hydrogen components and systems[125] and WHA International, Inc., a failure analysis and forensic engineering firm founded in 1987 by experts from NASA, that offers Technical Training for Hydrogen Safety.[126] Greater details on safety resources are detailed in **Appendix VIII.**

4. Education & Workforce Development

As fuel cell and hydrogen markets grow in New Jersey, workforce development efforts specific to those technologies will become increasingly important to provide educated and trained personnel for the growing industries, supply chain and R&D pipeline. Currently, there are no hydrogen or fuel cell workforce development efforts in the State and few specific educational opportunities. However, New Jersey is home to seven renowned R&D universities committed to science, technology, engineering, and mathematics (STEM) education and innovation that will enable the State to be a leader in the emerging hydrogen and fuel cell landscape.[127] The State is also home to several other 4-year and 2-year higher education facilities, which are detailed in **Appendix IX**. New Jersey state agencies support multiple efforts with universities and colleges across the state for an array of research and education purposes. The proposed Northeast Hydrogen Hub provides an opportunity for the State to work with its universities and with industry in a collaborative approach to enable a strong fuel cell and hydrogen workforce and the clean energy markets these technologies offer. **See Recommendation 4.1.** New Jersey employs a plethora of engineers and scientists, providing a large talent pool to drive and support those markets. University campuses are also a great place to expose students and the public to clean hydrogen energy markets, such as fuel cell buses and shuttles, which can also serve as educational demonstration projects.

Recommendation 4.1.

Education and Workforce Development. New Jersey should engage a broad hydrogen and fuel cell technology education, training, and workforce development program and identify areas where the state can take a leadership position in research and development and attract supply chain businesses. Further, university-led hydrogen and fuel cell summits or forums should be held to initiate comprehensive discussion among stakeholders, and educate students, teachers, policymakers, consumers, and the general public.

New Jersey universities and colleges host a number of Chemistry, Physics, Engineering, and Environmental Science degree programs in which hydrogen and fuel cell technology innovation could be integrated into the existing curriculum, including relevant courses to advance students' understanding of the technology area. These higher education institutions have faculty with expertise in related fields, such as chemical reactions, clean energy technologies, and sustainable development, and some faculty with technical knowledge in hydrogen and fuel cell systems. These resources provide an opportunity For New Jersey to build specialized programs and shorter duration certificate programs for fuel cell related workforce development across the supply chain.

A potential resource is US DOE workforce development efforts that specifically address emerging fuel cell and hydrogen energy markets.[128] The Hydrogen Education for a Decarbonized Global Economy (H2EDGE) initiative, led by the Electric Power Research Institute (EPRI), is developing newly trained personnel as well as enabling the existing workforce to migrate into the hydrogen fuel cell field through enhanced industry coordination and workforce readiness initiatives, including training, education, and recruitment of qualified people.[129] The Gas Technology Institute (GTI), Oregon State University, Purdue University, and the University of Delaware are partners in the initiative. Fellowships and internships specific to fuel cell and hydrogen projects are also needed to attract new talent and train a new workforce. Examples include the Hydrogen Shot Fellowship and the Robert Rose Education Award.[128, 130]

Higher Education in New Jersey

Public Research Universities

Rutgers University, with campuses in New Brunswick, Newark, and Camden, is the oldest and largest public university in the state, offering undergraduate, graduate, and doctoral degrees in engineering, environmental sciences, and physical sciences. Rutgers is home to multiple research centers, including the Rutgers Energy Institute (REI), which integrates the science, engineering, economics, and policy of alternative energy research and sustainable energy production.[131] REI research areas include water splitting and hydrogen production, fuel cells, catalysis and energy storage, energy policy, natural resource management, and energy economics.[132] The Institute partnered with the Solar Fuels Institute (SOFI) to build a modular solar fuel station (mSFS) to produce renewable hydrogen via water electrolysis and combine the hydrogen with CO2 to produce a liquid hydrocarbon fuel.[133] Rutgers is also home to the EcoComplex, a clean energy innovation center under the New Jersey Agricultural Experiment Station, which includes projects in agrivoltaics, food waste and biomass energy generation. These Institutes, as well as the New Jersey Innovation and Technology Hub (I&T Hub), to be built on the Rutgers campus by 2024, provide opportunities for increased hydrogen and fuel cell R&D to support the proposed Northeast Hydrogen Hub.[134]

Montclair State University is the second largest public university in the state, and offers undergraduate, graduate and doctoral degrees in physical and environmental sciences and environmental science and management. Montclair is home to the Clean Energy and Sustainability Analytics Center (CESAC), which supports clean energy development through stakeholder collaboration and environmental and economic analysis. CESAC's relevant research includes clean energy technology life cycle assessment, stakeholder perception and acceptance of clean energy, RGGI dispatch modeling, geospatial analysis for clean energy development, and economy-wide modeling of energy and environmental policies. CESAC is assessing economic and environmental implications of fuel cell and hydrogen projects such as policy and sustainability relevance, market dynamics, and stakeholder impacts. The Center is also developing early career and mid-career workforce development programs for the clean energy sector, including fuel cells.

Rowan University, located in Glassboro with medical campuses in Stratford and Camden, offers engineering, science, and environmental undergraduate and graduate degrees. Rowan's Sustainable Facilities Center (SFC), part of the College of Engineering, helps public and private entities sustainably manage facilities, through energy and water-use audits, for example.[135] The College of Engineering also supports the Advanced Materials and Manufacturing Institute (AMMI), which advances applied science and engineering technology to enhance material performance and improve global sustainability. [136 136 135 134 133 129 129 129] In 2019, Rowan hosted a Hydrogen Workshop in partnership with Pacific Northwest National Laboratory and other hydrogen and fuel cell experts, which covered the benefits, applications, and safety considerations of hydrogen and fuel cell systems.[137]

New Jersey Institute of Technology (NJIT), with campuses in Newark and Jersey City, is a polytechnic university with undergraduate, graduate, and doctoral engineering, physical science, and environmental science degree programs. NJIT is home to the Center for Energy Efficiency, Resilience and Innovation (CEERI), which is focused on sustainable technologies and their applications. CEERI's relevant research includes energy storage, energy distribution, renewable energy market penetration, EV charging station economics, and EV monitoring. Within the Department of Mechanical and Industrial Engineering is the Advanced Energy Systems and Microdevices Laboratory,[138] which researches catalysts and their applications for electrochemical energy systems, including fuel cells. This Department also offers a course "Introduction to Fuel Cells and Batteries" (ME 618-101, last offered Fall 2020).

Private Research Universities

Princeton University is an Ivy League school research university offering numerous undergraduate, graduate, and doctoral degrees in natural sciences and engineering. It is home to the Andlinger Center for Energy and the Environment, which focuses on sustainable energy technology development, energy efficiency, and environmental protection and remediation. Research projects included electrochemical fuel cell production, fuel cell membrane development, PEM fuel cell dynamics, SOFC catalysis, hydrogen production and purification, green fuel production incentive design, and supply chain optimization.

Stevens Institute of Technology, located in Hoboken, offers several undergraduate, graduate, and doctoral engineering and science degree programs as well as professional engineer and graduate certificate programs for working professionals. Stevens is home to the Stevens Venture Center, which teaches students to explore the commercialization of their science and technology ideas. The Center has been involved with the Hoboken Fuel Cell, provided by the recent university-based start-up ExoCell Power[139] [140140139138137133133133] and used to power drones collecting photo and video data for skyscraper safety inspections.[141]

Hackensack Meridian School of Medicine, located in Nutley, is the state's only private 4-year medical school. As a health sciences school, there is currently no direct relationship to hydrogen or fuel cells. The research that takes place includes educational, behavioral, community-based, and health services research. However, as a health sciences school there is opportunity to expand research for best practices for first responders when dealing with hydrogen and fuel cell-related accidents, including the treatment of patients.

Other Education Resources

The USDOE provides resources, including course materials, for safety and code officials, state and local governments, potential early adopters, including fleet owners and operators, students and educators, and those pursuing careers in the hydrogen fuel cell technologies. They also offer a "train the trainer" program that provides job certification and curriculum to experienced personnel.[142] They provide online training courses, along with webcasts and webinars targeting people in multiple sectors, including energy service companies, utilities, venture capital firms, insurance and underwriter industries, state government workforce development agencies, regulatory and other government officials, first responders, and local public and community outreach.

The USDOE has also created curricula for K-12 teachers and students. For grades 5-12, they provide classroom resources including lesson plans, visual aids, and laboratory experiments.[143] For college-level education, they include a course manual for the use of hydrogen as a transportation fuel, covering safety, technology, engine design using Ballard fuel cell buses as a case study.[144] For safety, they have developed the National Hydrogen and Fuel Cell Emergency Response Training Resource, which is a series of education slides useful for first responders in dealing with hydrogen and fuel cells through a number of potential incidents (single vehicle, multiple vehicles, hydrogen fueling station, etc.). These resources are low-hanging fruit which could easily be integrated into schools throughout the state either as standalone curriculum, components of existing courses, or external (non-enrolled students) workforce development programs.

5. Recommendations

Below are the recommendations of the New Jersey Fuel Cell Task Force. They involve electricity production, transportation, fuel production, and education & safety. The recommendations each include a suggested time frame for implementation, along with a suggestion on which entity or entities should implement each recommendation. Achieving action on these items will create momentum in advancing fuel cells and hydrogen within the State and strengthen New Jersey's hub proposal. Items in the Next Steps section are critical but not as time sensitive. Numbering of the recommendations is based on where they can be found within this report, not importance of the recommendation.

Immediate Action

1.1.	**Regional Hydrogen Hub.** Drive alignment at the State level to participate in the Northeast regional hydrogen hub. The recommendations that follow provide more detailed information that should be useful in planning New Jersey's hydrogen and fuel cell focus. New Jersey's participation in a regional hub, with Connecticut, Maine, Massachusetts, New York Rhode Island and Vermont, among potential partners, should explore hydrogen production via renewable energy generated by solar power and/or through leveraging the 7.5 GW of offshore wind power to be deployed by 2035 and 11 GW by 2040, and onshore wind power in the near term. State involvement in a successful hub proposal is critical as a broad engagement across the power, transportation, and industry sectors will be required. Further, establishment of a grid storage facility in the form of underground onshore or offshore hydrogen will require state assistance in location, management, and development. End uses should include fuel cell buses, rail, and other fleets; fuel cells as replacement for diesel engines/generators in port areas; fuel cell forklifts in New Jersey warehouses; stationary fuel cells for back-up power, microgrids, and resilience. Another beneficial use of hydrogen cited by

	the US DOE is hydrogen-natural gas blends to reduce the carbon footprint of electricity generation and lower the cost of hydrogen by producing it at scale. The New York/ New Jersey ports provide an excellent focal point for much hub development as it has the overlap of transportation, stationary power, and industrial energy use in a dense geographic location. Fuel cell buses and port end uses can also meet environmental justice needs. The State of New Jersey, through coordination from BPU, DEP, and NJEDA, should identify and convene appropriate stakeholders, collaborate with neighboring states, and determine necessary components for a strong proposal to the DOE, including identifying State cost-sharing sources. In addition, the infrastructure bill must be studied and scrutinized for all opportunities to finance clean transportation projects, new power generation, transmission, and distribution underpinnings with federal funds and support. **Responsible Entities: NJ Board of Public Utilities (BPU), NJ Department of Environmental Protection (DEP), NJ Economic Development Authority (EDA), NJ Department of Transportation (DOT), NJ Transit Corporation (NJ Transit)**
1.2	**Fuel Cells to Improve Local Air Quality.** Explore incentivizing replacement of diesel emergency generators with fuel cells to improve air quality in overburdened communities, reducing the restrictions on their use and fast-tracking permit processing. Replacing diesel powered generators with fuel cells will offer a dual benefit of building a more resilient power infrastructure by converting one of the highest emitting sources of electric generation to zero-emitting fuel cells. Additionally, targeting diesel-to-fuel cell conversions in environmental justice communities will have an immediate improvement on air quality in communities that have been exposed to disproportionately high levels of air pollution. **Responsible Entity: DEP**
1.3	**Fuel Cells for Demand Response**. Explore fuel cells as a non-combustion option for demand response programs. The flexibility for fuel cell powered emergency generators to operate outside of power outages will permit demand response use. The ability of operators to use fuel cell emergency generators for demand response will provide additional grid reliability as well as provide a revenue source as demand response sources are compensated for the value they provide to grid stability. **Responsible Entity: BPU**
2.1	**H2Biz to Assist Emerging Industry.** Establish an "H2Biz" function in the NJ Business Action Center to support development of hydrogen and fuel cell businesses within the State. Staff should be knowledgeable on hydrogen and fuel cell product offerings and New Jersey incentive programs, matching potential customers with suppliers for implementation, and advising original equipment manufacturers and infrastructure providers on interacting with New Jersey government agencies. In particular, a single point of contact to provide information that guides businesses through the permitting and other processes related to land use, air and water

	permits, and zoning could substantially reduce the timeline for projects and reduce the regulatory uncertainty commonly associated with the development of large projects within the State. An example of such a function is California's Go-Biz Office. **Responsible Entity: Department of State Business Action Center (BAC)**
2.6	**Spur Fuel Cell Electric Vehicle Adoption** through the following**:** • **Fuel Cell Electric Vehicles (FCEVs) for Clean Fleets**. Collect a list of state agencies and municipalities that have identified opportunities for FCEVs in their clean fleet transition plans as directed by P.L. 2021 c.91, as well as the infrastructure needs to support these fleets. The newly established H2Biz function in NJBAC should identify the best candidates for pilot projects and assist them in establishing infrastructure and/or acquiring vehicles. Early agency adopters can establish a "baseline of users" and spur infrastructure growth. **Responsible Entity: NJ Department of Community Affairs (DCA), BAC, BPU, DEP, DOT, EDA** • **Fuel Cell Electric Vehicle (FCEV) Purchase Incentives**. Renew (if necessary) existing state clean vehicle purchase incentives that currently only apply to PHEVs and expand eligibility to include FCEVs. Incentives include the Clean Fleet Incentive Program (light-duty and medium-/heavy-duty) for state agencies and Charge Up! New Jersey (light-duty only) for the general public. **Responsible Entity: Legislature** • **Fuel Cell Electric Vehicle (FCEV) Legislation to Spur Adoption**. Consider drafting a bill, like the EV law (P.L. 2019 c. 362), to add fuel cell vehicles and the necessary hydrogen infrastructure to the scope of existing targets for the State's light-duty vehicle population, state-owned non-emergency fleets, New Jersey Transit purchases, etc. **Responsible Entity: Legislature** • **Advocate for Federal Tax Credits**. Support, e.g., through a joint Assembly and Senate resolution, the expansion of Federal tax credits for FCEVs, stationary fuel cells, hydrogen infrastructure, and other hydrogen/fuel cell systems contained in any future Federal legislation(s). **Responsible Entity: Legislature**
2.7	**Hydrogen in Alternative Fuel Corridor.** Revisit current Federal Alt Fuel Corridor (AFC) designations in New Jersey and explore appropriate actions to be prepared to apply for AFC grants when funds become available. The Infrastructure Investment and Jobs Act, Pub.L.117–58, signed into law in November 2021, allocated $2.5 billion for AFCs, which include hydrogen infrastructure for appropriately designated corridors. The AFC program for hydrogen applies to light- and heavy-duty stations, and funding can be requested for either.[145] **Responsible Entities: DEP, DOT**

2.8	**Collaboration with New York**. Collaborate with the State of New York to propose end uses and seek federal funding for hydrogen/fuel cell technologies at the Port Authority of New York and New Jersey (PANYNJ), which recently issued a Request for Information (RFI) for Zero-Emission Technology. The RFI mentions electrification of vehicles and other equipment, EV charging for customers, electrification of ground support equipment at airports, material handling equipment to zero emissions by 2026, clean vessel incentive program, and sustainable aviation fuel. Hydrogen-based fuel cell systems can address several technology requirements for ports, including shore power, material handling equipment, heavy-duty vehicles, reefers, ship and ferry power, and resilient power for port operations and facilities. The goals of the PANYNJ RFI can dovetail with the Port Infrastructure Development Program detailed in the Federal Infrastructure Investment and Jobs Act and with New York's plan for a hydrogen hub in the State. **Responsible Entities: BPU, EDA**
2.9	**Fuel Cell Electric Vehicle (FCEV) Access**. Begin discussions with the Port Authority of New York and New Jersey (PANYNJ) to explore a pathway to allowing FCEV access to New York City from New Jersey. Sales of FCEVs cannot begin until the vehicles are granted the same access to public rights-of-way that all vehicles have. Chief among these are the tunnels and bridges connecting New Jersey to Manhattan. Deployment of controlled fleets that don't travel in the New York City area may be possible in the short term before tunnel access is allowed, but any sustainable growth into a scale that is commercially viable cannot happen until this is resolved. Representatives from the States of New Jersey and New York should work together to validate the issues and identify a formal path forward to resolve this in a timely manner. **Responsible Entity: State of New Jersey**
2.12	**Fuel Decarbonization Programs**: Establish an incentive for displacing existing fossil- based fuels with low-carbon equivalent in hydrogen. Today, hydrogen produced in New Jersey is more expensive than gasoline or diesel on a per mile driven basis. While it is expected that hydrogen will reach parity with these other fuels as production scale increases, an economic bridge is necessary to enable the first generation of vehicles to be adopted without significant fuel cost increases. New Jersey should ensure that any standards or regulatory definitions it establishes are consistent with other State and Federal policies. An economic incentive can be structured in one of two ways: • Establish a Low Carbon Fuels Standard (LCFS). A low-carbon fuel standard encourages carbon intensity reduction in transportation fuels by establishing state target reductions compared to conventional gasoline and diesel usage. Examples of successful programs include those enacted in California, Oregon, Washington, British Columbia, and a number of other states and regions. LCFS programs have been successful in quickly establishing incentives and priority for low carbon hydrogen production with incentives in the $1 to $3/kg range, depending upon levels of carbon reduction.

	Responsible Entity: Legislature • Engage with the US Environmental Protection Agency to approve pathways for hydrogen within the existing Renewable Fuels Standard (RFS). The RFS program was established to require the displacement of conventional gasoline and diesel usage with bio-based fuels. While hydrogen produced from bio feedstocks such as landfill gas, dairy gas, agricultural waste, and other forms of biomass are eligible within the RFS program, hydrogen pathways have not advanced in the approval process. **Responsible Entities: DEP, EDA**
2.13	**Funding for Fuel Cells.** Allocate and/or apply for federal funds to support the development and deployment of resilient fuel cell systems and clean FCEVs. Examples of funding sources eligible to support this activity, and some recommended changes, include but are not limited to: • In support of the goals of the EMP and the 80 x 2050 target, the BPU Clean Energy Program budget should increase the incentive for non-combustion generation, like fuel cell systems, that emit no air pollutants. The program currently allocates an incentive that could be three times greater for the installation of a combustion CHP system that increases air pollutants. • Coronavirus State Fiscal Recovery Funds (CSFRF) under the American Rescue Plan Act. • Department of Housing and Urban Development (HUD) - Community Development Block Grant (CDBG) and CDBG Disaster Recovery Funds. • FEMA Building Resilient Infrastructure and Communities (BRIC) funding, an annual competitive grant program to support innovative proactive investments in community resilience. • Infrastructure Investment and Jobs Act (IIJA) and any future legislation. IIJA funds new and existing grant programs for buses, trucks, locomotives, ferries, material handling equipment, cargo handling equipment, and others as well as support facilities and fueling infrastructure. **Responsible Entities: BPU, DOT, DCA, EDA**
2.14	**Fuel Cell Demonstration Projects**. Engage private sector industry partners to develop pilot/demonstration projects in New Jersey that help strengthen the ecosystem for fuel cell technology and next generation hydrogen production methods to showcase their benefits for various industries, and create the demand required to grow the manufacturing base and supply chain in the State. Pilot demonstrations, which could include hub projects or not, should include fuel cell buses, rail, and other fleet vehicles, the supporting hydrogen refueling infrastructure, and resilient power generation. Until regulations allow for widespread, public introduction of FC passenger vehicles in New Jersey, fleet owners should consider FC passenger vehicles in order to enjoy their benefits and encourage expanded adoption. University campuses are one potential location for fuel cell buses that could incorporate education and workforce

	development. Disadvantaged communities are another potential location to provide ZEV transit and improved air quality. Ohio's SARTA program, which operates a fleet of fuel cell buses in revenue service, provides a good example. The USDOT/FTA Lo-No Bus Program is a potential source of funds. **Responsible Entities: EDA, BPU, DOT, NJ Transit**
2.16	**Online Resources.** Create a New Jersey Fuel Cell Task Force website that provides information to businesses and the public on state and federal resources for hydrogen and fuel cell systems, including incentive programs, funding opportunities, and potential partners, e.g., the DOE H2 Matchmaker program. The website should also include distributable information for the public and stakeholders, including first responders and permitting authorities. Information should include the following: • Fuel cell infrastructure permitting requirements • Fueling station safety • Vehicle safety, including light, medium and heavy duty (cars, trucks, buses, rail etc.) • First responder training • Lessons learned, best safety practices, and other relevant hydrogen safety information Information on the comparative benefits of fuel cells Note: Hydrogen safety information and resources exist to aid the deployment of fuel cell technologies such as the Hydrogen Tools Portal (https://h2tools.org) and the Center for Hydrogen Safety (www.aiche.org/chs), among others. Additional information may be needed to address issues specific to New Jersey. **Responsible Entities: BPU, NJ Fuel Cell Task Force**
4.1	**Education and Workforce Development.** New Jersey has established a strong foundation for the clean energy economy with approximately 52,000 New Jerseyans employed in energy efficiency, clean vehicles, biofuels, storage, and renewable energy industries. To catalyze growth and ensure sustainability of the clean hydrogen industry in the state, New Jersey should engage a broad hydrogen and fuel cell technology education, training, and workforce development program and identify areas where the state can take a leadership position in research and development and attract supply chain businesses. As the clean energy economy expands in the coming years it is critical for the state to work with public and private partners to understand specific industry needs and develop programs that train new workers and support those transitioning from industries in decline. For example, the New Jersey Department of Labor's Industry Partnerships initiative is an innovative program that matches labor demand with training programs and offers opportunities to retrain state residents for clean energy occupations. The state should also work directly with vocational schools and community colleges to establish training, certification, and apprenticeship programs that create pathways to better paying jobs and advanced credentials.

	Responsible Entity: NJ Department of Labor (DOL), **NJ Council of County Colleges, NJEDA** University-led series of hydrogen and fuel cell summits or forums should be held to initiate a comprehensive discussion among a broad set of stakeholders, including government officials, academic researchers, industry representatives, and the public. These summits will educate students, teachers, policymakers, consumers, the general public and other stakeholders about hydrogen and fuel cells and keep them up to date on New Jersey's and the Nation's progress in building the hydrogen infrastructure. **Responsible Entity: Rutgers University, Montclair State University**

Next Steps (1-5 years)

2.2	**In-State Fuel Production Investment Incentives**: To encourage private investment in in-state hydrogen production, consider options for state tax credit on investments or production of low-carbon hydrogen. Like those incentives included in the Federal Inflation Reduction Act[146,147], such incentives should be directed toward significant carbon reductions when compared to current fossil-based hydrogen production and should provide options for either credits in the production of low-carbon hydrogen or in the investment in low-carbon production facilities. **Responsible Entity: Legislature** **Timeframe: 2 years**
2.3	**Promotion of Existing Incentives:** Given the unique role of hydrogen production facilities as a supply-side and demand-side resource, New Jersey should: promote efforts to educate hydrogen production facilities on their ability to participate in demand response programs, educate project developers on the economic benefits of hydrogen as a peak shaving demand response resource, and work with PJM and FERC to eliminate barriers to entry. **Responsible Entity: BAC, NJ Fuel Cell Task Force** **Timeframe: 1 - 2 years**
2.4	**NJ Resiliency Tariff (Retail):** BPU should consider requiring electric distribution companies to propose electricity tariffs that recognize the system, environmental, and resilience benefits created through behind-the-meter fuel cell systems and electrolyzers. **Responsible Agency: BPU** **Timeframe: 2 years**
2.5	**Fuel Cells for Distributed Energy Resources.** Grid modernization goes beyond simply addressing interconnection standards for distributed energy resources (DER), such as renewable generation, storage, and EV supply equipment. New Jersey must focus BPU's grid modernization program on valuing (and potentially compensating) desired operational attributes for this DER on the grid such as air quality improvement, carbon reduction, grid flexibility for reliability and

	hosting capacity, and grid-edge resilience while also allowing for attaching local clean energy provided by stationary sources of electricity generation, including hydrogen and RNG powered fuel cells. DER systems can supply a distribution system with behind-the-meter generation. Where the resource is meter connected, it is generally not "sub-metered" to distinguish and separately treat this generation under different billing or regulatory terms. Because fuel-cell augmented DER systems can be aggregated to satisfy size and performance requirements under Federal Energy Regulatory Commission (FERC) Order 2222, they can serve as DERs to participate in wholesale markets in addition to the distribution systems using rapidly advancing control technologies, and there should be specific legislative and regulatory language removing barriers for these applications. **Responsible Entity: BPU** **Timeframe: 2 - 5 years**
2.10	**Climate Change Resilience.** Take action to implement New Jersey's Climate Change Resilience Plan Strategy utilizing fuel cell systems. Areas of focus should include the following: • Consider grid hardening using stationary fuel cell systems. Require low- and zero-emission backup emergency generation to replace diesel generators • For private investment by developers, utilize a "green bank style" funding approach to emphasize deployment of fuel cell systems to displace legacy diesel generation for improved air quality and supplying long-duration community resilience. Identify sources of additional funding whether through future disaster appropriations or other available sources. • Include resilience for areas beyond coastal regions. **Responsible Entity: NJ Interagency Council on Climate Resilience** **Timeframe: 2 years**
2.11	**Fuel Cells in Net Metering.** The Board of Public Utilities' net metering rules set forth net metering requirements that apply to electric power suppliers, basic generation service providers, and electric distribution companies, which have customers who generate Class I renewable energy on the customer's side of the meter. Explore the economic and technical barriers that may limit adoption certain Class I resources, like fuel cell systems operating on hydrogen, and hydrogen production from electrolysis. A multiple-technology net energy metering protocol and associated tariff is also a recommended approach to incentivize customers who operate a combination of net energy metering (NEM) and non-NEM renewable generation behind the same meter. **Responsible Entities: Legislature, BPU, DEP** **Timeframe: 2 years**

2.15	**Address Supply Barriers to Clean Transportation**. Request a temporary waiver of the Buy America requirements that is phased out over time in order to facilitate the acceleration of domestic manufacturing capacity while allowing an adequate supply of ZEV's and refueling infrastructure. **Responsible Entities: DOT, Legislature** **Timeframe: 2 years**
3.1	**Safety Reviews**. Incorporate requirements for safety planning/reviews for hydrogen projects that include New Jersey state dollars. This includes requiring a hydrogen safety plan for all projects, and reviews could be accomplished through one or a combination of the following activities: • Utilize a single state agency for performing safety reviews and permitting for all hydrogen projects. Ensure that those performing the reviews have hydrogen safety experience/expertise or provide education to equip them to do so. • Utilize an outside agency such as the Hydrogen Safety Panel[v] to support state reviews or state agencies in their review activities. • Provide training for all state agencies/personnel that are involved in safety reviews and permitting. **Responsible Entity: DCA** **Timeframe: 2 years**

Appendices

Appendix I. Hydrogen production and use: efficiency and emissions

Hydrogen must be produced from sources like water, methane or other hydrocarbons, as it does not exist on Earth in its pure state.[148] Producing hydrogen from natural gas is the most efficient and least expensive method currently; this method results in greenhouse gas emissions unless the carbon dioxide is captured and sequestered (C&S). Today's R&D efforts are focused on producing green hydrogen, made by electrolyzing water using electricity generated from renewable energy sources, usually wind or solar.

A common argument against the use of hydrogen fuel cells is their lower efficiency relative to batteries on a well-to-wheels (WTW) basis – why make hydrogen using grid electricity and then compress, store, transport and deliver it to a fuel cell powered vehicle/device, when we can simply plug a battery directly into the grid to recharge it? However, as discussed in several places in the report, in addition to being a zero-emission technology, green hydrogen fuel cells offer advantages in terms of utility, productivity, reliability and resilience in many applications.[149] Fuel cells are two to three times more efficient than internal combustion engines running on gasoline.[150] However, the WTW efficiency depends on the method used to produce and deliver the hydrogen.[148] Argonne National Laboratory has examined the WTW energy use, emissions and cost of fuel cells for a number of applications and using various hydrogen fuel production and distribution pathways.[151]

The cost of hydrogen is one of the main factors in the cost of owning FCEVs. As the price of hydrogen comes down, FCEVs will become more competitive. While the HEV is currently the lowest cost powertrain for small SUVs, FCEVs are forecasted to reach cost parity by 2030 when hydrogen prices are expected to reach $5/kg. BEVs are expected to reach cost parity by 2035 when a battery cost of $98 per usable kWh of capacity is expected.[152] Analyses of maintenance costs of light duty vehicles as a function of powertrain, vehicle age, vehicle mileage and maintenance schedule also show that on average electrified powertrains (HEVs, PHEVs, BEVs, and FCEVs) all have lower maintenance costs than internal combustion engine vehicles (ICEVs). Analyses of the depreciation of cars and light trucks show that FCEVs depreciate at a rate that is no greater than that of BEVs and PHEVs, indicating that FCEVs hold their value reasonably well.

For the sake of simplicity, hydrogen has recently been characterized using a color code (Table A.1) based on the level of carbon emissions resulting from the production method.[153]

Table A. 1 Hydrogen Color Codes

Hydrogen Color Code	Production Source	Production Process	Carbon Emissions/Notes
Green	Water	Electrolysis using renewable power, e.g., wind, solar, geothermal	Zero - no net carbon
	Biomass (methane)	Steam Reforming	Zero- no net carbon
Pink (also purple or red)	Water	Electrolysis using nuclear energy	Zero- no net carbon
Yellow	Water	Electrolysis using solar power; can also leverage existing power grid	No to low
Blue	Natural Gas (methane)	Steam Reforming with carbon capture and sequestration	Low
Turquoise	Methane	Pyrolysis	Low, instead of CO_2 solid carbon is produced
Grey	Natural Gas	Steam Reforming	Medium
Black/Brown	Black or brown coal (lignite)	Gasification	High
White	Geological Hydrogen in underground deposits	Fracking	Not demonstrated

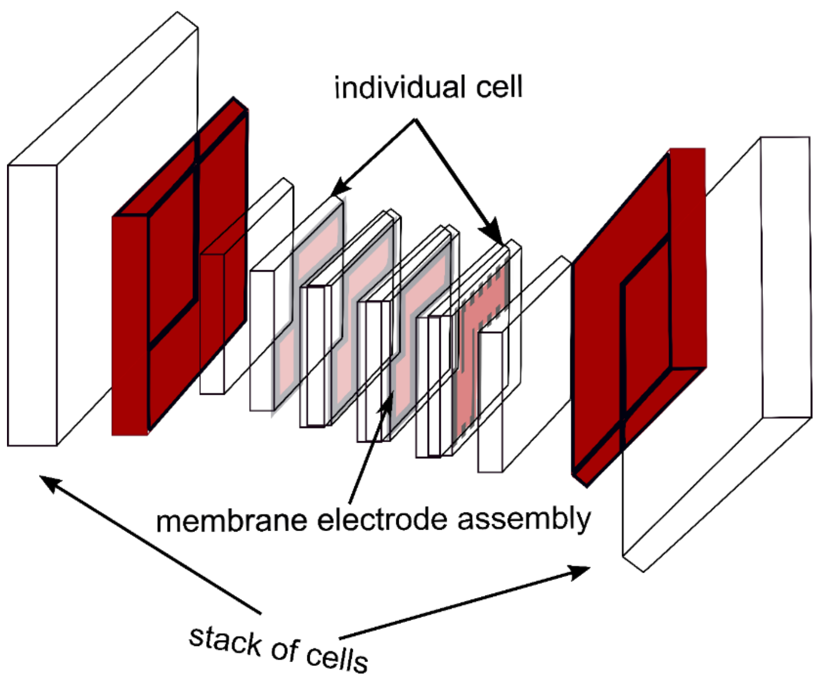
Note: Information for this table was sourced from multiple resources[154-156]

Appendix II. Fuel cell working principles and types

Fuel cells are electrochemical conversion devices or galvanic cells that require a constant external supply of reactants because the products of the reaction are continuously removed. Unlike a battery, a fuel cell does not store chemical or electrical energy but enables electrical energy to be produced directly from a chemical reaction. Thus, a fuel cell requires a continuous supply of fuel such as hydrogen or natural gas, and an oxidant such as oxygen or air. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte (often a membrane) to the cathode, where they combine with oxygen and the electrons to produce water and heat.

To attain a useful output power, individual cells - membrane electrode assemblies - are "stacked" in series via interconnections that connect the anode of one cell to the cathode of another. Increasing surface area of each cell increases the current, while stacking them in series increases the voltage. A representative example of a Proton Exchange Membrane Fuel Cell (PEMFC) stack (sometimes referred to as Polymer Electrolyte Membrane) is presented in the Figure A.1 below.

Figure A. 1 Proton exchange membrane fuel cell



There are several types of fuel cells, characterized by their electrolytes, which can be used in various applications depending on their operational characteristics and costs. These are detailed in Table A.2 below.

Table A. 2 Types of fuel cells

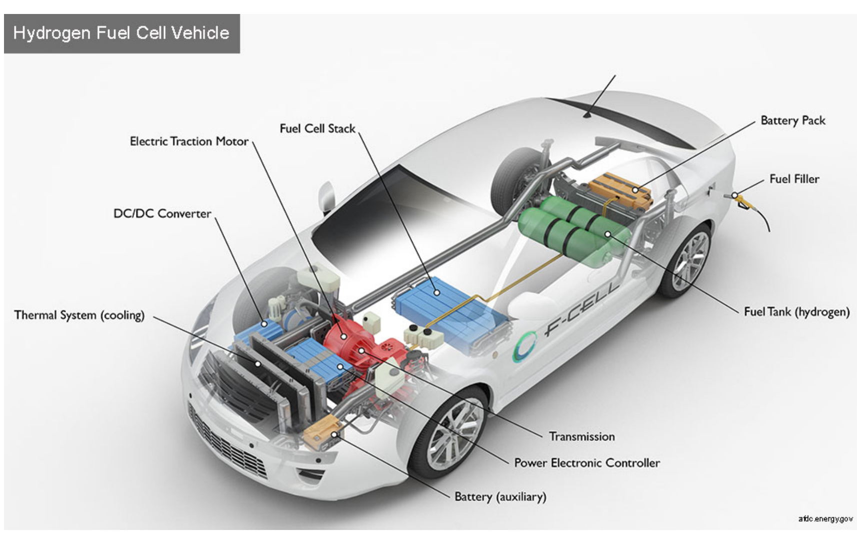
Types	Description
Proton exchange membrane fuel cell (PEMFC)	PEMFCs typically use platinum or platinum group metals, fluoropolymer membranes, a carbon-based gas diffusion layer (GDL), and two end plates, which can be carbon- or metal-based. Hydrogen or methanol are typically used as the fuel sources. Operating temperature is maintained as low as 100ºC or 212 ºF, allowing for fast start up and high energy density which makes the technology suitable for transportation and portable electronic devices. PEMFCs are versatile, being used in vehicles, material handling equipment, and in residential and commercial building applications. Research is mainly focus on reducing production and materials costs of the system components.
Alkaline fuel cell (AFC)	AFCs operate at relatively low temperatures like PEMFC. The electrolyte is an aqueous solution of potassium hydroxide (KOH), which facilitates transport of negatively charged ions from anode to cathode. However, KOH reacts with CO_2 present in the air, reducing the concentration of hydroxide ions during the chemical reaction and negatively affecting fuel cell performance and lifetime. AFCs have been used for aerospace applications since the Apollo missions, and remote or inaccessible areas.
Phosphoric acid fuel cell (PAFC)	PAFCs operate at relatively higher temperature (>200 ºC or >392 ºF) with liquid phosphoric acid as the electrolyte. Reformed hydrocarbon fuels (e.g., methane) are used as fuel sources. PAFCs are primarily used for generating CHP for decentralized stationary power systems.
Molten carbonate fuel cell (MCFC)	MCFCs operate at very high temperature (600-800 ºC or 1100-1500 ºF) use molten carbonate electrolytes (Li_2CO_3, K_2CO_3). Purified coal gas, natural gas, and reformed hydrocarbons are typically used as fuel sources. Use of a relatively affordable catalyst nickel oxide (NiO) makes the system more commercially viable. They are primarily used for medium and large power in stationary applications, for example 2 MW MCFC or higher.
Solid oxide fuel cell (SOFC)	SOFCs are widely used technology in medium and large power and CHP applications due to their high temperature operating ability (1000 ºC or 1832 ºF). Additionally, they do not require a separate reformer to extract hydrogen from fuel due to their internal reforming ability, having sufficient thermal energy to perform fuel reformation. However, the high temperature operation causes slow start up times and corrosive reactions.
Direct methanol fuel cell (DMFC)	DMFCs use liquid methanol or small alcohols as fuel instead of reformed hydrogen. Like PEMFCs, polymers are used as electrolytes in DMFC. Due to their relatively low power density, DMFCs are primarily used in portable electronic devices with 1 W-1 KW capacity range (e.g., notebooks, laptops, video cameras etc.).

Appendix III. How a hydrogen fuel cell works in an electric vehicle

Fuel cell electric vehicles (FCEVs) have an architecture similar to series hybrid, as seen in Figure A.2, with a fuel cell replacing the engine and generator. The hydrogen-powered fuel cell is combined with a battery, which stores the energy generated from the regenerative braking and provides supplemental power to the electric traction motor as needed. The fuel cell and battery are sized to provide the most efficient combination of constant and peak power.[157] The key components of a hydrogen fuel cell electric vehicle include:

- **Battery (auxiliary):** In an electric drive vehicle, the low-voltage auxiliary battery provides electricity to start the car before the traction battery is engaged; it also powers vehicle accessories.
- **Battery pack:** This high-voltage battery stores energy generated from regenerative braking and provides supplemental power to the electric traction motor.
- **DC/DC converter:** This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.
- **Electric traction motor:** Using power from the fuel cell and the traction battery pack, this motor drives the vehicle's wheels. Some vehicles use motor generators that perform both the drive and regeneration functions.
- **Fuel cell stack:** An assembly of individual membrane electrodes that use hydrogen and oxygen to produce electricity. In the vast majority of vehicles, the fuel cell is a PEMFC.
- **Fuel filler:** A nozzle from a fuel dispenser attaches to the receptacle on the vehicle to fill the tank.
- **Fuel tank (hydrogen):** Stores hydrogen gas onboard the vehicle until it's needed by the fuel cell.
- **Power electronics controller:** This unit manages the flow of electrical energy delivered by the fuel cell and the traction battery, controlling the speed of the electric traction motor and the torque it produces.
- **Thermal system (cooling):** This system maintains a proper operating temperature range of the fuel cell, electric motor, power electronics, and other components.
- **Transmission (electric):** The transmission transfers mechanical power from the electric traction motor to drive the wheels.

Figure A. 2 Fuel cell electric vehicle



Vehicle Classifications

Class 2 – Passenger cars. All sedans, coupes, and station wagons manufactured primarily for purpose of carrying passengers. **Class 2B** (8,500-10,000lbs) applies mostly to heavier pickup trucks, vans, and SUVs.

Class 3 – Other two-axle, four-tire single units. Included in this classification are pickups, vans, campers, ambulances.

Class 4 – Buses. All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles.

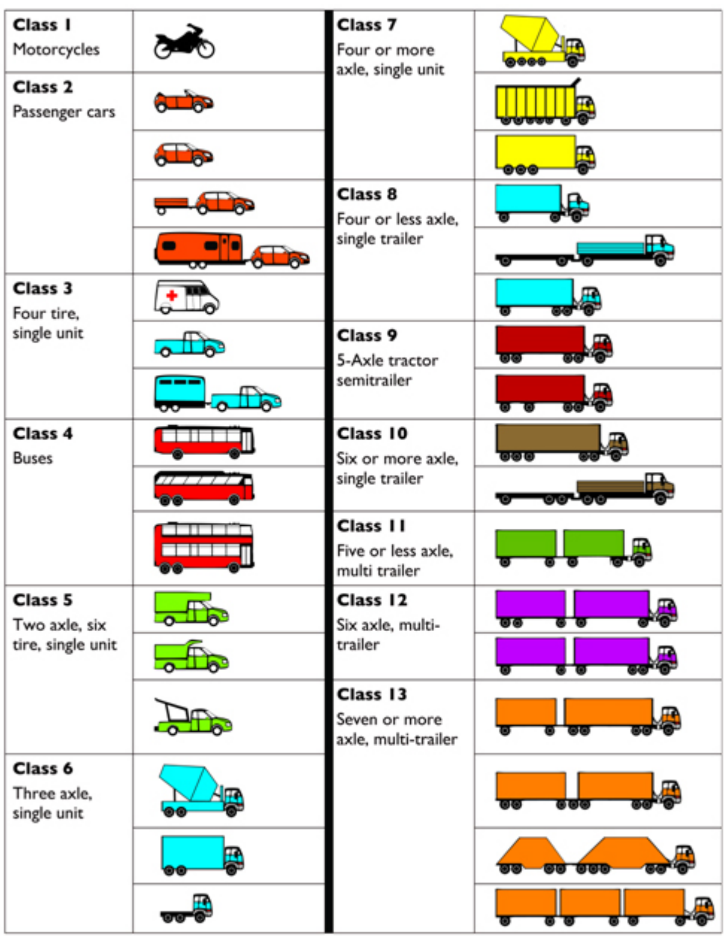
Class 5 – Two-Axle, Single Unit Trucks. All vehicles on a single frame including trucks, camping and recreation vehicles

Class 6 – Three Axle Single Unit Trucks. All vehicles on a single frame including trucks, camping and recreational vehicles.

Class 7 and above – Four or more axle. Includes 4+ axle single unit trucks, two-axle trucks pulling one- and two-axle trailers, two-axle tractors pulling three-axle trailers, and others.

Figure A.3 provides pictures of vehicles and their respective classes.[158]

Figure A. 3 Vehicle classifications



Appendix IV. Main suppliers of fuel cells nationally and globally

Below is a list of some key fuel cell and hydrogen suppliers found in the US and globally, detailing some information about the company and their products. While it includes many of the major companies, it is not comprehensive.

Plug Power Inc., headquartered in Latham, New York, manufactures fuel cell systems as alternatives to battery and diesel-powered equipment and vehicles. They have developed multiple fuel cell systems including ProGen for light, medium and heavy-duty fuel cell engines, GenDrive for material handling power (converting class-1 -2 and -3 electric truck fleets), GenSure for high and low backup power ranging from 200W to an array of 125kW allowing for MW scale applications. Plug Power also provides GenFuel green hydrogen for mobile and stationary applications, as well as the necessary tools such as hydrogen stations, hydrogen storage, and GenFuel dispensers.

Ballard Power Systems Inc., headquartered in Burnaby, British Columbia, is a developer and manufacturer of PEM fuel cell products for both mobile and stationary power, and has shipped over 400 MW of fuel cell products across the globe. Their heavy-duty modules allow for 30-100kW net power, which can be applied to buses, trucks, and trains. They have also developed FCwave, a scalable fuel cell system to power marine vessels up to MW applications. Ballard also provides air- (FCgen-1020ACS) and liquid-cooled (FCgen-HPS, LCS, and 9SSL) fuel cell stacks, which can be applied as backup power, motive power, and material handling equipment. Further, their stationary applications are scalable, ranging from 1.7KW to multiple MWs.

Bloom Energy in San Jose, California manufactures fuel cell systems that use hydrogen or biogas fuel for primary or backup power and for microgrids. Bloom's Solid Oxide Fuel Cells (SOFCs) have been deployed globally across multiple sectors, including healthcare, data centers, and manufacturing. Bloom has also developed an energy-efficient electrolyzer to produce clean hydrogen.

FuelCell Energy Inc., in Danbury, Connecticut, is considered a leader in the development and commercialization of high efficiency fuel cells. They have a global fleet of SureSource power plants, providing millions of MW of fuel cell power. SureSource 1500 supplies 1.4MW for on-site power generation; SureSource 3000 provides 2.8MW continuous power for larger applications such as universities and manufacturing facilities; and SureSource 4000 provides 3.7MW power for large industrial use and data centers.

HyAxiom, a subsidiary of Doosan Corporation, located in South Windsor, Connecticut, has developed the stationary PureCell System, which is a scalable technology capable of generating 460 kW of electricity and 1.7 million BTU/hour of heat. **Doosan Corporation** (Seoul, South Korea) is renowned for creating the world's first by-product hydrogen fuel cell power plant in 2021, which is powered by the same PureCell system. They have also contributed to development of the world's largest fuel cell power plant with a total capacity of 78.96 MW.

Cummins, Inc., a multinational company headquartered in Columbus, Indiana, is an engine and power generation designer and manufacturer, and has developed fuel cells for vehicles with power ranging from 30 kW to 180 kW. They have also developed a Power Plant Platform with offers MW scale power generation required for large stationary applications. In addition to being a fuel cell developer, Cummins has created electrolysis technologies (HySTAT and HyLYZER), which can be used to generate on-site hydrogen, providing a scalable range of 10Nm3/h to 1000N3/h.

Globally, there are numerous fuel cell developers, the largest company (and second largest market share following Plug Power) being **Toshiba Corp.**, headquartered in Tokyo, Japan. Toshiba is one of the pioneers in fuel cell development having begun in the 1960s. They have developed fuel cell technology that is scalable and can be applied to both mobile and stationary uses supporting up to MW scale. They have delivered over 100 fuel cell systems across Japan, making Japan the largest user of fuel cell technology in the world. In 2020, Toshiba (in collaboration with New Energy and Industrial Technology Development Organization, Tohoku Electric Power Co., and Iwatani Corporation) launched the 'world's largest hydrogen plant' - the Fukushima Hydrogen Energy Research Field (FH_2R). FH_2R is a 10MW production plant that can produce up to 1200m^3 of hydrogen per hour and is powered by 20MW of solar power and by the local grid, relying heavily on renewable energy.[159]

Linde, a global multinational industrial gases and engineering company headquartered in Dublin, Ireland, is the largest supplier of industrial gases globally. Linde is the largest liquid hydrogen producer in the US. In September 2022, they announced their plans to build a 35-megawatt proton exchange membrane electrolyzer to produce green hydrogen in New York, which will be the largest Linde electrolyzer, doubling their green liquid hydrogen production capacity in the US.[160]

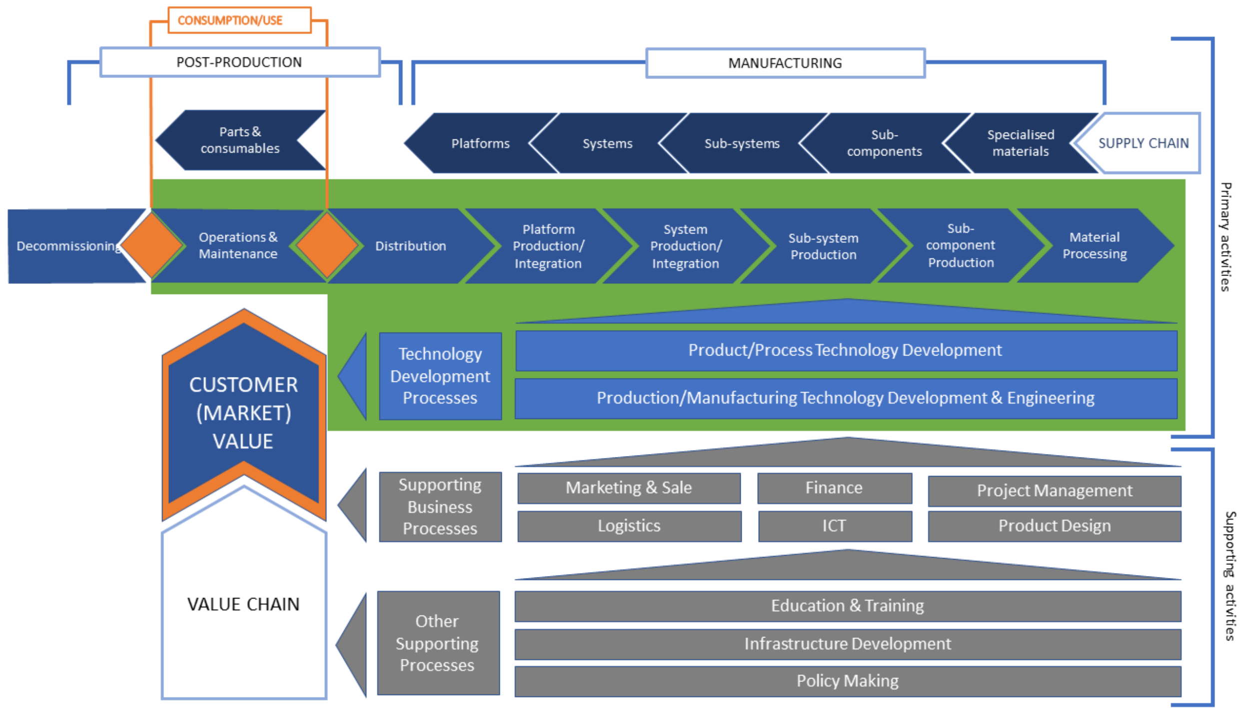
Air Liquide, a multinational company headquartered in Paris, France, is the second largest supplier of industrial gases. Air Liquide recently opened its largest liquid hydrogen production facility in Nevada, capable of producing 30 tonnes of liquid hydrogen per day to be used primarily by California customers.[161] **Airgas,** an Air Liquide company headquartered in in Radnor, Pennsylvania, is one of the largest US suppliers of industrial, medical, and specialty gases, including hydrogen.[162]

Air Products, an international corporation headquartered in Allentown, Pennsylvania, is an industrial gas producer and provide offering both liquid and compressed gas hydrogen.[163] Air Products has a working relationship with NASA, and has supplied the liquid hydrogen used for every space shuttle launch and the Mercury and Apollo missions.

Appendix V. Overview of the value chain in fuel cells and hydrogen

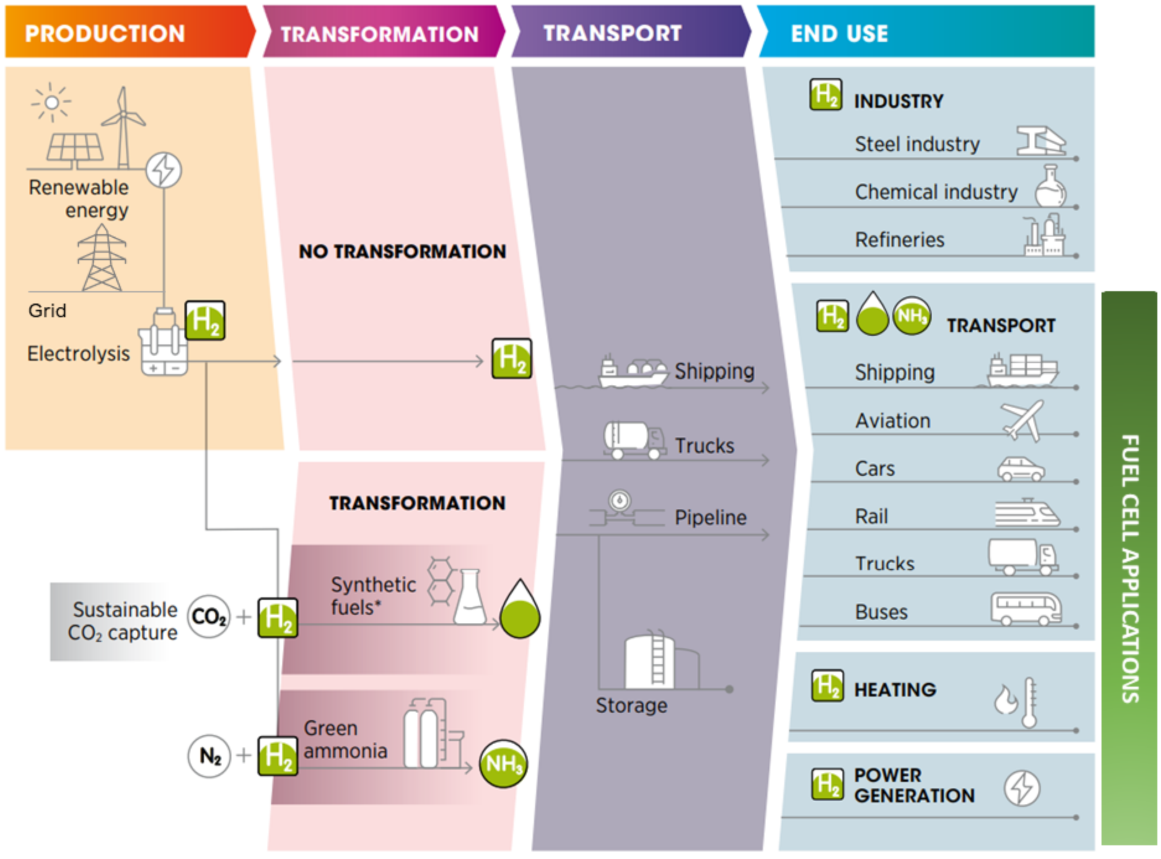
Value chains help to map the physical flow of raw materials and components from suppliers, through manufacturing, to finished goods delivered to customers.[23, 164] Value chains also highlight the actors involved in delivering the specific components and subsystems of a valuable product. By comparing value chains of technologies, we can identify their similarities and differences and assess the implications. Figure A.4 represents a visual simplification of a value chain in terms of primary activities, supporting activities, and final use.

Figure A. 4 Mapping the value chain (Figure adapted from E4tech 2019[23])



A value chain involves horizontal and vertical supply chain extensions; horizontal extensions are those that occur along the same business line, and vertical extensions are those that feed into a different business line. Figure A.5 summarizes the primary activities and end uses for hydrogen and fuel cell technologies, showing the production, delivery and end-use of hydrogen, as well as hydrogen-based synthetic fuels. Many end-use applications benefit from highly efficient, low or no-emissions fuel cell technology.

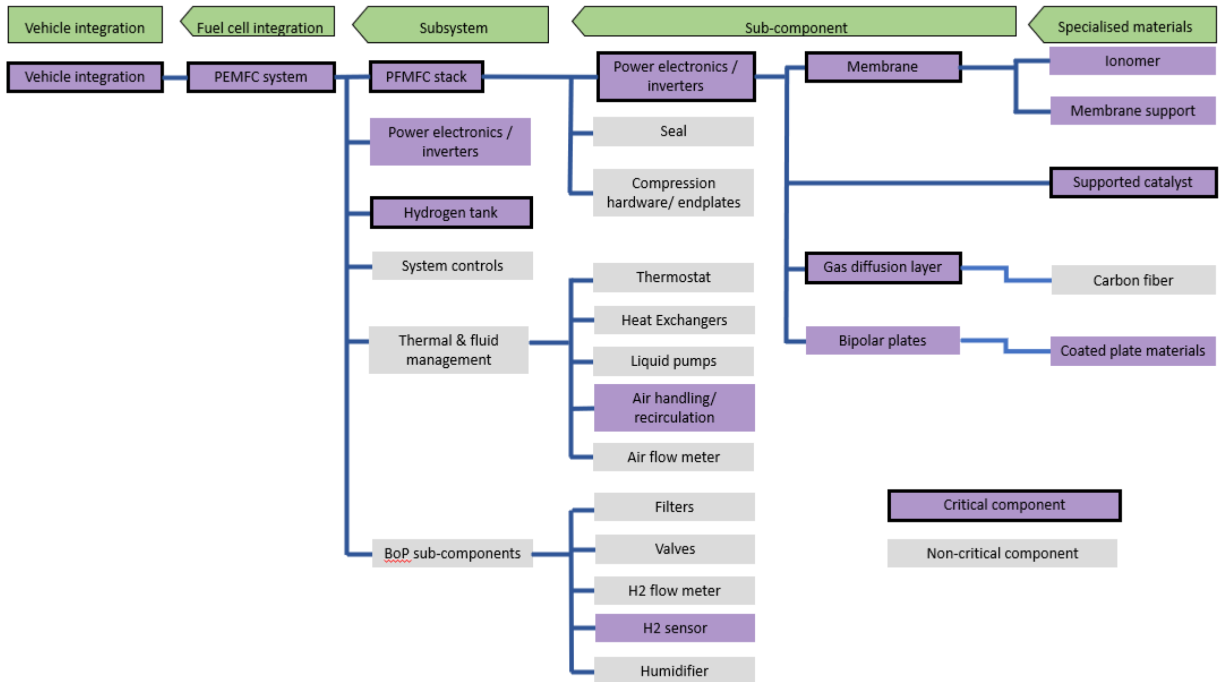
Figure A. 5 Mapping the value chain primary activities of low-carbon sourced hydrogen production, distribution, storage, and use (Figure adapted from International Renewable Energy Agency 2021[165]).



Overlap with BEV value chain

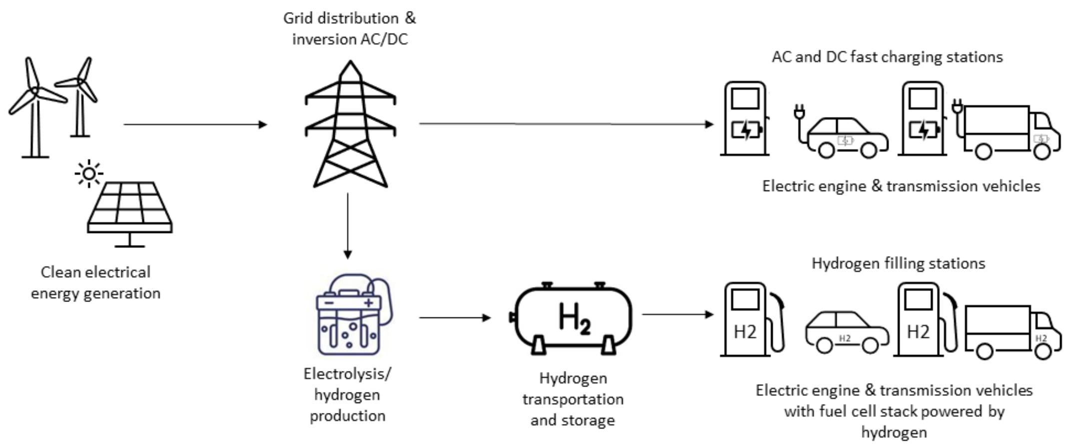
While FCEVs and BEVs have similiarties in some of the vertical and horizontal extensions of their supply chains such as distribution, after-sales operations, and maintenance support, they have differences in the manufacturing and use stages that affect their deployment. Figure A.6 provides a visual of the FCEV supply chain, with critical components (those which are exclusive to the FCEV supply chain) highlighted in purple. The hydrogen fuel cell sector includes a wide variety of applications, each with a supply chain having a multitude of components. The non-critical components include those which are less likely to affect the system's performance and cost competitiveness and do not require a specialized product or supply base.

Figure A. 6 Mapping the supply chain of the physical manufacturing of fuel cell electric vehicles (Figure adapted from E4tech 2019[23]).



The primary difference between a BEV and a FCEV is the infrastructure required to fuel their electric drivetrains (see figure below). BEVs require public charging stations, including fast charging (150kW+) systems and/or at-home charging capacity (typically 3-20kW), both of which are connected to the existing power grid and may not initially require substantial electrical system upgrades to support refueling demand. Future investments will likely be needed to enable fast charging as BEV penetration increases and commercial vehicles are introduced. However, fueling FCEVs with hydrogen requires the development of specialized hydrogen fueling stations, which require liquid or compressed gas delivery from a hydrogen production facility.

Figure A. 7 Electric vehicle operational logistics (Figure developed by the Clean Energy and Sustainability Analytics Center, Montclair State University)[166]



Hydrogen distribution (if not produced on site) is compressed into liquid or gaseous form which is then delivered via truck in gas cylinders for on-site storage. In the future, hydrogen will likely be distributed via pipeline. AC= alternate current; DC= direct current.

Thus, in terms of the energy resource used and fueling systems required, there is limited overlap between the BEV value chain and that of FCEVs. The four elements in a hydrogen supply system that will be different from that serving electric power to BEVs are: (1) hydrogen production, (2) compression and transport of gas via pipeline, tankers, ports etc., (3) hydrogen storage, and (4) hydrogen fuel energy conversion (see Figure A.7). Of note is that the end use for drivetrain propulsion through energizing electric motors is identical, with the exception that regenerative braking cannot convert withdrawn kinetic energy to replenished hydrogen; rather, it is stored in a smaller hybrid battery in the same manner as a gasoline-electric hybrid. The benefit of both BEVs and FCEVs is that the entire powertrain (battery, fuel cell, motor) operates on electricity, whereas in a gas-electric hybrid, the kinetic energy of the combustion engine must be intermixed with the electrical energy from the hybrid battery.

FCEV and BEV value chains: Opportunities and challenges

Opportunities

Both BEVs and FCEVs are viable approaches to decarbonizing the transportation sector. BEVs are ideal for light duty vehicle (LDV) applications in cases where long driving ranges and short refueling times are not critical. FCEVs offer the option of a driving range and a refueling time comparable to conventional gasoline vehicles. Because of their high energy density, FCEVs are likely to be a better choice for medium- and heavy-duty vehicles that require higher power and/or energy levels. If one needs to double the energy level of a battery system, the complete mass of the system will have to be doubled. However, for a hydrogen-based system, only the hydrogen tank volume will need to be increased. This saves weight, which is critical when powering heavy-duty vehicles because less weight means more load can be transported.[167] The FCEV fueling infrastructure will be more challenging to scale than the BEV recharging infrastructure; however, when considering the cost per mile, the infrastructure costs are expected to be comparable in the long term due to the investments that will be needed in ultra-fast charging for BEVs.[168]

Although commercial FCEVs (first offered for sale in 2015) are relatively new compared to BEVs (the most recent continuous sales beginning in 2011), the hydrogen they consume can be produced and used in many industrial applications. With the appropriate scaling up, existing applications can easily meet that fuel demand. A hydrogen production and supply plant can even be integrated with existing industrial operations at a chemical or petrochemical plant that produces hydrogen or hydrogen-containing compounds as a byproduct.[23]

Thus, the adoption of FCEVs will create upstream demand and new business opportunities in the supply chain, ranging from new fuel cell and hydrogen tank manufacturing to new hydrogen production and dispatching businesses. Renewable sources of electricity, which are both efficient and environmentally friendly, are another industry that can be included in this upstream supply chain. Considering the amount of renewable energy projects being driven by the New Jersey EMP and its targets of achieving 80% reduction of carbon by 2050, surplus electricity produced from renewable energy sources can be productively diverted to hydrogen production, storage, and use.[152]

Fuel cell vs battery-powered forklifts

Hydrogen fuel cell systems are used in material handling equipment (MHE) including counterbalanced forklifts, narrow aisle lift trucks, pallet jacks, and stock pickers. Forklifts are used in diverse industries spanning grocery distribution centers, beverage handling facilities, and automotive manufacturing operations. Fuel cell powered forklifts are increasingly popular because they help to address the challenges presented by the logistics of battery-operated forklifts, especially for high freight volume throughput with multiple daily shifts. These challenges include the special electrical infrastructure and maintenance requirements, including the time needed for frequent battery changes (approximately 15-20 min/shift in many facilities) and battery cool down along with the infrastructure for extra batteries and charging equipment.[42]

The fuel cell's ability to be rapidly refueled boosts productivity by eliminating the time and cost associated with battery change-outs and charging. Fuel cell powered lift trucks also provide consistent power throughout shifts, while battery performance often degrades. These features allow fuel cell forklifts to be cost-competitive with batteries on a lifecycle basis.

In multiple-shift operations where a large truck fleet is used, fuel cell material handling power units and their required infrastructure have a lower total cost of ownership compared to their battery counterparts. This performance is driven in part by the savings due to fuel cell forklift's increased productivity and decreased maintenance and warehousing need. Fuel cell forklifts have 80% lower refueling/recharging labor cost as well as requiring 75% less space compared to battery recharging infrastructure.[42]

Challenges

As noted above, FCEVs require the build-out of new infrastructure for hydrogen production, compression, storage, and distribution to enable widespread adoption. With relatively more mature value chains, such as those for BEVs, the supply of components, especially non-critical components, are outsourced to external suppliers, allowing the manufacturer to focus on vehicle design and manufacturing. Because the supply chain and necessary infrastructure are not well developed for FCEVs, fuel cell vehicle manufacturers may have to produce components in-house initially.

The requirement for this specialized infrastructure and the limited number of key operators along the supply chain today poses challenges for manufacturers. These effects can directly impact:

(1) the manufacturer's ability to meet end-consumer requirements such as expectations of price, delivery time, customization, and product life cycle;

(2) whether the FCEVs are manufactured continuously, in high volumes, and on a forecast-matching basis;

(3) the manufacturer's ability to change its product rapidly in response to shifts in the market requiring short production runs against forecasted demands;

(4) the manufacturer's ability to control supplier prices and influence product specifications;

(5) FCEV demand volume and how it could affect the location and other logistical decisions for suppliers of critical components, especially early in the development of this value chain.

These logistical and technical constraints along with the lack of technical standards that can help reduce customization and achieve faster economy of scale are even more important when it comes to the supply of critical components, which require vertical integration or partnership with suppliers. This highlights the need for collaboration among key stakeholders in the value chain and the importance of a regional innovation hub to accelerate infrastructure development. Such a hub could also help to mitigate the adverse impacts of the key actors' location differences, which include higher production/transport/delivery costs and lower overall competitiveness.

As for any energy/fuel infrastructure, these systems will also require safety monitoring and control/suppression systems in accordance with emerging codes and standards. For vehicle applications, the lessons learned and other resources from California's build-out of hydrogen fueling stations will be useful. Other significant resources, driven by the USDOE, are the Center for Hydrogen Safety (CHS) established by the American Institute of Chemical Engineers (AIChE); the Hydrogen Safety Panel, experts who can provide hydrogen fuel cell project development support; and H2Tools, which supports the implementation of practices and procedures to ensure the safe handling and use of hydrogen in fuel cell applications.[113, 116, 121] These resources are discussed in the report.

Appendix VI. Northeast Electrochemical Energy Storage Cluster (NEESC) New Jersey hydrogen and fuel cell deployment plan

Regional User Themes for Stationary and Motive Users

NJ Hydrogen Economy: Economic Development, Environmental Performance, Energy Reliability

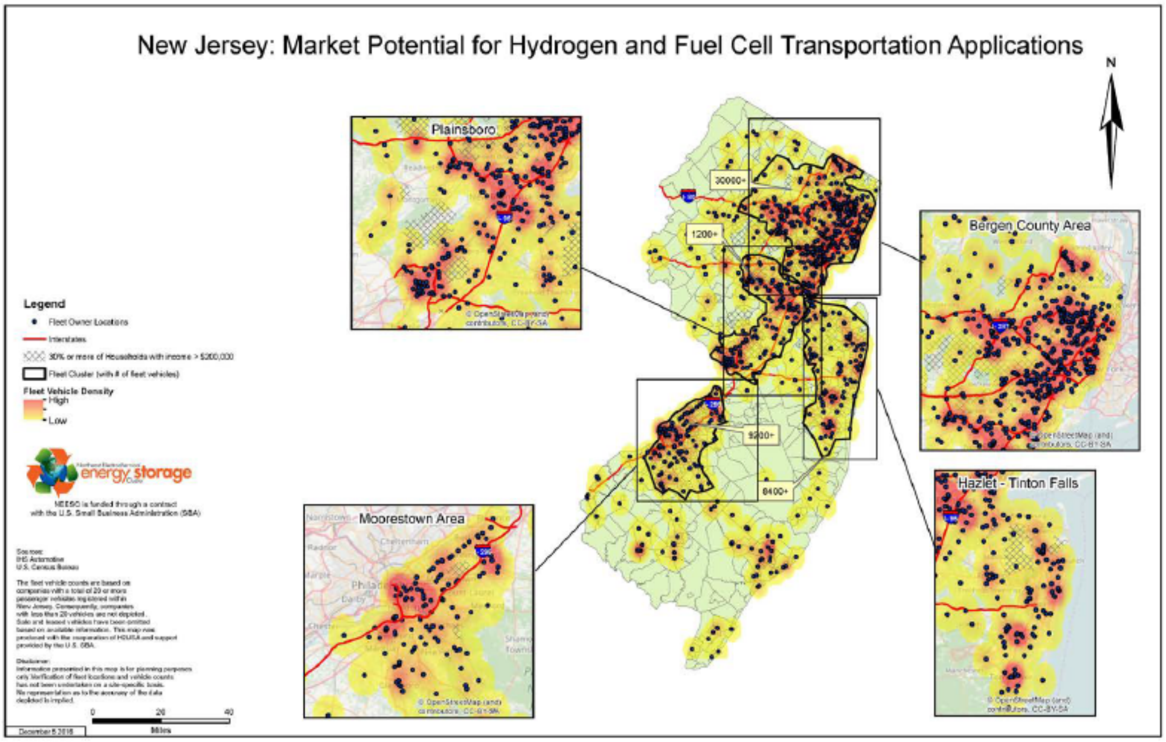
Connecticut Center for Advanced Technology

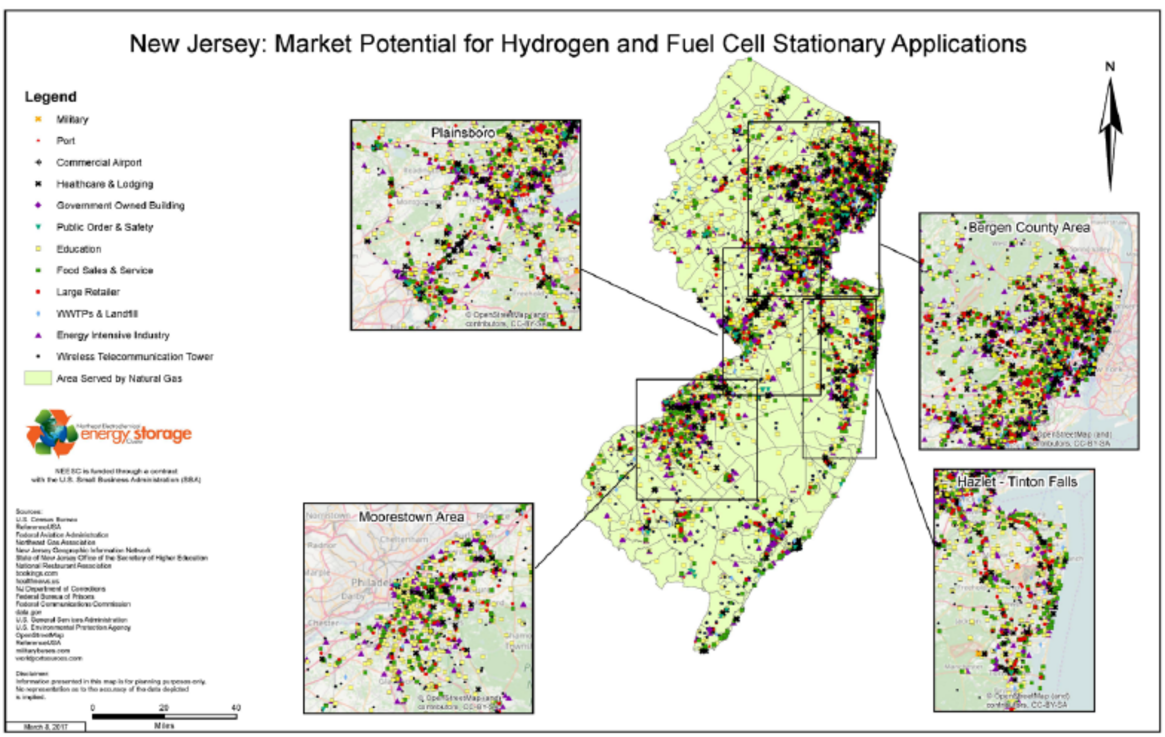
CBECS Data

Category	Total Sites	Potential Sites	Potential Sites		
			FCs < 400 kW (#)	FCs ≥400 kW (#)	FCs >1,000 kW (#)
Stationary Targets					
Education [50]	2,580	105	70	19	16
Food Sales/Services[51]	21,614	1908	1842	52	14
Healthcare & Lodging[52]	1,757	32	8	14	10
Retail	9,405	44	23	19	2
Public Order & Safety[53]	2,331	50	22	11	17
Energy Intensive Industries[54]	2,628	72	37	27	8
GSA Operated Buildings[55]	180	11	11	0	0
Wireless Telecommunication Towers[56]	598	60	60	0	0
WWTPs & Landfills[57]	67	7	4	2	1
Commercial Airports, Military, and Ports[58]	332	20	8	6	6
Total Locations	**41,492**	**2,309**	**2,085**	**150**	**74**

Category	Total Units	Potential Targets	CO2 Emissions (Metric Tons/Year)	
Transportation Targets			**CO2**	**NOx**
FCEVs	69,194	3,232	15,100	8
Transit Buses	2,970	139	12,400	3
Retail Refueling Stations	2,372	31 – 34	NA	NA

[49] Potential sites and capacity estimated by NEESC.
[50] Buildings used for academic or technical classroom instruction, such as elementary, middle, or high schools, and classroom buildings on college or university campuses.
[51] Buildings used for wholesale of food or for preparation and sale of food and beverages for consumption.
[52] Buildings used as diagnostic and treatment facilities for inpatient care and buildings used to offer multiple accommodations for short-term or long-term residents.
[53] Buildings used for the preservation of law and order or public safety.
[54] Buildings that are industrial or agricultural.
[55] Buildings actively used by the General Services Administration.
[56] Off-site telecommunication towers that may require back-up power.
[57] Wastewater treatment plants and landfills.
[58] Commercial airports, military bases, and active ports.
[59] Assumes a 97% availability factor for fuel cell units ranging from 2.5 kW through 1.4 MW.
[60] Many of the targets were identified based on assumptions provided by EIA's 2012 Commercial Building Energy Consumption Survey (CBECS).


New Jersey: Market Potential for Hydrogen and Fuel Cell Transportation Applications
N
Plainsboro
Bergen County Area
Hazlet - Tinton Falls
Moorestown Area
30000+
1200+
5200+
8400+
Legend
Fleet Owner Locations
Interstates
30% or more of Households with income > $200,000
Fleet Cluster (with # of fleet vehicles)
Fleet Vehicle Density
High
Low
energy storage
NEESC is funded through a contract
with the U.S. Small Business Administration (SBA)
Sources:
IHS Automotive
U.S. Census Bureau
0
20
40
Miles
December 5 2016


New Jersey: Market Potential for Hydrogen and Fuel Cell Stationary Applications
N
Legend
Military
Port
Commercial Airport
Healthcare & Lodging
Government Owned Building
Public Order & Safety
Education
Food Sales & Service
Large Retailer
WWTPs & Landfill
Energy Intensive Industry
Wireless Telecommunication Tower
Area Served by Natural Gas
energy storage
NEESC is funded through a contract
with the U.S. Small Business Administration (SBA)
Sources:
Disclaimer:
Information presented in this map is for planning purposes only.
No representation as to the accuracy of the data depicted
is implied.
Plainsboro
Bergen County Area
Hazlet - Tinton Falls
Moorestown Area
0
20
40
Miles
March 8, 2017

Appendix VII. Federal laws and incentives related to fuel cells

Incentives

1) **Airport Zero Emission Vehicle (ZEV) and Infrastructure Incentives** – provides funding to public airports for up to 50% of the cost to acquire ZEVs and install or modify supporting infrastructure for acquired vehicles.
2) **Alternative Fuel Corridor (AFC) Grants** – provides funding for installing infrastructure to convert Corridor-Pending AFCs to Corridor-Ready AFCs, and for installing infrastructure for Corridor-Ready AFCs to meet higher demand.
3) **Alternative Fuel Tax Exemption** - the IRS deems certain uses of alternative fuels nontaxable, such as when used by non-profit educational organizations, state use, school buses, farming purposes, and certain local buses.
4) **Alternative Fuel and Advanced Vehicle Technology Research and Demonstration Bonds** - provides funding for capital expenditures on qualified energy conservation research and demonstration projects related to non-fossil fuels and technologies.
5) **Clean School Bus** - provides funding (up to 100%) for replacement of existing school buses with alternative fuel or ZEV buses and infrastructure.
6) **Community Alternative Fuel Infrastructure Grants** - provides (up to 80%) funding to expand access to gas or alternative fueling charging infrastructure in community locations.
7) **Congestion Mitigation and Air Quality (CMAQ) Improvement Program -** provides funding to state department (governments agencies) for projects/programs that help meet the Clean Air Act requirements by reducing mobile source emissions and congestion on transportation networks.
8) **Environmental Justice Community Technical Assistance Program**- LEAP program facilitates community economic and environmental benefits through DOE's technical assistance in clean energy work.
9) **Freight Efficiency and Zero-Emission Vehicle Infrastructure Grants-** provides funding to aid transportation infrastructure projects that address climate change and environmental justice.
10) **Hydrogen Demonstration Project Grants**- funds hydrogen demonstration projects with the goal to reduce the cost of clean hydrogen by 80% to $1/kg in 1 decade, reduce carbon emissions and air pollution, create good jobs, & provide benefits to disadvantaged communities.
11) **Improved Energy Technology Loans**- provides loan guarantees (up to 100%) to projects that reduce air pollution, GHGs, and support early commercial use of advanced technologies (biofuels & alternative fuel chevilles).
12) **Innovative Research and Development Competitive Prizes**- these challenges seek to incentivize entrepreneurs to re-energize innovation, reassure American leadership in the energy marketplace, and connect them to the private sector and the US DOE's laboratories.
13) **Low and Zero Emission Public Transportation Funding updated -** funding is available to local and state governments for the purchase or lease of low-to-zero emission public transit buses and the development of supporting facilities.
14) **Low or Zero Emission Ferry Program-** provides purchase of electric or low-emitting ferries & the electrification of or reduced emissions (alternative fuel-methanol, natural gas, propane, hydrogen & electricity) from existing state serving ferries.

15) **National Alternative Fuels Corridors updated** - FHWA awards grants to officials (local, state, or federal) and industry stakeholders who aim to aid in the use of charging and fueling infrastructure along national highway system.
16) **National Multimodal Cooperative Freight Research Program**- NAS will establish a committee that may award research contracts or grants to those who seek to improve the efficiency and resilience of freight movement including those who look to add zero-emissions transportation.
17) **Port Infrastructure Development Program updated** - fund projects (electrification, micro-grids, worker training, EV charging or h-fueling infrastructure) that improve port resiliency to address sea-level rise, extreme weather events (earthquakes, tsunamis), and projects that reduce or eliminate port related pollutant or GHG emission.
18) **Public School Energy Program**- grants funds for energy improvements (installation of AFV fueling or changing infrastructure) on school grounds and purchase or lease AFVs.
19) **Public Transportation Research, Demonstration, and Deployment Funding** - provides financial aid to government entities, public transportation, private & non-profit organizations, high research institutions; demonstration and deployment projects involving low-to-zero mission public transportation vehicles to reduce energy consumption or harmful emissions.
20) **State Carbon Reduction Program**- funding is used to reduce transportation emissions (electrification, EFVS or zero emission vehicles, charging or fueling infrastructures) and support the development of state carbon reduction strategies.
21) **State Energy Program (SEP) Funding**- provides grants to aid states in implementing renewable energy and energy efficiency programs that reduce carbon emission in the transportation sector by 2050 and raise the use of alternative transport and electrification of vehicles.
22) **Zero Emission Vehicle Infrastructure and Advanced Vehicle Grants**- provides financial aid to transportation infrastructure projects (electric, automated vehicles, reduced GHG emission, zero emission).

Laws and Regulations

1) **Alternative Fuel Definition**- Defines pure methanol, ethanol, other alcohols, blends of 85% or more of alcohol and gasoline, natural gas and liquid fuels derived from natural gases, propane, coal derived liquid fuels, hydrogen, electricity, pure biodiesel fuels, and p-series fuels as alternative fuel options by the Energy Policy Act of 1992.
2) **Alternative Fuel Definition - Internal Revenue Code**- Defines propane, natural gas, liquified hydrogen, liquid fuel derived from coal, liquid hydrocarbons, and p-series fuels as alternative fuel options by the Internal Revenue Service. This purposely excludes biodiesel, ethanol, and renewable diesel.
3) **Alternative Fuel Labeling Requirements**- Labels on fuel dispensers must inform the consumer with the name of the fuel, minimum percent of the main component of the fuel, and percentages of other components. EV supply equipment manufacturers must include kw capacity, voltage, ac or dc distinction, average, and if it is conductive or inductive.
4) (4) **Emerging Alternative Fuel Vehicle (AFV) Study**- Study will include 5 year AFV ownership projections, infrastructure siting locations and graphs of forecasts, evaluation of emerging AFVs to meet infrastructure needs, barriers to deploying AFV infrastructure, and information for states

to evaluate AFV use.(5) **High Occupancy Vehicle (HOV) Lane Exemption**- Vehicles operating on alternative fuels defined by the EPA and vehicles that recharge from external electricity and contain battery life of at least 4 kw hours qualify for this exemption. States can also allow low emission and energy efficient vehicles to pay a toll to access HOV lanes.

5) **Joint Office of Energy and Transportation** - Collaborates the DOT and DOE to manage issues such as technical assistance for EV supply equipment (EVSE) and hydrogen fueling infrastructure, data sharing of any work performed on this equipment, performance of a study of EVSE and hydrogen fueling needs, development of a workforce for this industry, and further research to reduce emissions and climate change.
6) **Procurement Preference for Electric and Hybrid Electric Vehicles**- DOD must make sure electric or hybrid cars are available to consumers by making sure they are a reasonable price in comparison to internal combustion powered cars.
7) **Truck Leasing Task Force**- Will examine truck leasing agreements that decrease port operating emissions and report to Congress.
8) **Vehicle Acquisition and Fuel Use Requirements for Federal Fleets**- Existing federal fleet requirements were reviewed to increase performance while reducing costs. Strategies found were to right size the fleet, reduce miles traveled, implement fuel efficient vehicles, and begin the transition to AFVs and necessary fueling infrastructure.
9) **Vehicle Acquisition and Fuel Use Requirements for Private and Local Government Fleets**- Has a goal to achieve a domestic production capacity for replacement fuels sufficient to replace 30% of the US motor fuel consumption. As of March 2008, the DOE has not implemented a fleet compliance mandate.
10) **Vehicle Acquisition and Fuel Use Requirements for State and Alternative Fuel Provider Fleets**- State that any fleet operating 50 vehicles or more must acquire AFVs as a portion of their acquisitions. Doing so will earn them a credit that can be banked toward future compliance.
11) **Vehicle Incremental Cost Allocation**- The US General Services Administration must allocate incremental cost of purchasing AFVs across all vehicles distributed by the GSA.

Appendix VIII. Hydrogen safety codes and standards development organizations

ORGANIZATION		RESPONSIBILITY
AGA	American Gas Association	Materials testing standards
API	American Petroleum Institute	Equipment standards for petroleum production, storage, and handling
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers	Promoting sustainability through research, standards writing, publishing, and education
ASME	American Society of Mechanical Engineers	Mechanical and multidisciplinary engineering, design codes and standards
ASTM	American Society for Testing and Materials	Technical test standards for materials, products, systems
CGA	Compressed Gas Association	Equipment design and performance standards for compressed gas systems and components
CSA	CSA Standards	US and Canadian equipment standards
GTI	Gas Technology Institute	Supplies technical support and training for the energy industry
ICAO	International Civil Aviation Organization	Promotes understanding and security through cooperative aviation regulation
ICC	International Code Council	Family of model building codes, including the International Fire Code
IEC	International Electrotechnical Commission	International performance standards
IEA	International Energy Agency	Energy policy advisor to 28 member countries ensuring clean energy for their citizens
ISO	International Organization for Standardization	Supports US concerns at key international codes and standards
OIML	International Organization of Legal Metrology	Intergovernmental treaty organization
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy	Facilitating commercial utilization activities related to hydrogen and fuel cell technologies
IEEE	Institute of Electrical and Electronics Engineers	Electrical standards
NFPA	National Fire Protection Association	Model codes and standards, including the National Electric Code
NIST	National Institute of Standards and Technology	Measurement standards
SAE	SAE International	Vehicle standards
UL	Underwriters Laboratory	Equipment and performance testing standards
UN	United Nations	Developing friendly relations among nations to promote social progress and human rights

Source: https://www.energy.gov/eere/fuelcells/standards-development-organizations[118]

Appendix IX. High School and Other Higher Education Opportunities in New Jersey

Several high schools from Morris, Sussex, Union, and Middlesex counties have participated in the TransOptions Hydrogen Challenge, where students designed, built, and raced model fuel cell cars.[169] TransOptions provides teachers with kits (motor, gears, battery holder, wheels, axles) and a mini fuel cell, and awards prizes to students for craftmanship, engineering, and the speed of their racecars. Hands-on educational activities like this allow youth to gain an early interest in the processes (chemistry, physics, and engineering) behind the end-result, supporting continued appeal towards STEAM (Science, Technology, Engineering, Arts and Mathematics) education and careers.

Continuing Education and Development (CED) offers an online engineering professional development course on Fuel Cell Basics.[170] The three-part course is designed for engineers who want to learn more about renewable energy. The CED certificate provided upon completion is accepted in 43 states, including NJ. EdQuip, a technical training systems company, distributes didactic equipment for teaching about renewable energy, including hydrogen fuel cells.[171] EdQuip has created a guide that emphasizes the relevance of hydrogen training and provides best practices and tools for providing training in the field. The guide is intended primarily for those involved in teaching or training students or employees in hydrogen and fuel cell technologies. They've partnered with Horizon Educational and Heliocentris Academia to provide training programs on renewable energy technologies, including PEM fuel cell systems and FCEVs, battery hybrid systems, and energy storage.

In addition to these opportunities and those listed in chapter 4, Tables A.3 and A.4 highlight other 2-year and 4-year colleges and universities in New Jersey.

Table A. 3 Other 4-year colleges and universities in New Jersey (see Education & Workforce Development chapter for more higher education information)

Name	Location	Relevant Existing Programs	Fuel Cell Activity
Caldwell University	Caldwell	Offers BA Environmental Science.	NF
Centenary University	Hackettstown	Offers BS in Data Analytics, Sustainable Practices, and Environmental Science	NF
College of Saint Elizabeth	Morristown	Offers BS in Chemistry, Physics and Data Science.	NF
Drew University	Madison	Offers BS in Chemistry, Physics Engineering, Engineering Physics, Environmental Science, Environmental Management, and Environmental Studies and Sustainability. Offers MS in Data Analytics.	NF
Farleigh Dickinson University	Teaneck	Offers BS in Chemistry, Physics, Electrical Engineering, Mechanical Engineering. Offers MS in Electrical Engineering.	NF

Georgian Court University	Lakewood	Offers BS in Chemistry and Physics.	NF
Kean University	Union	Offers BS in Environmental Science.	School of Environmental and Sustainability Science has faculty members with expertise in clean energy.
Monmouth University	West Long Branch	Offers BS in Chemistry and Physics and MS in Data Science.	School of Science has faculty researching energy transfer efficiency.
New Jersey City University	Jersey City	Offers BA Sustainability Studies, BA and BS in Environmental Science.	NF
Ramapo College of New Jersey	Mahwah	Offers BS in Chemistry, Physics, Data Science, Engineering Physics, Environmental Science, Environmental Studies.	In 2002, two 200 kW fuel cells were purchased to provide a portion of heat and power to a computer lab and parking area.[172]
Rider University	Lawrenceville	Offers BS Chemistry, Physics Environmental Sciences, and Supply Chain Management.	Has 10 total EV charging stations on campus.[173]
Seton Hall University	South Orange	Offers BS in Chemistry, Physics and Environmental Studies. MS in Chemistry. MBA in Supply Chain Management. PhD in Chemistry.	Physics Department research has explored SOFC conductivity films.[174]
St. Peter's University	Jersey City	Offers BS in Applied Science and Technology, Chemistry, Data Science, and Environmental Studies. MS in Data Science.	NF
Stockton University	Galloway	Offer BS in Chemistry, Physics Environmental Science, and Sustainability. MS in Data Science, and PSM in Environmental Science.	Chemistry Department research has explored hydrogen as a renewable energy source and has created semiconductors in collaboration with Rutgers University.[175]
The College of New Jersey (TCNJ)	Ewing	Offers BS Chemistry, Physics, Electrical Engineering, Engineering Science, and Physics.	The Division of Operations released their 2002 EMP, which planned to use fuel cell technology for 600 kW of outside generation.[176]

			Within the Mechanical Engineering Research Mentored Undergraduate Summer Experience (MUSE) research program, the project Effect of Inlet Flow Conditions on Flow Uniformity Within a Fuel Cell Manifold under Dr. Lisa Grega (2013).[177]
Thomas Edison State University	Trenton	Offers AAS in Environmental, Safety, and Security Technologies AAS degree, BS in Energy Systems Technology, and MS in Nuclear Energy Technology Management.	NF
William Paterson University of New Jersey	Wayne	Offers BS in Chemistry, Environmental Science, Physics, Environmental Sustainability, and MS in Materials Chemistry.	NF

**Not all colleges and universities are included in this chart, those without relevant existing programs or fuel cell activities have been excluded.*
**NF= no information found*

Table A. 4 Community colleges in New Jersey

Name	County Served	Fuel Cell Activity
Atlantic Cape Community College	Atlantic, Cape May	NF
Bergen Community College	Bergen	Biology professor and students developed microbial fuel cells from soil.[178]
Brookdale Community College	Monmouth	NF
Rowan College at Burlington County	Burlington	NF
Camden County College	Camden	CCC Green Team taking projects focusing on reducing the college's carbon footprint including EV charging stations.
County College of Morris	Morris	NF
Essex County College	Essex	Faculty member has presented on fuel cells.[179]
Rowan College of South Jersey	Gloucester, Cumberland	NF
Hudson Community College	Hudson	Partnered with GE in 2014 to develop a fuel cell technology curriculum at the school's satellite campus (TEC-SMART) in Malta, NY.[180]
Mercer County Community College	Mercer	Offers course in alternative energy which discusses fuel cells within Chemistry Dept.
Middlesex College	Middlesex	NF
Ocean County College	Ocean	Installed 250 kW Direct FuelCell power plant in 2004.[181]
Passaic County Community College	Passaic	NF
Raritan Valley Community College	Hunterdon, Somerset	First carbon-neutral 2-year higher education institution in the country.
Salem Community College	Salem	NF
Sussex County Community College	Sussex	NF
Union County College	Union	NF
Warren County Community College	Warren	NF

**NF = no information found*

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Endnotes

[i] A dispatchable electric generating source is a source that can be called upon in real time to respond to increased electric demand.

[ii] "Blue Sky" represents nominal conditions where the electric grid is operating within normal limits and all connected load is balanced with available generation, and excursions are anticipated and covered through incremental capacity procurements.

[iii] "Gray Sky" represents abnormal operation where grid stresses create abnormal voltages and frequencies and require adjustment or isolation of the grid connected edge devices.

[iv] 1.00784 is the atomic weight of hydrogen.

[v] The Hydrogen Safety Panel (HSP) (https:h2tools.org/hsp) was formed in 2003 and represents almost 500 years of combined industry and hydrogen experience. The 18-member panel is comprised of a cross-section of expertise from the commercial, industrial, government, and academic sectors. They help integrate safety planning into hydrogen and fuel cell projects to ensure that the appropriate safety practices are addressed and incorporated. This HSP also reviews safety plans and hydrogen fueling station designs as part of the CEC competitive grant funding in the State of California. The HSP is a fee-for-service organization and can be consulted to review innovative projects and provide feedback and insights to both station developers and AHJs through the Center for Hydrogen Safety (www.aiche.org/chs).