New Jersey: Opportunities and Options in the Hydrogen Economy

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CENTER FOR ENERGY, ECONOMIC & ENVIRONMENTAL POLICY

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Preface

This report describes to policymakers and stakeholders the opportunities and options for state policy to facilitate the commercialization of hydrogen fuel and build out of related infrastructure with a particular focus in New Jersey. A fundamental question must first be considered: Can we really manage technological transitions? Scott Weiner and Clinton Andrews recently addressed this question in the context of a hydrogen economy in a paper published in *IEEE Power and Energy Magazine*. [1]

Can we really manage technological transitions?

There's no disputing the world's progression through several energy eras, from the predominance of wood, to coal, to oil, toward less carbon-intensive natural gas and nonfossil sources. In freight transportation, there has been a centuries-long evolution from walking, to beasts of burden, to ships, to railways, to trucks, to aircraft. Similar transitions are apparent in most areas of human endeavor. Historians of technology point to regularities in technological transitions, showing that major innovations follow an S-shaped trajectory of market penetration, only slowly wax and wane in popularity, and depend on complementary innovations to be successful. The historians have identified regular stages from innovative market niche, to rapid adoption and imitation, to saturation and maturation, to decline and substitution. Managers, especially in industries with short product cycles such as consumer electronics, have embraced these models of technological transitions and use them in strategic planning. Government officials charged with managing the public R&D portfolio also use these models widely.

But just because successful innovations follow a regular path, does that mean we can actually engineer large-scale technological transitions? There is good reason to be skeptical. Introducing the hydrogen era is no one manager's job. If it happens, it will require concerted efforts by thousands of individuals, lucky breakthroughs on several technological fronts, and support from society's largest and sometimes most recalcitrant economic and political institutions.

But neither does that mean that modern technology evolution has been the outcome of random acts nor that private and public institutions do not have an essential proactive role to play in charting the course to the next era of fuel. "Free markets" versus "planning" is a false dichotomy. In fact, the evolution from horses to horsepower and kerosene lamps to electric lights represents the interplay of discovery, consumer demand, public incentives, and private motivation by both suppliers and consumers. We need not and must not leave the evolution to the next generation of fuel to be characterized as the result of random actions that resulted in an unpredictable outcome.

In contrast, all sectors of society should prepare to participate in that process. That preparation will take many forms and will be selected by each acting organization. We suggest that among them should be: 1) Understanding the issues and objectives that satisfy *the needs of the organization; 2) developing a set of strategic interventions that are likely to achieve the sought after objective; and 3) standing ready to implement a strategic intervention when a window of opportunity arises.*

As sectors, industries, and individual organizations define objectives from their unique perspective, each will be able to effectively identify opportunities for collaboration that can lead to success in the terms desired by the organization.

So, the question is not whether a state can manage the transition of its energy portfolio towards hydrogen. Rather, the issue is whether and how a state will elect to actively contribute to the transition process. Whether New Jersey decides to take a leading or adaptive role in managing this transition is up to the policymakers and stakeholders. States, like all enterprises, face the strategic decision whether to be an innovator or an adapter. While the determination is fact-specific, the decision should be informed and not made by default. This report provides the initial discussion of the issues facing hydrogen commercialization and sets out a number of policy recommendations to guide the state towards making this decision.

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Scott Weiner, Director of the Center for Energy, Economic and Environmental Policy (CEEEP) served as the Principal Investigator for this study. Dan Benson, Project Manager at CEEEP, lead the research and drafting of the report. Nora Lovrien, a Graduate Research Assistant at CEEEP, made significant contributions to the research and writing of this report.

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Summary of Recommendations

Policymakers must determine if and how hydrogen fits into their energy policy goals. Proponents of hydrogen see it as a solution to dwindling fossil fuel resources, dependence on foreign oil and negative environmental impacts. Detractors contend that hydrogen is unproven, requires a whole new infrastructure, and is a costly diversion from greater fuel efficiency standards and renewable energy solutions. Under President George W. Bush, hydrogen has become a central part of federal energy policy. While at the federal level, easing the U.S. dependence on foreign oil is driving the push for hydrogen, state policy reflects concerns focused on airborne emissions. About one third of the states incorporate hydrogen to some degree as part of their energy or environmental policies. California, Hawaii, New York, Connecticut and Michigan are examples of states that are aligning hydrogen with their own specific policy goals and state interests.

New Jersey has the opportunity to take a leadership role in the commercialization of hydrogen fuel and the build out of its corresponding infrastructure. The decision whether or not to act upon this opportunity will require further analysis of a number of issues, including likely environmental impacts, prospects for economic development, and how other policy initiatives will compete for the attention and resources of the state. Public policies at the state level can have a significant impact on developing technologies. However, regulatory requirements must be achievable, without excessive cost to accomplish the underlying objective. This report makes five specific recommendations that taken individually or together build a foundation for New Jersey to consider its role as a leader in the commercialization of hydrogen fuel and its related infrastructure.

Recommendation #1 - The New Jersey Board of Public Utilities, Office of Clean Energy, should proceed with its initiative to establish a Hydrogen Learning Center to act as a focal point for education and outreach for all New Jersey's stakeholders regarding the state's consideration of policies related to hydrogen fuel.

The Office of Clean Energy requested that this study specifically consider the value of establishing a Hydrogen Learning Center. Such a center can be an effective vehicle for the required education, outreach and involvement, and can facilitate collaboration among a number of state colleges and universities in research and curriculum development. The Center can also serve as a venue and vehicle for consultation among all stakeholders. The establishment of the Center will prepare stakeholders to make informed contributions to state policies addressing the role of hydrogen fuel as a part of the state's energy portfolio and as a component of a strategic policy determination that holistically considers the energy, economic and environmental implication of action or inaction.

Recommendation #2 - The state should initiate a New Jersey Hydrogen Vision and Roadmap process.

Building upon the demonstrated success of similar Vision and Roadmap processes initiated by the U.S. Department of Energy (DOE) and other states, New Jersey can construct a framework for public-private cooperation in the development of policy recommendations for consideration by the Governor and Legislature. This process would help New Jersey determine its overall strategy on hydrogen as to whether or not it will take a leading role in the commercialization of hydrogen fuel and infrastructure deployment.

Recommendation #3 - The Governor should consider establishing a Hydrogen Policy Working Group across key state departments and agencies.

The working group should include the senior officials at the Board of Public Utilities, Department of Environmental Protection, Economic Development Authority, Commerce and Economic Growth Commission and the Department of Transportation. Collectively, the working group would coordinate a review of the state policy implications of a leading or adaptive approach to hydrogen fuel commercialization. As such, the working group would be an important complement to the Vision and Roadmap process.

Recommendation #4 - The Office of Clean Energy should continue to encourage the deployment of fuel cell applications in the state through its clean energy programs.

New Jersey has been successfully involved in demonstration projects with fuel cells and hydrogen technology. Those efforts can be enhanced and expanded as part of a strategic policy initiative. Moreover, the state can expand its own direct participation through programs such as the deployment of fuel cells at state institutions and the use of a portion of the state vehicle fleet and related fuel infrastructure as part of a coordinated demonstration project.

Recommendation #5 - The state should expand on the research programs in basic and applied research at New Jersey universities to assist in solving the technical barriers to hydrogen fuel and infrastructure deployment.

Regardless of the path chosen by New Jersey policymakers and other stakeholders with respect to hydrogen, remaining committed to new energy sources and technologies will be important to ensure a sustained energy supply, strong economic growth and continued environmental stewardship for the Garden State.

Introduction

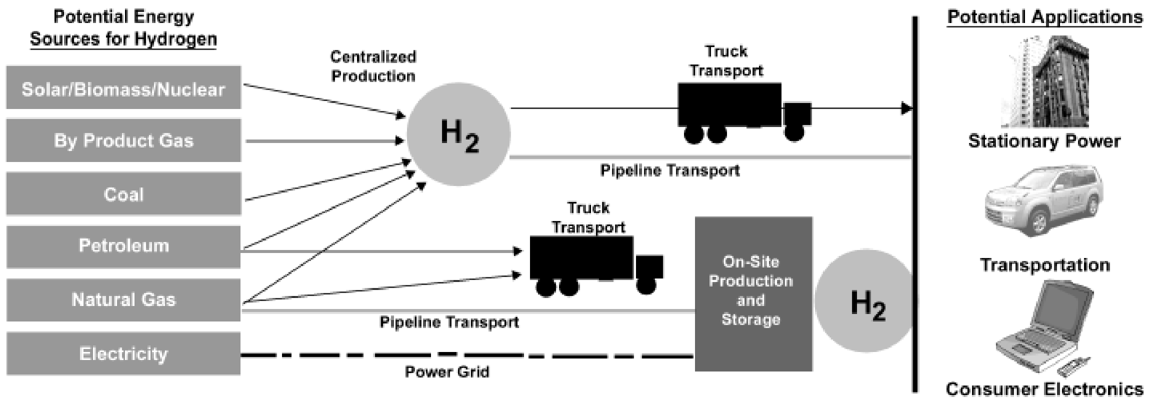
Policymakers must determine if and how hydrogen fits into their energy policy goals. Proponents of hydrogen see it as a solution to dwindling fossil fuel resources, dependence on foreign oil and negative environmental impacts. Detractors contend that hydrogen is unproven, requires a whole new infrastructure, and is a costly diversion from greater fuel efficiency standards and renewable energy solutions. Different policy drivers influence the debate over the need for hydrogen as a fuel. While at the federal level, dependence on foreign oil is driving the push for hydrogen, the state governments are mostly being driven by concerns over airborne emissions. Under President George W. Bush, hydrogen has become a central part of the federal energy policy. At the state level, about one-third now incorporate hydrogen to some degree as part of their energy or environmental policy. California, Hawaii, New York, Connecticut and Michigan are examples of states that are aligning hydrogen with their own specific policy goals and state interests.

Strategically positioned at the center of the technology rich and densely populated Boston-Washington, DC corridor, New Jersey may be in a position to emerge as a regional leader in developing a hydrogen infrastructure and economy. The goal of this report is to provide New Jersey policymakers, business leaders and other stakeholders with information that they can use in determining what role, if any, the commercialization of hydrogen fuel should play in the state's energy and economic policies.

Hydrogen, like electricity, must be manufactured from other sources. Any form of energy – fossil, renewable or nuclear – can be used to generate hydrogen. Each has its own set of advantages and disadvantages that policymakers must sort through and weigh to gauge the various trade-offs. Renewable energy and nuclear energy can produce hydrogen from water through electrolysis. Natural gas, coal, gasoline, and propane can yield hydrogen using a process called reformation. This diversity of possible production methods, coupled with the fact that hydrogen used in fuel cell applications is totally emission free at the point of electric generation, has gained hydrogen an equally diverse set of supporters. Environmental groups; oil, natural gas and nuclear energy companies; automobile manufacturers and stationary power companies all regard hydrogen as a potential future source of energy. However, the different processes used to extract hydrogen, some argue, can be costly, energy intensive or create their own sources of pollution. This has generated criticism that there are more proven, less costly ways to reduce pollution and energy consumption.

This report identifies these and other key policy issues and provides the information for policymakers, business leaders and other stakeholders to make informed decisions on hydrogen. State and local public-private partnerships will play

Figure 1. Hydrogen Production, Distribution, Storage and Applications [2]



a significant role in determining how or whether the much talked about hydrogen economy develops in the United States. Figure 1 below illustrates some of the many, complex possibilities for hydrogen production, distribution, storage and applications that policymakers, business leaders and other stakeholders will need to consider in the context of a potential transition to hydrogen fuel.

The number of configurations for hydrogen infrastructure will likely reduce over time as inefficient combinations are abandoned. However, it is unlikely that only one of these infrastructure paths will be adopted for all applications in all areas. Application and regional requirements will produce different infrastructure results. The lack of an existing nationwide hydrogen infrastructure is cited by many as a significant challenge to adopting hydrogen as a future fuel. However, for proponents, the potential benefits if successful – a truly clean, domestic and renewable fuel – are worth overcoming any initial obstacles. The initial sections that follow provides a brief introduction to the basics of hydrogen and fuel cells, summarizes the current hydrogen political and policy landscape, and hydrogen's commercialization issues, and outlines relevant information about New Jersey that will affect a potential transition to the commercialization of hydrogen as a fuel. This is followed by a discussion of the policy options all stakeholders can consider in deciding whether New Jersey should take a leading role to facilitate a transition to a hydrogen economy.

Chapter 1: Hydrogen and Fuel Cell Basics

In order to understand the key commercialization issues facing hydrogen and fuel cells and the subsequent policy questions that arise, it is important to first discuss the properties of hydrogen and the state of fuel cell technology. This section examines the chemical properties of hydrogen gas, the technology and types of fuel cells, fuel cell applications and hydrogen production. This will provide some familiarity with the basic concepts and provide a common foundation from which to examine more thoroughly the choices facing policymakers, business leaders and other stakeholders.

Hydrogen Properties

Hydrogen is the simplest of all elements with one electron and one proton. Two hydrogen atoms form one hydrogen gas molecule, or H_2, but this gas is rarely found in large quantities in nature. Hydrogen's chemical properties allow it to combine easily with other elements to form other molecules. The simplest example is hydrogen's presence in water, or H_2O. As water makes up 70 percent of the Earth's surface, hydrogen is in abundant supply. Moreover, hydrogen can be extracted from fossil fuels through reformation. Similarly, hydrogen can be extracted from organic materials such as bio-waste, solid waste, landfill gases or biomass (agricultural products specially grown for fuel or parts of agricultural products, such as stalks and stems, not used for human or animal consumption).

Hydrogen has the highest energy content by weight of any fuel – 52,000 Btu per pound. [3] Hydrogen gas is nontoxic with no color, odor or taste; a pure hydrogen flame is invisible without special glasses. Like gasoline, hydrogen ignites easily. Hydrogen compared to other gases has a high diffusion rate, the process by which the gas molecules spread out and interact as a result of energy and random motion. This requires that hydrogen be stored in ways to ensure the gas has a reasonable density for applications.

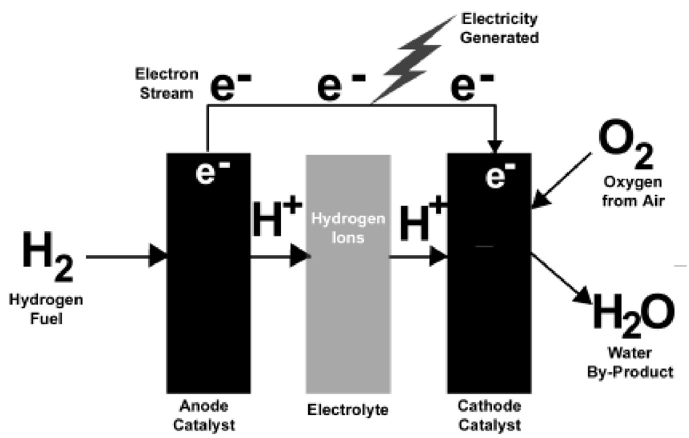
Hydrogen can be used to increase efficiency in internal combustion engines (ICEs). It is estimated that a direct-injected hydrogen ICE could have 20-25 percent greater efficiency than a similar gasoline ICE. [4] However, most proponents of hydrogen envision its use to generate electricity when powering a fuel cell. In a fuel cell, the theoretical efficiency can reach 83 percent; in practice 60 percent of hydrogen's energy is converted to electricity with the rest generating heat energy that can be used in combined heat and power (CHP) applications. Comparing gasoline to hydrogen, the energy in one gallon of gasoline is roughly the equivalent to 1 kg of hydrogen. [5] By weight, hydrogen has about three times the amount of energy as gasoline.

Most hydrogen today is not used as a fuel source, but rather as a chemical for oil refining and ammonia production. [6] About two-thirds of industrial hydrogen is used in ammonia production for fertilizer. [7] Hydrogen can also be used in fat hydrogenation, methanol production, welding, and the production of hydrochloric acid. To give an idea of the amount of hydrogen in use in today's economy, the small amount of merchant hydrogen produced in the United States in 2002, according to one estimate, could suffice to support a fleet of 20-30 million fuel cell cars. [8]

Fuel Cells

The technical understanding of fuel cells has existed since the 19th century. Fuel cells were first created in 1839 by Sir William Grove and refined in 1932 by Francis Bacon. The most well known application of fuel cells was aboard NASA space shuttles to provide electricity to various systems. A fuel cell provides electricity in a manner similar to a battery. Like a battery, a fuel cell produces direct current (DC) power, not alternating current (AC) power. However, the fuel cell can continue to provide energy so long as a fuel is present. A battery, in contrast, has a finite storage of energy before it needs to be recharged. A graphical depiction of the electrochemical process of turning hydrogen fuel into energy using a fuel cell is shown in Figure 2. All fuel cells contain an anode, cathode and electrolyte. The hydrogen fuel is broken into electrons and protons by virtue of a catalyst, and combines with oxygen supplied to the fuel cell to create electricity, water and heat.

Figure 2. Diagram of Fuel Cell Operations [9]



The hydrogen fuel is fed into the anode (a negative electrode that repels electrons) of the fuel cell. Oxygen enters through the cathode (a positive electrode that attracts electrons). Encouraged by a catalyst, such as platinum, the hydrogen atom splits into a proton and an electron. The electrons cannot permeate the electrolyte and therefore are released through an external current to produce electricity. The hydrogen protons filter through the electrolyte to the cathode. The electrons provide an electrical current before returning to the cathode to be reunited with the hydrogen and oxygen (usually coming from ambient air, but sometimes pure oxygen) in a molecule of water.

Types of Fuel Cells

There are different types of fuel cells that can be used to generate energy. The properties of each fuel cell provide the basis for deciding their most suitable application. The top fuel cell designs are Polymer Electrolyte also known as Proton Exchange Membrane (PEM), Phosphoric Acid, Molten Carbonate, and Solid

Table 1. Types of Fuel Cells.

	Polymer Electrolyte Membrane Fuel Cell (PEM)	Phosphoric Acid Fuel Cell (PAFC)	Molten Carbonate Fuel Cell (MCFC)	Solid Oxide Fuel Cell (SOFC)
ELECTROLYTE	Polymer	Phosphoric Acid	Molten Carbonate Salt	Ceramic
OPERATING TEMPERATURE	175°F (80°C)	375°F (190°C)	1200°F (650°C)	1830°F (1000°C)
FUELS	Hydrogen Reformate	Hydrogen Reformate	Hydrogen and Carbon Monoxide Reformate	Hydrogen, Carbon Dioxide and Methane Reformate
REFORMING	External	External	External/Internal	External/Internal
OXIDANT	O_2/Air	O_2/Air	CO_2/O_2/Air	O_2/Air
APPLICATION	Small stationary or transportation applications	Small distributed generation units	Large stationary applications, combined heat and power units	Industrial applications, combined heat and power units, possible residential uses
TECHNOLOGY STATUS	Demonstration/ Commercial	Commercial	Demonstration	Development/ Demonstration

Oxide. Main characteristics of each fuel cell design presented in Table 1 and the text that follows below are adapted from the U.S. Department of Defense's online *Fuel Cell Information Guide*. [10] There are a few other types of fuel cells, but these are the models being developed and marketed by manufacturers for commercial applications.

Polymer Electrolyte/Proton Exchange Membrane Fuel Cell (PEM) - The PEM fuel cell uses an advanced plastic electrolyte to move protons from the anode to the cathode. The PEM uses a solid electrolyte and operates at a low temperature. The PEM uses a thin platinum catalyst to split the electrons from the hydrogen protons. PEM fuel cells are best suited for 1kW to 100kW applications.

Phosphoric Acid Fuel Cell (PAFC) - This fuel cell has been commercially available since 1992. The PAFC is suited for small Distributed Generation (DG) units. They are highly reliable, quiet to operate, and highly efficient. The PAFC runs at a medium temperature range and uses impure hydrogen, which makes them more flexible with multiple sources of hydrogen and production methodologies.

Molten Carbonate Fuel Cell (MCFC) - MCFCs use a ceramic electrolyte filled with carbon and salt. MCFCs operate at high temperatures (800°F), which best suits them for large stationary applications. These fuel cells operate at 85 percent efficiency when operated in conjunction with traditional energy grids. MCFCs are currently used in many demonstration projects, and are expected to be market ready in 2004. Large buildings like hospitals, hotels, or other industrial facilities that require electricity and heating (or cooling) around the clock would be likely applications for the MCFC.

Solid Oxide Fuel Cell (SOFC) - These fuel cells are considered utility grade and are well suited for large-scale stationary power generators that could provide electricity for factories or towns. SOFCs use a ceramic oxide electrolyte. Like MCFCs, they operate at higher temperatures (about 1,000°F) and work best as cogeneration devices for industrial applications where high temperature steam is required. These should be commercially competitive in the 2005 to 2007 timeframe. SOFCs are also being developed for residential CHP applications.

Hydrogen Applications

Hydrogen's proponents envision a future where end uses for energy are domestically supplied principally by hydrogen through the generation of heat and electricity. This, they argue, will complete the historical transition from a carbon-based energy economy to one based on carbon-free hydrogen. The transition from solid fuels (like wood and coal) to liquid fuels (like oil) and then to gaseous fuels (like natural gas) has decreased the amount of carbon in each unit of fuel. With hydrogen as a fuel this transformation becomes complete, providing energy to applications in transportation, stationary CHP systems, portable power systems and microelectronics without carbon. Critics charge that if fossil fuels like coal and natural gas are used to produce hydrogen, the dependence on carbon-based energy will only continue. Also, the transition from solid to gaseous fuels has never been a complete one. Even as natural gas usage has increased, coal continues to be a dominant source of electricity generation and related greenhouse emissions.

Transportation modes, from automobiles to trucks and specialty vehicles, would be powered hydrogen fuel cells. Stationary power to buildings is provided through cogeneration of electricity from fuel cells and through heat generated from hydrogen electric conversion. Heat is captured to provide additional ambient environmental control. Portable fuel cell systems would replace portable gasoline generators for various power needs. Micro-fuel cells, using a direct methanol version of a miniature PEM fuel cell, would provide power to consumer electronics such as laptops and cell phones. How hydrogen is generated and distributed in this future is the source of heated debate among hydrogen's proponents; critics argue that alternatives to hydrogen can provide greater short-term benefits.

Many hydrogen and fuel cell research, development and demonstration (RD&D) projects are aimed at creating vehicles that can be powered by fuel cells. The primary objective is to replace the current ICE with a fuel cell "stack" (multiple fuel cells bundled together to provide produce more power) to power the various systems of the vehicle. The challenges faced in achieving this goal differ depending on the type and use of the vehicle – personal vehicles or fleet applications. Personal automobiles are consumer owned, residentially stored and range from compact cars to light trucks (such as SUVs). Fleet vehicles are generally government or commercially owned, have defined routes of travel, generally are stored in a central location, and often centrally fueled as well. Examples of fleet vehicles include taxis, buses, trucks, and delivery vehicles. While transportation often is the main focus of the debate between hydrogen proponents and its critics, there are other applications that also employ hydrogen fuel cells and may provide less controversy.

Hydrogen fuel cells can be used in distributed generation (DG) systems to power buildings. Distributed generation describes small electricity-generating power plants that are located near or at the site of the end user. Not all DG systems use hydrogen fuel cells, but their potential high efficiencies and low environmental impact at the point of deployment have made them attractive to DG proponents. The onsite storage, production and release of hydrogen in DG systems can be in a cogeneration configuration where the heat generated in operating fuel cells can be used to provide climate control, thereby increasing the function, efficiency and value to the system. In addition, portable gasoline generators used in a variety of applications can be replaced with quieter, cleaner, more efficient hydrogen fuel cells. Furthermore, both stationary and portable fuel cells offer the potential for reduced permitting and site rules due to their low to zero emission operation.

Consumer electronics are also envisioned to be powered through the use of a fuel cell. The range of power generated from these fuel cells, which are still under development, is between 25 watts and 10 kilowatts of power. In these applications, the goal is to create a fuel cell that would provide a much longer operating life than a conventional battery, in a package of lighter or equal weight per unit of power output. Fuel cells also have an environmental advantage over batteries, since certain kinds of batteries require special disposal. If successfully developed, these "micro" fuel cells could deliver much higher power density, storing more power in a smaller space than current batteries.

Hydrogen Production

In hydrogen production there are four considerations:

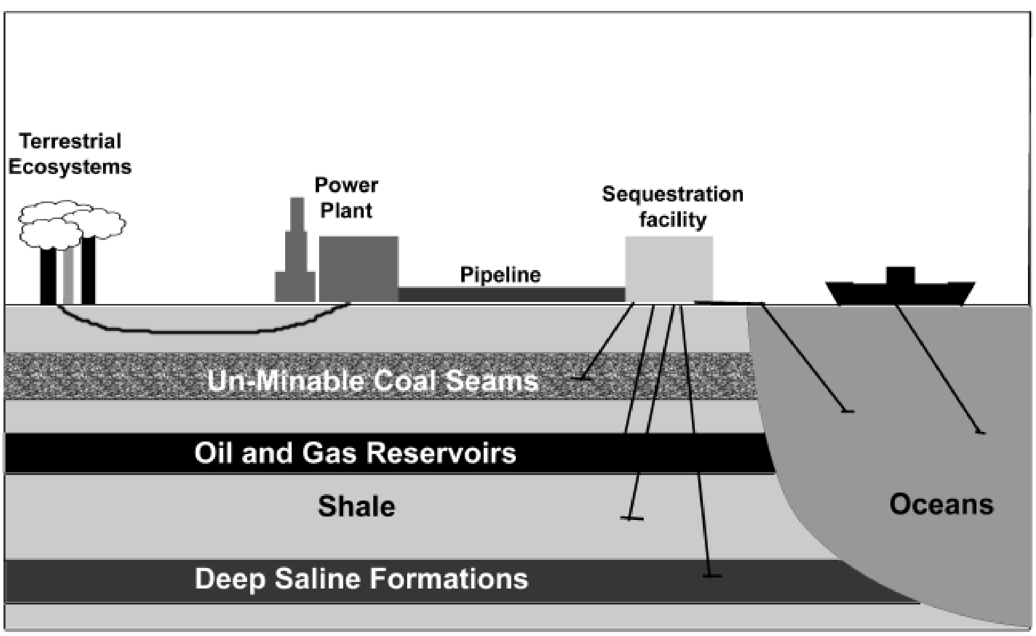
- The process used – electrolysis, reformation, partial oxidation or gasification;
- The source of the hydrogen - water, fossil fuels, biomass or landfill gas;
- The source of power in the process – nuclear, renewable energy, grid electricity or fossil feedstock; and
- The byproducts of production – CO_x and SO_x emissions or nuclear waste.

Each of these considerations brings with it a set of trade-offs and policy implications. While economic realities and market forces will guide what forms of hydrogen production will be used, existing policies and new initiatives will create the rules under which the market will operate and affect how hydrogen competes. The differing benefits of each source of hydrogen to policy goals such as energy independence or reduced emissions will drive policymaking. Lifecycle analysis such as described later in this report benchmarks the relative benefits of different hydrogen production methods compared to gasoline and other fuel options.

Electrolysis, at its simplest, breaks water molecules down into hydrogen and oxygen gas molecules by running an electric current through a cathode and anode present in water. Often a catalyst is used to speed the chemical reaction. The electricity can come from fossil power plants, renewable energy sources, or nuclear energy. In 2002, about 4 percent of the world's hydrogen was produced using electrolysis. [11] This form of production can be prohibitive in terms of capital and energy costs. Controlling these costs is essential for electrolysis to become a viable option for a hydrogen fuel infrastructure.

Two processes use fossil fuels to extract hydrogen: steam reformation and partial oxidation. Steam methane reforming uses high temperatures to extract hydrogen from natural gas, propane, biogas, landfill gas, or methane. In the process, carbon dioxide

Figure 3. Carbon Sequestration Options [13]



is a byproduct. Steam methane reforming can be done at a number of scales, from large centralized production to small, onsite DG units. In this process, the methane or CH_4 in natural gas is heated in the presence of a catalyst to create a chemical reaction that removes an initial amount of hydrogen. The resulting components are then mixed with steam in order to generate greater concentrations of hydrogen while producing CO_2 as the waste product. In the process of partial oxidation, the fuel source is combined with pure oxygen or air at high pressures and temperatures. The source may be oil, gasoline, methanol, or biomass. During the process, some of the fuel content is burned in order to create steam and high temperatures to produce hydrogen, carbon monoxide, carbon dioxide and smaller contaminants. The hydrogen is then separated out and used for desired applications. Heat from the processes during partial oxidation is controlled using steam, and any byproducts are used to run gas turbines in combined cycle systems to improve overall efficiency. The carbon dioxide produced is greater than natural gas steam reformation and can be captured.

Biomass and landfill gases are possible approaches for using existing domestic sources of fuel for hydrogen. A number of different research and development programs, some at the demonstration stage, have provided examples of hydrogen production using partial oxidation of biomass sources. These sources include agricultural products like corn, animal waste, and organic trash. While in most cases this hydrogen has a higher production cost than natural gas steam reformation, it can provide an additional revenue stream and reduce disposal costs and excess material. Altogether this makes the production of hydrogen a potentially positive venture in these circumstances. Since approximately half of most trash going into landfills is made up of organic material, trash may become a source of hydrogen for municipalities and counties looking to reduce transportation and landfill costs associated with solid waste disposal. Agricultural companies can use excess crops or crop byproducts to create hydrogen either directly or as a byproduct of fertilizer production. Biomass and landfill production of hydrogen creates CO_2, and landfills also must remove sulfur and other impurities before production of hydrogen through the use of scrubbers or other separation technology.

The large quantities of coal available in the US have led many to look at generating hydrogen from that source. In a process called coal gasification, coal is subjected to high temperatures and mixed with steam and oxygen. This creates a reaction that generates hydrogen, carbon monoxide and various impurities. The H_2 and CO mixture is cleansed of impurities and mixed again with steam at lower temperatures to create pure H_2 and CO_2 gas. The hydrogen is separated for use and the CO_2 is either vented or captured. No coal plants currently exist beyond the demonstration phase that are designed to optimally generate hydrogen and separate CO_2. The U.S. Department of Energy (US DOE) has funded a project called FutureGen, an integrated gasification combined cycle (IGCC) coal plant that will be a test bed for coal gasification technology and hydrogen production with carbon capture and minimal production of other harmful gases.

Steam reformation, coal gasification, and partial oxidation all generate emissions of carbon dioxide, carbon monoxide, and other environmentally harmful substances, a major concern for environmentalists, since the overall advantages of hydrogen as a clean fuel would be significantly reduced. Those proponents of using fossil fuels like coal for production of electricity or hydrogen believe that one solution is through carbon sequestration. In carbon sequestration, carbon dioxide created as a result of hydrogen production from fossil fuels is pumped into the ground to prevent its release into the atmosphere. This process captures CO_2 emissions during production and stores them in various locations, such as depleted oil or gas fields, deep coal beds, deep saline aquifers, or deep ocean fields. [12] If successfully developed, this technology would allow hydrogen production from current natural resource supplies while maintaining the environmental integrity of hydrogen as a clean end-use fuel.

Chapter 2: National Hydrogen Landscape

Hydrogen policy is not formed in the vacuum of a laboratory or in the decisions of boardrooms. Federal energy policy, stakeholder interests, state policy actions and academic research form a mosaic upon which hydrogen is developing as an energy solution. There are competing visions for the direction of hydrogen among proponents, as well as objectors who have a less positive view of hydrogen's prospects. The following sections attempt to summarize these important views and the actions taken in each area. As New Jersey examines its potential role in actively encouraging a transition to hydrogen, many of these same issues and stakeholders will be involved. Understanding the general nature of their arguments will assist in the development and management of state energy policy decisions.

Federal Hydrogen Policy

In the last two years, hydrogen has moved to the forefront of the U.S. energy policy debate. This was fueled by President Bush's National Energy Policy (NEP) released in May 2001 that named hydrogen as a key component of the future energy economy. [14] Hydrogen is briefly mentioned in Chapter 6 of the NEP, *Nature's Power: Increasing America's Use of Renewable and Alternative Energy,* under potential future energy sources. Hydrogen is described in the NEP as a long-term alternative energy technology that is compatible with existing technologies and traditional fuels as well as renewable energy sources. It recognizes the potential for hydrogen to enhance distributed generation systems. The NEP identifies significant challenges to hydrogen as the current high costs of technology, and the ability of vehicles to accommodate the size and weight of current fuel systems. But the biggest obstacle to hydrogen, the NEP concluded, is the cost of production, storage and distribution. Despite these challenges, the NEP recognizes that significant progress is being made on each of these issues and that in the distributed energy market, a first generation of hydrogen fuel cell products are already being deployed.

In February 2002, expanding upon the NEP, the US DOE released a report – *A National Vision of America's Transition to a Hydrogen Economy (Hydrogen Vision)* – based on a series of workshop meetings in late 2001. [15] In its Hydrogen Vision, the US DOE laid out its view of the potential hydrogen economy and the benefits that could be gained. Its major findings were that hydrogen could potentially meet the two greatest challenges in energy policy – reducing reliance on foreign oil and eliminating the generation of pollutants. The report recognized that a transition to hydrogen could take several decades and identified the need to speed up the readiness of hydrogen technology in production, storage and fuel cells. Another transition challenge is the "chicken and egg" issue on infrastructure deployment, whereby consumers demand the same easy access to their energy as they do enjoy today with gasoline, electricity and natural gas, but the required investment will not occur until the demand is sufficient to justify such a ubiquitous build-out. The US DOE's Hydrogen Vision concluded that the federal government and the states must create and maintain energy policies that make hydrogen a priority. Public-private partnerships would be required to develop and transition to a hydrogen economy. Finally, the Hydrogen Vision called for the creation of a roadmap to coordinate the important facets of a hydrogen economy – research, development and demonstration, as well as education, outreach, standards and codes in hydrogen production, distribution and application.

In November 2002, the US DOE released its *National Hydrogen Energy Roadmap* (Roadmap), which was written with input from prominent representatives of public and private sector entities already working in the area of hydrogen. [16] Building on the Hydrogen Vision report, the Roadmap examined the steps the United States should take to make hydrogen the foundation for the future U.S. energy economy. It also discussed the main obstacles to reaching that future. Like the Hydrogen Vision, it called for strong government-industry partnerships and significant, long-term investment to achieve the goals of the hydrogen economy. The Roadmap had more specific recommendations in seven areas – production, delivery, storage, conversion, end-use applications, education and outreach, and codes and standards.

- **Production** – existing commercial processes should be built on and adapted to work within a hydrogen economy as a practical start to the transition. Processes such as steam methane reformation, multi-fuel gasification and electrolysis would be able to make this switch. Additional development is also encouraged for nuclear and solar powered thermo-chemical hydrogen production.

- **Delivery** – demonstration projects are recommended to examine various centralized and distributed infrastructure solutions and their compatibility with end-use applications.

- **Storage** – greater research and development is required to meet commercial application needs, both in existing compression and liquefaction technologies and in newer, advanced hydrides and nano-technologies.

- **Conversions** – the report focused on fuel cell technology and the need to reduce costs and advance research into advanced materials. Further development in reciprocating engines, turbine and process heaters is also encouraged. In order to advance hydrogen applications, the Roadmap sees initial uses in distributed generation, combined heat and power and vehicle fleets. Ultimately, applications should expand into diverse transportation, stationary power and portable uses.

- **End-Use Applications** – the report foresees the use of hydrogen in all spheres of transportation, electricity generation and mobile applications. The main drivers will be cost competitiveness and capacity to meet consumer demands for safe, easy to use, affordable and environmentally friendly products and services. The Report recommends that in developing new energy applications, attention be paid to these drivers from the start to minimize the need to redevelop beyond demonstration and into production. Applications that are initially promising are again suggested in the areas of distributed generation, combined heat and power, and fleet vehicles.

- **Education and Outreach** and **Codes and Standards** – these areas are presented as cross-cutting issues that touch on all aspects of the hydrogen economy. Education and outreach are important to inform consumers about energy choices, safety and environmental impacts. Codes and standards are needed to speed development of design, manufacture and operation of hydrogen technologies. Based on these recommendations, the Hydrogen Roadmap envisions a hydrogen economy that can improve energy supply, security, air pollution, and greenhouse gas emissions – all based on domestic hydrogen energy resources.

On January 8, 2002, U.S. Energy Secretary Spencer Abraham announced for the Bush administration a new partnership between the federal government and the U.S. automotive industry to improve fuel efficiency in consumer vehicles. [17] The program would essentially replace the Clinton administration's Partnership for a New Generation of Vehicles (PNGV), whose goal was to triple the fuel economy of passenger vehicles through hybrid vehicle technology. The new program was called FreedomCAR (Cooperative Automotive Research) and also had the goal of improving fuel efficiency; but the program's focus was on hydrogen fuel cell vehicles. FreedomCAR extended the goal of fuel efficiency targets by 10 years and encouraged research that would result in technology breakthroughs while reducing the cost of fuel cell technology to be used in future Ford, GM and Chrysler vehicles.

In 2003, President Bush announced his Hydrogen Fuel Initiative calling for an investment from Congress of $1.2 billion for hydrogen development and deployment in transportation and refueling. [18] Under the president's initiative, $720 million in new funding over five years would be dedicated to develop technologies and infrastructure to produce, store, and distribute hydrogen for use in fuel cell vehicles and electricity generation. This would be in addition to the president's earlier investments proposed under FreedomCAR. If fully funded by Congress, FreedomCAR and the Hydrogen Fuel Initiative together would produce a total of $1.7 billion over five years to develop hydrogen-powered fuel cells, hydrogen infrastructure and advanced automotive technologies. [19]

Outside of the federal government, there are competing visions for the future of energy in the United States. Two books, one by Jeremy Rifkin and the other by Joseph Romm, exemplify these alternate energy visions. Each takes a view different from the president's hydrogen vision. Rifkin is a frequent author of books on changes in science and technology in society and currently serves as president of The Foundation on Economic Trends in Washington, DC. Rifkin's book *The Hydrogen Economy* is supportive of hydrogen and points to the multiple benefits of a hydrogen economy on energy supply, domestic security, environmental pollution, increased efficiency, and greater reliability and consumer choice. [20] He argues that focusing on better fuel efficiency takes only a short-term approach that will lead to the same transition to hydrogen, but in a shortened time frame most likely characterized by spiking energy prices. Rifkin sees hydrogen as the only long-term solution to all of the energy policy challenges. Romm, a former high-level Clinton appointee in the Department of Energy, believes on the other hand that hydrogen and its perceived benefits are hyped up beyond current realities. His book, *The Hype About Hydrogen,* argues that the actual benefits are smaller and the costs much higher than proponents argue. [21] Romm contends that hybrid vehicle technology can achieve much of the same benefit with fewer technological barriers.

Hydrogen Stakeholders

In the context of these differing visions, several key players are shaping the hydrogen economy debate – automotive, energy, fuel cell, and industrial gas companies, state governments, environmental groups and the academic community. As state policymakers consider whether or how their state will be involved with hydrogen, these stakeholders will be likely participants in the decision-making process. Understanding their support or opposition to hydrogen and the nuanced positions unique to these stakeholders will assist in determining the overall direction the hydrogen debate may take.

Automotive Industry

Domestic and international automakers have invested billions of dollars in developing hydrogen fuel cell powered vehicles. This investment is either in their own fuel cell operations or in partnerships with companies involved in fuel cell and hydrogen technology. Hydrogen offers a number of opportunities that make it worthwhile for these companies to invest in developing these new vehicles. First, fuel cell "engines" can provide up to three times the output and efficiency of current ICEs. [22] Since hydrogen can be made from a variety of sources, ranging from oil and natural gas to "green" solar and wind, the technology becomes fuel neutral. A principal concern for automakers is that hydrogen fuel is economic and accessible for drivers. Finally, and most significantly for automakers faced yearly with new demands regarding the environmental impact of cars and trucks, hydrogen fuel cell powered cars and their zero emission technology remove vehicles from the environmental debate. Automakers can focus on designs based on meeting customer needs rather than government environmental regulations. However, automakers must first overcome the technical issues to achieving these goals. This has not stopped automakers from arguing that new regulations and higher fuel efficiency standards are unnecessary because new technologies will achieve these goals. The date for production of hydrogen-powered vehicles has become a moving target with estimates starting after 2010. [23] Nevertheless, there are hundreds of hydrogen fuel cell vehicles being tested in California and elsewhere today and automakers continue to state their commitment to offer these vehicles to consumers in the next decade.

As previously described, U.S. automakers have joined the federal government in a commitment to fuel cell technology as the future for vehicle production under FreedomCAR. At the time of the announcement of the initiative, the heads of each of the Big Three U.S. automakers made statements of support.

- GM Chairman Jack Smith – "With the FreedomCAR program, we are taking a major step towards creating a future where the vehicle is no longer part of the energy and environmental debate."

- DaimlerChrysler, Chrysler Group CEO Dieter Zetsche – "FreedomCAR focuses on jointly developing technologies that are important to the entire automotive industry. This program allows us to continue to work together as an industry in a way that can make a difference."

- Ford Chairman and CEO William Clay Ford Jr. – "Our companies have made significant progress in reducing the environmental impact of our products. Our participation in FreedomCAR signifies our commitment to continue that progress." [24]

Oil Companies

Oil companies have begun to expand their horizons beyond their core source of revenue and are changing their market view from delivering fuels to delivering energy. This transformation has begun in some companies including BP, ChevronTexaco and Shell. Each has started company branches devoted to hydrogen, fuel cells and other alternative energy sources, and become involved in various partnerships with automakers and fuel cell manufacturers. Other activity has focused on the marketing, business development and public relations aspects of new fuels and technology. In all, a little more than half of the world's leading oil and gasoline companies are investing to some extent in fuel cells or hydrogen as a fuel. [25]

Hydrogen has become of interest to the oil industry because it may provide another revenue stream, can maintain the relationship with its largest use – transportation, and can also prolong the use of oil as hydrogen can be made from fossil fuels. As Lauren Segal, general manager of hydrogen development for BP, stated, "We view hydrogen as a way to really grow our natural-gas business." [26] These companies are also big supporters of carbon sequestration research. If successful and cost effective, this can provide a way to make hydrogen production from fossil fuels a more environmentally sound endeavor as well. The prospect of a "greener" image for this industry has also been a focus of much of the public relations material produced on fuel cells and hydrogen fuel.

Coal Industry

The dwindling supply of fossil fuels and the United States' reliance on foreign sources of oil have brought significant discussion of coal as another source of hydrogen. The United States is estimated to have a 250-year supply of coal. [27] "The coal industry continues to face challenges, however, including prices that have dropped about 30 percent in the past decade and public aversion to what is seen as a dirty fuel," according to Patty Morrison, principal deputy/assistant secretary of land and minerals management for the U.S. Department of Interior. [28] Coal is abundant in the United States, but its carbon content poses a potentially large source of pollution if used to produce hydrogen when compared to oil and natural gas. There are already a large number of coal powered electricity generation power plants, producing half of the nation's electric energy. If plants are either built or upgraded to manufacture hydrogen from coal as well as provide for carbon dioxide capture and sequestration, then coal power plants could also benefit from a hydrogen transition. However, their viability will depend on the ability to combine coal gasification with carbon sequestration. The technology required to optimally produce hydrogen from coal – coal gasification – is significantly more expensive than new coal-burning plants. Since current scrubber and other capture technologies available to coal plants today meet existing environmental standards, there is little incentive to leapfrog into advanced gasification plants. Unless the costs of carbon sequestration are factored into existing plants versus a new gasification plant, gasification will continue to be cost-prohibitive.

Nuclear Energy Companies

Nuclear energy companies are also very much interested in hydrogen. As an energy source that does not produce greenhouse gas emissions, advocates view nuclear-generated hydrogen as another potential product of nuclear plants besides electricity for the grid. This would allow nuclear plants to assume a greater role in the future energy economy. Nuclear power companies argue that long-term production of hydrogen must be done through electrolysis. They further argue that renewables like wind and solar cannot produce baseload power economically in most markets, and that they are too expensive to compete with reformed natural gas as a primary means to produce hydrogen.

Nuclear power companies like Entergy and Exelon are exploring the role that nuclear could play in hydrogen production, and the US DOE wants to exame the potential of nuclear energy as a source for hydrogen production. The challenge for the nuclear industry is that, other than using nuclear generated electricity to generate hydrogen from electrolysis, the technology is still in the research stage and has yet to be developed. Also the challenge of building new plants to meet the needs of a hydrogen economy will require greater public acceptance of nuclear power. Public ambivalence is perhaps the largest barrier to nuclear hydrogen production, with questions of waste handling and storage still unresolved.

Advocacy Groups

There exists a range of positions throughout advocacy groups on hydrogen. For some, hydrogen embodies a cure-all for all of society's energy problems that will usher in a purely green future based on renewable energy and hydrogen fuel. For others, hydrogen is a costly diversion from increased environmental regulation and development of truly renewable resources like solar, wind, hydroelectric and geothermal energy. Some environmental groups are extremely critical of the idea of using fossil fuel to power the hydrogen economy, unless for a short transition to greener sources. [29] This is even more so for nuclear power. Many environmental groups believe the waste material generated by these plants outweighs any benefit from reduced emissions or increased hydrogen production. They see the green potential of hydrogen being spoiled by oil, natural gas and nuclear power companies that will continue to generate large amounts of pollutants or waste producing hydrogen. [30]

While these are the extremes of the debate, they demonstrate the diversity of opinions about hydrogen and its perception within the environmental community. Many environmental advocates are wary about supporting hydrogen because of the many questions that remain about the hydrogen economy. Adding to their concern is suspicion of the commitment to a cleaner environment by the Bush administration, automakers and energy companies. Many environmental groups are concerned about the use of coal and nuclear power to generate hydrogen and perceived attempts to use support for hydrogen as a reason to delay stricter standards. Groups like the Natural Resources Defense Council argue that programs like Bush's FreedomCAR cannot delay oil-saving measures that are available now, such as increasing fuel economy standards. [31] The Sierra Club as well has been critical, arguing that while increased funding of new technologies is good, there needs to be deadlines to ensure that automakers produce these vehicles for the public. [32]

Consumers

Consumers have come to expect vehicles to travel at least 300 miles per tank of gas, [33] comfortably carry passengers, and provide a practical amount of storage space. In addition, consumers expect their vehicle and its engine to last seven years or more with reasonable maintenance expenses. When refueling, consumers expect gas stations to be accessible – meaning within a short distance and along a main travel route. Refueling the car in most places will provide motorists the option of fueling their own vehicle in a simple and safe manner. If the vehicle is not in use, drivers expect to park their vehicle either near their home or inside a garage. Finally, consumers want cars that are priced close to the current range of vehicles sold today. All of these expectations, many taken for granted in today's world, impose limitations and challenges on anyone trying to design a personal hydrogen-fuel-cell automobile and the infrastructure to support it.

Another major issue facing hydrogen as a fuel is public perception about its safety. While hydrogen has many safety issues that need to be addressed, images of the Hindenburg and the hydrogen bomb often cloud meaningful discussion of hydrogen's safety as a fuel. The Hindenburg is perhaps the most spectacular disaster where hydrogen was erroneously reported as the culprit. While hydrogen did indeed burn in the disaster, a new coating used on the zeppelin cover was highly flammable and was the primary cause for the major fire engulfing the frame. [34] The misidentification of hydrogen with nuclear power has caused similar consternation. While there are some who believe hydrogen energy is somehow inherently linked with the hydrogen bomb or the deuterium and tritium components of nuclear energy, this belief is simply rooted in a misconception that can be allayed through education and outreach.

Other Stakeholders

A number of industries will naturally be affected by a transition to hydrogen because of their business model. Fuel cell companies, natural gas utilities and industrial gas companies all have a component of the hydrogen lifecycle as part of their value chain. Whether they are directly involved in the transition, like fuel cell companies, or more likely to reap initial benefits of increased demand for their products, like the natural gas and industrial gas companies, these stakeholders will be active as issues of the transition develop and impact them.

Using fuel cells in distributed generation applications, utilities see opportunities for new technologies both in meeting new regulatory standards as well as providing new services to their customers. Because natural gas reformation is currently the cheapest method of production, natural gas companies potentially would be the first to benefit from a hydrogen transition. If large amounts of hydrogen are needed for either stationary or transportation applications and the production method is natural gas reformation, then more natural gas will be used in either large hydrogen generation plants or in small on-site reformers at refueling stations, residential and commercial buildings. In both cases, the demand for natural gas would increase significantly in the short term of a hydrogen transition. Also, natural gas companies have a great deal of expertise in delivering gas to residential and business customers everywhere, which puts them in good position to take advantage of applying their knowledge to hydrogen distribution issues.

Leading fuel cell manufacturers such as Ballard Power Systems, FuelCell Energy, Plug Power, and United Technologies Company have been at the forefront in pushing the envelope of this developing technology. [35] Since most fuel cells use hydrogen, having the infrastructure in place to supply hydrogen on demand for fuel cell applications is critically important to these companies. Through demonstrations and partnerships with research institutions, federal agencies and automobile and power companies, fuel cell companies are pushing to break open the market for this technology, citing its benefits over current combustion methods and the potential environmental benefits.

The merchant gas industry was involved in hydrogen production, storage and distribution long before being touted as the fuel of the future. Companies like Air Liquide, Air Products, Praxair, and BOC Gases are all heavily involved with the public and private sectors in advocating the commercialization of hydrogen as a fuel. The benefits to these companies are obvious: they have already a certain level of infrastructure in place to produce, store and distribute hydrogen, and would be well poised to take advantage of any increase in market demand. Beyond this immediate benefit, industrial gas companies also have tremendous experience with codes and standards, as well as all aspects of safety with regard to hydrogen. This information and experience is invaluable in designing the next set of codes and standards necessary for hydrogen to be used safely in vehicle, stationary power and portable applications. With one of the main stumbling blocks to hydrogen implementation being the "chicken and egg" question of available infrastructure, industrial gas companies have the technical know-how and the infrastructure already in place to build off or to design new facilities to meet increased hydrogen demand.

Recent Evaluations of Hydrogen Fuel

For the most part, the debate in academic research resembles the policy debate currently taking place among the stakeholders of a hydrogen economy. Most of the academic research examines various aspects of the potential hydrogen transition and seeks to improve the understanding of life-cycle issues when comparing hydrogen to other energy choices, as well as the policy and technical obstacles in a transition to hydrogen. Authors such as Joan Ogden have provided the groundwork necessary to understand the implications and quantify the potential benefits of a hydrogen economy. [36] As hydrogen has moved beyond an academic discussion to occupy a central role in federal research policy, a number of studies have begun to explore whether current efficiency policies being considered would provide more benefits than hydrogen. Authors such as David Keith and Alex Farrell have written papers [37] that compare the oil- and pollution-saving benefits resulting from greater fuel efficiency standards and hybrid technologies versus hydrogen vehicles. They conclude that hydrogen, while achieving desired results, costs significantly more and faces greater technological barriers than raising fuel efficiency standards.

In March 2004, the American Physical Society's Panel on Public Affairs released a study examining President Bush's Hydrogen Initiative. [38] It concluded, "current technology is promising but not competitive" and that "more emphasis [is] needed on solving fundamental science problems." The APS panel recommended "basic science must have greater emphasis both in planning and in the research program" and that "bridge technologies should be given greater attention." Similar to other recommendations by environmental groups, the study also concluded that federal efforts with hydrogen should augment, rather than displace support for efficiency and renewable energy.

Adding to the debate, the National Academies of Science (NAS) in 2004 released a report –*The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs* – detailing its own analysis of the issues facing the hydrogen economy. [39] The NAS studied the twin goals of the hydrogen economy – hydrogen can be domestically and cleanly produced and that it can become competitive with other energy sources in its end-uses. In its conclusions, the NAS report focused on four main areas – national goals, R&D priorities, transition challenges and light duty vehicles. While not disagreeing that the hydrogen economy if successfully implemented could improve national security and reduce environmental damage, the NAS report noted that other methods could achieve reductions in foreign oil dependence and in greenhouse gases.

The NAS recommended that the US DOE maintain a "balanced portfolio," citing battery and synthetic fuel research as examples. In research and development, the report cautioned of "major hurdles on the path to achieving the vision of the hydrogen economy." For hydrogen-powered vehicles, the report concluded that fuel cell, storage and distribution technology needed "dramatic progress" and that "widespread success is not certain." In the area of green hydrogen – hydrogen produced from renewable sources – the added cost and lost energy from using renewables to create electricity in order to produce hydrogen would be too costly, the NAS found, urging that such research be refocused. The exception the report made was for wind, though it encouraged further research in thermo-chemical solar processes. In order for the use of fossil fuel generated hydrogen to be successful, it continued, further breakthroughs must be made in carbon sequestration.

The NAS report recommended that in order to ease the transition into a hydrogen economy, focus must be placed on distributed generation (DG). NAS highlighted DG because it does not need as large an infrastructure as hydrogen vehicles, nor as many of the technical breakthroughs. Distributed generation also allows multiple sources of hydrogen generation from small reformers to renewable energy. In the area of light duty vehicles (cars and light trucks), the NAS believes that the impacts of hydrogen on foreign oil dependence and greenhouse gas emissions will be "minor during the next 25 years." However, thereafter, if all of the research breakthroughs and investments are made both in hydrogen and fuel cell technologies, the long-term impact on the U.S. energy economy may be "great."

In 2003, the US DOE's Basic Energy Sciences Advisory Committee (BESAC) [40] examined the basic science research needs necessary to achieve the goals of the Bush administration's Hydrogen Fuel Initiative. This led to the *Basic Research Needs for the Hydrogen Economy (Hydrogen Economy)* report, released by BESAC in July 2003 and updated in February 2004. [41] The report followed an earlier study, *Basic Research Needs to Assure a Secure Energy Future (Secure Energy)*, from BESAC that listed hydrogen among the 10 areas of research of "greatest urgency" for future energy security. The earlier *Secure Energy* study argued that, in order for hydrogen to compete in current markets, costs must be reduced tenfold for fuel cells and fourfold for hydrogen production. [42] BESAC concludes in the *Hydrogen Economy* report that the only way to accomplish this is through technical breakthroughs that can close the gap, rather than through incremental improvements in current technologies. The BESAC *Hydrogen Economy* report argues that comprehensive programs of interdisciplinary research be coordinated across academia, industry and the national laboratories.

The BESAC Hydrogen Economy report identified six areas of interdisciplinary research that should be targeted in order to achieve the desired breakthroughs for hydrogen technology:

- Catalysts
- Nanostructure materials
- Membranes and separations
- Characterization and measurement techniques
- Theory, modeling and simulation
- Safety and environmental issues

Apart from the more technical areas, safety and environmental issues were identified as important because of their psychological and sociological impacts. The BESAC study calls for public safety education and worker training programs. The need is to understand the impacts of hydrogen on the environment, especially due to leakage in the atmosphere, and to determine hydrogen's full environmental benefits.

Examples of State Hydrogen Initiatives

The federal government has taken the lead in nationwide planning for a hydrogen transition. Several states, meanwhile, have established or are developing programs to support hydrogen fuel production, infrastructure, and use. Leaders in these efforts are California, New York, Michigan, Connecticut and Hawaii, which will be highlighted below. These states are involved for a variety of reasons that make sense in the context of their particular environmental, policy or industrial landscapes. These examples provide insight into the multiple directions state hydrogen policy can potentially take in New Jersey.

California

California is the nation's most populous state and, as the nation's single largest market for motor vehicles, has an overriding interest in minimizing the impacts of a car-dependent society. To meet this goal, California has enacted the strictest vehicle emissions standards in the nation. New York, Massachusetts, Vermont, and New Jersey have all adopted similar standards based on California emission laws. It is in this landscape that the state's hydrogen-related initiatives take shape.

The most prominent hydrogen and fuel cell participant in the state today is the California Fuel Cell Partnership (CaFCP). The CaFCP serves as a focus and catalyst of hydrogen and fuel cell activities for the state. The CaFCP formed in 1999 as a public-private partnership focused on developing fuel cell electric vehicles. Its members include local, state, and federal policymakers; energy companies (BP, ChevronTexaco, ExxonMobil, and Shell Hydrogen); automotive and engine manufacturers (DaimlerChrysler, Ford, GM, Honda, Hyundai, Nissan, Toyota, and Volkswagen); fuel cell companies (Ballard and UTC); transit agencies (AC Transit, Sunline Transit, and Santa Clara Valley Transportation Authority); and other associate partners. Activities range from education and outreach to demonstration projects and support for fuel cell technology development. Although the organization is officially "fuel neutral," it has proclaimed hydrogen as the "gold standard" fuel source to develop the technology and markets for fuel cell vehicles. [43] To help this market expand, the CaFCP operates a state-of-the-art testing facility at its headquarters in West Sacramento to support the development of fuel cell vehicles by each of the automotive industry members.

Since 1999, CaFCP has successfully completed a number of demonstration projects. The zero emissions bus demonstration sponsored by the CaFCP was completed in late 2001. During the yearlong project, the bus traveled more than 14,900 miles, running for a total of 865 hours. Ballard Power Systems supplied the bus with its fuel cell technology. The zero emission bus completed the 275-mile drive between Los Angeles and Las Vegas with only one refueling stop and cruising at 75 mph. In 2003, 43 vehicles were on the road, seven buses had been ordered, and seven hydrogen fuel stations existed in the state. [44]

To complement the efforts of the CaFCP, Governor Schwarzenegger campaigned during Fall 2003 on the idea of promoting the construction of an extensive hydrogen fueling station infrastructure in the state by 2010. This project, called "Hydrogen Highways," is taking shape through state support of private initiatives to build hydrogen fueling stations, though little public money is available for publicly directed projects. The program's goal is to construct hydrogen fueling stations every 20 miles along major highways in the state. While this is only a fraction of California's more than 14,000 gas stations, it would allow a consumer to buy a hydrogen fuel cell vehicle without the worry of running out of fuel in the state. On April 20, 2004, Governor Schwarzenegger signed Executive Order S-7-04 designating California's 21 interstate freeways as the "California Hydrogen Highway Network." The California Environmental Protection Agency and other relevant state agencies were directed to work with state legislators and key stakeholders to plan and build a network of hydrogen fueling stations along these roadways and in major cities, so that by 2010, access to hydrogen fuel will be available throughout California. In addition, a significant and increasing percentage of hydrogen is to be produced from clean, renewable sources. [45] Also, the Executive Order directed that the state develop a California Hydrogen Economy Blueprint Plan by January 1, 2005 for the rapid transition to a hydrogen economy. The plan is to be updated bi-annually thereafter and contain recommendations to the Governor and the State Legislature. Finally, the Executive Order set out a number of other goals for the state to achieve by 2010 relating to the transition to a hydrogen economy.

Since the early 1990s, California's low and zero emissions fuel standards have dominated the political landscape and shaped the way the retail automotive business has developed in the state. These standards govern the technology for cars sold and driven in the state and therefore directly affect the private sector. These standards have become increasingly stringent over time. The California Air Resources Board (CaARB) has established the strictest standards to date for 2004 model year cars. To meet these requirements, public money has been put toward consumer incentive programs. As part of the ZIP (Zero Emission Vehicle Incentive Program) I and ZIP II programs, motorists who purchase zero or low emission personal vehicles are eligible for rebates of up to $5,000. The newer Fleet ZIP program makes rebates of up to $11,000 available per vehicle to fleet operators of at least two vehicles. [46] Funding for these grant programs, however, is in question for the state's 2005 budget. In addition to zero emissions standards, the Clean Gasoline Standard was introduced in California in 1996. State regulation also specifies the level of sulfur in gasoline and requires it to go through a special desulfurization process before being sold in California.

In June 2004, CARB released a report analyzing the best methods to reduce greenhouse gas emissions from motor vehicles. The report sets out new recommendations on more stringent restrictions to automotive emissions and examines different technologies including hydrogen. The report views hydrogen initially having a small impact in overall emissions as the technology is only in demonstration form. It concludes that long term, hydrogen has the potential to be a significant technology choice in meeting the new proposed standards.

Also actively involved is the California Energy Commission (CEC). The CEC was formed in the 1970s and has been at the forefront of research on the state's energy future. While alternative energy is only part of the organization's portfolio of projects, the CEC has participated in research since its founding aimed at adopting alternative fuel technology. Prominent projects in the past have demonstrated the use of ethanol and methanol, natural gas, and electric vehicles. While not the focus of alternative fuel vehicles today, there are fuel stations from these projects that still exist around California and could potentially be converted to hydrogen fueling stations.

Ongoing work of the CaFCP deals with the transportation piece of the equation. However, stationary power and grid reliability are also major concerns for the public and policymakers. The California Stationary Fuel Cell Collaborative (CaSFCC) was formed in 2001 in an effort to think comprehensively about energy, the environment, and reliability in the state of California. Essentially it serves as the stationary version of the CaFCP and seeks to be a catalyst and coordinator of hydrogen and fuel cell activity for stationary applications. This partnership between federal, state, and non-governmental organizations (including academic institutions) concentrates on promoting the development and dissemination of stationary fuel cells for distributed generation (DG). As part of the CaSFCC's active promotion of the California fuel cell market, which they anticipate will comprise between 5 and 25 percent of global market share in coming years, the Collaborative plans to install cells in state government buildings. [47]

Michigan

Michigan is home to the Unites States automotive industry. The automakers have supported hydrogen fuel cell vehicles in order to meet new demands for cleaner cars that can reduce dependence on foreign energy sources. In the past, state policymakers have worked with the industry to meet these goals through aggressive policies. For example, in response to the federal Energy Policy Act (EPACT) of 1992, Michigan invested in the requisite percentage of alternative fuel vehicles (AFVs) for its state fleets along with four ethanol-fueling stations across the state to serve them. [48] According to the Michigan Energy Office, by 1999 half of the state's new fleet vehicle purchases were AFVs. [49] Promoting new transportation-related legislation in tandem with successful investments and demonstrations helps to support the United States auto industry's competitiveness in the global market.

As hydrogen moves into the spotlight at the federal level and stricter emissions regulations are driving hydrogen use as a fuel at the state level, Michigan is promoting research and education dealing with alternative energy and fuel sources to help support the state's automotive industry and encourages new and sustained economic development. To this end, Michigan has started the Next Energy initiative, which provides tax breaks and other incentives to spur new business growth in the alternative energy sector. Embracing hydrogen and other alternative energy sources is viewed as a forward-thinking economic development strategy and is strongly supported by the public sector, as well as the automotive and other industries and several academic institutions in Michigan. [50]

The concept of the state's alternative energy plan emphasizes that new energy solutions will be adopted over the near, middle and long-term. With the ultimate vision of creating an operational transportation infrastructure for hydrogen fuel, the near and middle term visions concentrate on investments in stationary applications, such as distributed generation units for residential, commercial, and industrial applications. Another part of the Next Energy initiative is the creation of a consortium of five colleges and universities that work with the program to create an alternative energy curriculum. Once completed, this curriculum will be used to train the workforce necessary to develop, operate and maintain new alternative energy technologies.

New York

The New York State Energy Research and Development Authority (NYSERDA) along with the Long Island Power Authority (LIPA) and New York Power Authority (NYPA) completed a funding competition in January 2004 offering organizations from around the country and internationally a grant of up to $750,000 to design a Hydrogen Roadmap for the State of New York. A final proposal for the Roadmap was chosen and began in May 2004; design of the plan is expected to take about nine months. [51] Along with a plan for building out necessary infrastructure to support stationary and mobile uses for hydrogen fuel, the grant also funds education and outreach programs, and the development of codes and standards. Support is provided organizations active in promoting other renewable energy resources and distribution methodologies to help conceive of ways to integrate these areas into a successful hydrogen economy in the state.

New York State has supported renewable resources and distributed generation (DG) projects for several years through programs like the Renewable & Indigenous Energy R&D Program that facilitates efforts to make alternative and renewable energy sources cost-competitive. The 2002 State Energy Plan adopted measures to improve energy diversity in the state and launched efforts to develop and implement a renewable portfolio standard for electricity generation in the state. [52] The goal is to increase the level of electricity generated from renewable resources to 25 percent, an increase of almost 10 percent, of the total state portfolio over the next decade. [53] These activities are based on a desire to protect the environment and promote energy reliability. As home to the nation's most populous city, concerns about grid reliability are key to New York's energy agenda. Embracing hydrogen as a future energy source for the state will require integrating it with other renewable energy resources. How to integrate PV, wind, and indigenous resources, such as biomass, geothermal, or natural gas – are all included in the winning proposal for the Hydrogen Roadmap.

Hawaii

Nearly 90 percent of Hawaii's energy is imported from Alaska or foreign sources. [54] This dependence on imported energy puts the state in a particularly vulnerable position to fluctuations in price and supply. As a state with multiple natural renewable energy resources—such as solar, wind, geothermal, and biomass—Hawaii could capture the benefits from locally generated energy. For several years, state policymakers have been thinking about how to help Hawaii become independent from imported oil. One result has been an increased support for hydrogen. Jet fuel demand is the most significant driver of overall price and mix of supply at Hawaii's refineries. Gasoline and other uses become almost secondary. However, hydrogen's use as a transportation and stationary fuel source will allow for the decoupling of energy prices for these uses from the fluctuation of jet fuel supply and demand.

In 2002, the Hawaii Department of Business, Economic Development, and Tourism commissioned the Hawaii Natural Energy Institute and Sentech, Inc. to conduct a feasibility study. [55] The study concluded that each island might be able to benefit from hydrogen, using production methods designed to capitalize on the indigenous strengths of each island rather than adopting a single statewide strategy. The life cycle of hydrogen production, distribution, storage, and end-use may seem cost prohibitive compared with current fossil fuel prices on the islands. However, when the fuel efficiency of fuel cell cars (estimated by the report to be 2.2 times that of traditional internal combustion engines) plus the use of local energy sources to generate hydrogen were calculated in the report, prices for hydrogen were found to be on a par with petroleum fuel prices for the state.

In support of the efforts already made by state leaders Hawaii implemented the Energy Policy Act which called for a full assessment of the economic impacts of the state's oil dependency, including the impacts should fossil fuel supplies expire or be cut. To respond to this assessment, the Act also calls for an island-by-island approach to developing a hydrogen fuel generation system from natural, renewable resources native to the Hawaiian Islands.

The Office of Naval Research, the Hawaii Natural Energy Institute, the University of Hawaii at Manoa, and the Naval Research Laboratory have begun the Hawaii Energy and Environmental Technology Initiative (HEETI). This initiative has opened a state-of-the-art research and demonstration facility to develop and test hydrogen fuel cell technology. The group partners with several private businesses, including United Technologies Companies, Inc. In addition to HEETI, Hawaii had funded and plans to open a Hydrogen Power Park located on one of its islands. This facility would develop and demonstrate an "integrated system comprising electrolysis for hydrogen production, hydrogen storage, and a 50 to 75 kW grid-connected fuel cell." [56] The state may receive additional support from the federal Energy Policy Act of 2003, sponsored by Senator Peter Domenici (R-NM) that includes a line item promoting Hawaii's energy independence.

Connecticut

Connecticut views support for hydrogen fuel infrastructure development as support for state economic development. Several prominent fuel cell companies are located in Connecticut; United Technology Companies, Inc. and Fuel Cell Energy, Inc. for example, are poised to become leaders in stationary and transport related fuel cell markets regionally, nationally, and internationally. To nurture this burgeoning market, the state legislature established the Connecticut Clean Energy Fund (CCEF) in 1998. This group is charged with encouraging "growth, development and commercialization of renewable energy technologies and sources; [stimulating] Connecticut consumers' demand for renewable energy; and [promoting] deployment of renewable energy sources that serve Connecticut's energy customers." [57] The CCEF has allocated grant money for a number a years to organizations and companies to conduct fuel cell related demonstration projects that are judged to be helpful in leading to the commercialization of fuel cell technology. In 2003, CCEF allocated $4 million as part of this effort. [58]

In March 2004, representatives from UTC and Fuel Cell Energy asked Connecticut's Assembly Committee to exempt fuel cells and other alternative energy related technologies from the state sales tax. [59] This exemption would save about $60,000 for a fuel cell costing $1 million. The hope is that this will provide further incentive to purchase these units. [60] As of this report's publication, the Committee is considering the proposal.

Chapter 3: Hydrogen Fuel Commercialization Issues

There are several primary issues that New Jersey policymakers should consider as they decide whether to take a leading role in the commercialization of hydrogen fuel and infrastructure build out. In transportation applications, the biggest barrier is the lack of infrastructure supporting hydrogen fueling and transport. Described as a classic "chicken and egg" problem, the lack of infrastructure does not have to be insurmountable. Fleet and stationary applications can provide an early commercialization path that requires less infrastructure while establishing an initial footprint in a state.

Another issue to be addressed in the commercialization of hydrogen fuel is public perception of its safety. Understanding and addressing safety issues that face hydrogen fuel applications will be essential to their adoption in the marketplace.

Finally, many hydrogen detractors are comparing hydrogen vehicles unfavorably to current hybrid electric vehicles. While the two sets of vehicles are often compared as an either/or proposition, this may not be the case. A life-cycle analysis that examines the energy and environmental impacts from "well to wheels" can illustrate that hybrids and hydrogen vehicles may be complementary and that the goals of the state will determine which application is best suited for both the near-term and long-term. While stationary applications are also discussed in this section, the most complex commercialization issues affecting deployment of hydrogen as a fuel are found in transportation applications. Consequently, the focus here will mostly be on examining these issues from a transportation application perspective.

Infrastructure

The requirements of hydrogen infrastructure are highly dependent on the end-use. There are a number of different combinations and choices that can be made as infrastructure develops. Various options are discussed in this section and the benefits and drawbacks of each are considered. However, it is important to recognize that infrastructure decisions are not always an "either/or" situation; the particulars of the end-use will determine which deployment is best suited. It is expected that a diversity of infrastructure deployments will occur over time.

One of the first issues to decide when designing a hydrogen fuel cell car for consumer use is whether the car will be fueled by direct hydrogen or obtain hydrogen through reformation of natural gas, ethanol, methanol [61], or gasoline. Using a reformer allows for the car's fuel tank to be filled with conventional liquid fuels or compressed natural gas. This can eliminate some of the challenges presented by storing hydrogen in the vehicle as well as the absence of an extensive hydrogen infrastructure network similar to gas stations. However, adding a reformer to a hydrogen fuel cell vehicle takes up significant space and adds weight to the vehicle, reducing the appeal of the vehicle to the consumer. Generally, by 2003 most vehicle manufacturers had abandoned the concept of on-board reformation due to technical limitations and cost considerations. [62] The concept has now moved to on-site reformation at refueling stations or centralized production and distribution of hydrogen.

In the absence of a reformer, the fuel tank must be designed to hold hydrogen similar to how it now holds gasoline. The two main solutions that car manufacturers are examining are compressed hydrogen tanks and liquid hydrogen tanks. Metal hydrides and other storage solutions have also been examined and are discussed below, but are not viewed as promising at this time. The goal of tank design is storing enough hydrogen to power a vehicle for distances comparable to today's standards while minimizing size and weight and maximizing safety. Compressed hydrogen is stored in cylindrical shaped tanks for vehicle use under pressures of 5,000 psi or 10,000 psi. [63] The trade-off at 10,000 psi is that while a greater amount of hydrogen is stored and therefore delivers more miles per tank, there are greater safety concerns. Materials for such tanks are made from a variety of specialty composites designed for the special demands of a vehicle fuel tank.

Liquid hydrogen tanks require special cryogenic storage tanks that maintain the low temperatures required to keep hydrogen in liquid form. The benefit of liquid hydrogen storage tanks is their smaller size and weight and higher mileage per amount of hydrogen stored. However, keeping the necessary low temperatures consumes electricity, while the difference in temperature between the tank and outside environment can lead to loss of hydrogen through evaporation. Newer cryogenic tank designs operating at higher pressures are being developed to minimize this drawback.

Metal hydrides are special alloys that absorb and chemically bond the hydrogen in a solid state of the hydride. Their biggest benefits are size and safety. Metal hydrides can store the same amount of hydrogen at a third the volume of compressed tanks and a quarter of the volume of cryogenic tanks. Damage to the tank does not release hydrogen because it remains a solid bonded to the hydride. The main drawback of metal hydrides is their very heavy weight which can reduce or negate a vehicle's overall fuel efficiency.

Other tank solutions being explored include storing hydrogen in carbon nanotubes, glass microspheres, liquid hydrides, or ammonia. These new options could overcome the weight concerns of traditional metal hydrides. However, all of these hydride solutions will require breakthroughs in basic science in order to make them suitable for storage in vehicles.

Besides the tank design and fueling options, vehicle designers must also consider these issues as they attempt to make a commercially viable hydrogen fuel cell vehicle:

- Cold weather operation
- Packaging
- Reliability
- Safety
- Consumer acceptance
- Manufacturing issues

If the reformer is not on the car, as expected, and hydrogen is going to be "pumped" directly to the vehicle, then fueling stations would have to be redesigned or retrofitted to be capable of completing this task. The first consideration is whether hydrogen fuel (in liquid or compressed gas form) is produced on-site or off-site and then transported to the fueling station through tanker trucks and/or pipelines.

On-site production can be performed through reformation of gasoline, natural gas, ethanol or methanol as just discussed as part of the car, but in larger quantities. Separate storage tanks would be needed for the fuel to be reformed and for the subsequent hydrogen produced. Space considerations would be part of any new design in order to accommodate the new tanks and the reformer. Gasoline, liquid natural gas, ethanol and methanol could be transported to the station as now by truck while natural gas would be delivered by pipeline. Hydrogen may also be produced on-site through electrolysis. This would eliminate the need for the reformer, but would require a source of electricity. This could come straight from the grid at off-peak periods in the evening when electricity prices are lowest, or from a renewable source such as solar.

Off-site production of hydrogen could occur at central production facilities using any combination of potential sources. These may include hydrogen from reformation of coal, petroleum, by-product gases, methanol, ethanol, and natural gas, or from electrolysis using solar, wind, biomass, hydroelectric and nuclear power. Once produced at the central facility, hydrogen can be delivered to the fueling station either by truck or through pipelines. Since pipelines for hydrogen exist in limited quantity and cover limited territory, either they would have to be installed or natural gas lines upgraded to transport hydrogen, if feasible.

In addition to the safety concerns regarding hydrogen fueled vehicles, the design and building of hydrogen fueling stations pose safety concerns for consumers that must also be responsibly and thoroughly addressed. The main issue is the risk caused by hydrogen stored at high pressure in a tank and the subsequent risk of leakage, especially in non-vented area such as an enclosed garage. There are also concerns about hydrogen accidents at refueling stations, either while the vehicle is being refueled or as hydrogen is being stored and in some cases produced on-site. Tank-design is crucial to reducing risks created by hydrogen to a level at or below current risks posed by gasoline. The U.S. Department of Transportation and the Society of Automotive Engineers have recommended standards that must be met for fuel tanks before they are approved for use on the road. [64] There are recommended safety standards for the transfer of fuel from compressed tanks to the uncompressed gas in the fuel cell and for refueling connection devices to ensure that only proper fuels at correct pressures are pumped into the fuel tank. Manufacturers are running hydrogen tanks through a series of rigorous tests to ensure that under all extreme operating conditions the tanks will hold up and limit the risk for explosion and rupture to an acceptable level.

Fleet vehicles face many of the same issues as consumer automobiles, but have greater flexibility in meeting these challenges. Depending on the size of the vehicle, the tank may have to be larger to handle a greater vehicle weight. Also, while the distances traveled by fleet vehicles may be regular and known, these distances may exceed those of average motorists and therefore require a greater amount of fuel. Buses and trucks can accommodate larger tanks, as design space may be less of a premium in these vehicles. Fuel cell buses often have their tanks situated on the roof. Since fleet vehicles are centrally stored, it is possible to locate refueling stations in the garage facility. This removes the need for an external refueling infrastructure, since the vehicles could be fueled each day before going on their routes. If the distance traveled requires refueling along the route, additional fueling stations can be placed strategically along the route as needed. As fleets expand across state lines, refueling infrastructure could be placed along major interstates at rest stops or weigh stations in order to maximize coverage and allow for a slow build-out of infrastructure. Safety issues still remain for those with larger fuel tanks and depending on their use, fleet vehicles may also have different accident patterns than personal vehicles. Just as standards for consumer automobiles will need to be adopted regarding tank design, refueling, and hydrogen leakage, fleet vehicles will require their own standards.

Just as fleet vehicles have fewer infrastructure challenges, stationary storage fuel cell applications also may come to fruition before passenger vehicles. This allows for stationary fuel cell systems to compete today in this market while costs continue to be reduced over time. Most stationary fuel cell systems in operation today use natural gas reformers in conjunction with a distributed generation system. Over time as more buildings use hydrogen fuel cells, central production of hydrogen may occur and be piped to the location similar to natural gas today. For the medium to small-scale storage needs of most residential and commercial stationary power systems, liquid hydrogen and compressed hydrogen gas in cylinders are used today. In stationary power systems, the storage of hydrogen would be small, as steam methane reformers create the hydrogen on demand from natural gas. Stationary fuel cell power systems, because of their lack of emissions, may require little or virtually no regulatory site review, which can be an added bonus for businesses looking to add premium or back-up power within a short time frame. This is also true for portable fuel cell devices. These small fuel cell packages generate smaller amounts of electricity and usually use self-contained hydrogen canisters. They can replace portable gasoline generators or applications that require large batteries.

Micro-fuel cell devices face a completely different set of challenges, mostly technical, in order to become competitive in their market. The challenge is to make the fuel cells compact for the end use and provide an easy way to add or change fuel. For consumer electronic devices like cell phones and laptop computers, companies are looking at changeable methanol cartridges combined with either reformation or direct methanol fuel cells. Toshiba has created a methanol cartridge and fuel cell system whereby a single cartridge weighing 72 grams with 50 cc of high concentration methanol can achieve approximately five hours of operation. [65] Manufacturers must consider factors such as fuel density and circulation, air supply levels, and byproducts of the fuel cell operation. While the main demand for micro-fuel cells is from newer electronics with power needs greater than batteries may be able to deliver, successful development of micro-fuel cells will not totally replace the battery. For most applications, a small battery is needed to act as a buffer and to store energy to balance high loads and electricity flow. [66] Most of these fuel cells are still in the research and development stage with many of the aforementioned challenges still needing work before mass production and sale is a reality.

Safety of Hydrogen Fuel

In addition to the safety concerns that consumers have regarding hydrogen fuel, there are important technical considerations to be addressed when working with hydrogen fuel. The amount of energy needed to ignite hydrogen is comparable to natural gas but is one-tenth the energy needed to ignite gasoline. In a number of areas, hydrogen has properties that are more beneficial than gasoline. Hydrogen is nontoxic and it is difficult to create a high enough concentration of hydrogen to combust due to its light and buoyant nature. Gasoline, when leaked, can puddle at the source and emit fumes that can build and linger.

A number of studies have examined hydrogen and conclude that while hydrogen raises a different set of safety concerns, experience has shown that they can be addressed. The American Physical Society released a report prepared for their Panel on Public Affairs (POPA) describing many of these studies and their conclusions. [67] These included tests by Lockheed Martin, Arthur D. Little, BMW and the University of Miami that all conclude hydrogen is no more dangerous than gasoline. BMW undertook a number of crash tests and found the safety of the fuel to be sufficient. The University of Miami, in its test, set fire to two cars, one with hydrogen and the other gasoline. While both created fires when ignited, the gasoline fire engulfed the entire car causing total damage, whereas the hydrogen flame vented vertically and failed to spread to the rest of the vehicle. As early as 1994, the Sandia National Laboratories performed a vehicle safety study and concluded, "there is abundant evidence that hydrogen can be handled safely, if its unique properties—sometimes better, sometimes worse, and sometimes just different from other fuels are respected." [68] Similarly in 1997, a vehicle safety study by the automaker Ford concluded hydrogen is potentially a better fuel source than gasoline when proper controls are built into the vehicle. [69]

Just as gasoline tanks in today's cars are manufactured and tested under a number of codes and standards, hydrogen tanks too will need their own set of standards to meet safety concerns arising from the unique properties of hydrogen fuel. There has been a significant amount of work already performed to achieve this goal. The U.S. Department of Energy coordinates its codes and standards efforts through the National Renewable Energy Laboratory. The hydrogen industry trade group, the National Hydrogen Association, also has organized codes and standards working groups to address safety needs. International codes and standards work is coordinated through the International Energy Agency and the International Standards Organization. Other groups involved include the National Fire Protection Agency and the Society for Automotive Engineers. Fuel cell manufacturers, hydrogen tank manufacturers and automakers are also developing best practices for hydrogen use and safety.

Life-cycle Analysis

Policymakers will find it difficult to make "apples to apples" comparisons between fuel cell vehicles, current gasoline cars and other alternatives, like hybrid vehicles. The complexities of hydrogen production, storage, distribution and use are very different than traditional technologies. With petroleum-based gasoline, there are significant costs associated with recovery, processing and production. Hydrogen does not have recovery or processing costs, but it can have significant production costs and energy losses depending on the hydrogen source. To aid in comparisons among these different systems, vehicles and fuels researchers attempt to quantify a fuel across its complete life cycle. This "cradle to grave" analysis considers all inputs and outputs of the competing products and quantifies the economic, energy and environmental impacts at each stage. There are three main issues that policy-makers will want to consider when making a life cycle analysis: costs, efficiency and emissions. A life cycle analysis can be made for each of these different categories of comparison.

The analysis can be further broken down in order to make comparisons among hydrogen production techniques or among different vehicles. As shown in Figure 4, there are two main stages into which this analysis can be divided. The first is called "Well to Tank" and tracks every step from obtaining a fuel from its initial source to the point it enters the fuel tank of the vehicle. From there, the second stage, or "Tank to Wheel," examines refueling and vehicle operation. Combining these two analyses allows for the total comparison in a "Well to Wheel" analysis. These two stages are important because they allow a better comparison of various options of hydrogen production, storage and distribution on the "Well to Tank" stage and isolate the impacts of various options. Also, examining just the "Tank to Wheel" stage allows for a better comparison of fuel cell versus internal combustion engine operation, as well as the impacts of hybrid technologies on both types of engines.

There are a growing number of studies examining various life cycle issues comparing hydrogen, gasoline and other alternatives. While these different analyses often differ in methodologies and results, the range of data output is generally in agreement on a qualitative level. A number of examples of life cycle analyses are presented below to give the reader an appreciation of the different areas of examination and of the general conclusions the results provide.

Figure 4. Components of a Well to Wheel Analysis [70]

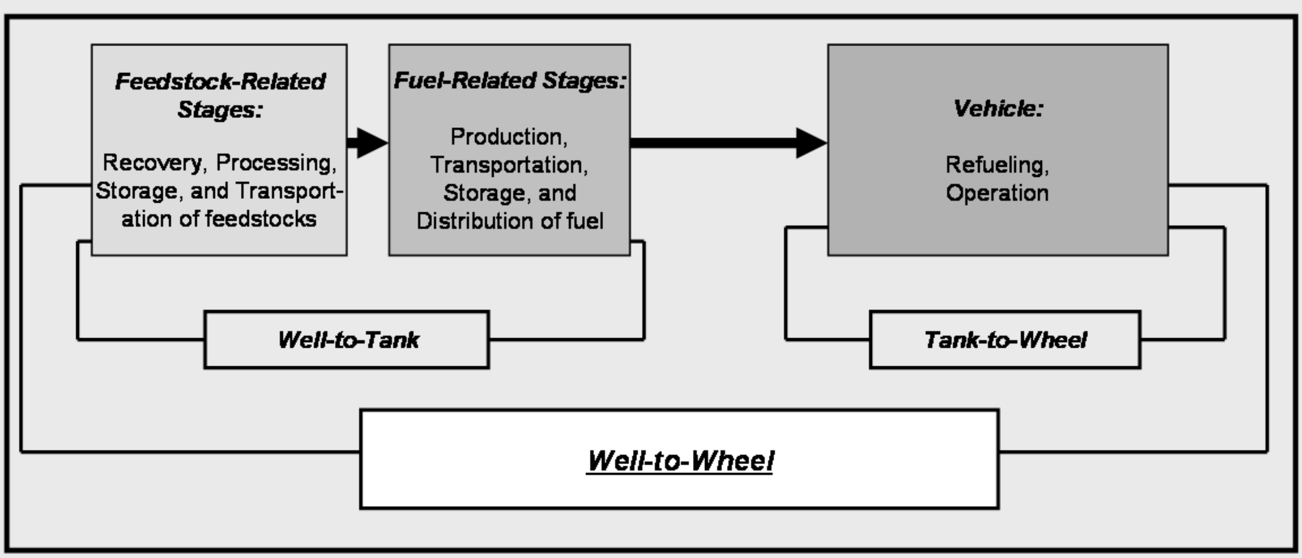
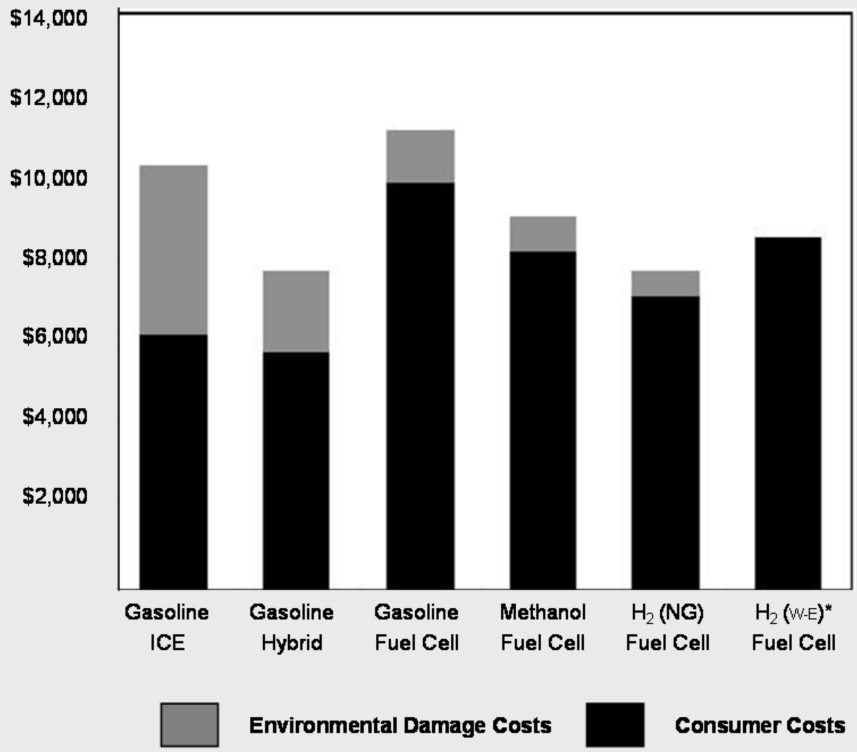


Figure 5. Life Cycle Costs, Selected Fuel/Vehicle Combinations [71]



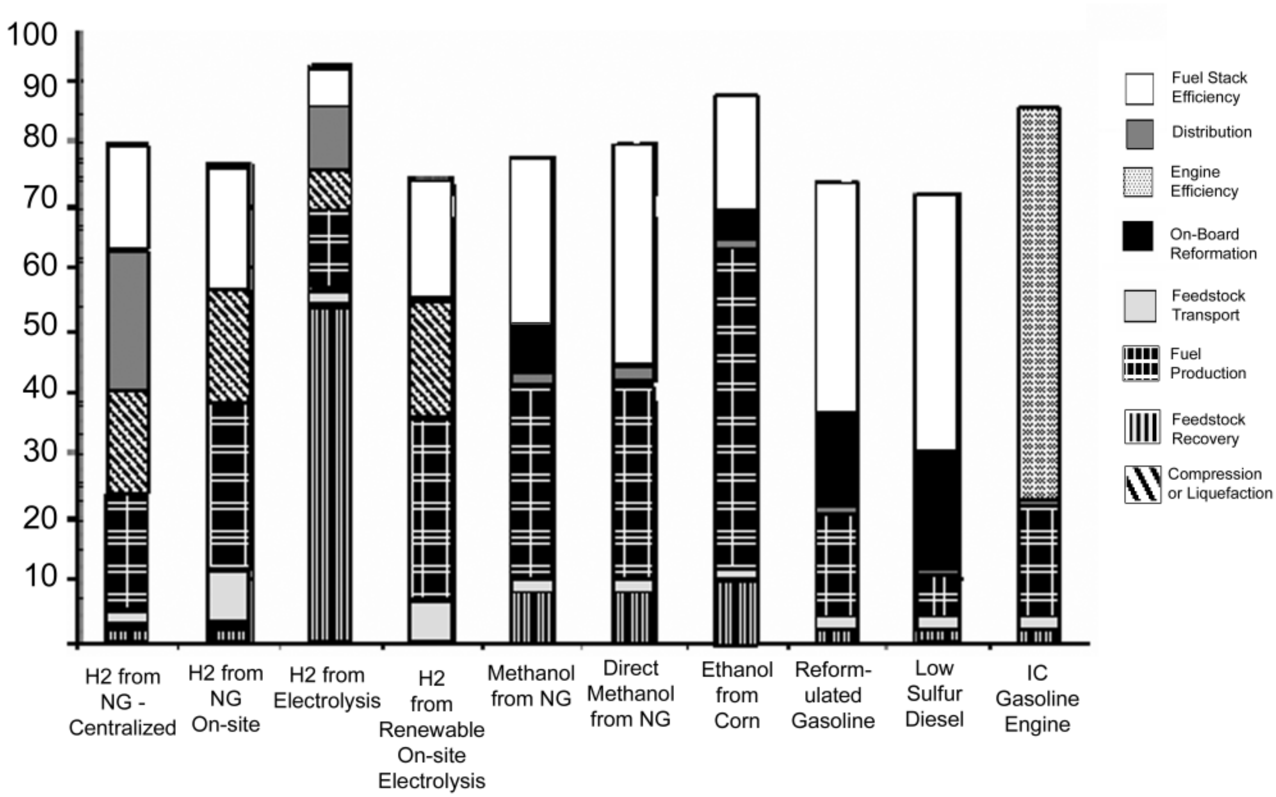
* - Wind-electric

Figure 5 provides an example of a life cycle analysis of costs across different vehicle and fuel choices. In this comparison, both the consumer costs of a vehicle and the impact of emissions on the environment are factored into the overall cost. As one would expect, when just the consumer costs are examined, the current gasoline ICE vehicle technology is the least expensive. However, the gasoline ICE is also the greatest polluter and when the costs of this pollution are added to the life cycle, it now becomes more expensive than all but the gasoline fuel cell. Interestingly, a hydrogen fuel cell vehicle with hydrogen produced from renewables, despite having no environmental damage, is still more expensive than a gasoline hybrid even under the full life cycle analysis. This can be attributed to the high costs of the fuel cell, electrolysis and renewable power.

The next two life cycle comparisons are taken from the Panel on Public Affairs (POPA) *Hydrogen Fuel Cell Vehicle Study* prepared by Craig Davis for the American Physical Society. [72] The first set is a compilation of source data examining the net energy losses by type of engine and its source of fuel and a comparison of energy efficiencies of different engine types. The second set comes from a 2003 MIT study [73] that modeled the current technologies that most likely will be included in future vehicles and attempts to compare their life-cycle energy consumption and greenhouse gas emissions.

Figure 6 provides a good cross-comparison of the lifecycles for the many vehicle options of vehicles facing automakers. Subtracting the energy losses from 100 percent obtains the overall efficiency rate of the vehicle's lifecycle. The eight different possible steps examined in the life-cycle analysis identify which areas are most limiting to a potential fuel source. Also, it must be understood that while the data helps to show how competitive fuel cell technologies are versus current ICE technology, it does not examine the two largest perceived

Figure 6. Net Energy Losses "Wells to Wheels" for Fuel Cell Vehicles [74]



benefits of fuel cells – reduced oil dependence and greenhouse gas emissions. Reformulated gasoline and low sulfur diesel fuel cells have overall the lowest net energy losses in this analysis. However, in the tank to wheels portion, the vehicle has high energy losses and very low efficiency versus other fuel cell vehicles due to losses from on-board reformation and a low fuel cell stack efficiency.

Fuel cells with direct hydrogen using central or on-site natural gas reformation and renewable electrolysis have major increases in tank to wheels efficiency, but losses in production and storage. In the case of centrally produced hydrogen, transportation losses also are significant. Each of the factors may improve over time as these costs decrease due to technology breakthroughs and improved processes. For the long-term only, renewable electrolysis can provide the life-cycle zero emission and oil independence that proponents of hydrogen desire.

In Figure 7, the efficiencies of various fuel cells are compared with other current competitive technologies, such as compressed natural gas (CNG), hybrid and conventional ICE vehicles. Again, the diesel hybrid ICE and fuel cell vehicles score high, as do all fuel cells and hybrids, over the CNG and conventional ICE vehicles. The general conclusion of this analysis is that hybrids perform better than standalone ICE or fuel cell vehicles and that fuel cell vehicles perform better than ICE gasoline. However, the evidence points to similar results between hybrid fuel cells and hybrid ICE gasoline vehicles. Without improvements in the well-to-tank portion of the life cycle, hybrid ICE gasoline vehicles are likely in the short term to share similar overall efficiencies as hybrid fuel cells.

In the 2003 MIT life cycle analysis of light duty vehicles, the authors took a different approach and looked at technology currently being developed and individually tested the components that would likely be commercialized into future vehicle models by 2020. The tests performed in conjunction with computer modeling helped to create an overall comparison to a reference vehicle from 2001 – an average U.S. mid-size family sedan. The 2020 baseline ICE gasoline vehicle incorporates improvements other than hybrid electric components or engine changes modeled after improvements achieved during the last 20 years in passenger vehicles.

As in the previous results, Figure 8 from the MIT study demonstrates that hybrids and fuel cell vehicles will show substantial improvement over the baseline and reference vehicles. However, the hybrid-electric vehicle and the fuel cell as in previous studies perform comparably in this analysis. The diesel hybrid again shows the highest fuel economy and therefore holds its own against the gasoline hybrid or fuel cell. Since this study is short to middle term, it assumes petroleum or natural gas as the source of fuel for the vehicles.

Figure 9 (SEE page 35) shows the impact on greenhouse gas emissions of the top performing vehicle choices versus the reference vehicle from 2001 in the MIT study. As expected, the fuel cell vehicle outperforms both the gasoline and diesel ICEs in vehicle operation. However, because the hydrogen for the fuel cell is generated using natural gas, the rest of the life-cycle greenhouse gas emissions bring it in a range similar to the gasoline and diesel ICEs. Emissions of greenhouse gases are more centralized under natural gas hydrogen production, whether centralized or on-site reformation, versus source emissions from vehicles under gasoline and diesel. This centralization would more likely allow for sequestration of greenhouse gases during hydrogen production. If sequestration technology can be added to the lifecycle, then the improvements in the fuel cell vehicle over the gasoline and diesel hybrids would be significant.

Figure 7. Comparison of Energy Efficiencies for Fuel Cells, Internal Combustion and Hybrid Vehicles [75]

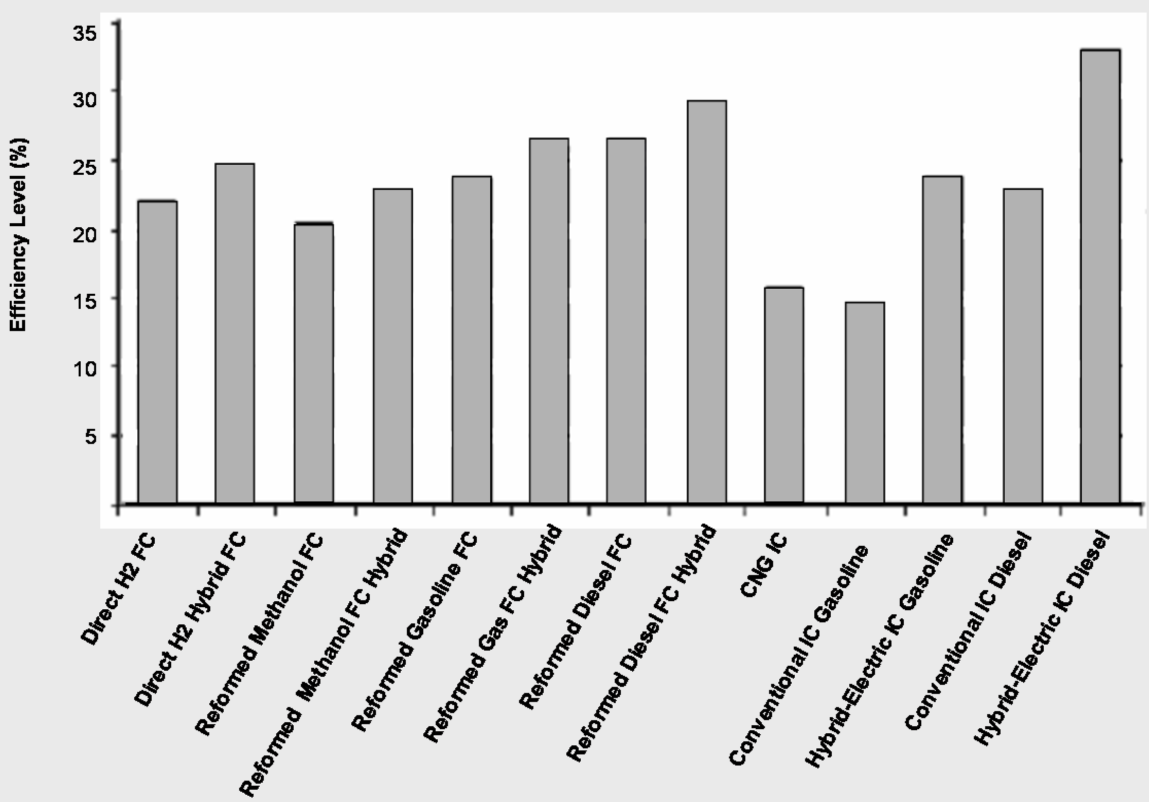
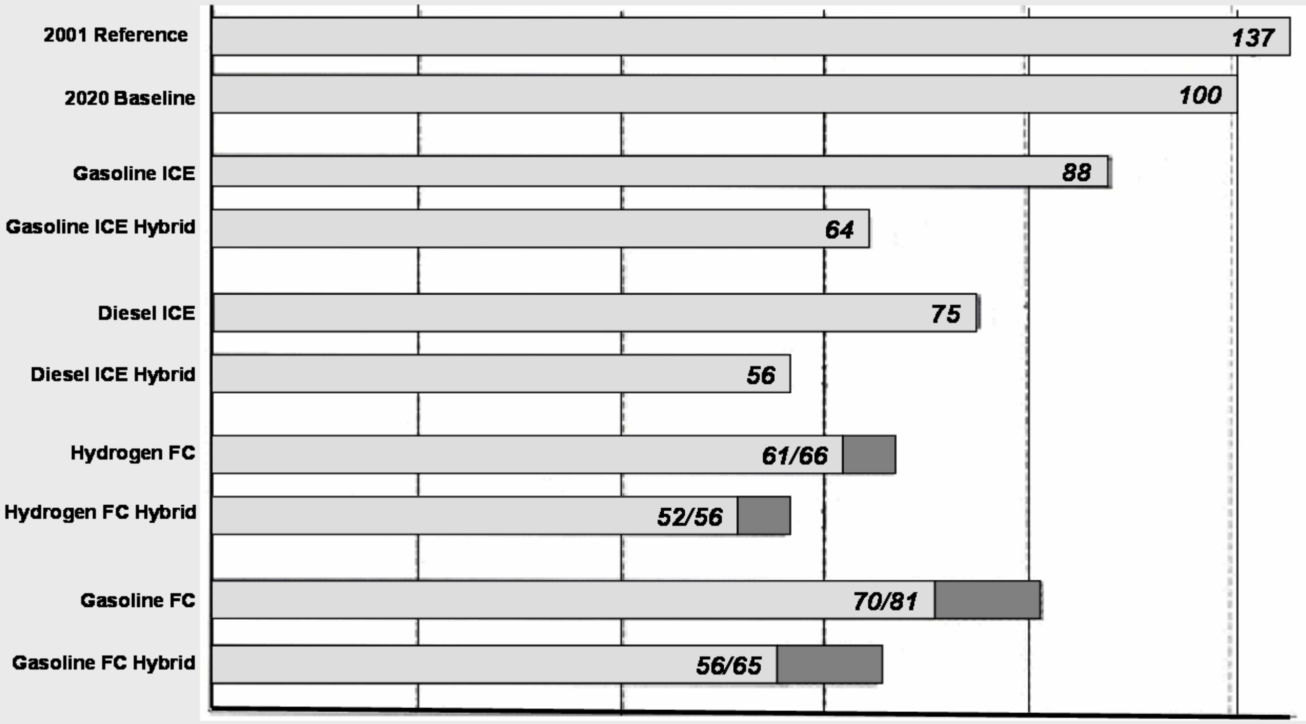


Figure 8. Relative Consumption of Life-Cycle Energy* [76]

Total Energy (LHV) from all Sources Consumer During Vehicle Life Time

(Shown as percentage of baseline vehicle energy consumption)

** Total Energy includes vehicles operation and production of both vehicle and fuel*



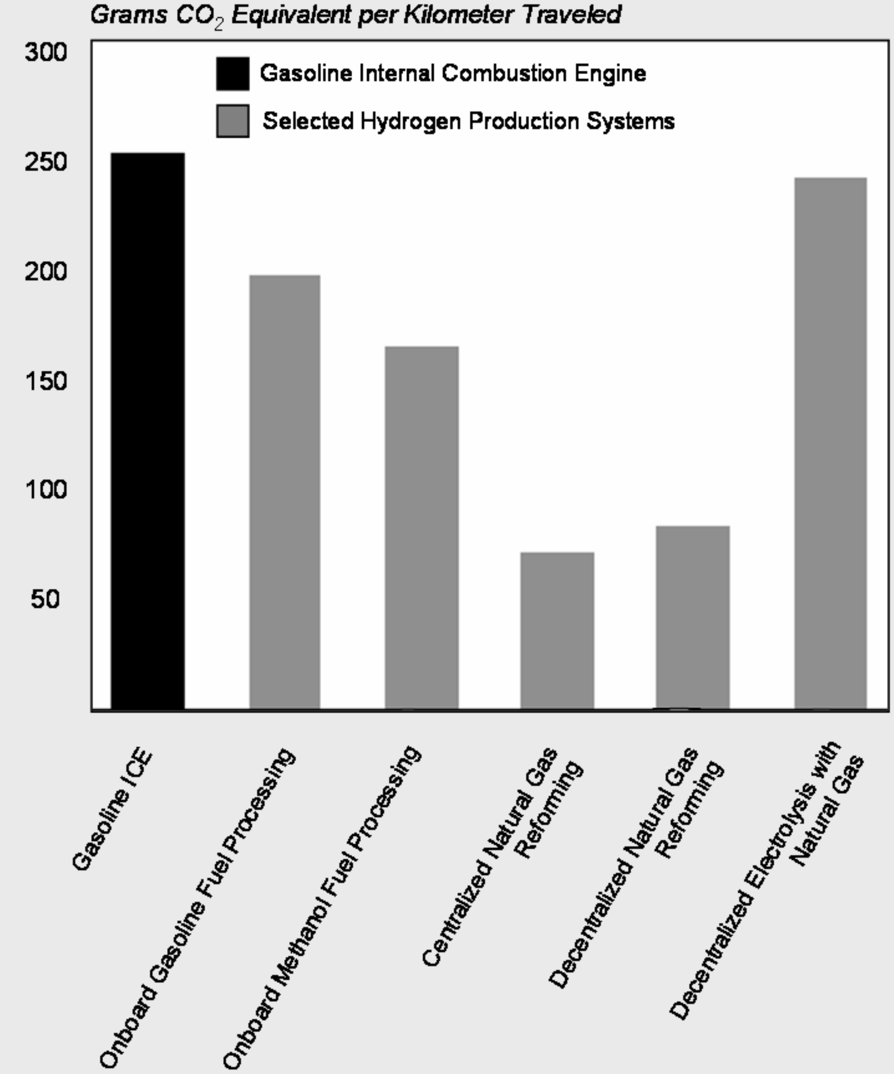
A Princeton University study shows similar results as the MIT study, with the fuel cell vehicles powered by natural gas reformed hydrogen emitting less than half the greenhouse gases as the gasoline ICE. Interestingly, using decentralized electrolysis with natural gas emits almost the same amount of CO_2 as the current gasoline ICE. If the CO_2 could be captured on-site, at point of reformation, something impractical with cars, then there may be a CO_2 emissions benefit over the ICE engine not shown by the results in the study.

Table 2. Relative Emissions of Life-Cycle Greenhouse Gases [77]

	2001 Gasoline ICE	2020 Gasoline ICE - HEV	2020 Diesel HEV	Fuel Cell Vehicle
Vehicle Operation	48.5	21.0	19.1	0
Fuel Cycle	12.1	5.2	3.0	19.4
Manufacturing	5.5	5.0	5.1	5.3
Total	66.1	31.2	27.2	24.7

Each of the various study results illustrates the many different ways that the life cycle of competing fuels, processes and vehicles can be compared. It is important when examining such comparisons not to look at just one type of comparison, but rather across all of the issues of cost, efficiency and emissions. Also important is to understand these comparisons in the context of a state's goals and their relative importance to those goals.

Figure 9. Well-to-Wheels Greenhouse Gas Emissions from Gasoline ICE and Hydrogen Fuel Cell Vehicles [78]



Chapter 4: The Hydrogen Opportunity for New Jersey

New Jersey has the opportunity to take a leadership role in the commercialization of hydrogen fuel and the build out of its corresponding infrastructure. Whether state policies and resources should be directed to such an effort is a question ripe for consideration. The implications of action or inaction in terms of costs, benefits and alignment with state policies and institutions should be evaluated. The quality and breadth of stakeholder involvement will influence this analysis.

Accordingly, New Jersey policymakers and other stakeholders should decide whether to encourage hydrogen fuel and fuel cell commercialization. Based on population density, current industry demographics, and other advances in alternative energy technology, New Jersey may be in a good position to start capturing the benefits of hydrogen's use as a fuel. New Jersey stakeholders can determine whether or not state policies should be focused more on hydrogen fuel, or develop new initiatives in energy, economic development and environmental policy to encourage the commercialization of a hydrogen fuel infrastructure.

Current energy resources, their consumption in New Jersey and the environmental impact of their use in the state must be taken into consideration to determine whether hydrogen can lead to improvements. Identifying companies engaged in the nascent hydrogen economy and those companies likely to benefit from it will help determine whether this sector of the New Jersey economy should be specifically nurtured. Finally, New Jersey's research institutions both in universities and in the private sector can also play a role in growing a hydrogen economy. These strategic initiatives may be appropriate for New Jersey and can form the building blocks of a focused policy in the Garden State for hydrogen fuel commercialization and infrastructure build out.

New Jersey Policy Landscape

Despite the adoption of a state policy framework that has made New Jersey a leader among states in energy and environmental policy, the state currently has no articulated policy toward hydrogen. However, there have been numerous initiatives and demonstrations that can provide the foundation for the development of a policy for the state. Below are brief descriptions of recent policy initiatives that have been adopted by the state legislature or state agencies that address hydrogen or related energy and environmental issues.

In 1998, New Jersey awarded a contract for the commercial use of fuel cell power in a highway Variable Message Sign (VMS). The New Jersey Department of Transportation (NJDOT) awarded the $748,800 contract to a New Jersey-based firm, H-Power of Belleville. Sixty-five existing solar-powered VMS units were outfitted with the fuel cells as a backup stationary power source. Plug

Power subsequently acquired H-Power, which is located in Latham, New York.

In 1999, the New Jersey Project Venturer [79], in conjunction with several universities, technology companies and public agencies, came together to demonstrate building and operating a hydrogen fuel cell and battery powered electric vehicle. The vehicle, named New Jersey Project Venturer, was entered in the Northeast Sustainable Energy Association's (NESEA) 1999 Tour de Sol rally. The NJ DOT's Technology Bureau, NJ Board of Public Utilities (NJ BPU), and NJ Department of Environmental Protection (NJDEP), and NJ Commerce Commission represented the government partners in the project. New Jersey's participation in the Tour rally reflected the interest by both the state and the involved organizations in showing the public and the business community that hydrogen could in fact be used for vehicular fueling purposes. The Tour de Sol was a seven-day educational road rally event for electric vehicles and featured 50 electric, hybrid-electric and solar-assisted electric vehicles built by major auto and bus manufacturers, students and individuals from North America and abroad.

Also in 1999, as part of a comprehensive electric utility restructuring law, New Jersey adopted a Renewable Portfolio Standard (RPS) that requires electricity suppliers to acquire a minimum percentage of their power from renewable sources. The law included provisions for net metering [80], the creation of a "clean energy fund", and disclosure of energy sources to customers. In addition, a "societal benefits charge" or SBC is added to the cost of each kilowatt-hour of electricity sold in the state. The SBC yields approximately $125 million annually to support renewable and energy efficiency programs; 25 percent is earmarked for renewable energy technologies.

In April 2003, Governor McGreevey's Taskforce on Renewable Energy made three major recommendations:

- Double the RPS in 2008 from 2% to 4%
- Establish a goal of photovoltaics providing 120,000 MWh of electricity generation by 2008
- Establish an RPS of 20% by 2020

In April 2004, the NJ BPU adopted the first two recommendations and is reviewing the third. In June 2004, the NJ BPU commenced the statutorily required update to the "comprehensive resource analysis" (CRA) to determine the market demand and appropriate level of funding energy efficiency and renewable energy programs to be supported by the SBC for 2004 through 2008.

In 2002, the Clean Air Council [81] recommended that various state agencies, including the BPU and NJDOT, should coordinate efforts to adopt and adhere to low-emission vehicle (LEV) standards similar to California. These standards would help to bring New Jersey into compliance with the U.S. Environmental Protection Agency's National Ambient Air Quality Standards. This policy framework for LEV adoption encouraged more discussion about hybrid electric, bio-diesel, and other low- and non-polluting vehicles including hydrogen fuel cell vehicles.

In 2004, Governor McGreevey signed legislation adopting the environmental standards recommended by the Clean Air Council in 2002, similar to California's strict Round II Low-Vehicle Emission (LEV) standards. When the law takes effect, automobile manufacturers will be required to introduce a complete line of low-emission new cars by 2009. However, hybrid vehicles and other vehicles with low emissions will likely be available sooner as automotive firms begin to bank credits before the most stringent regulations come into effect. [82] The new standards would reduce air toxics (a classification of carcinogenic pollutants primarily emitted from cars and trucks) by almost a quarter more than current federal standards.

The New Jersey Clean Energy Program [83] offers a series of financial and technical assistance programs to help the public and private sectors embrace alternative energy technologies. The main programs target different potentially interested groups:

- **CORE** – The Customer Onsite Renewable Energy program rebates up to 70 percent of the installed cost for renewable energy systems such as solar, wind, and sustainable biomass systems.

- **REAP** – The Renewable Energy Advanced Power program provides incentives and financing for renewable electricity generation facilities.
- **REDO** – This program offers local governments and schools low interest financing to implement energy efficiency and renewable energy projects.
- **REED** – The Renewable Energy Economic Development program provides venture capital and comprehensive business assistance to renewable energy companies growing their business and employment in New Jersey.

New Jersey Energy and Environmental Landscape

Data for the state of New Jersey for 2000 reveal a larger percentage of end-use energy devoted to transportation than in the nation as a whole, which makes the state more vulnerable to changes in petroleum supply. In this state, 34 percent of energy consumption goes to transportation, 27 percent to industrial uses, 20 percent to residential, and 19 percent to commercial uses. [84] Of total energy used in the state in 2000, 47 percent came from petroleum and 23 percent was from natural gas. Only 4 percent came from coal, 11 percent from nuclear electric power, and about 2 percent from a combination of alternative sources, such as wood and solid waste, hydroelectric power, and a combination of geothermal, wind, photovoltaic (PV), and solar thermal energy. [85] This suggests that New Jersey in a hydrogen economy would reap greater benefits from reducing petroleum dependence than the average state, especially in transportation, where an effective deployment of hydrogen fuel cell vehicles would impact New Jersey's energy consumption greater than the average state.

In energy consumption and imports, state rankings for the year 2000 published by the Energy Information Administration reveal the state of New Jersey to be among the largest consumers of energy. In all sectors – residential, commercial, industrial, and transportation – New Jersey ranks among the top 15 states. Moreover, when total consumption is calculated per capita, New Jersey ranks just below the middle of the pack at 32 out of 50. The per capita energy consumption is higher in this state than many other states with a high population, including California, Massachusetts, New York, and Florida. [87]

New Jersey has traditionally been concerned with environmental degradation. Because of its density, heavy reliance on personal automobiles for transportation, as well as external pollution received from Midwestern coal power plants, New Jersey is a leading state nationally in curbing environmental damage. While external sources of pollution make up approximately a third of New Jersey's greenhouse gas levels, transportation accounts for a large portion of state-produced pollution. New Jersey is home to 36,609

Table 3. Energy Consumption and Type - United States and New Jersey 2000 [86]

END USE	*U.S.*	*New Jersey*	ENERGY TYPE	*U.S.*	*New Jersey*
Transport	27%	34%	Coal	23%	4%
Residential	19%	20%	Natural Gas	23%	23%
Commercial	15%	19%	Petroleum	39%	47%
Industrial	39%	27%	Nuclear Electric Power	8%	11%
			Hydroelectric Power	3%	-0.05%
			Wood and Waste	3%	1%
			Other	0.4%	0.03%
			Net Inflows	0%	14%

Table 4. New Jersey's Ranking in the Nation in Energy Consumption 2000 [88]

CATEGORY	RANK	CATEGORY	RANK
Per Capita Consumption		*Sector Consumption*	
Coal	36th	Residential	11th
Natural Gas	9th	Commercial	9th
Petroleum	9th	Industrial	15th
Electricity	20th	Transportation	8th
Total	32nd	Total	12th

of highways, streets and roads. New Jersey could benefit from extending its practice of interagency coordination of its energy and environmental policies to include a focus on the use of hydrogen as a fuel.

There are a number of companies and organizations involved in research, development, production and sale of fuel cells, hydrogen, metals, merchant gases, and other products that could be involved in designing and building a hydrogen fuel infrastructure. While most of these companies do not necessarily regard themselves as building blocks of a hydrogen economy their work related to hydrogen and fuel cells means their participation in this market growth would be imperative to the ultimate success of hydrogen as the fuel of the future in New Jersey and across the nation. Already in place are policies encouraging the growth of renewable energy resources, as described previously in the *New Jersey Policy Climate* section. Moreover, hydrogen currently is a significant component of the state's industrial sector. For example, New Jersey's large petrochemical industry currently uses hydrogen to remove sulfur from petroleum during the refining process. In the Mid-Atlantic region, New Jersey has 60 percent of all oil refineries. Half the oil refineries in New Jersey use hydrogen in their refining process.

New Jersey's Commitment to Innovation

New Jersey ranks among the top 10 states in overall research and development spending, primarily in the pharmaceutical industry. New Jersey is home to 20 four-year colleges, 21 two-year colleges, and two engineering colleges. Rutgers University, Princeton University, the University of Medicine and Dentistry of New Jersey, the New Jersey Institute of Technology, and Stevens Institute of Technology comprise most of the academic research done in the state. These institutions combine to form a powerful nexus of research and development that already is exploring various aspects of a hydrogen economy. With technology and business incubators throughout the state and various tax credits and loan programs for research, there is substantial support available for new ventures. New Jersey is also home to a large number of engineers and scientists per capita, which can provide the necessary workforce for start-ups and new technology companies.

One example of collaboration between the private sector and universities in the state is The New Jersey Corporation for Advanced Technology (NJCAT). NJCAT is a private/public partnership that pools the best talents and diverse resources of business and industry, entrepreneurs, university research centers, utilities and government to promote the development and commercialization of exciting, new energy and environmental technologies. NJCAT seeks to provide technology innovators with the technical, commercial, and regulatory required bringing promising new ideas to market. NJCAT also identifies demands for new technological systems and seek out innovators who can meet those demands. [89] Under NJCAT's technology assessment program a technology developer can seek a verification of claims that will be conducted by evaluators from the state's public universities together with the opportunity to negotiate a tailored regulatory construct with the New Jersey Department of Environmental Protection. [90]

Additional examples of innovation in the field of hydrogen fuel and fuel cell research and demonstration exist at many of New Jersey's universities. At the Rutgers University, Ceramics and Materials Engineering Department in Piscataway, the Sol-Gel group is working on various projects that develop coatings for applications such as PEM and SOFC fuel cells. Sol-Gel is a process that makes materials highly heat and cold resistant and has a glass-like appearance. Treating the anode and cathode elements of the SOFC fuel cell, for example, with sol-gel would allow more flexibility in the components and therefore reduce the overall cost of maintenance and construction. In a PEM fuel cell, using Sol-Gel with good proton conducting glasses can increase the conductivity, making the whole unit more efficient. [91]

Also at Rutgers University is the Center for Advanced Energy Systems (CAES) and the NJ Agricultural Experiment Station. The CAES combines expertise from the various engineering departments (industrial and systems, mechanical and aerospace, electrical and computer, chemical and biochemical, and civil and environmental) and those of the Rutgers Center for Operations Research and the Bloustein School of Planning and Public Policy to promote the development and promotion of new energy related technologies. Part of the mission is to educate and transfer knowledge and technology that will shape the present and future energy policy of the state and nation. [92] The NJ Agricultural Experiment Station is affiliated with the Department of Environmental Science in New Brunswick and has faculty researching anaerobic digestion (extracting methane from biowaste products). In the area of transportation at Rutgers University, the Voorhees Transportation Center conducts policy and economic research and the Center for Advanced Infrastructure and Transportation is studying the impacts of fuel cells on transportation infrastructure.

Richard Stockton College in Pomona, NJ installed a natural gas fuel cell as a combined heat and energy unity in May 2003. The unit, produced by United Technologies Companies cost $1.3 million and was financed almost two-thirds (over $700,000) by the New Jersey Board of Public Utilities and the U.S. Department of Energy through the state's Clean Energy program. The school partnered with South Jersey Industries who, through its subsidiary South Jersey Energy, provided the unit, maintenance, and natural gas infrastructure to keep the unit operating. The fuel cell will mean a savings of over $80,000 per year in energy costs for the school. [93]

The Ramapo College of New Jersey in Mahwah operates two fuel cells, both installed in 2000. The college invested in the units with financial support from the federal government and before demand for the units raised the cost to a more prohibitive level for many academic institutions. In 2000, the school paid about $600,000 per unit, after a government rebate of $200,000; between that time and the next year, the price for a unit increased as much as $350,000, making the total over one million dollars. Both units operate using natural gas. Fuel Cell #1 provides 80 percent of the energy for Oak Hall and surrounding parking areas, while Fuel Cell #2 supplies heat to an academic building and power to communications and computer facilities. [94]

The College of New Jersey in Ewing Township plans to unveil three new fuel cells to be the main energy sources for a new student housing facility scheduled to open in the Fall Semester of 2004. The natural gas fuel cells cost over $3 million, most of which came from grants from the U.S. Department of Energy and the NJ BPU. The college was responsible for funding $770,000. The installation of the fuel cells will mean a cost savings of $259,000 annually in energy costs. [95]

In providing funding for this study, the BPU asked that consideration be given to the costs, value and goals that would be associated with the establishment of a Hydrogen Learning Center in New Jersey. The aforementioned activities at New Jersey colleges and universities provide a strong foundation upon which a Hydrogen Learning Center could be established. In addition, the Rutgers EcoComplex in Burlington County will be another site for a fuel cell demonstration to complement the other energy efficient technologies under demonstration there.

It is envisioned that a Hydrogen Learning Center would provide opportunities for hands-on demonstrations, tours of facilities and other activities to enhance public knowledge in subjects of hydrogen and fuel cells. A Hydrogen Learning Center would facilitate collaboration and networking among stakeholders. This will help to build upon the activities associated with the current demonstration projects to enhance and increase discussion among policymakers, educators, students, and other stakeholders. In addition, a Hydrogen Learning Center could contribute to the development of courses to be integrated in to the curricula at New Jersey's colleges and universities.

Significantly, the center itself need not be limited to one location. In fact, it is envisioned that such a center would incorporate each of the university based demonstration sites into a "distributed" Hydrogen Learning Center. This would maximize the ability for students and other stakeholders to obtain hands-on learning experiences at facilities close to their communities. The overall coordination of activities across the distributed sites could be managed by an entity selected to serve in such a capacity. Because of the capital costs associated with the installation of demonstration sites need not be provided, it is believed that a Hydrogen Learning Center could be established with initial funding of $250,000.

Chapter 5: Policy Recommendations for New Jersey

Public policies at the state level can have a significant impact on developing technologies. Policy can create demand for new technology by setting standards that challenge the capabilities of existing technologies. For example, emission standards for automobiles and stationary power sources can contribute to the demand for cleaner fuel, including hydrogen, as a means of meeting these stricter standards. Regulation can contribute to a long-term economic development strategy. However, the regulatory requirements must be achievable, without excessive cost to accomplish the underlying objective.

Since state law is tailored to currently available energy options, a periodic and regular review of these is necessary in order to identify and address regulations that may be outmoded or create market barriers to new energy sources like hydrogen. Public awareness campaigns can improve the public's access to information and counter myths and misconceptions about hydrogen that may stir consumer wariness. Public policy-makers can support education and outreach programs to improve information diffusion within the state. State governments can also provide incentives such as grants, tax incentives and loans to new energy sources like hydrogen. As a purchaser of energy, state governments can aid new energy technologies through set-asides or other purchasing programs.

Tax credits to municipalities, counties, schools, private companies and individuals can provide incentives to increase demand and investment in new energy. How policymakers write the rules will determine whether they are technology- or energy-neutral, or if they are favoring a particular energy to be key to stated policy goals.

New Jersey has the opportunity to take a leadership role in the commercialization of hydrogen fuel and the build out of its corresponding infrastructure. The decision whether to act upon this opportunity will require further analysis of a number of issues, including likely environmental impacts, prospects for economic development, and an assessment of other policy initiatives that will compete for the attention and resources of the state. If New Jersey policymakers and other stakeholders decide state policies and resources should be directed to a hydrogen fuel initiative there are several concrete steps that can be taken to inform that decision making process. This report makes 5 specific recommendations that fall into four major categories:

- Education and Outreach;
- Public/Private Cooperation;
- Cross-Agency Coordination; and
- Research, Development and Demonstration Projects.

These recommendations, whether taken individually or together, build a foundation for New Jersey to consider its role as a leader in the commercialization of hydrogen fuel and its related infrastructure.

Education and Outreach

Recommendation #1 - The New Jersey Board of Public Utilities, Office of Clean Energy, should proceed with its initiative to establish a Hydrogen Learning Center to act as a focal point for education and outreach for all New Jersey's stakeholders regarding the state's consideration of policies related to hydrogen fuel.

The use of hydrogen as a fuel is on the periphery of public understanding. Education and outreach to policymakers, consumers, public interest groups, environmental groups, and businesses is needed for New Jersey to develop an informed public policy addressing hydrogen fuel. The New Jersey Office of Clean Energy requested that this study specifically consider the value of establishing a Hydrogen Learning Center. Our research for this report has shown that New Jersey must choose whether to take a leadership role among states in evaluating and pursuing the commercialization of hydrogen fuel and its related infrastructure. Informed stakeholders who actively contribute to the development of policy options and choices will enhance the process of making that strategic policy decision. A Hydrogen Learning Center can be an effective venue and vehicle for the required education, outreach and involvement among all stakeholders.

The establishment of a Hydrogen Learning Center should incorporate a full array of activities, including diverse education programs directed to all stakeholders that can be provided through schools or in coordination with non-profit and industry groups. Demonstration sites for fuel cell applications and hydrogen fuel infrastructure can serve as connecting activities for a "distributed" center that would involve many state universities and other public institutions.

In addition, a Hydrogen Learning Center should facilitate networking among NJ stakeholders to encourage coordination, information sharing and innovation. More specifically, the Center should serve as a catalyst for coordination and collaboration among New Jersey's public and private colleges and universities in research and curriculum development.

Through these activities, a New Jersey Hydrogen Learning Center will prepare stakeholders to make informed contributions to state policies addressing the role of hydrogen fuel as a part of the state's energy portfolio and as a component of a strategic policy determination that holistically considers the energy, economic and environmental implication of action or inaction. Additionally, education and outreach activities will help to break down myths about hydrogen's use as a fuel and allow for an informed discussion.

Public/Private Cooperation

Recommendation #2 - The state should initiate a New Jersey Hydrogen Vision and Roadmap process.

There is a clear and unquestioned value to promote coordination among government, academic and private interests. Since innovation will be driven by private sector demand and nurtured in academic and private research and development, government can play a role in ensuring that linkages among the various actors occur and be willing to fill gaps when they appear. A number of companies already are poised to take advantage of the hydrogen economy, but there is less of a sense whether New Jersey, as a state, will be devoting policies specifically aimed at hydrogen fuel. Building upon the demonstrated success of similar Vision and Roadmap processes initiated by US DOE and other states, New Jersey can construct a framework for public-private cooperation in the development of policies recommendations for consideration by the Governor and Legislature. This process would assist New Jersey in determining its overall strategy on hydrogen as to whether or not it will take a leadership role in the commercialization of hydrogen fuel and infrastructure deployment.

Cross-Agency Coordination

Recommendation #3 - The Governor should consider establishing a Hydrogen Policy Working Group across key state departments and agencies.

Cross-agency coordination among state departments and agencies is one of the most important steps in determining state energy policy. In the case of hydrogen fuel, issues can affect many aspects of public policy, including transportation, environment, energy, utilities, and economic development, to name just a few. Maximizing the potential benefits of public policy initiatives requires that activities are coordinated across agencies and that any new governmental programs, investments or requirements are reviewed in the context of the subject of the initiative. The working group should include the senior officials at the Board of Public Utilities, Department of Environmental Protection, Economic Development Authority, Commerce and Economic Growth Commission and the Department of Transportation. Collectively, the working group would coordinate a review of the state policy implications of a leading or adaptive approach to hydrogen fuel commercialization. As such, the working group would be an important complement to the Vision and Roadmap process.

Research, Development and Demonstration

Recommendation #4 - The Office of Clean Energy should continue to encourage the deployment of fuel cell applications in the state through its clean energy programs.

New Jersey is encouraging research in the area of emerging clean energy technologies including hydrogen. Those efforts should be encouraged, if only based on the value of emerging clean energy technologies. For these RD&D programs to have enhanced and lasting benefits to New Jersey, it is important to ensure that linkages between public research and private companies are available so that investment benefits do not leave the state once innovative technologies reach commercial deployment stages. New Jersey has been successfully involved in demonstration projects with fuel cells and hydrogen technology. Those efforts can be enhanced and expanded as part of a strategic policy initiative. Moreover, the state can expand its own direct participation through programs such as the deployment of fuel cells at state institutions and the use of a portion of the state vehicle fleet and related fuel infrastructure as part of a coordinated demonstration project. Evaluation and monitoring of current fuel cell projects in New Jersey is also important to ensure that the experiences of these demonstrations can be shared to improve future projects.

Recommendation #5 - The state should expand on the research programs in basic and applied research at New Jersey universities to assist in solving the technical barriers to hydrogen fuel and infrastructure deployment.

While New Jersey is in the process of deciding whether or not to actively encourage hydrogen fuel and infrastructure deployment, it is not precluded from continuing to encourage research, development and demonstration in hydrogen technology as a component to the state's commitment to clean energy. Regardless of the path chosen by New Jersey policymakers and other stakeholders with respect to hydrogen, remaining committed to new energy sources and technologies will be important to ensure a sustained energy supply, strong economic growth and continued environmental stewardship for the Garden State.

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