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HyTeP
Hydrogen Technology Partnership

A NEW MEXICO HYDROGEN CLUSTER OPPORTUNITY ASSESSMENT

Final Report
Prepared for the New Mexico Economic Development Department

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Executive Summary

In March 2003, House Joint Memorial 6 was passed asking the legislature to support state action to promote New Mexico as the world leader in hydrogen and fuel-cell research and development and to enable the growth of a related fuel-cell industry cluster, i.e., a group of interdependent hydrogen and full-cell companies that could spawn wealth creation in New Mexico, primarily through the export of goods and services.

Industry clusters are indicative of prosperous geographic regions, the most famous of which is Silicon Valley, often referred to as “the cradle of America’s electronics industry.” Because science and technology resources are often a significant factor in successful clusters, the availability of a scientific workforce, superior research facilities and a large base of federal research and development dollars, together, represent an important asset base for the state. The New Mexico Economic Development Department (NMEDD) is therefore chartered to develop a state plan for fuel-cell research and development including initiatives that encourage industry to establish fuel cell and hydrogen-related research, manufacturing or service operations in New Mexico. The Hydrogen Technology Partnership (HyTeP)—an alliance of industry, research laboratories, universities, and government collaborating to establish a hydrogen industry cluster in New Mexico—is working closely with NMEDD on this initiative. The objective of this report is to provide an initial “opportunity assessment” that may be used as the basis for a state hydrogen-cluster strategic plan.

Hydrogen is one of the most promising energy sources for the future and represents a viable alternative to the existing energy system and dependence on foreign oil. Hydrogen and fuel-cell technologies can provide key improvements in energy efficiency, greenhouse gas emissions, pollution abatement and quality of life. Hydrogen is renewable, can be derived from a variety of different feedstock, and produces byproducts that are less hazardous to the environment and human health than byproducts from other fuel sources. Most countries have an abundance of at least one potential feedstock, enabling some energy independence.

The hydrogen economy will be driven by several enabling technologies, the most important of which are fuel cells. A fuel cell is similar to a battery, however it will continue to generate electrical power indefinitely as long as fuel is supplied. The superior efficiency of fuel-cell technology and its environmental and social benefits have attracted the attention of governments and industry alike, many of whom have accelerated their investments through targeted policies, program support, and strategic demonstrations. The United States, Canada, the European Union and Japan are investing several billion dollars over the next five years toward the development and commercialization of hydrogen technologies. These investments include research and development at national laboratories and universities as well as grants to large corporations for demonstration projects and direct investments in new companies. Without massive government support, the envisioned “hydrogen economy” may never come to pass.

The basic components of the hydrogen value chain are very similar to our existing energy infrastructure. The infrastructure must include a means to produce hydrogen fuels from fossil fuels, biomass, or water. Other components include storage and distribution from point of production to point of use or application. The most promising applications for hydrogen and fuel cells reside in three major markets: portable, stationary, and transportation, in order of projected broad market realization. Stationary fuel cells are the most commercially mature although not yet used in broad consumer applications. Transportation applications are the furthest from market due primarily to the enormous infrastructure transition that needs to take place and lingering technical challenges for storage.

As the hydrogen and fuel-cell industry is nascent and current production costs are prohibitively expensive, broad-based consumer demand does not exist. Therefore, current demand for fuel-cell products and services consists primarily of materials, services and supplies utilized in demonstration projects. The high price of new fuel-cell products—reflecting higher production costs associated with small production volumes—poses a prohibitive barrier to potential purchasers beyond demonstration ventures.

Within each market in the hydrogen value chain are companies at different stages of development. The needs of these companies are highly dependent on where they fall in this lifecycle. Start-ups often seek seed capital from government sources to fund technical and business development. Up-and-comers show promise of revenue in the near future or currently have a nominal revenue stream from existing hydrogen or fuel-cell product lines. Although not yet profitable, businesses that are most advanced currently consist of large public companies or subsidiaries of large corporations that are financing operations through the public markets and government subsidies.

Many challenges remain to the realization of a hydrogen economy including proving the economics, solving tough technical challenges, establishing codes and standards, and mitigating poor consumer perception. (Hydrogen's reputation as a dangerous material is an adoption barrier to the average consumer.) Despite the challenges, government and private sector entities alike are positioning themselves now in order to reap benefits in the future. Projected global demand for fuel cells could reach $46 billion by 2011, with a market potentially exceeding $2.6 trillion by 2021.[1]

More than 24 states so far are pursing a hydrogen cluster initiative, trying to attract and grow young companies. Although there is currently no critical concentration of private sector activity within any region, many states have a head start with mature, well-funded initiatives in place and a small cadre of fuel-cell companies in tow. At least 15 states have a public benefits fund to quickly build money for renewable energy and energy efficiency programs. It is estimated that from 1998 to 2012, these funds will amass more than $4.3 billion.[2]

Various state incentive packages focus on tax rebates, grants or research centers. States that are the most advanced (Tier 1) including California, Connecticut, Hawaii, Massachusetts, Michigan, New York, Ohio and Texas have robust programs that include progressive supplier and buyer incentives, fuel-cell technology centers, actively involved universities, organized partnerships, general grant programs, dedicated funding, and ongoing demonstration projects. Tier 2 states, which include Florida, Illinois, Minnesota, Montana, New Jersey, New Mexico, and Pennsylvania, are in the process of developing initiatives in the hydrogen area; most states have been designing their initiatives and programs within the last year. Tier 3 contains the remaining states. These states do not currently have a program or the program is very small and not dedicated to the development of a hydrogen or fuel cell cluster.

State sponsored incentives are only one factor in the evolution and success of an industry cluster. Michael Porter, the preeminent expert on cluster theory, suggests that factor inputs and conditions will either positively or negatively influence the emergence of an industry cluster. Such factors include basic assets

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[1] "Canadian Fuel Cell Commercialization Roadmap," Industry Canada and Price Waterhouse Coopers, http://strategis.ic.gc.ca/epic/internet/inmse-epe.nsf/vwGeneratedInterE/ep00031e.html

[2] Hopkins, Barry, "Renewable Energy and State Economics," The Council of State Governments, May 2003.

such as land, natural resources, and geography. Advanced factors include science and technology resources, research and development (R&D) investments, and entrepreneurial support programs among many others. Other influences include the context for individual firm strategy and rivalry among firms, demand for the outputs of the cluster and the status of related and supporting industries. The existence and strength of these various elements is only an asset when they are utilized and deployed productively. Although New Mexico has been a leader in hydrogen and fuel-cell research and development for over a quarter of a century, many of the commercial fuel-cell developments have been commercialized outside the state.

New Mexico's key strengths for cluster development include an abundance of natural and renewable power sources, a successful fuel-cell research and development track record, an ability to attract large R&D dollars from federal sources and a variety of entrepreneurial support programs. These factors represent variables that the state should leverage and nurture in its marketing efforts and in the development of a comprehensive strategy.

Areas in which New Mexico reflects a weaker position include a skilled labor pool, established hydrogen codes and standards, large and funded alternative energy initiatives, an ability to translate R&D into commercial ventures, significant industry-led R&D, large industrial base, transportation infrastructure, university hydrogen or fuel-cell degree programs, technology management skills, risk investment track record, business incentives, early home demand, energy infrastructure, and demonstration projects. Although the level of weakness varies (in some cases the factor is actually neutral), these factors are those on which the state should focus its efforts. It is very important to consider that the evaluation of these factors will vary dependent upon the type of business New Mexico expects to attract or grow.

The following recommendations represent a set of synergistic approaches that the state should consider in the development of the state's strategic plan for hydrogen.

Enhance Skill Base. New Mexico is rich in science and technology resources but relatively poor in technology management expertise. The state should develop a strategy to ensure a sufficient supply of skilled resources for the fuel-cell sector that includes community college training programs and advanced degrees in energy or fuel cells at New Mexico universities.

Develop Demonstration Projects. The state can use its political muscle and experience in attracting federal dollars to attract demonstration projects that showcase fuel-cell technology and provide essential commercialization data.

Create Hydrogen Business Incentive Package to Grow Industrial Base. New Mexico lacks the established industrial base of many of the other states currently pursuing a hydrogen strategy. A region that conveys a business-friendly climate, high quality of life, and an economic infrastructure that minimizes the cost of doing business will attract established businesses and support the start up and growth of new companies. The state must develop a competitive incentive package to attract a "champion" firm to the state and to nurture hydrogen and fuel-cell start-ups.

Support and Enhance Industry-Led R&D. Public R&D tends to create private R&D. Therefore, providing incentives to entice more R&D by the private sector could help encourage the establishment of R&D outposts for large corporations.

Create Early Demand. The state should establish early purchase programs to encourage product procurement and benchmarking and develop public information programs to educate policy makers, service providers, consumers, and students.

Take a Leadership Role in Codes and Standards Development. By taking a lead role in the development and implementation of hydrogen codes and standards, the state will help to establish itself as hydrogen friendly and enable early adoption within New Mexico of hydrogen products and services by minimizing risks associated with testing and usage of new products.

Enhance Alternative Energy Initiatives. New Mexico should support the passage of The Clean Energy Act as the first step towards the accrual of funds to support implementation of renewable energy initiatives.

Explore Local Hydrogen Generation. New Mexico's large deposits of natural gas could allow for cheap generation of hydrogen. This option makes sense only in the case where profits are larger that the cost of importing hydrogen for local demand.

Further study is wise to solidify specific steps to properly execute these strategies. A funded and responsible organization should be established to manage the strategic planning process, implementation, and evaluation. The timeline for plan development and execution must be expeditious as there is significant competition from other regions with more mature cluster development programs.

Introduction

Hydrogen and fuel-cell technologies are poised to provide major improvements in energy efficiency, greenhouse gas emissions, pollution abatement, and quality of life. Governments in the United States, Canada, the European Union, and Japan are currently committing several billion dollars over the next five years towards the development of these technologies and their widespread commercialization. It is well understood that without massive government support, the envisioned "hydrogen economy" may never come to pass based on the enormous competition represented by an installed base of technologies, infrastructure and capital serving current energy needs. Compounding the difficulty of early market penetration, hydrogen and fuel-cell technologies are not currently poised to attract the private sector "risk" capital essential for accelerated growth and adoption. To quote the most recent U.S. Department of Energy (DOE) Fuel Cell Report to Congress (February 2003):

> ***Industry's goal is to provide customers with clean, energy-efficient technology that performs as well as, if not better than, the commercially available product and at comparable cost. However, major technical and institutional barriers must be overcome. Because of the high cost and risk involved with overcoming these barriers, no single company or consortia of industry partners could be expected to make the huge investments that would be required.***

The long-term potential for this industry however is enormous and despite the challenges, government and private sector entities alike are positioning themselves now in order to reap benefits in the future. In spite of no substantial demand currently for hydrogen or fuel cells, it is projected that the global demand for fuel cells could reach $46 billion by 2011, with a market potential to exceed $2.6 trillion by 2021.[3] It is important to note that this projected future growth rate is highly speculative and dependent upon critical technology improvements and market acceptance.

For the United States (and New Mexico specifically) opportunities exist to establish a global leadership position, but to do so, quick and decisive action by both industry and government is urgently required. The why for New Mexico (why should New Mexico care about a seat at the Hydrogen Economy table) is best described as the opportunity to create new, high-value, knowledge-based jobs, attract more investment capital, and generate new revenue streams into the state. In addition, the state's involvement in research and development today gives the state a strong technology portfolio for exploitation tomorrow.

The remaining challenges are not insignificant. Support for the development of this industry cluster must be dedicated, direct, and sustained. This is not a short-term initiative. The evolution of a true hydrogen economy is in its earliest stages and is expected to take years or even decades to materialize.

Regions that are successful in creating hydrogen clusters will prosper greatly as a result of job creation and tax income, benefiting the local economy. Presently, New Mexico has demonstrated significant political will to nurture hydrogen technology in the state through Governor Richardson, U.S. Senator Domenici, and U.S. Senator Bingaman. This leadership has not gone unnoticed by the private sector, which is anxious for the state of New Mexico to roll out and implement a strategic plan for hydrogen.

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[3] "Canadian Fuel Cell Commercialization Roadmap," Industry Canada and Price Waterhouse Coopers, http://strategis.ic.gc.ca/epic/internet/inmse-epe.nsf/vwGeneratedInterE/ep00031e.html

Objective

One of Governor Bill Richardson's key initiatives is to develop a strategy that places New Mexico at the fore of a hydrogen-based economy. In March 2003, House Joint Memorial 6 was passed requesting:

> ***The legislature support state action to reinforce New Mexico as the world leader in hydrogen and fuel cell research and development and in the development of related fuel cell industry clusters.***

The NMEDD has therefore been chartered to develop a state-wide plan for fuel-cell research and development including programs that encourage industry to locate fuel-cell and hydrogen-related research, manufacturing, or service operations in New Mexico. During the 2003 legislative interim, the Secretary of Economic Development is requested to appear before the appropriate interim committee and report on the status of this plan as well as on any suggested legislation.

Working closely with NMEDD in this effort is the Hydrogen Technology Partnership (HyTeP)—an alliance of industry, research laboratories, universities, and government collaborating to establish a hydrogen industry cluster in New Mexico through cooperative research, development, demonstration, and commercialization of fuel cells and hydrogen technology. Los Alamos National Laboratory (LANL) has assigned one full-time employee to support the HyTeP initiative and assist in the development of the hydrogen cluster strategic plan. This report is the first action towards that goal. The objective of this report is to provide an initial "opportunity assessment" that may be used as the basis for an in-depth, comprehensive, strategic plan. (See Appendix I for more details on the HyTeP Strategic Planning Workshop.)

Methodology

This opportunity assessment culminates in a set of recommendations for leveraging New Mexico strengths and overcoming identified challenges. Based on primary and secondary research, this report:

1. Describes the current state of the Hydrogen Economy.
2. Utilizes Michael Porter's Cluster Theory Framework to assess New Mexico's current strengths and weaknesses.
3. Presents a competitive analysis of other state hydrogen incentive programs and initiatives.
4. Provides recommendations for a path forward.

An important first step has been taken by the state of New Mexico via the production of this opportunity assessment. However, it is only a first step. New Mexico state government, academia, and industry must now take these findings and come together in a leveraged effort to devise a comprehensive strategic plan to confront challenges, identify public and private sector resources necessary to achieve results, and establish a timetable with milestones that will provide clear measures of success.

Current State of the Hydrogen Economy

Facilitating the expanded and efficient use of hydrogen represents a potentially viable alternative to the existing energy system and possibly our dependence on foreign oil production. Hydrogen is sometimes depicted as a "universal" fuel that can be used for electric, mechanical, and thermal energy. It is abundant and compatible with existing energy conversion technologies such as fuel cells and combustion turbines. And possibly most importantly, it is considered a "clean" energy source. Although the potential is enormous and praiseworthy, the road to a complete energy infrastructure fueled by hydrogen involves major infrastructure investments to be comparable with those already in place for natural gas, such as pipelines and storage tanks. The eventual transition to a hydrogen economy will be highly dependent upon solving technical challenges, reducing costs, ensuring safety, and gaining public acceptance.

Despite the challenges, many world governments, captains of industry, and private citizens strongly believe that action is needed now to accelerate the realization of the hydrogen economy. Investing in the development of alternatives provides insurance against an uncertain energy future.

There are many advantages to migration away from a fossil fuel economy. Hydrogen is renewable, can be derived from a variety of different feedstock, and the byproducts created by the energy conversion are safe for the environment and human health. Hydrogen can be generated from a variety of sources, such as petroleum, natural gas, water, biomass, and alcohol. This diversity of feedstock allows for decreased dependence on commodity price fluctuation, resulting in a more stable economy. Should one of the possible feedstock become scarce, hydrogen can just as easily be produced from a variety of other abundant resources. Most countries have an abundance of at least one potential feedstock, allowing for local production and energy independence. Most importantly, the environment would no longer be polluted by energy generation.

"Leading petrol geologists disagree about when global production of oil will peak – that is, reach the point where half the known oil reserves and projected oil yet to be discovered are exhausted. After that point, the price of oil on world markets will steadily rise, as oil production declines. The Cassandras say that peak production is likely to occur as early as the end of this decade, but probably no later than 2020. The optimists say global peak production won't occur until around 2040. What's most striking, however, is how little time separates the two camps—only 20 to 30 years."[4]

These metrics are the subject of much debate, but the fact that fossil fuels are not renewable and that they will expire eventually is undeniable. If hydrogen were to replace fossil fuels as this alternative, the world markets would no longer be dependent on oil producers in the Middle East. Purchasing hydrogen from a local producer rather than foreign oil would decentralize world energy profits.

One result of distributed power is a significantly lower cost to developing nations to bring power to their citizens. Since fuel-cell energy may represent a lower capital cost than building central power plants and a grid for distribution, developing nations will have lower barriers to industrialization. A grid also has certain vulnerabilities, as the world witnessed August 14, 2003, when more than 50 million consumers found themselves powerless in the northeastern part of North America. Having distributed power generation would alleviate U.S. vulnerability to such technical failure or even a terrorist attack.

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[4] "End of the Fossil-Fuel Era," Jeremy Rifkin, 9-26-2002

Technical benefits from a hydrogen economy would also accrue to consumers. For example, the ability to affect distributed power becomes possible, no longer required to be centrally generated, but created by a fuel cell in each individual home or business, independent from a grid. Mobile phones powered by fuel cells would provide more than double the amount of available talk time and are very close to market according to most handheld electronics developers. Fuel cells also enable improved mobile power solutions for U.S. soldiers, lowering the weight burden and increasing the power density of equipment packs.

Hydrogen and Fuel Cells

The Hydrogen Economy is driven by several, novel, under-pinning technologies, the most important of which is fuel cells. Fuel cells were invented in 1839. The National Aeronautics and Space Administration (NASA) has used them for decades; fuel cells were actually part of the first Apollo trip to the moon. A fuel cell is much like a battery, except that it will continue to generate electrical power indefinitely as long as fuel is provided.

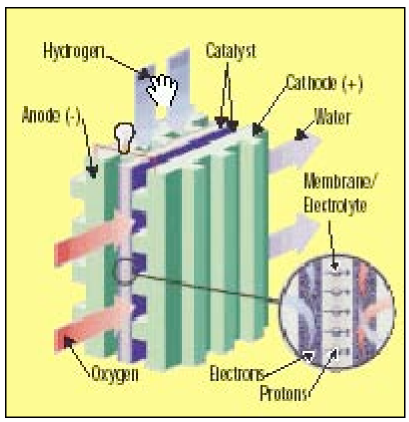

Figure 1: Anatomy of a Hydrogen Fuel Cell

Source: Fuel Cells—Green Power, Los Alamos National Laboratory (Document ID: LA-UR-99-3231)

The space program uses a particular type of fuel cell called an alkaline fuel cell. There are many different kinds of fuel cells, each utilizing different materials with varying operating parameters. (See Appendix II for a matrix of fuel-cell types.) The various fuel-cell types lend themselves to different applications due to their varying operating properties.

Since one fuel cell rarely generates enough power for most applications, fuel cells are arranged in a "stack." For example, General Motor's (GM) PureCell requires 640 fuel cells to deliver 137 hp,[5] the amount of power required to operate an automobile. A stack's power output scales linearly with the number of fuel cells in the stack.

Most fuel cells use hydrogen and air as their inputs and output water and heat. There are a variety of ways to obtain hydrogen from a litany of hydrogen-containing substances, or feedstock, such as water, fossil fuels, and biomass. The most cost-effective way to obtain hydrogen from fossil fuels is steam reforming of natural gas.

[5] Byron McCormick, HyTeP Presentation, Santa Fe, NM (4-22-2003)

Production Method	$/GJ	Production Method	$/GJ
Steam Methane Reforming	6.00-8.40	Electrolysis	25.20-30.00
Coal Gasification	12.00-14.40	Electrolysis (wind)	13.20-20.00
Non-catalytic Partial Oxidation	8.40-12.00	Electrolysis (solar)	30.00-50.40
Biomass Gasification	10.80-19.20	Electrolysis (concentrated solar)	40.80-78.00

Figure 2: Cost Breakdown of Hydrogen Harvesting Technologies

Source: Introducing Hydrogen to the Dutch Natural Gas Network (http://www.swhconf.com/abstracts/SWH03_O_JALZachariah.pdf)

When hydrogen is extracted from a fossil fuel such as natural gas, pollutant byproducts are created such as carbon dioxide, carbon monoxide, sulfur, and nitrogen. On average, energy generated from the harvested hydrogen will yield approximately 60% less CO_2 than the same amount of gasoline-generated energy (see Figure 3 for an emission comparison). Although not ideal, using hydrogen reformed from natural gas in a fuel cell is still an environmental improvement compared to internal combustion engines (ICE).

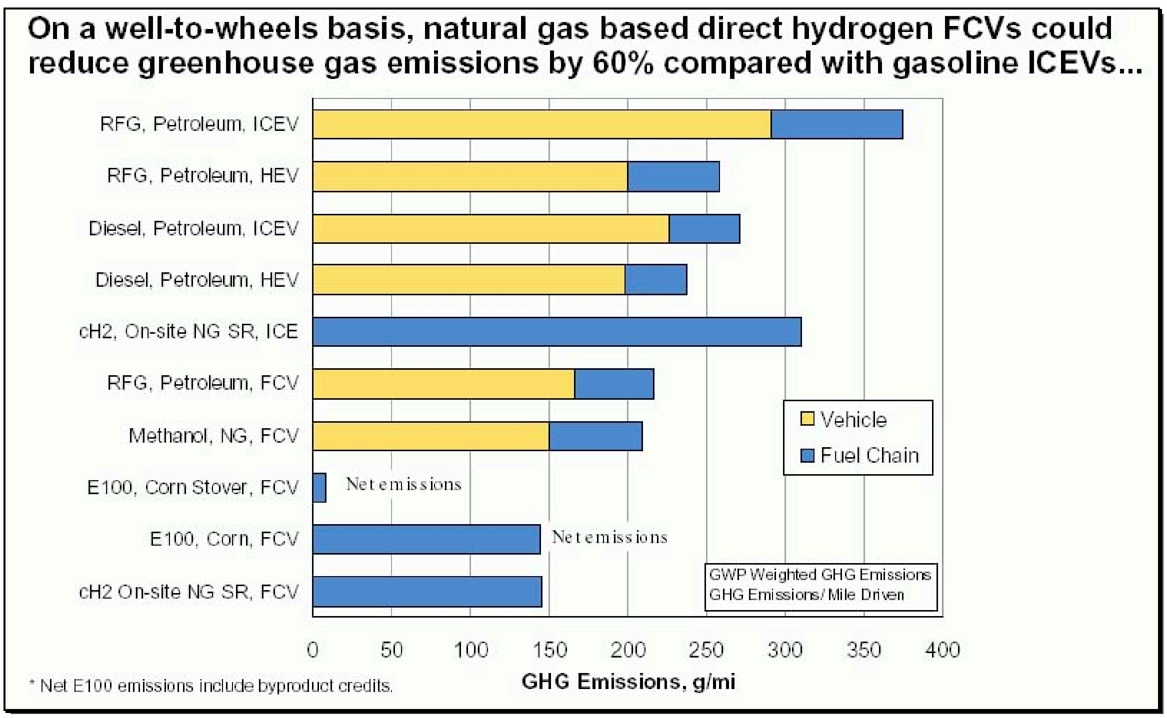

Figure 3: Emission Comparison of Fossil Fuel Based Hydrogen Production*

Source: Guidance for Transportation Technologies – Final Report, Arthur D. Little, Feb 6 2002
**Definitions for the following terms are as follows: RFG-reformulated gasoline, ICEV-internal combustion engine vehicle, HEV-hybrid electric vehicle, ICE-internal combustion engine, FCV-fuel-cell vehicle*

Ideally, hydrogen should be harvested from water (H_2O) via electrolysis, which yields only oxygen gas (O_2) as a byproduct. However this process requires a large amount of power to split the water molecule. If this power is yielded via the burning of fossil fuels, then the environmental benefits of using electrolysis are diminished. Alternatively, the power for electrolysis could be obtained through established renewable sources, such as wind, solar, and biomass, but cost effective means to do so have yet to be developed. A renewable, non-polluting hydrogen value chain is the ultimate goal.

The Hydrogen Value Chain

Today's hydrogen market exists primarily as an input to the petroleum market for crude oil processing, but has other industrial uses as well. When people refer to a hydrogen economy, they are not referring to this established market. Coined in 1970, the term "hydrogen economy" describes a proposed system where hydrogen is used to store, distribute, and utilize energy. Although not ideal, as we reduce our dependence on fossil fuels for energy, hydrogen will be produced from hydrocarbons and distributed much like gasoline is today, leveraging the existing energy infrastructure and lowering some of the initial high costs of hydrogen distribution. Although significant technical challenges remain, the long-term goal of the hydrogen economy is forecourt production—renewable, electrolysis-generated hydrogen on-site and on-demand.

A consumer market has not yet materialized for hydrogen fuel cells—the most likely means of converting the chemical energy stored in hydrogen to electrical energy. Even so, many companies and government entities are actively investing millions of dollars in fuel cells and supporting hydrogen technologies. As a result, a discernable value chain of suppliers and buyers is beginning to emerge.

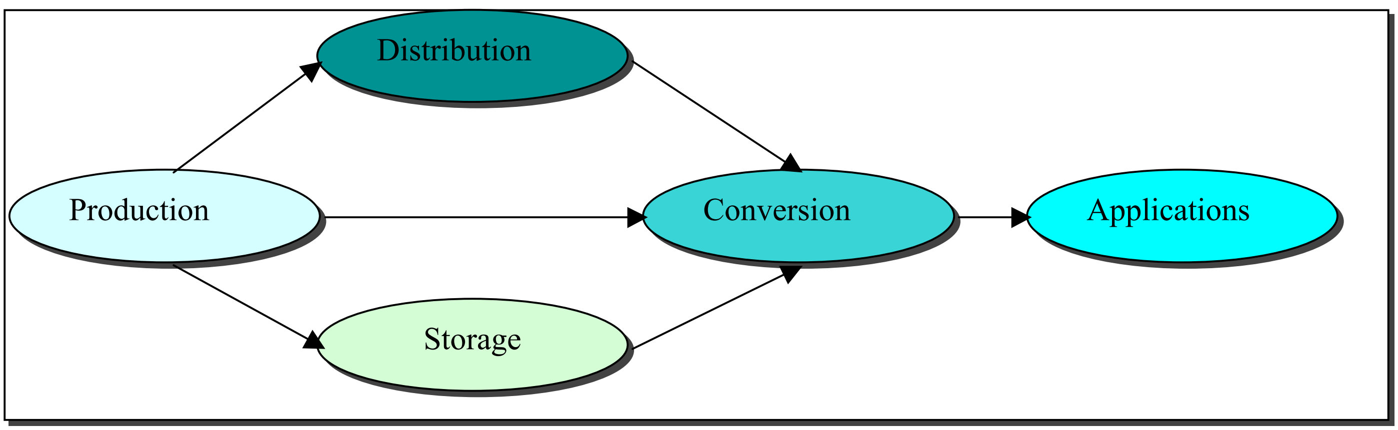

Figure 4: Hydrogen Value Chain

Source: National Hydrogen Energy Roadmap, DOE, November 2002

The basic components of the hydrogen value chain are very similar to our existing energy infrastructure as shown in Figure 4. For example, the infrastructure must include a means to produce hydrogen fuels from resources that include fossil fuels, biomass, and water. Other major elements include storage and distribution from point of production to point of use. The ongoing development of the infrastructure to support distributed energy systems is a critical step in the process of building a hydrogen energy economy. Table 1 describes the main elements of the hydrogen value chain.

Hydrogen Industry Segment	Explanation
Production	• the production of hydrogen from fossil fuels, biomass, or water • involves thermal, electrolytic, or photolytic processes
Delivery	• the distribution of hydrogen from production and storage sites • involves pipelines, trucks, barges, and fueling stations
Storage	• the confinement of hydrogen for delivery, conversion, and use • involves tanks for both gases and liquids at ambient and high pressures • includes reversible and irreversible metal hydride systems
Conversion	• the making of electricity and/or thermal and mechanical energy • involves combustion turbines, reciprocating engines, and fuel cells
Applications	• the use of hydrogen fuel cells for portable power devices such as mobile phones and computers • the use of hydrogen for transportation systems, including as a fuel additive, fuel-cell vehicles, internal combustion engines, and in propulsion systems for the space shuttle • the use of hydrogen for stationary power generation systems, including central station, distributed, and CHP systems

Table 1: Main Elements of the Hydrogen Value Chain

Source: U.S. Department of Energy: "National Vision of America's Transition to Hydrogen Economy—To 2030 and Beyond," March 2002

Production

The most common methods for producing hydrogen are steam-methane reforming, electrolysis, gasification and thermo-chemical. Steam Methane Reforming (SMR) is the most common way to produce hydrogen in the U.S., constituting 95% of total U.S. production.[6] While its production of greenhouse gas is undesirable, SMR represents the cheapest technology available today from which to produce hydrogen. (Note: For a detailed description of technologies discussed in this section of the report, see Appendix III: Brief Technology Descriptions from the Hydrogen Value Chain.)

Hydrogen production is a mature industry with many large industrial chemical suppliers. These suppliers have been producing hydrogen for the oil industry and a variety of other markets for decades. However, there is considerable uncertainty surrounding the future method of hydrogen production, shedding doubt on how or if these existing players will participate in future markets for hydrogen energy. Established players in the industrial chemicals market are actively investing in hydrogen, anticipating the use of hydrogen as an energy commodity. However, it is unclear how well positioned these players who currently hold most of the world market—Air Liquide-France, Praxair-U.S., BOC-UK, Air Products-U.S., and Linde-Germany[7]—are to capitalize on this potential transition. It will take significant cultural, operational, and financial changes at these industrial gas companies to compete with the experience and resources of current energy producers, the world's petroleum companies, many of which are investing heavily in hydrogen.

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[6] "Hydrogen roadmap calls for use of solar energy," Combustion-net, 02-05-2003 (http://www.combustion-net.com/media_centre/2003releases/030502-hydrosolar.htm)
[7] Interview with John Royal of Praxair (8-12-2003)

All the current players produce most of their hydrogen in large-scale plants that are located near their demand. Should hydrogen be centrally produced, industry clusters will likely form around the production facilities (SMRs) and near areas with excellent transportation infrastructure (port cities, major airports, highway networks and railways, etc.). If, however, forecourt hydrogen production technology is accepted, clusters could form in a multitude of areas as R&D and manufacturing facilities are not geographically constrained.

One of the most important considerations in determining methods for hydrogen production will be the effect on greenhouse gas emissions. Almost all hydrogen production in use today produces greenhouse gases as a byproduct. Ideally, if hydrogen is adopted as a fuel, limiting or eliminating this pollution will be necessary. Figure 5 depicts a breakdown of feedstock by percent hydrogen, energy, and pollutant content.

Fuel Type	% Hydrogen	Energy Content (BTU per lb)	Particulates (lbs per million BTU)	Carbon Dioxide (lbs per million BTU)
Dry wood	5	6,900	5.22	775
Coal	50	10,000	5	240
Oil	67	19,000	0.18	162
Natural gas	80	22,500	<0.01	117
Hydrogen	100	61,000	0	0

Figure 5: Breakdown of Hydrocarbon by Greenhouse Gas Emission

Source: Cannon, James S., Harnessing Hydrogen, 1995.

Storage

There are a variety of promising technologies for hydrogen storage, each having its own limitations and advantages. The most promising methods for storing hydrogen are pressurized storage tanks, liquefaction, hydrides and novel nanotechnology methods. Currently, it is this link of the value chain that represents the largest technical shortcoming of a hydrogen economy when compared to conventional power generation by fossil fuels.

Distribution

Methods of distribution include pipeline, hauling and fueling stations. In general, hydrogen storage and hydrogen distribution are inversely related in terms of cost, i.e., cheaper means of storing hydrogen are generally more expensive to distribute and vice versa. A trade-off must be calculated for different circumstances to uncover the most cost effective means of storing and distributing hydrogen. Figure 6 gives a cost breakdown of all distribution methods and their associated costs for different feedstock.

(1,000 kg/d hydrogen)

Delivery Pathway	Liquid Tanker Truck, $/kg	Gas Tube Trailer, $/kg	Pipeline, $/kg
Natural Gas			
Production	2.21	1.30	1.00
Delivery	0.18	2.09	2.94
Dispensing	1.27	1.00	1.07
Total	3.66	4.39	5.00
Coal			
Production	3.06	2.09	1.62
Delivery	0.18	2.09	2.94
Dispensing	1.27	1.00	1.07
Total	4.51	5.18	5.62
Biomass			
Production	3.53	2.69	2.29
Delivery	0.18	2.09	2.94
Dispensing	1.27	1.00	1.07
Total	4.98	5.77	6.29
Water			
Production	6.17	5.30	5.13
Delivery	0.18	2.09	2.94
Dispensing	1.27	1.00	1.07
Total	7.62	8.39	9.13

Figure 6: Hydrogen Distribution Costs Estimates

Source: Hydrogen Supply: Cost Estimate for Hydrogen Pathways – Scoping Analysis, National Renewable Energy Laboratory, Dale R. Simbeck and Elaine Chang, July 2002 (Document ID: NREL/SR-540-32525)

Conversion

Once the hydrogen is produced and distributed, the energy that is chemically stored in the hydrogen molecules must be converted to electrical energy in order to be useful in powering mobile devices, homes, and cars. The most common methods of conversion include combustion and fuel cells. By far the most efficient way discovered to date to achieve this end is the fuel cell, but hydrogen can also be burned in an internal combustion engine much like gasoline.

Hydrogen Energy Applications

An efficient means to produce and deliver hydrogen will enable many market applications. However, it is widely accepted that the most promising future applications for hydrogen and fuel cells reside in three major markets: portable, stationary, and transportation, in order of projected broad market realization.

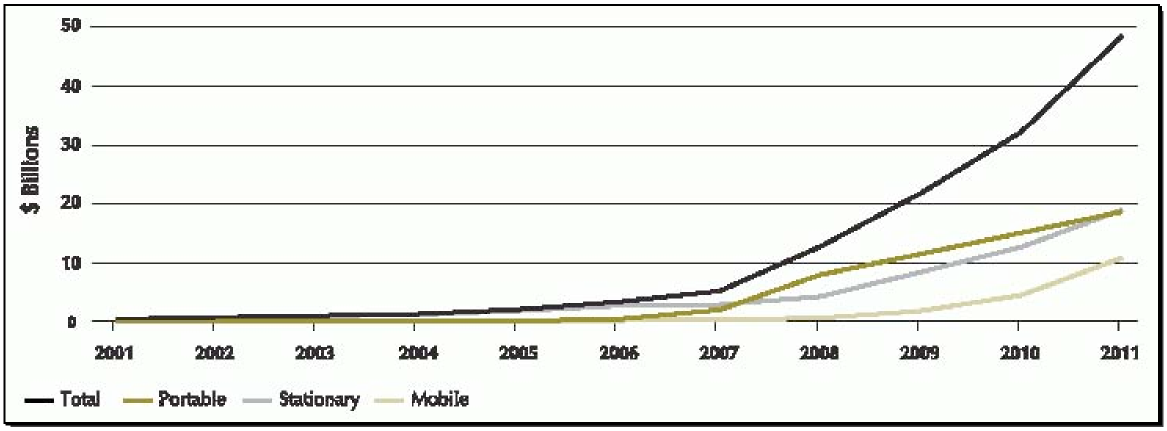

Figure 7: Global Estimated Demand

Source: "Canadian Fuel Cell Commercialization Roadmap," Price Waterhouse Coopers

Portable

Currently, most portable applications utilize direct methanol fuel cells (DMFC). Because the storage challenges are not as difficult to solve for methanol as for pure hydrogen, portable fuel cells are the closest of all three major applications to commercialization. Many electronic equipment manufacturers have already announced the intended release of fuel-cell laptops and mobile phones in order to respond to a clearly articulated market need. The electronic and network technology of the mobile phone industry has outpaced the battery's ability to power the handheld appliance with the advent of 3G. Fuel cells offer a solution to this problem, forecasting usage lifetimes double or triple what is currently available using rechargeable batteries. NTT Docomo in Japan already has 3G phones on the market, which means that demand for fuel-cell-powered cell phones will very likely materialize in the Japanese market first.

DMFC and solar fuel cells (SOFC) are also likely to replace the battery as the individual mobile power source for the U.S. military. The Defense Advanced Research Projects Agency's (DARPA) "Palm Power" program is tasked with creating a power source that has 15 times the energy content of the best battery.[8] Both of these fuel-cell types can take liquid fuel, methanol for DMFC and fossil fuels for SOFC, which make them highly desirable for portable military operations. The military will most likely be the first portable market to materialize, as it is the least price sensitive.

Currently, soldiers use batteries to meet their mobile power needs. According to Ned Godshall, CEO of Albuquerque-based MesoFuel, these batteries can weigh 80 pounds for an individual mission lasting several days.[9] Batteries have a lower power density than fuel cells, meaning that a soldier could get more power while carrying less weight if using mobile fuel cells. By one study, a portable fuel cell using methanol had an energy density of 5.5 kW-hr/kg[10] compared with a lithium ion battery with an energy

[8] "DoD End User Perspective and DARPA Palm Power Program," Dr. Robert Novak and Dr. Karen Swider Lyons, DOE Fuel Cell Portable Power Workshop, January 15–17, 2002 (http://www.cartech.doe.gov/pdfs/FC/129.pdf)
[9] Interview with Ned Godshall, CEO of MesoFuel (8-27-2003)
[10] Kilowatt-hours per kilogram

density of only 0.3 kW-hr/kg.[11] Also, the battery technology currently used is very expensive to buy and maintain.

The potential of fuel cells has generated interest within the U.S. Military, which represents a sizeable market that is less cost conscious than the consumer market. "[P]ortable power in military applications is becoming increasingly important for the individual soldier because of the various devices that support his/her mission. Devices like radios (4 W), navigation aides (2.7 W), night vision goggles (0.08 W), laser weapon ranging (7 W) and air conditioning for protective suites (200 W) are some examples where electrical energy is needed in the field. There are many other military applications that could benefit from high-energy devices with low weight and small volume. In fact, electrical power has risen to the fourth position in the priority list of military technological needs."[12] This technical and price advantage of fuel cells, coupled with the deep-pockets of the Department of Defense (DoD), suggest that the military is a likely first market for portable fuel cells. The military is, in fact, mandated to use alternative energy under the Energy Policy Act of 1992.

Stationary

Stationary fuel cells are the most commercially mature although not yet used in broad consumer applications. Fuel-cell technology in the stationary market is designed to be immobile allowing a certain degree of design freedom. Stationary fuel cells can be used as backup power to replace diesel generators or as a power source in cell towers and other remote locations. One of the advantages of a stationary fuel cell is its ability to supply distributed power in areas where access to a grid is prohibitively expensive. Remote cell towers for mobile phones are an example of an application that is limited to areas where there is a power supply available. Using a stationary fuel cell could make this process more economical for the telecommunications industry, should the price of buying and operating fuel cells drop. Stationary markets represent the uninterruptible power supply (UPS), premium power, and distributed or remote power markets.

The UPS market consists of small-scale backup power for electronics, such as personal computers and small-scale servers. Premium power refers to power sources that, if they were to fail, would result in a very expensive power outage for a business including credit card transaction servers, telephone ticket sales, and cellular communication towers. Distributed or remote power provides an alternative to the grid as the primary power supply for residences or businesses.

Connecticut-based United Technologies has had a Phosphorous Acid Fuel Cell, used in many stationary applications, on the market since 1991 with over 250 installed worldwide.[13] Although stationary applications were the first to materialize, they are not predicted to penetrate consumer markets as quickly as the portable market. Currently, this emerging market is very crowded, with most of the world's largest fuel-cell manufacturers vying for leadership.

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[11] "Fuel Processor Development for a Soldier-Portable Fuel Cell System," D.R. Palo, J.D. Holladay, R.T. Rozmiarek, C.E. Guzman-Leong, Y. Wang, J. Hu, Y.-H. Chin, R.A. Dagle, E.G. Baker; Battelle, Pacific Northwest National Laboratory
[12] "Fuel Cell Technology News," Business Communications Company, October 2002
[13] UTC Fuel Cells (http://www.utcfuelcells.com/residential/history.shtml)

Transportation

Transportation applications are the furthest from market. This is largely due to the infrastructure costs and technical limitations of hydrogen storage and distribution described earlier—the enormous infrastructure transition that needs to take place, the storage issues that still must be addressed, and the cost of hydrogen fuel compared with oil.

The transportation market is made up of automobiles, trains, buses, etc., therefore, only when hydrogen is used in transportation will the U.S. be liberated from foreign oil and the energy volatility that comes with it. Most of the large auto manufacturers have created fuel-cell vehicles, however broad market adoption necessitates access to fueling stations and a price point acceptable to the average consumer. Fleets of fuel-cell buses are in use in Palm Springs, California, and Vancouver, British Columbia, but these are largely demonstration projects and do not represent affordable consumer products. For example, the SunLine fuel-cell buses in Palm Springs, California, cost approximately $3.13 million dollars each,[14] excluding the increased operational cost of obtaining hydrogen as fuel. There are many technical advances in hydrogen storage and fuel-cell technology that need to occur before the economics of transportation are comparable to current solutions.

Stages of Company Development

Within each market in the hydrogen value chain are many companies at different stages in their development. The motivations and needs of these companies are highly dependent on where they fall in this lifecycle. In the fuel-cell sector, for example, there are a handful of mature fuel-cell companies, most of which are in North America and Japan. However, none of these companies have ramped up production to any sizable scale, because no sizeable demand exists at current production costs.

Start-up

Many of the technologies arising out of the move to a hydrogen economy are considered strategic to U.S. energy policy providing alternatives to foreign oil dependence and methods of reducing pollution. Therefore start-ups in this market often seek initial seed capital from federal and state government sources to fund their technical and business development. In general, government funds are more difficult to find and in smaller amounts than traditionally available from private equity or public markets. Consequently, many start-ups have also secured corporate partners through either collaborative projects or capital investments.

The primary concern of players at this stage of development is financing. Due to the large technical and market risk associated with many of these emerging technologies, start-ups in this space have had a hard time securing funding from private sources. However, there are a few successful recipients so far and the sector in general is one in which venture capitalists are beginning to show some interest. Examples of companies in this stage are MesoFuel and Superior MicroPowders (purchased by Cabot Corp on June 2, 2003 for $16 million).

[14] Facts and Figures, AC Transit of Oakland and Sunline Transit of Thousand Palms Fuel Cell Development—Zero Emissions Bus Program (http://www.actransit.org/pdf/fuelcell_factsheet.pdf)

Up-and-Comers

Up-and-comers are companies that show promise of revenue in the near future or currently have a nominal revenue stream from existing hydrogen or fuel-cell product lines. Many are established players in other industries, sometimes a tangential industry such as oil and gas, and have established what might be considered "exploratory programs" in hydrogen or fuel-cell products. The most successful businesses at this stage are companies that have secured large corporate investors to help ensure financial stability and access to markets. The principal concern at this stage is to gain market traction. Examples of companies in this stage are QUANTUM Technologies and Hydrogenics.

Most Developed

Businesses that are most advanced in terms of "product life cycle" and/or market penetration currently consist of large public companies or subsidiaries of large corporations. Most are not yet profitable. Companies at this stage finance operations through the public markets and, to a greater degree, government subsidies. Their principal concern long-term is to find a market for their products, but in the near-term they are looking for demonstration projects. Examples of companies in this stage are Ballard and United Technologies.

International Conglomerates

This segment comprises very large, multinational corporations that have diversified and profitable revenue streams. Many have made sizable investments in smaller technology companies. The principal concern of many in this segment is to hedge against obsolescence or gaining competitive advantage in a potentially enormous emerging market. Examples of companies in this stage are General Motors and Shell. (For a listing of companies within each sector of the value chain, see Appendix IV.)

Risk Capital

Financing can be difficult to secure for hydrogen-fuel-cell-related businesses given the high risk of failure. Access to investment, from both private (venture capital) and public (government) entities, is a large concern for many in the hydrogen business.

Venture Capital

Hydrogen technology start-ups are not ideal investments for a venture capital (VC) firm for a number of reasons. For most, partners have not invested in this area before and lack the expertise to effectively evaluate deals. Also, energy start-ups require more up-front capital than their traditional biotech or information technology (IT) investments. This, coupled with the fact that energy is a highly government regulated commodity whose profitability can be subject to world events, often leads to lower returns than traditional VC investments. In addition, it is very difficult to predict if, and when, hydrogen-fuel-cell markets will materialize. This clouds the VC's ability to envision an exit within 5–8 years of the investment, a typical exit horizon. All of these factors increase the VC's investment risk in hydrogen or fuel-cell technology.

Given the present depressed state of the VC industry, this risk has proven to be a strong deterrence from most investments. According to Venture Wire the only fuel-cell investments made in 2001 were to three start-up companies totaling $8.7 million. Investment in 2003 was $7.5 million in one company, Avista Labs. Escalating oil prices, more stringent environmental laws, and hopes for an economic recovery, however, have reignited interest in the area.

The glaring exception to the current trend has been investments from corporate VCs, such as Chevron-Texaco Technology Ventures and Conduit Ventures (Shell, Mitsubishi). These VCs have strategic reasons for investment beyond pure return and are thus willing to overlook some of the shortcomings of risk investments in hydrogen technologies.

Government Investments

Government investment in hydrogen research has grown exponentially over the last five years and must continue to grow at this rate if the hydrogen economy will ever become viable. These investments include research and development at national laboratories and universities as well as grants to large corporations for demonstration projects and direct investments in new companies. The U.S., Germany, and Japan currently contribute over 60% of total world spending on fuel-cell-related activities, and will continue to be the engines of the hydrogen economy.[15]

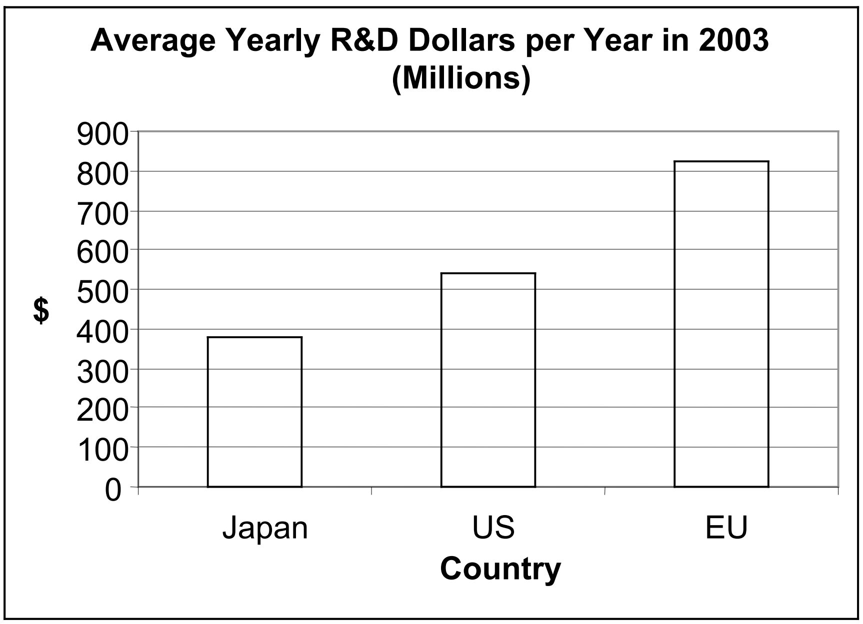

Figure 8: R&D Expenditure by Country

Source: "Canadian Fuel Cell Commercialization Roadmap," Industry Canada and Price Waterhouse Coopers. http://strategis.ic.gc.ca/epic/internet/inmse-epe.nsf/vwGeneratedInterE/ep00031e.html

United States

Distributed through a variety of federal organizations and programs, the federal government proposes spending $2.7 billion over the next five years on hydrogen and fuel-cell research and development and

[15] "Fuel Cells," The Fredonia Group

advanced automotive technologies. The DOE FreedomCAR and Freedom Fuel programs to develop next-generation efficient automobiles in conjunction with private industry are expected to receive $1.5 billion over five years, including $272 million in R&D funds in FY 2004. Firms accepting these three to five year grants are required to share at least 20% of the project costs. In 2003, 24 solicitation awardees, including companies and educational institutions, received government funds totaling $96 million and will contribute $40 million of their own assets.

The 2003 Hydrogen Fuel Cell Act calls for $555 million in fuel-cell research and development and hydrogen infrastructure investments. The bill will fund a stationary hybrid-power and stationary fuel-cell grant demonstration; a fuel-cell vehicle demonstration program; a heavy duty fuel-cell vehicle fleet demonstration program; put fuel cells on tribal American lands; and demonstrate co-production of hydrogen and electricity in fueling stations. In 2004, with required matching funds, industry spending is projected to top $1.1 billion, augmenting these and other government programs for fuel-cell and hydrogen research. Government matching funds are expected to continue, increasing to $741 million in 2005, $890 million in 2006 and $940 million in 2007.

Among organizations that provide grants is the Office of Naval Research, which funds The Hawaii Energy and Environmental Technology Initiative (HEET), Hawaii Natural Energy Institute's newest and largest program, involving research and testing of fuel cells for commercial and military applications and the assessment and characterization of methane hydrates as a potential future energy resource. It is very important to recognize that federal dollars also influence demand as government agencies have assumed the early adopter role. Fuel-cell products have been deployed in numerous government facilities including military bases and DOE and DoD facilities. Federal purchase programs also facilitate other early adopter buying through "buy-down" grants in which companies, universities, or state agencies pay two thirds of the cost of fuel-cell power systems.

In addition to federal programs, many state governments are supporting development of the hydrogen economy through incentive and educational programs. For instance, California offers companies economic incentives, emission targets, and demonstration activities. Michigan's NextEnergy program appears to be one of the most pioneering and comprehensive providing $79 million over the next three years, plus a 700-acre tax-free research zone to the effort. This nonprofit organization recently granted Wayne State University $300,000 to develop an Alternative Energy Technology (AET) master's degree program. Top automakers are among the AET program's advisers and dominant fuel-cell companies such as Ballard have offered equipment and internships. Other examples of progressive state programs include Ohio's support for fuel-cell initiatives of $162 million over three years, and Connecticut's Clean Energy Fund, which invested close to $15 million in 2002 in various development and commercialization activities.

European Community

European Community spending has grown dramatically from $140 million during the period 1999 to 2002 to an expected $3.3 billion from 2003 to 2006 on renewable energy—mostly hydrogen and fuel cells.[16] Under the European Economic Union's 6th Framework Program (2002–2006), over $2.5 billion will be dedicated to fuel-cell and hydrogen initiatives.

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[16] The Canadian Fuel Cell Industry.

Germany

In Germany, total annual spending for hydrogen initiatives is estimated at $58 million. Under one program, $99 million will fund 44 R&D projects involving fuel cells for stationary and mobile applications. In 2002 the government also passed "Kraft-Warmekopplungs Gesetz," which subsidizes the produced electricity of combined heat and power (CHP) stations of up to 2 MW with 4.4 billion euros until 2010. This program also supports fuel-cell generated electricity of stationary power plants of up to 50 kW with 0.0511/kWh for 10 years after installment, if installation is before the end of 2005. In addition to federal funding nearly every state has a budget for fuel-cell projects. [See footnote 16.]

Japan

The government has reportedly spent 25 billion yen annually in fuel-cell R&D since 2000. For the fiscal year 2004, over 31 billion yen have been budgeted. The Japanese government also directs a great deal of resources to support Japanese automakers, spending over $380 million a year on fuel-cell research, development, and commercialization. [See footnote 16.]

China

China plans to invest $120 million in fuel-cell powered automobiles and has over 20 institutes and enterprises specializing in fuel cells. The Shanghai municipal government also has plans to invest $12 million per year to support fuel-cell R&D. [See footnote 16]

Challenges Facing the Industry

There are many technical and societal benefits associated with the adoption of hydrogen power, which begs the question of why it has not occurred on a large scale. The reality is that there are many challenges to hydrogen economy realization including unproven economics, lingering technical challenges, lack of codes and standards, and poor consumer perception.

Unproven Economics

There have been many efforts to show the technical feasibility of hydrogen fuel cells in a variety of applications, such as fuel-cell powered buses. These projects do not attempt to achieve profitability and are subsidized by government entities. It is unclear if the economies of hydrogen will ever work, despite the government tax breaks and subsidies to ease the incremental cost of hydrogen fuel-cell energy over conventional power. Figure 9 displays a sensitivity analysis of different vehicle fuel costs that can be used to forecast demand at different price points. However, it must be considered in conjunction with gained efficiencies. Although hydrogen is more expensive to obtain and distribute than gasoline, a fuel-cell vehicle achieves 2.5 times the energy efficiency of an ICE.[17] With technical advances in hydrogen distribution and improvements in fuel-cell efficiency, the price of owning a fuel-cell vehicle could rival that of an ICE.

[17] "Hydrogen Delivery: An Option to Ease the Transition," John C. Winslow, presentation at The DOE Hydrogen and Fuel Cells Coordination Meeting, June 3, 2003

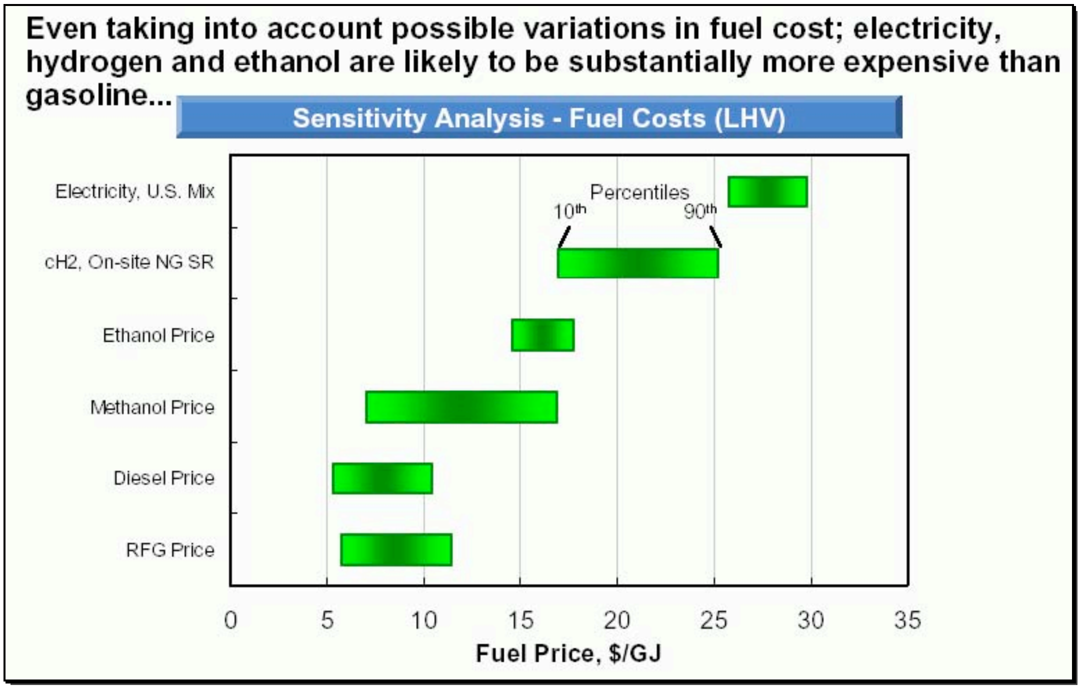

Figure 9: Fuel Cost Sensitivity Analysis

Source: Guidance for Transportation Technologies – Final Report, Arthur D. Little, Feb 6 2002

Today, no large-scale manufacturing facility exists that has produced a low-cost fuel cell through economies of scale. This drives the high purchase price of fuel cells, as many are made-to-order. The high purchase price prevents the creation of significant demand. Without significant demand, industry is wary to invest in augmented capacity, preventing attainment of economies of scale. This "chicken-and-egg" problem is a strong inhibitor to broad market adoption.

Technical Shortcomings

Today's fuel cells lack the quality needed for everyday consumer use. Consumer applications have durability and safety requirements that are generally not met by the fuel-cell products currently available. There will have to be substantial technical improvements made to fuel-cell technology before mass-market penetration is possible. Exacerbating this issue is the fact that some fuel-cell technologies contain highly corrosive electrolytes that are dangerous to humans and the surrounding materials powered by the fuel cell. These safety issues need to be addressed before fuel cells can gain broad market acceptance and penetration.

Lack of Codes and Standards

Codes and standards for practically every link in the value chain are currently under review at a national level. There is no single, controlling authority for all hydrogen applications and components. Therefore, multiple controlling authorities must be coordinated. The National Renewable Energy Laboratory published its latest revision of the Hydrogen Codes, Standards and Regulations Matrix on June 27, 2003. This matrix provides a breakdown by application and component, a description of the applicable code, standard and/or regulations, the governing authority, technical contacts, and current status.

Without established codes and standards, the cost of doing business can be prohibitively expensive for a hydrogen or fuel-cell company. The immature state of the regulatory environment increases the risk to hydrogen businesses. Fewer regulations leave the manner in which operations are conducted open for interpretation, thereby increasing risk. If hydrogen power is to gain market adoption, the codes and standards detailing every part of the hydrogen value chain need to be established. Until that time, because of the producer's increased liability costs, the cost of hydrogen-powered products is a key element hindering significant market adoption. This process has started, but there is still a long way to go.

Poor Consumer Perception

When many think of hydrogen, the first thought that comes to mind is the Hindenburg. Many consumers associate hydrogen with a hazardous chemical, one that should be kept as far away as possible. The reality is that hydrogen is, in many ways, safer to handle than gasoline. It is the lightest element in the universe so if there is a leak, it instantly moves to the highest possible point. Gasoline fumes are heavier than air, which causes them to pool. The result is that the risk of explosion from a spill remains long after the gasoline leak has sprung. Although hydrogen has its own set of risks and dangers that will need to be addressed, it does not necessarily put humanity in any more danger than fossil fuels if handled correctly. Hydrogen's underserved reputation as a dangerous material is an adoption barrier to the average consumer.

New Mexico's Position in the Hydrogen Economy

In assessing New Mexico's potential to develop an industry cluster around hydrogen, it is important to understand why clusters are important. Industry clusters are often defined as the key to robust economic development. Silicon Valley is the most famous example of a successful industry cluster bringing significant wealth to a region as well as to many individuals. Silicon Valley, often referred to as "the cradle of America's electronics industry," spawned the development of the integrated circuit, the microprocessor and the personal computer industry. Silicon Valley is home to PC industry heavyweights Hewlett-Packard, Intel, and Apple and scores of smaller firms that supply and support the sector.

The World Bank provides a summary of two important studies on cluster development:

Advanced levels of innovation and economic growth are often found where there is a unique combination of firms tied together by knowledge and production flows enabled by industry clusters. Industry clusters are "production networks of strongly interdependent firms (including specialized suppliers), knowledge producing agents (universities, research institutes, engineering companies), bridging institutions (brokers, consultants) and customers, linked to each other in a value adding production chain.

Industry cluster competitiveness derives not only from the concentration of related industries, but a business-friendly regulatory climate, high quality of life and a supportive "economic infrastructure". This infrastructure includes organizations that provide such assets as skills training, technology, financing, infrastructure, and advanced communications.[18]

[18]http://www.worldbank.org/html/fpd/urban/led/cluster2.html

A specific deliverable for this study was to investigate the viability of a hydrogen cluster in New Mexico. Michael Porter's cluster theory framework as laid forth in his book *The Competitive Advantage of Nations* provides a mechanism to identify strengths and weaknesses specific to New Mexico in its proposed development of a hydrogen industry cluster. Michael Porter is considered the preeminent expert on this subject. Porter's framework utilizes "four broad attributes of a [region] that shape the environment in which local firms compete that promote or impede the creation of competitive advantage."[19] These mutually reinforcing attributes, described in detail in this section, are as follows:

1. Factor conditions
2. Demand conditions
3. Related and supporting industries, and
4. Firm strategy, structure, and rivalry.

Although Porter's book is geared primarily toward nations, the author writes "Its concepts and ideas, however, can be readily applied to political or geographic units smaller than a nation."[20]

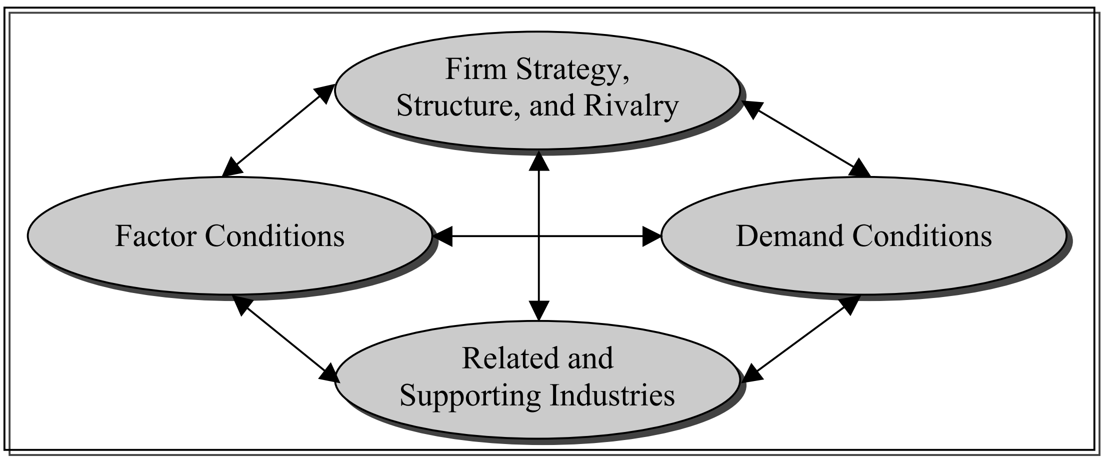

Figure 10: Cluster Theory Framework

Source: The Competitive Advantage of Nations, Michael E. Porter, 1990

Factor Conditions

"Factors of production" is an economic term used to describe the inputs needed to compete in an industry. Examples include labor, natural resources, capital, and transportation infrastructure. Each region has advantages and disadvantages in certain factors that may allow better positioning in certain industries or for certain types of businesses. According to Porter,

> ***It is not mere access to factors but the ability to deploy them productively that takes on central importance to competitive advantage.***[21]

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[19] *The Competitive Advantage of Nations* (Michael Porter, 1990, p. 71, Free Press, Simon & Schuster, NY, NY, 1998)
[20] *Ibid.* p. 29
[21] *Ibid.* p. 76

It is very important to consider that in this section, an evaluation of these factors will vary dependent upon the type of business New Mexico expects to attract or grow. For example, many of these factors would receive an unfavorable evaluation if the only objective was to attract established, large-scale, manufacturing-intensive companies. These companies will most like have heavy-hauling needs with customers primarily out of state. In this case, our current incentive packages may not be competitive and our transportation infrastructure may not be adequate in comparison to other states when considering the total cost of doing business for these companies.

(Note: As a point of clarification, when referring to rankings by state in the following sections, first is considered best of the 50 states, 50th is considered worst for any given comparison.)

Basic Factors

Basic factors are resources available to the state that require no or minimal investment. It is difficult for a region to impact or facilitate a change to basic factors or to sustain a competitive factor advantage if a state's strengths are primarily basic. Examples of strengths include availability of natural resources, location, and weather.

Land—Strength

New Mexico offers an abundance of wide-open spaces and affordable real estate for new companies or established companies considering opening up outposts for R&D, testing, or manufacturing operations. However, some remote locations suffer from limited access to the power grid, paved roads, water, or railway. New Mexico's transportation infrastructure (discussed in more detail in Advanced Factors) is sparse at best, making a large portion of the state expensive to industrialize due to high transportation costs.

Natural Resource—Strength

New Mexico has proven reserves of natural gas, ranking it second in the nation for this resource.[22] As described earlier, natural gas is the most likely feedstock of hydrogen production until cleaner, cost-effective means are developed. The abundance of this natural resource positions New Mexico favorably as a supplier of natural gas in the hydrogen value chain.

Renewable Power Sources—Strength

New Mexico has abundant sunshine, wind, and geothermal energy. In fact, New Mexico ranks second among all U.S. states in solar energy resources and has annual wind energy potential estimated to be 435 billion kWh.[23] It is generally believed that solar-powered or wind electrolysis will pose the most cost-effective means to split hydrogen from water molecules to create clean, renewable hydrogen. An abundance of these resources could be considered an attractor to renewable energy companies and possibly enable quicker clean energy adoption and early market demand within the state.

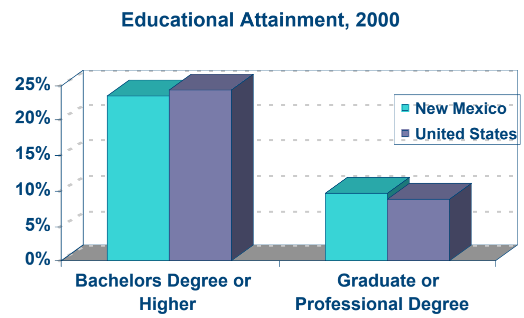
[22] "New Mexico's Natural Resources 2002", Energy, Minerals and Natural Resources Department
[23] Interview with Rene Parker, New Mexico Department of Energy, Minerals, and Natural Resources Department, 8-22-2003

Advanced Factors

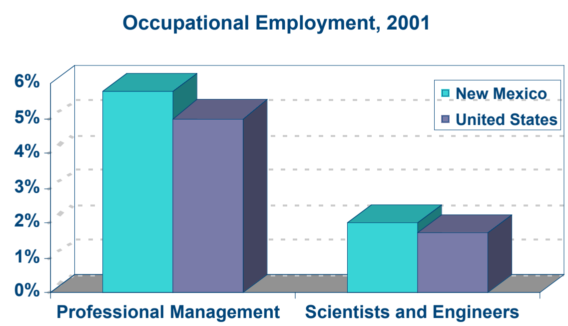
Advanced factors are necessary to achieve sustainable competitive advantage in developing and growing industry clusters. Examples of advanced factors include transportation infrastructure, educated workforce, and research institutions.

Skilled Labor—Strength

Statistics from a recent study by the Council of Competitiveness show that New Mexico has a greater percentage of its population with bachelors/graduate degrees in comparison to the national average and outpaces the U.S. in relative percentage of knowledge workers—particularly in science and engineering.



Source: Bureau of Labor Statistics



Source: Bureau of Labor Statistics

However, even though New Mexico has high levels of skilled human capital, average wages remain well below the national average. New Mexico ranks 48th out of 50 in per capita income[24] and 15th in lowest average wage per job.[25] Although, our affordable labor rates are attractive to businesses in that employees will not require the salaries demanded in more populous states like California in order to sustain equivalent standards of living, this statistic most likely reflects quality of jobs available within New Mexico's private sector. In New Mexico, the highest wages are found in the government sector.

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[24] Bureau of Economic Analysis, Annual State Personal Income (2001)
[25] Bureau of Economic Analysis, U.S. Department of Commerce, May 6, 2003

It is probable that the average hydrogen or fuel-cell industry worker will require advanced training and will necessitate a higher than average wage rate.

Fuel Cell Research and Development Track Record—Strength

For more than 25 years, New Mexico has held a leadership position in hydrogen and fuel-cell research and development. Technologies developed primarily at Los Alamos and Sandia National Laboratories offer New Mexico an opportunity to attract strategic partners and to create new businesses. For example, LANL's fuel-cell program has produced a significant portfolio of fuel-cell technologies for use in hand-held and portable electronics, stationary power, military, space, and transportation applications. LANL has established numerous formal (through licenses or cooperative agreements) and informal relationships with the private sector, universities, and other research organizations.

However, New Mexico's position at the forefront of R&D in this new industry is not guaranteed. The superior efficiency of fuel-cell technology and its environmental and social benefits have attracted the attention and investment of governments and industry in most industrialized countries, many of whom have accelerated their investments through targeted policies and program support, and through strategic corporate and research alliances.

Science and Technology Resources—Strength

According to the NMEDD's Office of Science and Technology, New Mexico claims a technology position far larger than its size would suggest. New Mexico ranks

- Second among the 50 states in Ph.D. scientists and engineers as a percentage of the civilian work force. (National Science Foundation, 1999)
- Eleventh in federal obligations for research and development. (National Science Foundation, Fiscal Year 2000)
- Fifteenth in total Small Business Innovation Research (SBIR) awards. (SBA, Office of Technology, 2000)
- First in high-tech exports as a percentage of total state exports. (USDOC, Census Bureau, MISER)
- Second in R&D intensity. ("R&D as a Percentage of GSP," National Science Foundation, March 2001)

Three federal research laboratories, Los Alamos National Laboratory, Sandia National Laboratories and Air Force Research Laboratory; three growing research universities, the University of New Mexico, New Mexico State University and New Mexico Institute of Mining and Technology; as well as three developing research parks drive New Mexico's high-tech growth. (For a complete list of available science and technology resources applicable to a hydrogen cluster, see Appendix V.)

Science and technology resources are a very prominent advanced factor in determining the success of cluster initiatives. Therefore, the availability of a scientific workforce, superior research facilities and a large base of federal research and development dollars, is New Mexico's strongest asset in terms of high-tech cluster growth.

Ability to Translate R&D Into Commercial Ventures—Weakness

The true value of advanced science and technology resources is in the successful transfer of technological ideas and inventions to the private sector for commercialization. In more mature and very successful industry clusters (Silicon Valley, Route 182, Austin) universities have played a critical and necessary role generating start-ups both from students and faculty.

Despite New Mexico's science and technology strengths and decent intellectual property portfolio much of the commercial fuel-cell activity has spawned outside the state. Although, New Mexico ranks second in the U.S. in Ph.D. scientists and engineers as a percentage of the civilian workforce,[26] New Mexico has seen only small successes parlaying this asset into any type of industry cluster. According to Porter:

> ***Research in government labs is often far removed from commercial applications, diffusion is difficult, and researchers are less prone to understand market needs or think entrepreneurially.***[27]

Statistics on spin-offs from the national laboratories and universities in New Mexico vary dramatically from year to year based on the criteria used to define a "spin-off" and the time frame reviewed. As shown below, UNM appears to do well in the initial phases of innovation but falters in eventual commercialization. Statistics are similar for Los Alamos and Sandia National Laboratories.

Ranking of 117 universities	UNM Science & Technology Corp	New Mexico State University	University of Texas at Austin	Arizona State University	University of Arizona
Number of inventions disclosed per $1M spending on research	69	116	79	10	76
Number of U.S. patent applications filed per $1M spending on research	34	99	77	5	113
Licenses & options executed relative to number of inventions disclosed	114	62	39	76	50
Licensing income per dollar of	101	116	75	39	108

26 National Science Foundation, 1999
27 *The Competitive Advantage of Nations,* p. 632

research spending					
Average income per license	50	116	34	38	104
Universities that formed the most start-up companies	64	108	29	47	34
Number of start-up companies formed per $10M spending on research	60	108	58	7	80

Source: Central New Mexico Regional Development Initiative, September 2003, Council on Competitiveness (Statistics gathered from Chronicle of Higher Education Based on 1996-2000 AUTM Surveys)

Industry-Driven Research and Development—Weakness

According to 2000 National Science Foundation statistics, 5% of R&D funding at New Mexico's academic institutions is sourced from industry, compared to the national average of 7%. The federal government both provides and uses the majority of R&D funding in New Mexico. In dollars, industry's investment in New Mexico universities was $11 million in 2002, compared to $294 million in California, $165 million in Texas and $139 million in Massachusetts. Although the relative size of state university systems must be taken into consideration, the investment by private industry in R&D cannot be underestimated in the development of clusters. Only 38% of New Mexico's total R&D expenditures are conducted by industry compared with 83% for California, 78% for Texas, and 76% for Massachusetts. Industry is much more adept at application-based research and product development—key to moving pure R&D into commercial products and services.

Federal R&D Investments—Strength

New Mexico has been a major recipient of federal R&D funding for many years. For New Mexico, this can be seen as a competitive advantage, one that could be leveraged when one considers the millions of dollars being spent by the federal government to support hydrogen and fuel-cell technologies.[28] In 2000, at the request of the White House Office of Science and Technology Policy, RAND prepared the most comprehensive and detailed information to date on the Federal government's R&D portfolio. In this extraordinarily comprehensive report, "Discovery and Innovation: Federal Research and Development Activities in the Fifty States, District of Columbia, and Puerto Rico," New Mexico ranked 13th among the 50 states in federal R&D investments. (More recent statistics published by the National Science Foundation rank New Mexico 10th in the nation for federal R&D performance.) The document reported that on average, the federal government spends in the neighborhood of $2.3 billion annually in New Mexico on R&D activities. Further, the report cited that most major federal agencies that currently support federal

[28] All rankings and statistics in this section are from the National Science Foundation, 1999.

R&D efforts fund significant R&D activities in New Mexico. Foremost among these agencies is the DOE, which at publication (2000) accounted for 58% of all federal R&D dollars spent in the state.

Industrial Base—Weakness

New Mexico ranks 37th in the U.S. in Gross State Product (GSP)[29] and was ranked 44th with an overall grade of "D" in business competitiveness by the Corporation for Enterprise Development.[30] This deficiency permeates many aspects of the state's competitive advantage in the hydrogen economy. First, New Mexico's small industrial base implies lower demand (or fewer potential users of hydrogen fuel-cell products) relative to more industrialized states. In the early stages of an industry cluster, suppliers tend to locate near the greatest demand.

Second, at first glance New Mexico also has a very small fuel-cell industrial base, which may be a reflection of a business climate that is not attractive to private industry. According to fuelcells.org, one online fuel-cell information center, New Mexico lists six "fuel-cell and related companies" (two of which are Los Alamos and Sandia National Laboratories). By comparison, Michigan lists over 30, New York over 40, and California over 90. Even considering the fact that many of the companies listed are not directly manufacturing fuel cells nor are they members of private industry, these numbers can be used as a proxy for the potential for an industry cluster in these regions. A true industry cluster will constitute a good mix of private companies, research institutions, and service organizations operating synergistically within that cluster. (For a listing of fuel-cell organizations by state, See Appendix VI.)

Transportation Infrastructure—Weakness

New Mexico has two major highways, one major airport, and is landlocked—railroad density ranks 48th in the U.S. New Mexico also ranks 48th among U.S. states in percentage of highway roads in deficient condition,[31] i.e., we have a high percentage of rural and urban highway mileage in poor condition and/or with poor accessibility. When considering all these transportation factors in terms of total cost, the infrastructure does not lend itself to heavy hauling and/or the easy shipment of goods and services intra-state or out-of-state. This may inhibit the state's ability to attract many types of manufacturing and assembly facilities when transportation costs are a key factor.

University Hydrogen or Fuel-Cell Degree Programs—Weakness

Researchers have begun to consider higher education as a market where individual institutions must compete for resources such as students, faculty, legislative appropriations, research funding, and donors. Because fuel cells and hydrogen are often referred to as the next big thing or the next grand challenge, many universities will be establishing curricula and research programs in these areas.

As in other markets and industries, success in competitive markets requires the creation of a strong brand. One of the ways that universities build a "brand" is by becoming a highly ranked institution. Currently, New Mexico universities are generally not considered as having top-tier engineering or business degree programs at either the undergraduate or graduate level. In the latest *U.S. News and World Report*—the

[29] Bureau of Economic Analysis, U.S. Department of Commerce (http://www.bea.doc.gov/bea/regional/gsp/)
[30] Corporation for Enterprise Development, Development Report Card for the States (http://drc.cfed.org/grades/new_mexico.html)
[31] Corporation for Enterprise Development, Development Report Card for the States (http://drc.cfed.org/measures/hwy_def.html)

most well-known university business and engineering ranking—survey, no New Mexico university appeared within the top 50 of "best graduate schools."

The three state universities in New Mexico, the University of New Mexico, New Mexico Institute of Mining and Technology, and New Mexico State University, have younger, smaller federally funded fuel-cell and hydrogen research programs but will likely see major advancement with the development of supporting curricula in both undergraduate and graduate degree programs. There are several other states that have already created a fuel-cell technology curriculum at their state engineering institutions. For instance, graduate study is offered in fuel-cell technology at the National Fuel Cell Research Center at the University of California Irvine at both the master of science (M.S.) and the doctoral (Ph.D.) levels. Case Western University in Ohio has received an $18 million grant from the state of Ohio to support the research, development and commercialization of fuel cells. Wayne State University is currently preparing to offer one of the nation's first master's degree programs in alternative energy technology. Other universities involved in fuel cells include Cal Tech, Princeton, Kettering University, Georgetown University, and many others.

Technology Management Skills—Weakness

There are few large technology corporations with headquarters or strategic business offices in the state. Intel has their most profitable fabrication facility in Rio Rancho and is the largest private sector industrial employer in New Mexico,[32] but the facility is primarily employing hundreds of factory workers and far fewer technical managers. In general, the state has fewer opportunities relative to other states for seasoned management talent. In addition, the MBA programs at the universities in the state are poorly ranked nationwide, attracting and spawning fewer aspiring technology managers. Industry interviews with corporations and VCs reveal that the private sector would be concerned that qualified management would be difficult to find within the state should they relocate or invest in New Mexico.

Risk Investment Track Record—Weakness

High-risk and early stage funding to incubate companies is a key factor in cluster development. In 2001, New Mexico ranked 44th among U.S. states in VC investments[33] and, according to Price Waterhouse Coopers Money Tree, there was zero VC activity in New Mexico in Q2 2003.[34] In an effort to change these statistics, the State Investment Council (SIC) has invested from New Mexico's permanent fund into venture capital firms that agree to maintain an office in the state and make a "best effort" to invest in New Mexico firms. Since 1993, the SIC has invested more than $150 million into about a dozen venture firms. In addition, recent legislation now allows the council to directly invest in companies from an available pool of about $200 million. Individual investments could be as much as $20 million provided there are other partners and the state's ownership in a company is no more than 51 percent.

The New Mexico venture capital landscape reflects venture money available, but not invested. Although the state of New Mexico has been proactive in the last few years in its efforts to attract a vibrant venture investment community, few investments in New Mexico companies have been made so far. This is largely due to the dearth of "investable deals." While the state is brimming with cutting-edge technology, cutting-

[32] NM Research Site, Metro New Mexico Development Alliance (http://www.nmsitesearch.com/ee/ee_1_4.htm)
[33] The 2002 State New Economy Index, The Progressive Policy Institute, (http://www.neweconomyindex.org/states/2002/05_innovation_06.html)
[34] Price Waterhouse Coopers Money Tree (http://www.pwcmoneytree.com)

edge also means early stage with large technical risk—too much technical risk for most "early-stage" venture firms.

Since the first investment in 1994, the New Mexico Venture Capital Fund has resulted in 15 New Mexico companies being funded:

MicroOptical Devices/EMCORE	$ 67.10M
Kinetisis	0.90M
Phase-1 Molecular Toxicology	12.63M
Quasar	3.00M
Bioreason	4.92M
Elisar	3.58M
Developing Minds	0.50M
Introbotics	0.62M
Amtech	84.20M
MEMX	10.00M
Lumidign	5.35M
Zia Laser	6.50M
Eclipse Aviation (Direct Investment)	10.00M
Exagen	0.51M
Mesofuel	0.53M
Total	**$203.83**M

With the exception of ARCH, all of the funds in the New Mexico Program started investment activities in September 1998 or later.[35]

Hydrogen Codes and Standards Development—Weakness

As is the case throughout the nation, New Mexico is faced with a lack of consistent codes and standards for hydrogen. Efforts are currently underway on a national level to coordinate codes and standards. Once completed, all states will be faced with whether to adopt the proposed standards and how best to implement those standards on a local level. New Mexico may have an advantage in the adoption and implementation of such standards given its existing experience with codes and standards in the compressed natural gas infrastructure, which may possess many similarities to the codes and standards for hydrogen. The Lyndon B. Johnson White Sands Test Facility, located in Las Cruces, NM, has been actively involved in the development of hydrogen systems and related safety issues for over 25 years and in the development of national and international standards for the past 10 years. The White Sands Test Facility offers both a hydrogen design and safety course and hydrogen handlers' safety course.

Alternative Energy Initiatives—Weakness

[35] **Source**: http://www.state.nm.us/nmsic/02invest.htm

The state of New Mexico has certain initiatives in place that either directly or indirectly support the advancement of clean energy. Although the presence of such initiatives and incentives is a positive step and is an asset, they are considered a weakness as an advanced factor **when compared to the heavily funded, established initiatives in other states.**

The most important initiative proposed by the state is the Clean Energy Act, consistent with more mature programs in other states. Other important collaborations in the state include the creation of HyTeP and the Hydrogen Business Council.

<u>Clean Energy Act</u>

House Bill 1025, submitted in the first session of 2003 to the New Mexico State Legislature, proposes the creation of a "Clean Energy Fund." Effective January 1, 2004, a clean energy charge of three-hundredths of one cent ($0.0003) per kilowatt-hour is imposed on all retail kilowatt-hour sales in the state billed by public utilities, municipal utilities and distribution cooperative utilities. Effective January 1, 2007, the clean energy charge will increase to 6/100ths of one cent ($.0006) per kilowatt-hour. The fund will be used for projects to research, develop or apply the use of energy efficient and renewable energy technologies. Proposals for specific allocations include:

- Annual disbursement of no more than one million dollars ($1,000,000) to encourage the use of energy efficiency and renewable energy through the initiation, development and evaluation of energy efficiency and renewable energy projects at state-owned facilities.

- No more than four million dollars ($4,000,000) to encourage the use of energy efficiency and renewable energy through the initiation, development and evaluation of energy efficiency and renewable energy projects authorized and directed by a public post-secondary educational institution, a school district or by a municipality or county.

- No more than four million dollars ($4,000,000) to projects sponsored by the governing body of an Indian nation, tribe or pueblo to develop electric service or increase energy efficiency and conservation through the initiation and implementation of new renewable energy projects in low-income communities.

<u>Hydrogen Technology Partnership</u>

This is an alliance representing industry, business, research laboratories, universities, and government, which seeks to enhance the economic development of New Mexico and the nation through a cooperative focus on hydrogen and fuel-cell research, development, demonstration, and commercialization. HyTeP aims to create a cluster of research, engineering, development, service, manufacturing, and business organizations that will make New Mexico the worldwide center for hydrogen and fuel-cell development. The members of HyTeP seek to reduce barriers to cooperation, to promote investment, to ensure continued funding and support for research currently underway at New Mexico's research institutions, and to support the creation of a Fuel Cell National Resource Center at Los Alamos National Laboratory.

<u>New Mexico Hydrogen Business Council</u>

The New Mexico Hydrogen Business Council is a 501(c)(6) trade association dedicated to supporting the efforts of its members to achieve success with fuel cells, hydrogen internal combustion, hydrogen distribution infrastructure, and all methods of hydrogen production. The Hydrogen Business Council supports and encourages national and statewide hydrogen and fuel-cell initiatives, provides a forum for members to develop strategic partnerships, educates the public about the capabilities of its members, identifies and generates market opportunities for hydrogen production and utilization, helps to shape public policy for the fast, efficient, and sensible deployment of a hydrogen infrastructure, and assists in the development and implementation of New Mexico codes and standards for hydrogen.

Entrepreneurial Support Programs—Strength

Entrepreneurs are a critical element in the formation and the sustainability of technology clusters, actively organizing resources and changing the environment in support of their personal ventures. Over time, a successful cluster becomes entrenched as the successes of the early entrepreneurs attract resources such as venture capital and specialized labor to the region and as institutions and government enact policies to promote the cluster. This induces others to entrepreneurship and deepens the cluster.[36] New Mexico has a wealth of organizations dedicated to the support of entrepreneurs and new company formation including Technology Ventures Corporation, NextGen, the Regional Development Corporation and many others. (For a listing of entrepreneurial support programs, see Appendix VII).

Business Incentives—Weakness

There has been a steady complaint in some economic development circles that New Mexico lacks economic development incentives (like Texas communities have) that allow cities and counties to offer direct aid to companies looking to relocate to the state. Industrial revenue bonds, various tax incentives and in-plant training funds are often cited as the state's only economic development tools.

The Small Business Survival Index provides a measure by which states can be compared according to how the state and local governments treat small business and entrepreneurs. In essence, it is a comparative measure of economic incentives relating to government policies: the lower the Small Business Survival Index number, the greater the incentives to invest and take risks in that particular state. In terms of their policy environments, New Mexico was among the most anti-entrepreneur policy environments, ranking 43rd out of 50 in 2003.

Home Demand

The character and breadth of local demand can have a broad effect on the competitive advantage of local firms. It is most beneficial to firms if local consumer demand is not only large and sustainable, but also anticipatory of the much larger global demand. If the latter holds true, local firms will be well positioned to successfully compete in the global market for their products, which materializes later. According to Porter,

> ***The composition of home demand shapes how firms perceive, interpret, and respond to buyer needs.***[37]

Home demand is best characterized as the number of potential buyers for a given technology or service within a geographic area. As the hydrogen and fuel-cell industry is nascent, broad-based consumer demand does not exist. Therefore, current demand for fuel-cell products and services primarily consists of

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[36] Feldman, Maryann P., "Entrepreneurs and the Formation of Industrial Clusters," Johns Hopkins University, 2001.
[37] *The Competitive Advantage,* p. 86

materials, services and supplies utilized in demonstration projects. The high price of new fuel-cell products — reflecting higher production costs associated with small production volumes — poses a prohibitive barrier to potential purchasers beyond demonstration ventures. Most fuel-cell companies are operating today due to government subsidies or investments from large corporate partners (i.e., GM holds a 20% stake in QUANTUM Technologies, a hydrogen, natural gas, and propane storage company). Production costs, and hence prices, will come down as demand stimulates increased production volumes. The sooner this demand is generated, the faster the industry will be able to reduce costs and access new markets.

Early Home Demand—Weakness

Early consumer demand will most likely appear in geographic regions where the high cost of energy necessitates a more expedient transition to an alternative energy source. For example, Japan has been the largest site for stationary fuel-cell demonstration projects, at 75% of total world installations.[38] This is in direct response to their current high-energy costs. It is assumed that early demand will materialize near these large demonstration projects. At the time of this report, New Mexico does not exhibit exorbitant energy costs, nor is it home to any large-scale demonstration project.

Efforts to stimulate demand within a state will center on incentives for suppliers to manufacture products and incentives for buyers to purchase them. New Mexico offers a few renewable energy incentives that could be used to stimulate the production and sale of hydrogen and fuel-cell products including a Renewable Energy Production Tax Credit and a green pricing program. (For a listing of Renewable Energy Incentives, see Appendix VIII.) The incentives however are not on par with those offered by other states which will be discussed in the next section of this report.

Demonstration Projects—Weakness

There are currently no ongoing demonstration projects for fuel cells or hydrogen products within the state of New Mexico. Building upon the state's current assets, HyTeP is proposing a partnership with the National Automotive Center (NAC) to conduct a hydrogen refueling station demonstration project in Albuquerque, New Mexico. This demonstration project will focus on using natural gas as a bridge to hydrogen and result in a roadmap for replication and implementation of hydrogen refueling infrastructure using existing natural gas infrastructure. The demonstration would consist of a phased approach that would identify and evaluate potential barriers and the necessary steps to mitigate those barriers when using hydrogen as an automotive fuel. The demonstration would also evaluate the feasibility of providing onsite primary or auxiliary power needs. Because the state of New Mexico has experience with the development of other alternative fuel infrastructure, critical data and lessons learned exist in the areas of siting, permitting, education and training. This project seeks to document these elements and present a template for replication within the state.

New Mexico is the 45th most densely populated state in the U.S. and therefore has many remote locations compared to most other states in the country. The availability of such remote locations within the state may pose an opportunity for demonstration projects for stationary fuel cells, helping to create early-adopters and in-state market demand. The military will most likely use portable fuel cells on desert missions. New Mexico offers many remote locations and comparable environments where development and testing can occur. Several of New Mexico's federal research and university facilities have controlled-

[38] EU Atlas web site (http://europa.eu.int/comm/energy_transport/atlas/htmlu/bfcdmarpos2.html)

access and large open spaces away from populated areas. These sites are appropriate for test and demonstration projects involving hydrogen and fuel-cell systems. Collectively, these facilities in New Mexico offer a unique resource for safe and remote testing and demonstration of hydrogen and fuel-cell systems in a variety of extreme environments, including high altitude and rugged terrain, both high and low temperatures, and harsh desert conditions.

Energy Infrastructure—Weakness

The support and involvement of a local power utility is vital to the adoption of hydrogen power in its service area for many reasons including, but not limited to, power grid access, gas distribution infrastructure, and power safety code expertise.

The energy infrastructure in New Mexico is served by 23 different utility organizations and is fragmented. Public Service Company of New Mexico (PNM), the largest power utility, ranks 41st in the nation in size with respect to the number of consumers to whom it distributes natural gas. This impacts New Mexico home demand in that there are fewer potential users of fuel-cell technologies. More importantly however, New Mexico's utility companies do not benefit from a large revenue base that can be re-invested into alternative energy projects. Many remote locations in New Mexico are served by undercapitalized rural co-ops that are not well positioned to invest in alternative energy solutions.

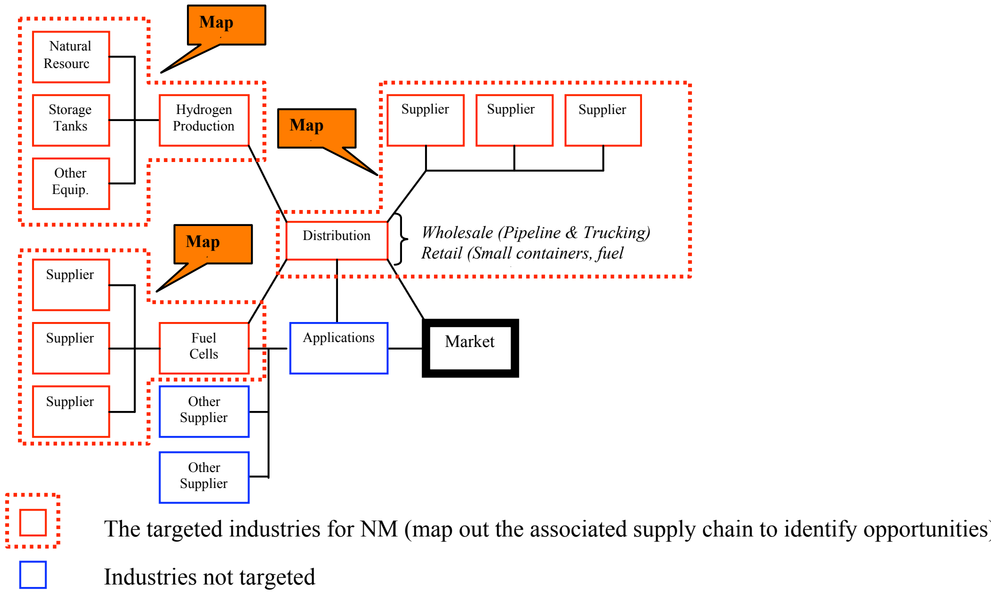
Many of the larger U.S. power companies have been leveraging their size and fiscal position to invest in hydrogen technologies and products either through internal R&D programs or through investments in hydrogen companies. Detroit Edison, for example, owns 32% of Plug Power, which was started as a joint venture in June 1997 between Detroit Edison and Mechanical Technology Incorporated (MTI). In 1998, the Connecticut General Assembly created the Connecticut Clean Energy Fund (CT CEF) as part of legislation deregulating Connecticut's electric utility industry. The statute directed that the fund be used to

- Foster growth, development and commercialization of renewable energy technologies and sources;
- Stimulate Connecticut consumers' demand for renewable energy; and
- Promote deployment of renewable energy sources that serve Connecticut's energy customers.

As provided in the legislation that created CT CEF, the funds used to stimulate the state's clean energy industry come from a surcharge on Connecticut ratepayers' utility bills. The fund is expected to aggregate to over $100 million in 5 years.

Related and Supporting Industries

Based on the current membership of the Hydrogen Business Council and other on-line databases, New Mexico has a very small set of fuel-cell or fuel-cell supplier companies. Below is a graph That depicts the supply chain from a macro level and identifies three critical areas which need to be mapped out in more detail (hydrogen production, distribution and fuel-cell manufacturing) to identify what types of companies may be suppliers or buyers in the hydrogen value chain that may be currently operating in another line of business. While not in the scope of this report, mapping of the hydrogen and fuel-cell supply chain from source to production to market would be a valuable exercise to identify New Mexico companies that could be involved in those parts of the value chain.



Firm Strategy, Structure, and Rivalry

New Mexico's local firms do not differ considerably in this cultural determinant from other states in the U.S. For this reason, this particular attribute will not shed further light on New Mexico's competitive advantage versus other states, and will not be detailed in this report.

Assessment of Other States

According to one report by the Clean Energy Group of Montpelier, VT, 21 states so far are jumping on the fuel-cell bandwagon, trying to lure and or grow young companies to base operations within their state borders.

For this report, states were analyzed and grouped into three tiers based on the magnitude, scope and the duration of their hydrogen or fuel-cell cluster initiatives. Various incentive packages focus on tax rebates, grants or research buildings.

Tier 1 States

Tier 1 represents those states that have established a leadership position in hydrogen cluster development, essentially setting the bar for New Mexico strategy development. Tier 1 states have comprehensive programs with elements of all the following: supplier incentives, buyer incentives, fuel-cell technology centers or technology parks, university involvement, organized partnerships, general grant programs, dedicated funding, and demo sites. Tier 1 contains seven states: California, Connecticut, Hawaii, Massachusetts, Michigan, New York, Ohio and Texas. (Indiana was not defined as a Tier 1 state in our analysis.) More detailed descriptions of these state initiatives follows. (Please see Appendix IX for more detail of all states.)

	Fuel Cell Center/Technology Park	University Involvement	Supplier Incentives	Buyer Incentives	Clean Energy Funds	General Grant Programs	Organized Partnerships	Demo Sites	Funds Available for Initiative*
California	NO	YES	YES	YES	NO	YES	YES	YES	~$50M
Connecticut	YES	YES	YES	YES	YES	NO	YES	YES	~$100M
Hawaii	YES	YES	YES	YES	NO	NO	YES	YES	?
Massachusetts	NO	YES	YES	YES	YES	YES	YES	YES	~$100M
Michigan	YES	YES	YES	YES	NO	YES	YES	YES	~$50M
New York	NO	NO	YES	YES	YES	YES	YES	?	$10M grant for fuel cell
Ohio	YES	YES	YES	YES	NO	YES	YES	YES	~$103M
Texas	In Development	YES	YES	YES	NO	YES	YES	YES	~$31.1M ($15M to develop statewide fuel-cell industry)

* These funds constitute state money, funds contributed by industrial partners and federal agencies.

California

California is home to a unique collaborative effort by auto manufacturers, energy companies, fuel-cell technology companies, and government agencies. Since 1999, the California Fuel Cell Partnership has been increasing public awareness of fuel-cell electric vehicles, advancing a new vehicle technology that could move the world toward practical and affordable environmental transportation.

Automobile companies and fuel suppliers have joined together to demonstrate fuel-cell vehicles under real day-to-day driving conditions. In addition to testing the fuel-cell vehicles, the partnership is examining fuel infrastructure issues and beginning to prepare the California market for this new technology. Specifically, the partnership aims to achieve four main goals:

- Demonstrate vehicle technology by operating and testing the vehicles under real-world conditions in California;
- Demonstrate the viability of alternative fuel infrastructure technology, including hydrogen and methanol stations;
- Explore the path to commercialization, from identifying potential problems to developing solutions; and
- Increase public awareness and enhance opinion about fuel-cell electric vehicles, preparing the market for commercialization.

This collaborative effort to encourage fuel-cell vehicle commercialization will continue through 2007.

Connecticut

Fuel cells took off in Connecticut; home to two big commercial producers, FuelCell Energy and United Technologies. The state is home to a number of small start-up fuel-cell research and technology development companies, as well as three major fuel-cell manufacturers—UTC Fuel Cells of South Windsor, FuelCell Energy of Danbury, and Proton Energy Systems of Rocky Hill. These companies have recently made great strides:

- The Connecticut Juvenile Training School in Middletown recently installed a 1.2 MW fuel-cell system—the largest single installation of fuel cells in the world. The fuel cells were provided by UTC Fuel Cells.
- In October 2001, a deal valued at $6.2 million was reached by the Naval Research Laboratory and Proton Energy Systems, Inc. to apply its technology to advanced space propulsion and energy systems.
- Also in October 2001, FuelCell Energy, Inc. received an order from PPL Spectrum, Inc., for the purchase of a 250 kW Direct FuelCell® power plant for the US Coast Guard Air Station in Bourne, Massachusetts.

Connecticut's Clean Energy Fund skims $20 million a year off electric bills for research centers and demonstration projects. To date, CT CEF has

- Committed more than one-third of its budget over five years to the development and deployment of fuel cells.
- Committed funding for two sustainable and renewable energy education and research facilities—Connecticut Global Fuel Cell Center at the University of Connecticut with a $3.5 million challenge endowment and the Institute for Sustainable Energy at Eastern Connecticut State University in Willimantic with a $3.5 million challenge grant.
- Funded the development and installation of a fuel-cell system, produced by FuelCell Energy, Inc., for a new building located at the University of Connecticut's Mansfield campus.
- Funded a fuel cell, produced by UTC Fuel Cells, to be used at South Windsor High School to enable the school to be used as an emergency shelter in the town's disaster-relief plan.
- Provided financial support to Proton Energy Systems, Inc. to accelerate the company's commercial deployment of Proton's UNIGEN® fuel-cell product family.[39]

Massachusetts

Massachusetts draws its strength from the significant brainpower resident at Harvard, MIT and its other state universities. The state's 20 fuel-cell companies get grants from the Renewable Energy Trust Fund. The Renewable Energy Trust was created in 1998 by the Legislature as a component of efforts to restructure the electric utility industry and to promote the development of renewable energy in Massachusetts. Between 1998 and 2003, the fund is expected to collect roughly $150 million through a charge to all customers at a rate of $6 per year. The fund supports distributed generation, principally fuel-cell technology through the Premium Power Program. In 2002, a pilot program was established for up to twenty organizations to power their facilities using fuel cells. RETF seeks to:

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[39] Chandra, Subhash, http://www.nesea.org/publications/NESun/fuel_cells_two.html

- Increase the supply of -- and demand for -- renewable energy
- Achieve the economic and environmental goals of the legislation
- Strengthen the ability of Massachusetts companies to compete in the marketplace, helping to establish the infrastructure needed to support a growing, sustainable and competitive market for renewable energy
- Leverage the resources and expertise of others in both the public and private sectors wherever possible, maximizing the impact of the Trust's investments
- Build upon consumer choice.[40]

Michigan

If, in 10 or 20 years, fuel-cell vehicles are a reality, no state stands to lose more than Michigan, home to the major U.S. automakers and their numerous suppliers. The advent of a new automotive power system would put at risk as many as 200,000 Michigan jobs and cut out $10 billion of the state's economy, the chief executive of the Michigan Economic Development Corp. recently told Congress.

Michigan has created its own state-level fuel-cell partnership with industry called NextEnergy, a comprehensive set of initiatives and incentives promoting alternative energy technology R&D, education, and manufacturing. A key aspect to NextEnergy is the establishment of a NextEnergyZone, close to both the University of Michigan and the Detroit airport. The zone will include business incubator space and an alternative energy "microgrid" that will power the site with new energy systems, including fuel cells. Any company within the zone will operate virtually free of all state and local taxes. At the zone's core will be the NextEnergy Center, a campus of laboratories, incubator space, and other facilities to support the alternative energy industry. The center will fund industry/university research and commercialization projects and develop other industry support services.

Michigan is also establishing a NextEnergy Development Fund to seed venture capital funds, provide working capital, and finance the construction of alternative energy facilities. The state legislature has passed all of the bills related to the NextEnergy initiative, and the Michigan Economic Development Corp. is committing $ 50 million to the initiative. The state is also planning a $30 million fuel-cell incubator in Detroit, including a mini electric grid for testing.[41]

Ohio

Well positioned to become a major player in the fuel-cell industry, Ohio is home to most auto suppliers in the country and the biggest producer of polymers, which are needed to make fuel cells. Fuel-cell development is particularly important to Ohio, which could lose untold numbers of manufacturing jobs with the demise of internal combustion engines. Part of the Third Frontier Project—which aims to create more high-tech, high-paying jobs in Ohio—is a $103 million, three-year, fuel-cell initiative. This initiative is being spearheaded by the Ohio Fuel Cell Coalition, a consortium of industry, academic, and government organizations. Case Western was awarded $18 million in Third Frontier funds to support fuel-cell research and development. The funds will be used to create the Power Partnership for Ohio, a group of colleges, businesses and other collaborators.[42]

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[40] http://www.nfcrc.uci.edu/fcresources/REGULATIONS-INITIATIVES/INITIATIVES/state/MA-RenewableEnergyTrustFund.htm

[41] "With Much to Win or Lose, Auto Capital Rushes to Embrace Fuel Cells," *Technology Week*, July15, 2002

[42] Montgomery, Christopher, "Ohio's Fuel Cell Plans Gain Momentum," *Dayton Daily News*, June 3, 2003

Hawaii

Hawaii is confident that with its current hydrogen fuel-cell R&D base and climatic advantages it stands a good chance of succeeding in the development of a viable fuel-cell cluster. Hawaii boasts 13 of the world's 15 climatic zones allowing researchers a chance to test drive a fuel-cell vehicle under nearly all conditions. Much of Hawaii's confidence stems from a recent three-year, $1.5 million grant the state received to develop a hydrogen park in partnership with a handful of local and mainland private and public entities.

The Hawaii Hydrogen Power Park, a three-phase project with the goal of taking to market hydrogen-based fuel cells will deploy and demonstrate an integrated system comprising a way to produce pure hydrogen, store it, and produce energy that can supply a grid. The goal is to run the whole operation on renewable energy resources, even the generation of hydrogen through electrolysis.

Apart from this, a fuel-cell test facility was opened at Hawaiian Electric Co. Inc. The facility houses three test stands and two more are to be added by the end of the year. The project is a partnership of the University of Hawaii's Natural Energy Institute, Office of Naval Research, UTC Fuel Cells, and Hawaiian Electric. The facility is expected to help researchers fine-tune the technology for commercialization. In addition, a distributed energy research center is being set up at the institute's campus as a catalyst to attract investments in testing, application, and development of energy technologies.

Hawaii hopes to work with its Hydrogen Park partners in developing a competitive bid for U.S. Department of Energy contracts. The contracts, for which the Energy Department has begun solicitations, require energy, auto and fuel-cell companies to be lead bidders. The University of Hawaii, local utility companies, and the Department of Business, Economic Development and Tourism hope to form a consortium that favors Hawaii as a test site.

The partners are actively seeking several multimillion-dollar systems application projects in the areas of hydrogen, fuel cells, and renewable energy. These projects are designed to take advantage of Hawaii's unique energy situation, including a vast array of potential renewable energy resources, and high costs for conventional energy. Generous state of Hawaii R&D tax incentives contribute to the positive climate for developing new energy technologies and products.[43]

New York

The New York State Energy Research and Development Authority (NYSERDA) administers the New York Energy $martSM program, which is designed to support certain public benefit programs during the transition to a more competitive electricity market. NYSERDA derives its basic research revenues from an assessment on the intrastate sales of New York State's investor-owned electric and gas utilities and voluntary annual contributions by the New York Power Authority and the Long Island Power Authority.[44]

A partnership of business and government recently unveiled the first fuel-cell system to power a single-family home in Western New York. Officials from NYSERDA, National Fuel Gas Company, Plug Power Inc., ATSI Engineering Services (ATSI), Integrated Building And Construction Solutions, Inc. (IBACOS), and the U.S. DOE met in Lewiston, N.Y., to showcase the installation.

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[43] http://www.hnei.hawaii.edu/hydro.partner.asp
[44] NYSERDA web site (http://www.nyserda.org/about.html)

National Fuel Gas Distribution Company and NYSERDA are co-funding these projects to help develop fuel-cell technology for the residential market. "Commercialization of new energy technologies is perhaps one of the most difficult tasks for entrepreneurs trying to bring their product to market," said NYSERDA President William M. Flynn. "With funding available for distributed generation projects, NYSERDA can help bridge the gap and bring an innovative technology, such as fuel cells, to consumers."

Texas

The role of Fuel Cells Texas is to promote the many public benefits of fuel cells and to bring together government agencies and private entities interested in accelerating the advancement and the commercialization of fuel cells in Texas. From its inception, Fuel Cells Texas members worked with the State Energy Conservation Office and their Fuel Cell Initiative Advisory Committee in the development of a proposed statewide plan for accelerating the commercialization of fuel cells.

The statewide commercialization plan included recommendations for private and public initiatives, as well as, recommendations for the 2003 Texas Legislature. Several bills were introduced in the 2003 Texas Legislature, each seeking to help accelerate the progress of fuel-cell commercialization in the state. As a result, the Texas Legislature adopted and funded the Texas Emission Reduction Plan (TERP), which makes fuel-cell commercialization funding a priority for the Texas Council on Environmental Technology. Technologies that emerge from this process may then be eligible for funding under TERP. The TERP language will also allow the Texas Commission on Environmental Quality to expand the use of its incentive funds (approximately $130 million per year) to apply to stationary applications of fuel cells that reduce emissions of nitrogen oxides. Finally, the legislature transferred economic development responsibility to the Governor's Office and created an Enterprise Development Fund. The budget rider language sets aside Economic Development funds for the newly formed Texas Energy Center, which highlights fuel cell funding.

Estimates of total Texas sources of research and development funding could represent as much as $20 million for fuel cells over the next several years. To the extent that fuel cell applications approach commercial viability or are otherwise capable of contributing to Environmental Protection Agency (EPA) recognized emissions reductions, they could be eligible for funding from the TERP fund, which is approximately $130 million per year through 2007.[45]

Tier 2 States

Tier 2 consists of states that are in the process of developing initiatives in the hydrogen area. Most states have been designing their initiatives and programs within the last year. There are seven states in Tier 2: Florida, Illinois, Minnesota, Montana, New Mexico, New Jersey and Pennsylvania.

State	Cluster Developments
Florida	• Home of the world's largest hydrogen-fueled vehicle • Formed the Florida Hydrogen Energy Initiative to facilitate commercial deployment of zero pollution hydrogen energy technologies in appropriate niche applications throughout Florida. • Home of The Florida Solar Energy Center (FSEC), the largest and most active state-supported renewable energy and energy efficiency research, training, testing and certification institute in the United States.
Illinois	• Launched Illinois 2H2-Public-Private Partnership to create an industry cluster centered on the development of

[45] http://www.fuelcellstexas.org/objectives/

	hydrogen as an energy carrier. Established by the Illinois Coalition and Illinois' Department of Commerce and Economic Opportunity. • In the process of developing a strategic action plan centered on hydrogen and fuel-cell opportunities in the state. • DOE has partnered with State of Illinois, Caterpillar Inc., Nuvera Fuel Cells (a company spun off from A.D. Little) and Williams Bio-Energy to demonstrate the nation's first commercial ethanol powered fuel cell.
Minnesota	• Has a cluster of companies involved in hydrogen fuel cells. • The state's vast wind and agricultural resources make it an ideal place to perfect the renewable production of hydrogen. • Minnesota Planning recently issued "Freedom Fuel: Preparing Minnesota for the Coming Hydrogen Economy."
Montana	• Montana is the only state in the U.S. that holds all the natural resources to become a hydrogen energy economy • Plan to initiate the following objectives: 1. Foster collaborative efforts promoting statewide hydrogen energy development by adopting the Montana Hydrogen Energy Plan 2. Establish a cohesive Best Business Environment Plan that creates significant partnerships in the state with business, industry and government. 3. Construct Montana's Futures Park @UM designed to incorporate future technologies and training that provides a highly qualified workforce for the hydrogen industry and other businesses throughout the state. 4. Quickly identify and secure funding opportunities that initiate the energy economy in Montana and establishes Montana as the preeminent hydrogen energy producer. 5. Foster future economic development by marketing hydrogen energy resources to bolster Montana's infrastructure.
New Jersey	• New Jersey Clean Energy Program—Funding available for fuel cells and other clean energy technology.
New Mexico	• Currently developing plan for how to position the state in the hydrogen economy.
Pennsylvania	• Alternative Fuels Incentive Grant—provides financial assistance for alternative fuel and vehicles.

Tier 3 States

Tier 3 contains the remaining states. These states do not currently have a program or the program is very small and not dedicated to the development of a hydrogen or fuel cell cluster. However, they do provide supplier and buyer incentives in the renewable energy area and could develop a plan at any time. Below is a matrix that illustrates the types of incentives different states have related to renewable energy. [46]

	Production Incentives	Sales Tax Exemption	Industry Recruitment Programs	Leasing/Lease Purchase Programs	Loan Programs	Grant Programs	Personal Tax Incentives	Corporate Tax Incentives	Rebate Programs	Property Tax Incentives
Alabama	X					X	X			
Alaska		X			X					
Arizona		X					X		X	
Arkansas			X							
Colorado	X						X	X	X	
Delaware									X	
Georgia	X						X	X		
Idaho					X	X	X	X		
Indiana	X					X				X
Iowa		X			X	X		X		X
Kansas	X					X	X	X		X
Kentucky	X									
Louisiana							X	X		

[46] Database of State Incentives for Renewable Energy: http://www.dsireusa.org/summarytables/financial.cfm?&CurrentPageID=7

Maine										
Maryland		X			X		X	X		X
Mississippi	X				X					
Missouri	X				X			X		
Nebraska					X			X		
Nevada		X							X	X
New Hampshire										X
North Carolina	X		X		X		X	X		X
North Dakota	X	X					X	X		X
Oklahoma			X		X		X	X		
Oregon	X				X	X	X	X	X	X
Rhode Island		X				X	X		X	X
South Carolina										
South Dakota	X							X		X
Tennessee	X				X					X
Utah		X			X	X	X	X		
Vermont										X
Virginia	X	X	X		X			X		X
Washington	X	X	X		X	X			X	
West Virginia							X	X		X
Wisconsin	X				X	X			X	X
Wyoming		X		X		X		X		

Recommendations

A recent report prepared for the Michigan Economic Development Corp. stated that although fuel cell mini-clusters are starting to emerge, there is currently no critical concentration within any region. However, it is evident many states have a strong start with initiatives in place and are home to many fuel-cell companies already. For example, Washington, Oregon, and British Columbia house nearly 40 of the industry's key global players. Ballard Energy Systems of Burnaby, BC, leads the world fuel-cell business and when Ford and Daimler roll out their first commercial fuel-cell powered vehicles, Ballard products will be under the hood. Spokane-based Avista is a pacesetter in fuel cells for home and business use. Xantrex/Trace, a dominant power electronics firm with headquarters in Burnaby and a manufacturing plant in Arlington, Washington, makes around half of the inverters and electronic intelligence built into the world's solar panels, fuel cells, and wind turbines.[47]

The challenge for New Mexico’s aspiring hydrogen and fuel-cell cluster initiatives is the tendency for industries to cluster where they are already established. The most useful role for government in nurturing such initiatives is as facilitator of communication among stakeholders and as creator of an efficient incentive structure that promotes and supports innovation.

The creation of a hydrogen cluster should not be a government-driven effort but should be the result of private sector-led initiatives. Private sector firms are better able to identify growing markets and discover more innovative ways to serve and attract those markets. In sum, New Mexico’s strategic plan for

[47] Mazza, Patrick, “Clean Jobs to Save the Climate,” *Earth Island Journal*, Summer 2002,Vol. 17, No. 2

hydrogen should be consistent with the existing direction and successes of the private sector, inducing an environment that makes the private sector successful.

In assessing the state's strengths and weaknesses below, a set of recommendations has been developed. The recommendations should be thought of as a synergistic set of actions that will work best when implemented as part of an overarching, coordinated initiative. Some recommendations will address multiple areas of weakness simultaneously.

This report's analysis suggests that New Mexico's strengths are an abundance of natural and renewable power sources, a successful fuel-cell R&D track record, an ability to attract large R&D dollars from federal sources and a variety of entrepreneurial support programs. These factors represent variables that the state should leverage and nurture in their marketing efforts and in the development of a comprehensive strategy.

Basic	*Land*	*Strength*
Basic	*Natural Resources*	*Strength*
Basic	*Renewable Power Sources*	*Strength*
Advanced	*Science and Technology Resources*	*Strength*
Advanced	*Fuel Cell R&D Track Record*	*Strength*
Advanced	*Federal R&D Investments*	*Strength*
Advanced	*Entrepreneurial Support Programs*	*Strength*
Advanced	*Skilled Labor*	*Strength*
Advanced	*Hydrogen Codes and Standards*	*Weakness*
Advanced	*Alternative Energy Initiatives*	*Weakness*
Advanced	*Ability to Translate R&D Into Commercial Ventures*	*Weakness*
Advanced	*Industry-Led R&D*	*Weakness*
Advanced	*Industrial Base*	*Weakness*
Advanced	*Transportation Infrastructure*	*Weakness*
Advanced	*University Hydrogen or Fuel Cell Degree Programs*	*Weakness*
Advanced	*Technology Management Skills*	*Weakness*
Advanced	*Risk Investment Track Record*	*Weakness*
Advanced	*Business Incentives*	*Weakness*
Home Demand	*Early Home Demand*	*Weakness*
Home Demand	*Energy Infrastructure*	*Weakness*
Home Demand	*Demonstration Projects*	*Weakness*
Related & Supporting	*Related and Supporting Industries*	*TBD*

Areas in which New Mexico reflects a weaker position include hydrogen codes and standards, alternative energy initiatives, ability to translate R&D into commercial ventures, industry-led R&D, industrial base, transportation infrastructure, university hydrogen or fuel-cell degree programs, technology management skills, risk investment track record, business incentives, early home demand, energy infrastructure and demonstration projects. Although the level of weakness varies, (in some cases the factor is actually neutral) these factors are those in which the state should focus their efforts.

Enhance Skill Base

New Mexico is rich in science and technology resources, but relatively poor in technology management expertise. Viable strategic economic development plans endeavor to attract higher-wage jobs to ensure long-term sustainability as lower wages and subsequent lower manufacturing costs will inevitably be found outside U.S. borders. Specifically, the state should

- Develop a strategy to ensure a sufficient supply of skilled resources for the fuel-cell sector that includes community college training programs and advanced degrees in energy or fuel cells at New Mexico universities;
- Fund fuel-cell R&D programs at New Mexico universities to attract prominent scientists and post-doctoral students to the area;
- Co-sponsor public/private partnerships for endowed chairs, grants or scholarships; and
- Support the creation of new curricula specific to the fuel-cell industry in both the business and engineering schools.

Develop Demonstration Projects

The state can use its political muscle and experience to attract federal dollars for demonstration projects that showcase fuel-cell technology and provide essential commercialization data. New Mexico's many remote locations are an attractor, however, the state should be prepared to use state money to fund demonstrations. For example, the state of California contributed $8 million to the SunLine Fuel Cell bus demonstration project in Palm Springs.[48] Specifically, the state must

- Identify and pursue private sector development partners;
- Provide tax incentives for research and development; and
- Dedicate matching funds for specific projects.

Create Hydrogen Business Incentive Package to Grow Industrial Base

New Mexico lacks the established industrial base of many of the other states currently pursuing a hydrogen strategy. Large corporations like Dupont and Gore and others who manufacture some fuel-cell stack component parts on a large scale are unlikely to move operations to the state in the near term. Attracting a large "champion" firm to the state will take aggressive marketing, courting, and a highly competitive incentive package.

Entrepreneurs, on the other hand, are often at the center of cluster formation as agents who re-define, combine and deploy resources to create new products, services, and companies. Individuals start companies in areas in which they have business networks and access to resources. In starting new companies, entrepreneurs will draw on resources in the local environment. Their success subsequently shapes the local environment as they reinvest their profits, extend relationships, and build companies.

Significant capital and business development resources will be required as fuel-cell companies move products along the path toward commercialization. Public funds may be most appropriately used for technology maturation, nurturing local start-ups to a stage where corporations, corporate VCs, and traditional VCs will take interest. Given the very early nature of much of the R&D in the state, particularly at the national labs, there would be many opportunities to invest funds dedicated to this end.

A region that conveys a business-friendly climate, high quality of life and an economic infrastructure that minimizes the cost of doing business will attract established businesses and support the start-up and growth of new companies. For this study, many companies interviewed, at all points in the value chain, expressed

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[48] Facts and Figures, AC Transit of Oakland and Sunline Transit of Thousand Palms Fuel Cell Development – Zero Emissions Bus Program (http://www.actransit.org/pdf/fuelcell_factsheet.pdf)

a desire to locate future production facilities where the cost of doing business could be minimized, and this locale would not necessarily be their current base of operations. This holds true for fuel-cell manufacturers and suppliers alike. In order to address this problem, the state must focus its efforts on

- Developing competitive incentive packages to attract a "champion" firm to the state;
- Pursuing supplier incentive programs that are competitive with other states;
- Nurturing the launch and growth of hydrogen and fuel-cell start-ups within the state;
- Creating a technology maturation fund;
- Developing innovative approaches to securing capital for hydrogen and fuel-cell companies; and
- Conducting an analysis of related and supporting industries.

Support and Enhance Industry-Led R&D

Public R&D tends to create private R&D. Therefore, improving the university research system should increase local innovation by attracting industrial R&D dollars, encouraging the establishment of R&D outposts, and increasing the university's own standing in this research area. Members of the New Mexico hydrogen and fuel-cell science and technology community should explore how they can cooperate and support each other in research, proposals for funding, training and education of students, collaboration with industry, and developing opportunities to commercialize the results of their research in New Mexico. Specifically, New Mexico should

- Aggressively pursue development of a nationally recognized center of excellence in academics and research in fuel cells and hydrogen technology;
- Ensure that such a center allows for testing and evaluation of new products; and
- Provide research and development incentives to entice more R&D by the private sector.

Create Early Demand

Several government entities have used fuel cells to satisfy their power needs. Government procurement policy can put pressure on suppliers to come up with innovative solutions to specific problems. This provides early demand for the developing cluster. Buyer incentives were used in the hybrid-vehicle market in much the same fashion. Here, buyers were offered $2000 in incentives from the federal government if they were to buy a hybrid vehicle. The tax credit against the purchase of qualified electric vehicles (EVs) included in the Energy Policy Act of 1992 has been in effect since 1993. Over this time, sales of EVs had grown from 39 in 1996 to 1,238 in 1998,[49] with more than 100,000 sold to date.[50]

A big component of creating early demand consists of educating potential users. Education materials should be developed to introduce hydrogen and fuel-cell systems and to clearly communicate to end users the potential benefits, safety, and utilization information. The state should

- Establish early purchase programs to encourage product procurement and benchmarking;
- Allow public demonstration of new technology and provide critical early revenues for the industry;
- Develop financial incentives for the production and purchase of fuel-cell products and services in order to reduce the risk and large cost associated with the introduction of new products; and

[49] Electric Vehicle Association of the Americas, Major OEM EV Sales and Leasing, January 18, 1999
[50] "Hybrid Electric Vehicles", Clean Car Campaign (http://www.cleancarcampaign.org/hybridelectric.shtml)

- Develop public information programs to educate policy makers, service providers, consumers and students.

Take a Leadership Role in Codes and Standards Development

The bylaws of most regulatory bodies lack codes and standards outlining the usage of hydrogen as a fuel. The development of a complete set of codes and standards would foster mass-market acceptance of fuel-cell technologies because of the safety and liability aspects of introducing a new technology. By taking a lead role in the development and subsequent implementation of new hydrogen codes and standards, the state helps to establish itself as hydrogen friendly and enables early adoption within New Mexico of hydrogen products and services by minimizing risks associated with testing and usage of new products. The state can establish a leadership role in this area by helping the regulatory commissions draft the hydrogen codes and standards as well as initiate some regulations at the state level.

Enhance Alternative Energy Initiatives

At lease 15 states have some sort of public benefits fund to quickly build money for renewable energy and energy efficiency programs. It is estimated that from 1998 to 2012, these funds will contribute more than $4.3 billion to the 14 states that require mandatory contributions.[51] New Mexico is lagging behind many other states in establishing funding resources to support the development of a hydrogen cluster. New Mexico should support the passage of the Clean Energy Act as the first step towards the accrual of funds to support implementation of renewable energy initiatives.

Explore Local Hydrogen Generation

New Mexico's large deposits of natural gas could allow for cheap generation of hydrogen via SMR. New Mexico could also pursue renewable generation via wind, solar, or biomass should the economics make sense. These options makes sense only in the case where local demand can be met and therefore profits kept in the state. The expense related to the hydrogen option is due, in large part, to the difficulty faced in hauling the output hydrogen, which will lower profitability. Also, hydrogen, as a commodity, earns margins not worthy of large initial investment. Developing hydrogen as a commodity only makes economic sense if New Mexico finds that dollars spent on importing hydrogen are substantial.

Conclusion

New Mexico can play a primary role in the emerging hydrogen economy, but it must decide where and how it will play given its current strengths and weaknesses. This report, a response to House Joint Memorial 6, has helped to identify these markets and a broad strategy to help build a hydrogen technology cluster in the state.

The recommendations in this opportunity assessment make up the key components of what should eventually constitute a state strategic plan for hydrogen. Further study must be conducted to outline more specific steps to properly execute these strategies. In addition, a responsible body should be establishing to manage the strategic planning process and subsequent implementation and evaluation. Because other

[51] Hopkins, Barry, "Renewable Energy and State Economics," The Council of State Governments, May 2003

states and regions already have much more advanced programs, it is imperative that a strategic plan be developed now, and that the actions are implemented immediately. Government and industry need to work together to support demonstration projects, provide early purchaser opportunities, and show leadership in overcoming the challenges facing fuel-cell commercialization in general.

Specifically, the state must work with private industry to

- Develop a hydrogen and fuel-cell strategic plan within the next year which reflects the collaborative commitment of all key stakeholders;
- Educate government and other early users as to the long-term benefits of fuel cells and why they should demonstrate/purchase fuel-cell products; and
- Support research and development, product demonstrations and early purchase programs.

Appendix I: HyTeP Strategic Planning Workshop

HyTeP Strategic Planning Workshop:
Hydrogen and Fuel Cell Commercialization Potential in New Mexico
April 23, 2003

Background: The Role of HyTeP
The Hydrogen Technology Partnership (HyTeP) was created in December 2002 when representatives of several public and private sector organizations met in Los Alamos to discuss the potential of hydrogen and fuel-cell technologies for creating significant economic development in New Mexico. The founding organizations of HyTeP were Motorola, PNM, Build New Mexico, The NM Chapter of AIA, Los Alamos National Laboratory, NM Economic Development Department, Regional Development Corp. and Los Alamos Commerce and Development Corp., Los Alamos County, and the Northern NM Economic Development District. The group sought out and engaged other interested organizations in New Mexico and formed the Organizing Committee list shown on the HyTeP website, www.hytep.org.

HyTeP is an alliance representing industry, business, research laboratories, universities, and government working together to enhance the economic development of New Mexico and the nation through a cooperative focus on hydrogen and fuel-cell research, development, demonstration, and commercialization.

To formalize a mandate for the New Mexico Economic Development Department (EDD) and state government work with HyTeP, Jeannette Wallace introduced a House Joint Memorial in the 2003 New Mexico Legislature. The Memorial directed the EDD to report back to the Legislature on the department's plan for hydrogen and fuel-cell R&D in New Mexico, as well as any recommended legislation needed to support the development of a hydrogen and fuel-cell economic business cluster in New Mexico.

HyTeP and EDD conceived of a strategic planning workshop to begin the analysis of New Mexico's competitive advantage in becoming a center of economic growth *vis-à-vis* other states in the emerging hydrogen economy. The workshop was planned to engage HyTeP members and other groups in New Mexico with hydrogen/fuel industry participants from outside the state. Planning and conducting this workshop became the primary near-term focus of the HyTeP group during the spring months of 2003.

Purpose of the Workshop: The HyTeP Strategic Planning Workshop was held in direct response to the New Mexico Legislature's Joint House Memorial 6 passed during the 2003 legislative session. The Department and HyTeP cosponsored the planning workshop on April 23, 2003 to begin the process of exploring opportunities for the state in the emerging hydrogen and fuel-cell markets, identifying the barriers and incentives required to overcome them, and recommending business-development and legislative initiatives to achieve the vision.

New Mexico Governor Bill Richardson invited leaders from the fuel-cell and hydrogen industries across the nation to meet with State and local business, economic development, research, education, and government leadership in Santa Fe to share their best thinking on how to enhance New Mexico's economic future and national leadership in taking fuel cells and hydrogen infrastructure from research and development to commercial applications. Governor Richardson attended the workshop and challenged the audience to help New Mexico become a national leader in the new hydrogen economy.

The workshop agenda is attached as an appendix and is summarized below (see end of this document).

Keynote speakers at the Workshop included three nationally prominent speakers: Cathy Gregoire Padro from the National Renewable Energy Laboratory provided an overview of the "Hydrogen Economy and Producing Hydrogen"; Douglas Wheeler from UTC Fuel Cells spoke on "Uses of Hydrogen"; and Byron McCormick from General Motors spoke on the "Future of Hydrogen and Fuel Cells in Transportation."

The workshop also had two panel sessions: The first was on "Transportation, Stationary Power, Microelectronics & Military Applications" and included representatives from General Motors, Motorola, UTC Fuel Cell, MTI Micro Fuel Cell, Shell Hydrogen and DARPA. The second panel discussed "Hydrogen and Fuel Cell R&D and Capabilities in New Mexico." This panel included representatives from New Mexico Tech, the University of New Mexico, New Mexico State University, Los Alamos National Laboratory, Sandia National Laboratories, and MesoFuel, Inc.

The Workshop then broke into separate small working groups to address the following subjects.

Group 1 – Incentives and Barriers – What programs or projects can be implemented to provide incentives to new or relocating hydrogen or fuel-cell businesses? What are the biggest barriers?

Group 2 – Pre-commercial R&D Needs – What existing R&D is needed and most relevant for commercial development?

Group 3 – Supporting Technology Needs – What related or ancillary technologies and capabilities are needed to support the industry? Training, education, manufacturing, etc.?

Group 4 – Technology Validation Projects – What types and locations of demonstration projects can be implemented in NM to increase public awareness and demonstrate application and feasibility of the technology?

Group 5 – NM Business Climate – What do start-up and relocating hydrogen and fuel-cell companies need in NM? How can the business climate be improved for these companies?

The results of the breakout discussion groups were reported back to a plenary session at the end of workshop. A large number of ideas and issues were raised by the breakout groups. These issues were collected and analyzed after the workshop as the initial input to the State's strategic planning process. A summary of these results is presented in the following table. The issues and suggestions are sorted into topical areas and ranked in order of the frequency that a particular subject was mentioned, i.e., the number of "hits" in each subject area.

Summary of Major Issues Raised in Breakout Sessions

Issue Category	Summary of Issues and Recommendations	Hits
Coordination, cooperation, and planning issues	New Mexico needs to integrate the diverse, potential participants in the new hydrogen economy. Many different players can contribute to success, but they are fractured and uncoordinated. We need government, labs, and industry to work together. This calls for a unifying vision and an integrated plan, e.g., the study to be conducted this summer by HyTeP and EDD. We need an economic analysis for the state. We need a plan for a business cluster in the state. NM has a history of institutions not working together. We need to create a one-stop-shop for companies to get what they need in NM that integrates production, manufacturing, training, uses and applications. Poor planning = dismal failure. We need a focal point for business assistance in NM. We need gap analysis of what we have and what we need, and a survey of company needs. We need a business model for commercializing technology out of the labs. Don't focus exclusively on recruiting new businesses to New Mexico; don't neglect the companies you have here already.	20
Technology validation opportunities	Use fuel cells to power the Governor's mansion. Rural electricity. We need a **hydrogen technology test-bed** in NM. Remember the difference between demonstration and validation. Other suggestions: Mesa del Sol, ABQ bus fleet, wind storage on calm days, forest thinning and dairy waste: biomass opportunities in NM, bus fleet concept for Northern New Mexico's new Park and Ride program, and Coal-to-Hydrogen with CO2 sequestration -- a $1 billion project.	13
Education and training issues	Hydrogen has a perception problem. We need to provide public education and build confidence that hydrogen is a safe energy source. Anything new is resisted; we need to overcome this inertia. Public education and university programs are needed to teach H2 and FC technology. Workforce training and education needs to be in place. "NM leads in hydrogen technician training." Hydrogen internships for science and engineering students to come to New Mexico. The Alvarado Training Center.	10
Communication issues	HyTeP needs a communications channel to share info on how we gain access to the resources at the labs? We need to get information from the government to businesses. We need to manage expectations of the public and business sectors about how long this will take. Need to engage at national level with decision makers, legislature. Be sure real estate people are included. HyTeP needs to define what next steps are and communicate with constituents ASAP.	8
Leadership issues	We need strong leadership at state and federal levels to lead the movement toward fuel cells. We need a strong core of business leadership. Who will assume leadership for the economic plan?	6
Assets	We need to inventory our assets and capitalize on them. We also need inventories of markets and infrastructure needs.	5
Focus issue	We need to have a focused message. Don’t try to be all things to everyone. HyTeP provides the focus. Need short-term successes but need to keep the long-term goals in sight. We need to identify our unique competitive strengths and capitalize on them. National interests may or may not match state interests; stay focus on New Mexico.	5
Infrastructure issues	Create a hydrogen infrastructure at Albuquerque Int'l Airport. We can set standards for hydrogen and fuel cells in NM; become the first hydrogen-friendly state. Verify that we have the necessary business infrastructure to keep companies in New Mexico.	4
Funding issues	Technology maturation funding and seed funds are needed. NMERDI model could be useful. State direct investment should give priority to supporting hydrogen economy. State funds can act as matching for other federal funds = leverage. We need a grant proposal process. What about FutureGen? State surpluses, casino revenues, and oil and gas industry funds rural electrification by fuel cells.	4
Market creation	We need to create local markets for hydrogen and fuel cells. NM government can be a market driver for some early technologies to build initial demand, e.g., hydrogen powered state vehicle fleets.	3
R&D issues	Does R&D attract businesses to NM? Can NM universities become centers of excellence? What is the role of the Fuel Cell National Resource Center?	3
Timing issues	We need to move forward now or we will lose opportunities. Future Gen project has short deadline for funding. We have a unique competitive advantage with the laboratories, state, and federal legislative support for this initiative; we need to take advantage of it now.	3
Intellectual property issues	need assistance in protecting IP, UNM law school assistance, IP insurance	1

<u>Analysis of Results:</u> The results of the Workshop were used by the EDD and HyTeP to begin economic opportunity analysis over the summer of 2003. The analysis was directed to develop recommendations in the following areas:

- Future R&D Needs: State and Federal Programs, Technology Validation Projects
- Business Development: Hydrogen Technology Clusters, Recruiting, New Business Start-ups
- Funding: State and Federal Investments, Venture Capital, Other Sources.
- Education and Training: University and Job Training Programs
- Legislation: Incentives, Barrier Elimination

The results of the legislation and the business-development initiatives developed by HyTeP members will form the action agenda for a coordinated, public-private partnership to strengthen the New Mexico economic climate, build the necessary mix of research, development and demonstration projects, and attract and develop a vibrant, growing cluster of companies and facilities commercializing hydrogen and fuel-cell technologies in New Mexico.

Agenda from the Workshop:

HyTeP Strategic Planning Session:
Hydrogen and Fuel Cell
Commercialization Potential in New Mexico

April 23, 2003

La Posada de Santa Fe
Santa Fe, New Mexico

7:00 – 8:00	Registration and Continental Breakfast	
8:00 – 9:00	Vision of a Hydrogen Economy and Fuels Cells: the New Mexico Opportunity	Rick Homans, Cabinet Secretary *New Mexico Economic Development Department* (Conference Moderator)
	<u>Federal</u> Pat Vanderpool, *U.S. Senator Pete Domenici's Office* Jill Halverson, *U.S. Senator Jeff Bingaman's Office* Pedro Sedillo, *U.S. Senator Jeff Bingaman's Office* Rep. Heather Wilson Rep. Tom Udall Rep. Steve Pearce	<u>State of New Mexico</u> Governor Bill Richardson Joanna Prokup, Cabinet Secretary *Energy, Minerals, & Natural Resources Department*
9:00 – 10:30	Education Session: Overview of Hydrogen Economy and Producing Hydrogen	Cathy Gregoire Padro *National Renewable Energy Laboratory*
	Uses of Hydrogen	Douglas Wheeler *UTC Fuel Cells*
10:30 – 10:45	Break	
10:45 – 11:30	Panel on Transportation, Stationary Power, Microelectronics, & Military Applications (*GM, Motorola, UTC Fuel Cell, MTI Micro Fuel Cell, Shell Hydrogen and DARPA)*	Karl Jonietz, Moderator
11:30 – 12:15	Panel on Hydrogen and Fuel Cell R&D and Capabilities in NM (*NMTech, UNM, NMSU, LANL, Sandia, and MesoFuel)*	Craig O'Hare, Moderator
12:15 – 1:30	Banquet Lunch	
	Future of Hydrogen and Fuel Cells in Transportation	Byron McCormick *General Motors*
	Kickoff to Breakout Groups	Rick Homans
1:30-1:45	Move to Breakout Groups	
1:45 – 3:30	**Breakout Groups:**	

Group 1 – Incentives and Barriers – What programs or projects can be implemented to provide incentives to new or relocating hydrogen or fuel-cell businesses? What are the biggest barriers?

Group 2 – Pre-commercial R&D Needs – What existing R&D is needed and most relevant for commercial development?

Group 3 – Supporting Technology Needs – What related or ancillary technologies and capabilities are needed to support the industry? Training, education, manufacturing, etc.?

Group 4 – Technology Validation Projects – What types and locations of demonstration projects can be implemented in NM to increase public awareness and demonstrate application and feasibility of the technology?

Group 5 – NM Business Climate – What do start-up and relocating hydrogen and fuel-cell companies need in NM? How can the business climate be improved for these companies?

3:30 – 3:45	Break	
3:45 – 5:00	Group Presentations (15 min. per group)	Stephen Littlejohn, Moderator
5:00 – 5:30	Wrap-up and next steps	Rick Homans
5:30	Adjourn	

Appendix II: Fuel Cell Matrix

Source: "Opportunities for Creating a Fuel Cell Industry in Ohio," George Stroup, November 2001

Fuel Cell	Electrolyte	Operating Temperature (°C)	Likely Applications
Proton Exchange Membrane (PEMFC)	Sulfuric Acid	50-80	Transportation, stationary & portable power
Solid Oxide (SOFC)	Yttria Stabilized Zirconia	850-1000	Transportation, stationary & portable power
Alkaline (AFC)	Potassium Hydroxide	50-200	Space, transportation
Phosphoric Acid (PAFC)	Phosphoric Acid	190-210	Stationary power generation
Molten Carbonate (MCFC)	Potassium and Lithium Carbonates	630-650	Stationary power generation
Direct Methanol (DMFC)	Sulphonic/Sulphuric Acid	80-120	Transportation & portable power generation
Aluminum/Oxygen (AOFC)	Potassium Hydroxide	60	Transportation, communication

Appendix III: Value Chain Technology Descriptions

Steam Methane Reforming (SMR)

SMR uses methane (CH_4), which is the main constituent of natural gas, as an input. A catalytic process using oxygen gas (O_2) is then used to extract two hydrogen gas molecules ($2H_2$) with a carbon dioxide molecule (CO_2) produced as waste. Although SMR is not a completely clean process, it is better than conventional power generation from the standpoint of noxious emissions. For example, gasoline is a blend of different hydrocarbons (mostly C_8H_{18}), all of which have a lower hydrogen-to-carbon ratio than methane. The high hydrogen-to-carbon ratio of methane (4:1) is more desirable than that of gasoline (9:4) from the standpoint of CO_2 gas byproduct per molecule of hydrogen produced.

Electrolysis

Electrolysis uses electricity to crack water molecules to produce hydrogen and oxygen. This requires significant energy input and is therefore an expensive process. If the energy used to crack the water molecule and compress or liquefy the hydrogen is generated by clean methods (wind, solar, biomass), then electrolysis is an entirely environmentally clean process.

Gasification

Gasification is used to extract the hydrogen from a hydrogen-rich feedstock such as coal, residual oil, or even biomass. Most often, it is referred to as the process used to obtain hydrogen from coal. Coal represents the lowest hydrogen-to-carbon ratio of any fossil fuel (aside from wood), enabling this process to release the largest amount of CO_2 of all hydrocarbon-based hydrogen harvesting processes. There are ways to sequester these gases to make the process more environmentally friendly, but this technology is relatively young and unproven in the marketplace. In addition, the CO_2 must be disposed of once sequestered, which is difficult. Coal is one of the least expensive feedstock possibilities, which makes this process relatively affordable.

Thermochemical

Thermochemical production of hydrogen is much like electrolysis except that heat is used to break the chemical bonds in the water molecule instead of electricity. For electrolysis, the energy stored in the fossil fuel, or radioactive material, is first used to heat water, which turns a turbine to generate electricity. This electricity is then used to make hydrogen via electrolysis. Energy is lost in this process so the potential energy stored in the hydrogen is much lower than what was stored in the original fossil fuel. Thermochemical production of hydrogen skips a step in this process and uses the heat directly to make hydrogen. Therefore, thermochemical production of hydrogen has a heat-to-hydrogen efficiency about 50% higher than electrolysis. Many believe that nuclear energy from existing reactors is a logical heat source for thermochemical production.

Pressurized Storage Tanks

This technology is fraught with shortcomings, but represents the most mature storage technology available today. Most of the fuel-cell bus demonstrations use small, pressurized tanks. Tube trailers are used to transport pressurized hydrogen on a large scale. Because it is the lightest element in the universe, considerable energy is required to compress hydrogen, a process that is costly from an efficiency standpoint. Since the hydrogen is an energy carrier, expending energy for compression lowers the net positive energy stored. This loss is dependent on the pressurization of the stored gas as it intuitively takes more energy to achieve higher pressures. Another technical difficulty is that hydrogen degenerates the physical properties of metal when stored at high pressures, a process called embrittlement. Over time, this will seriously impair the ductility and load-bearing capacity of the tank.[52] Perhaps the most crucial technical limitation of storing hydrogen in tanks is the size of the tank. In order to hold the same amount of energy as a tank of gas in a conventional car, a tank for hydrogen stored as a compressed gas will have to be many times the size of the current gas tank with the actual relative sizes dependent on the pressurization level of the stored gas. To give an idea of the size differential, a gallon of gasoline has the energy equivalent of 3.73 gallons of liquid hydrogen.[53] Liquid hydrogen is considerably denser than gaseous hydrogen, causing that factor to be much higher for tanks that store hydrogen gas.

Liquid
Liquefying hydrogen is by far the cheapest way to transport hydrogen. The difficulty with this process is the cost of liquefaction. Hydrogen liquefies at 20 degrees Kelvin or -253 degrees Celsius or -423 degrees Fahrenheit. Typically, 11 to 12 kilowatt-hours of electricity are needed to produce 1 kilogram of liquid hydrogen, which contains only 33.3 kilowatt-hours of fuel energy.[54] This means that in order to turn hydrogen into a liquid, one must sacrifice approximately one-third of the energy content, which is not an ideal level of efficiency loss.

Hydrides
The use of both chemical and metal hydrides to store hydrogen is a relatively young technology. Conceptually, certain materials are used to chemically bond the hydrogen so that it is no longer in a gaseous or liquid form but part of a solid. This makes it easy to handle and distribute. Also, you avoid the embrittlement and pressurization or liquefaction cost issues of the other technologies.

Nanotechnology
Hydrogen can been stored on a molecular level using carbon nanotubes. This is an infant technology and little is known about its applicability to consumer markets.

Pipeline
Hydrogen gas pipeline infrastructure exists today in the U.S. to service the oil industry in the Houston, Texas area, in Southern California, and near the southern tip of Lake Michigan. Using a pipeline method to distribute hydrogen is well suited to high capacity hydrogen needs, as volume is maximized in this distribution method. It requires very high fixed initial costs and, therefore, high volumes are needed to amortize these upfront costs.

Haul
This distribution method incorporates hauling hydrogen in trucks both as a gas in tube trailers and as a liquid in cryogenic tankers. This is a very established industry; with most of the large industrial hydrogen producers owning their own delivery fleets.

Combustion
The combustion technology exists to burn hydrogen in an ICE allowing every component in an automobile to remain largely the same with the exception of the engine. Ford developed a hydrogen ICE that burns

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[52] Corrosion Doctors, (http://www.corrosion-doctors.org/Forms/embrittlement.htm)
[53] "Hydrogen Supply: Cost Estimate for Hydrogen Pathways – Scoping Analysis," Dale R. Simbeck and Elaine Chang, National Renewable Energy Laboratory, July 2002 (Document ID: NREL/SR-540-32525)
[54] "Flexibly Fueled Storage Tanks Brings Hydrogen-Powered Cars Closer to Reality," Laurie Powers, Science and Technology Review (http://www.llnl.gov/str/June03/Aceves.html)

approximately 99% cleaner than gasoline and offers 25% greater fuel efficiency[55] (excluding distribution costs of hydrogen). Hydrogen ICE's efficiency gain over conventional ICEs is dwarfed by the gains of a fuel-cell automobile, which is 2.5 times as fuel-efficient.[56] Therefore, the hydrogen ICE solution requires large amounts of hydrogen when compared to a fuel-cell vehicle.

Proton Exchange Membrane Fuel Cell (PEMFC)

The PEMFC fuel cell operates at the lowest temperature[57] of all the fuel cells, making it highly popular for transportation applications because it requires less warm-up time. The fuel cell requires pure hydrogen and pressurized air as inputs and generates water, heat, and electricity. Due to its low temperature operation, the PEMFC fuel cell requires a catalyst in order to drive the chemical reaction inside the fuel cell. This catalyst is a precious metal that adds considerably to the fuel cell's cost. The fuel cell requires highly pure hydrogen because the catalyst is susceptible to carbon monoxide and sulfur poisoning. Fuel reformers for PEMFC fuel cells must filter out these contaminants, increasing the cost of the reformer or input hydrogen.

Direct Methanol Fuel Cell (DMFC)

DMFC is a variant of the PEMFC. The inputs are air and methanol (the simplest chemical form of alcohol, stored as a liquid) and the outputs are water, heat, small amounts of carbon dioxide, and electricity. The methanol molecule reacts with water to create protons, electrons, and carbon dioxide inside the fuel cell. Then, the reaction runs the same as it does in PEMFC with the protons and electrons reacting with O_2 to form water. Efficiencies of DMFC are not as high as PEMFC due to inefficiency of the methanol reaction compared to hydrogen. Since DMFC uses a liquid fuel that is easy to handle at room temperature and pressure, it will likely be used in small portable applications, such as cellular phones and laptops.

Alkaline Fuel Cell (AFC)

NASA has used alkaline fuel cells in space missions to produce both electricity and potable water since 1940 and continues to use them today. Carbon dioxide reacts with the electrolyte (KOH or NaOH usually) inside the fuel cell to form a carbonate that will severely decrease the fuel cell's performance. Therefore, this type of fuel cell requires very pure hydrogen and oxygen, making terrestrial applications difficult and expensive for this fuel-cell type. The corrosive electrolyte, which is dangerous to humans, makes this fuel cell unsuited for certain applications

Phosphoric Acid Fuel Cell (PAFC)

PAFC represents the most commercially mature fuel-cell type. United Technologies Corp. has been selling PAFC for stationary applications since 1991. PAFC uses phosphoric acid as its electrolyte and operates at high enough temperatures to tolerate a modest amount of carbon monoxide. Carbon monoxide reacts with the precious metal catalysts of lower temperature fuel cells, causing permanent damage. Higher temperature fuel cells do not require as much precious metal catalyst and are therefore less susceptible to carbon monoxide poisoning. PAFC is still intolerant to sulfur, which will damage the catalyst. This type of fuel cell can operate at 40–50% efficiency compared to the energy stored in the hydrogen fuel. If the waste heat is captured and reused in a cogeneration system, efficiencies can increase to 80%.[58] PAFC requires a warm-up period before electricity begins to flow, precluding it from many applications, such as transportation.

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[55] Vortech Engineering (http://www.vortechsuperchargers.com/news/model_u.html)

[56] "Hydrogen Delivery: An Option to Ease the Transition," John C. Winslow, presentation at The DOE Hydrogen and Fuel Cells Coordination Meeting, June 3, 2003 (http://www.eere.energy.gov/hydrogenandfuelcells/hydrogen/pdfs/winslow_fe_delivery.pdf)

[57] PEMFC are limited to operating temperatures below the boiling point of water, 100 degrees Celsius or 212 degrees Fahrenheit

[58] Smithsonian National Institute of American History (http://fuelcells.si.edu/phos/pafcmain.htm)

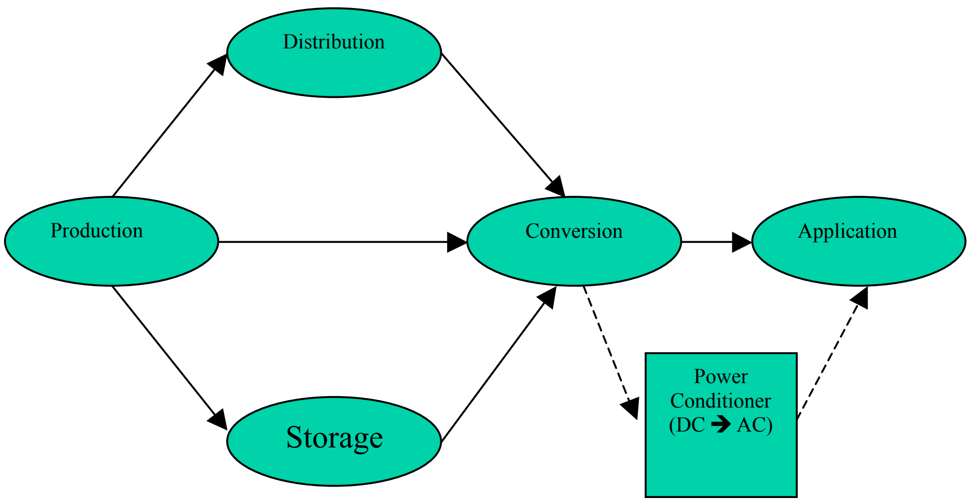
Molten Carbonate Fuel Cell (MCFC)
These fuel cells operate at very high temperatures, allowing them to use a variety of hydrogen containing fuel gases as the hydrogen is split from the fuel gas inside the fuel cell. The high operating temperature also raises its carbon monoxide poisoning tolerance, as described for PAFC. MCFC requires a fuel with hydrogen (but not necessarily pure hydrogen gas), heat, and carbon dioxide as inputs. The carbon dioxide is required because carbonate ions are used up in the chemical reaction inside the fuel cell.[59] Due to its high operating temperature, MCFC lends itself to stationary applications, as this use is generally more tolerant to a long warm-up period. Like AFC, the corrosive electrolyte, which is more corrosive for MCFC than for AFC, makes this fuel cell unsuited for certain applications.

Solid Oxide Fuel Cell (SOFC)
These fuel cells operate at very high temperatures, which allows them to use a variety of hydrogen-containing fuel gases. The high operating temperature also raises the fuel cell's carbon monoxide poisoning tolerance. SOFCs are more durable than MCFCs, as the electrolyte is a solid ceramic rather than a liquid. Like MCFC, the operating temperatures of SOFC lend the fuel cell to stationary applications. This fuel cell can take a tubular, as opposed to planar, shape, which may be an advantage in certain applications.

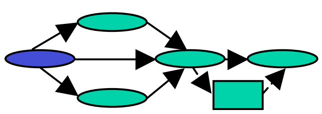
[59] Smithsonian National Institute of American History (http://fuelcells.si.edu/mc/mcfcmain.htm)

Appendix IV: Value Chain – Company Listing

Value System: Macro View



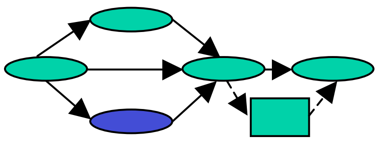
Production Overview



Approaches	Major Player	Trends	Barriers	Suppliers
Thermochemical-Natural Gas Steam Reforming	**Bulk:** Methanex (Methanol), Praxair, Air Products, Air Liquide, Harvest Energy Technologies, Linde, Norsk-Hydro, Shell Hydrogen, Valley National Gases **Low-volume, On-Demand Reformers:** IdaTech, Boeing, Chevron-Texaco Technology Ventures, Genesis, Fueltech, H2Gen, HyRadix, InnovaTek, MesoFuel, Nuvera, Osaka Gas, Tokyo Gas, Ztek, Johnson Matthey, Catalytica, Wellman CJB, GL&V Hydrogen, Hydrogen Systems, Waterflame,Gesellschaft, Chrysler	Oil companies taking increased interest. 95% of US H2 production, 50% of world production. \$0.32/lb if it is consumed on site, \$1.00–\$1.40/lb for delivered liquid hydrogen, and \$1.00–\$2.00/lb for hydrogen produced by electrolysis	Expensive on a per watt basis compared to traditional uses of hydrocarbon fuels. On-Demand reformers need ~30 min warm-up.	**Small Scale Compressors:** Neuman & Esser, PDC, Greenfield, Rix, Hydro-Pac, CompAir, Fluitron **Large Scale Compressors:** Dresser-Rand, Sulzer Burckhardt, Ariel, Neuman & Esser. **Gas Purification:** QuestAir, REB Research & Consulting, Wellman CJB, Parker-Hannifin, Johnson Matthey, Wah Chang Industrial H2 Gas **Purification:** UOP **Separation Membranes:** CHUBU Electric Power Company, UOP, Wah

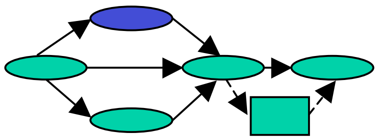
				Chang **Catalyst:** OMG Protonics **Input Gas Supply:** Kinder-Morgan Power Systems
Thermochemical- Partial Oxidation/Ceramic Membrane Reactor	Texaco			
Thermochemical-Autothermal (ATR)	Norsk-Hydro, Nuvera			
Thermochemical-Gasification of Coal	Southern Company, McDermott Technology	Germany, South Africa and the USA presently have large gasification plants, and technology for gasification of coal in thermal power plants is the subject of much R&D by the coal industry.	Twice as expensive as H2 from Natural Gas. The worst pollutant of all hydrocarbons.	
Electrolytic-Water Electrolysis	Norsk-Hydro, Proton Energy Systems, Stuart Energy, Tathacus, Hydro Environmental Resources Inc., Teledyne, Vandenborre Hydrogen Systems (bought by Stuart)	Electricity=80% of cost	Expensive. Produces low pressure gas which needs to be pressurized/liquefied for delivery	
Electrolytic-Reversible Fuel Cells/Electrolyzers	Hamilton-Sundstrand (UTC), Norsk-Hydro,Avalence, Giner, H_2-interpower, Proton Energy Systems, Stuart Energy, Treadwell Corp Gesellschaft, GreenVolt			**Peripherals:** Vanderborre
Renewables-Biomass	Onsite Power Systems (Biomass digestor**),** Thermogenics		Small yields (12-17%)	
Renewables-Solar	RECO, Solar Hydrogen Energy Corporation	Germans and Japanese are world leaders in this area.	40/MMBTU assuming photovoltaic electricity costs of 10 ¢/kWh	**Photovoltaic Cell:** Silicon Solar, BP Solar
Production-Wind	GE Wind, Kenetech, Cannon Power Corp., Shell		Windy areas far from population in general. Technology needs improvement.	**Turbines**: list of suppliers: http://www.awea.org/directory/wtgmfgr.html
Other	Alchemix (Fe+H20->FeO+H2), Membrane Reactor Technologies Ltd (One-step reforming of hydrocarbons)			

Storage Overview



Approaches	Major Player	Trends	Barriers	Suppliers
Pressurized Storage Tanks	Dynetek (Ballard Buses), Lincoln Composites, Quantum Tech, Impco, Raufoss Composites			**Small Scale Compressors:** Neuman & Esser, PDC, Greenfield, Rix, Hydro-Pac, CompAir, Fluitron **Testing:** PowerTech Labs
Metal Hydrides	Energy Conversion Devices, Voller, Ergenics, HERA, Hydrogen Components Inc., Varmaraf ehf, Altergy			**Alloys:** Ergenics, Gesellschaft fur Elektro-metallurgie, Surfect **Compressors:** Ergenics, Hydrogen Compenets Inc., **Interconnects:** Hydrogen Components Inc, **Purifiers:** Hydrogen Components Inc **Refilling stations:** Altergy **Material Coating:** Surfect
Chemical Hydride	Powerball Int. ($NaH+H_2O\rightarrow H_2+NaOH$), Millennium Cell, Safe Hydrogen LLC		Not scalable to large applications, low pressure H2	
Liquid H2	Praxair, Air Products, BOC	Hydrogen liquefaction expensive yielding high production costs but the lowest delivery costs of all proposed delivery methods. Net, this total cost. (NREL/SR-540-32525)	Expensive liquefaction process. Refrigerating (liquefying) hydrogen to -253 degrees Celsius "uses the equivalent of 25% to 40% of energy content	
Carbon Nanotubes				

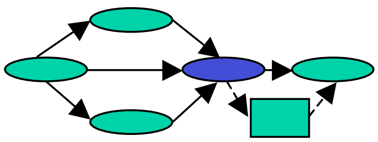
Distribution Overview



Approaches	Major Player	Trends	Barriers	Suppliers
Pipeline	**Large Scale Distributors:** Air Products, Air Liquide, Shell Canada, Praxair, Kinder-Morgan	High capital costs make this the most expensive delivery method. Best suited for High market demand	Odorless, hard to detect leaks. Easily ignited. Lower energy transmission capacity than for natural gas. H2 compression equipment is much higher than that used for natural gas.	**Large Scale Compressors:** Dresser-Rand, Sulzer Burckhardt, Ariel, Neuman & Esser.
Haul-Tube Trailer	Air Products, Air Liquide, Praxair	High costs, slightly less than pipeline cost. Low H2 density limits each load to about 300 kg. Well suited for low market demand. (NREL/SR-540-32525)		
Haul-Liquid	Praxair, Air Products, BOC	Hydrogen liquefaction expensive yielding high production costs but the lowest delivery costs of all proposed delivery methods. Net, this is the lowest total cost. Well suited for medium market demand. (NREL/SR-540-32525)	Expensive liquefaction process, but still 10% the cost of tube trailer. (NREL/SR-540-32525)	
Small Canisters	**Storage Technology**: Impco **Small Scale Compressors:** Neuman & Esser, PDC, Greenfield, Rix, Hydro-Pac, CompAir, Fluitron **Hydrogen Production:** Praxair			
Utilities/Energy Distribution	Avista Corp. (PEMs for residential use), DQE, DTE, Enbridge, IDA, Southern Company (H2 from coal)			

Fueling Stations	Norsk-Hydro, Avalence, Air Products, BC Hydro, FuelMaker, General Hydrogen, Stuart Energy			

Conversion Overview



Approaches	Major Player	Trends	Barriers	Suppliers
Combustion-Gas Turbines	Vandenborre			
Combustion-Reciprocating Engines				
Fuel Cell Hybrids	Ztek Corp, Siemens			
Fuel Cells- Polymer Electrolyte Mebrance (PEM)	Ballard (1kw-250kW), Plug Power (1kW-100kW), UTC, Manhattan Scientifics, Avista Labs, Nuvera, GM, Mitsubishi, Siemens **Minor Players:** Hydrogenics, Proton Energy Systems, Hydrogenics, Teledyne, Voller, Mosaic Energy LLC, ElectroChem, Anuvu Inc., MTU CFC Solutions, ITM Power, Nu, Element, H2 ECOnomy, Altergy, Gesellschaft	50% of weight and 15-30% of FC cost is BPP.		**Tier 1:** **MEA**: Celanese, DuPont, Gore, 3M, ElectroChem, OMG Johnson Matthey, DeNora (E-Tek), H2 ECOnomy **BPP**: DuPont, H2 ECOnomy, Porviar,SGL, Parker, BMC **Testing**: Advanced Measurements, Arbin, Electrochem, ENKAT, Greenlight Power, Hydrogenics, Lynntech, National Instruments, Scribner, H2 ECOnomy, Globetech, Fuel Cell Technologies, **Foils:** SGL **Balance of Plant:** **Heat Mgt:** Porvair (metal foam), Modine, Parker (heat exchangers), MesoScopic Devices **Water Mgt:** Porvair, MesoScopic Devices **Air Mgt:**Vairex **Piping, Fitting, Seals:** Parker **Emission Control:**

				Johnson Matthey **Afterburners:** Johnson Matthey **Filters:** Donaldson **Bubble Humidifier**: ElectroChem **Tier 2:** **Carbon Materials:** Technical Fibre Products, Ucar Graphtech **Membranes**: Celanese, DuPont, Gore, ElectroChem, FuMA-Tech, Hoku Scientific **Membrane/Electrode Seals:** Parker **Gas Diffusion Layer**: SGL, 3M, DeNora (E-Tek) **Electrodes:** ElectroChem, DeNora (E-Tek) **Catalyst:** Johnson-Matthey, Engelhard, ElectroChem AMETEK Specialty Metal Products, BASF, OMG elys, Superior MicroPowders, Porviar, DeNora (E-Tek) **Humidifier Parts:** Parker
Fuel Cells-Direct Methanol (DMFC)	MTI Micro, Manhattan Scientifics, Ballard, DMFCC, Hitachi, Jadoo, Smart Fuel Cell, Ball Aerospace, Giner **Minor Players:** ElectroChem, DTI Energy (JPL licensee, Ballard licensor), Energy Ventures Inc, Medis, NuVant, Gesellschaft	Attractive for portable apps. (ESECS EE-1973 p.34)	High Pt reqs, low power densities, and fuel crossover from anode to cathode restrict use for high power apps. (ESECS EE-1973 p.34). High catalyst loading needed at the anode.	**Tier 1:** **MEA**: Celanese, DuPont, Gore, ElectroChem, OMG Johnson Matthey, DeNora (E-Tek), H2 ECOnomy **Testing**: Advanced Measurements, Arbin, Electrochem, ENKAT, Greenlight Power, Hydrogenics, Lynntech, National Instruments, Scribner, H2 ECOnomy, Globetech, Fuel Cell Technologies, **Foils:** SGL **BPP**: DuPont, H2 ECOnomy,

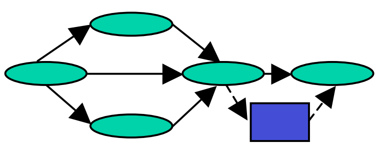
				Porviar,SGL, Parker, BMC **<u>Balance of Plant:</u>** **Heat Mgt:** Porvair (metal foam), Modine, Parker (heat exchangers), MesoScopic Devices **Water Mgt:** Porvair, MesoScopic Devices **Air Mgt:**Vairex **Piping, Fitting , Seals:** Parker **Emission Control:** Johnson Matthey **Afterburners:** Johnson Matthey **Filters:** Donaldson **Tier 2:** **Carbon Materials:** Technical Fibre Products, Ucar Graphtech **Membranes**: Celanese, DuPont, Gore, ElectroChem, FuMA-Tech, Hoku Scientific, PolyFuel **Membrane/Electrode Seals:** Parker **Gas Diffusion Layer**: SGL, DeNora (E-Tek) **Electrodes:** ElectroChem, DeNora (E-Tek) **Tier 3:** Conductive plate treatment: Surfect **Catalyst:** Johnson-Matthey, Engelhard, ElectroChem
Fuel Cells-Alkaline (AFC)	Astris Energi, Apollo Energy Systems, Eneco, UTC, Zetek, Cenergie	Used by NASA (ESECS EE-1973 p.34)	Not very attractive for terrestrial applications due to CO2 sensitivity. (ESECS EE-1973 p.34)	**Tier 1:** **Conductive Plates**: DuPont, H2 ECOnomy, Porviar,SGL, Parker **Testing**: Advanced Measurements, Arbin, Electrochem, ENKAT, Greenlight Power, Hydrogenics, Lynntech, National Instruments, Scribner, H2 ECOnomy,

				Globetech, Fuel Cell Technologies, **<u>Balance of Plant:</u>** **Heat Mgt:** Porvair (metal foam), Modine, Parker (heat exchangers), MesoScopic Devices **Water Mgt:** Porvair, MesoScopic Devices **Air Mgt:**Vairex **Piping, Fitting, Seals:** Parker **Emission Control:** Johnson Matthey **Afterburners:** Johnson Matthey **Filters:** Donaldson **Monitoring/Control:** Alternative Fuel Systems, Fuel Cell Control Ltd **Tier 2:** **Catalyst:** Johnson Matthey
Fuel Cells-Phosphoric Acid (PAFC)	UTC Fuel Cell (UTC and Toshiba), Fuji Electric Corporation, Toshiba Corporation, and Mitsubishi Electric Corporation, ElectroChem	Only commercially available fuel cell, reliable and market tested. Used in applications where backup power is needed due to low power-outage tolerance (i.e., banks). \$4000/kW. Reformer sold with FC as package.	Costs too high to be competitive with current technologies. (ESECS EE-1973 pg. 34). Must be heated before reaction begins. Requires <1.5% CO impurity inputs	**Tier 1:** **Conductive Plates**: DuPont, H2 ECOnomy, Porviar,SGL, Parker **Testing**: Advanced Measurements, Arbin, Electrochem, ENKAT, Greenlight Power, Hydrogenics, Lynntech, National Instruments, Scribner, H2 ECOnomy, Globetech, Fuel Cell Technologies, **Matrix Assembly:** ElectroChem **Electrodes:** ElectroChem **Balance of Plant:** **Heat Mgt:** Porvair (metal foam), Modine, Parker (heat exchangers), MesoScopic Devices **Water Mgt:** Porvair, MesoScopic Devices **Air Mgt:**Vairex **Piping, Fitting, Seals:** Parker

				Emission Control: Johnson Matthey **Afterburners:** Johnson Matthey **Filters:** Donaldson **Tier 2:** **Catalyst:**Johnson Matthey
Fuel Cells-Molten Carbonate (MCFC)	Fuel Cell Energy, Ansaldo Fuel Cells, CHUBU Electric Power Co., GenCell (make cond. Plates and interconnects as well), MC Power, Motoren-Und-Turbinenen (MTU), Brandstofel Nederland, Deutsche Aerospace AG, Hitachi, Ishikawajima Harima Heavy Industries, and Mitsubishi Electric Corporation, MTU CFC Solutions	Best suited for large power plants due to warm up time. (ESECS EE-1973 p. 34)		**Tier 1:** **Conductive Plates**: **Testing**: Advanced Measurements, Arbin, Electrochem, ENKAT, Greenlight Power, Hydrogenics, Lynntech, National Instruments, Scribner, H2 ECOnomy, Globetech, Fuel Cell Technologies, **Balance of Plant:** **Heat Mgt:** Porvair (metal foam), Modine, Parker (heat exchangers), MesoScopic Devices **Water Mgt:** Porvair, MesoScopic Devices **Air Mgt:**Vairex **Piping, Fitting , Seals:** Parker **Emission Control:** Johnson Matthey **Afterburners:** Johnson Matthey **Filters:** Donaldson **Tier 2:** **Catalyst:** Johnson Matthey
Fuel Cells-Solid Oxide (SOFC)	Siemens, Global Thermo, Allied Signal Aerospace Company, Ceramatec, Inc., Technology Management, Inc., Ztek, Inc, Adaptive Materials, Delphi, GE (bought Honeywell ip), McDermott/Ceramatec, Rolls-Royce, Altair, Ceres Power <u>Minor Players:</u> CellTech Power, Acumentrics, CeresPower, CHUBU, Ceramic Fuel Cells**,** EBZ Gmbh, Franklin Fuel	Best suited for large stationary applications.	Price.	**Tier 1:** **Membranes:** Altair Nanotechnologies **Catalyst:** Altair Nanotechnologies **Gas Purification:** QuestAir **Electrolyte:** NexTech Materials, Altair Nanotechnologies, Fuel Cell Materials **Testing**: Advanced Measurements, Arbin, Electrochem, ENKAT, Greenlight Power, Hydrogenics,

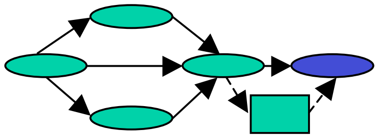
	Cells, Fuel Cell Technologies ltd., Sulzer, TechSys Inc., ITN Energy Systems			Lynntech, National Instruments, Scribner, H2 ECOnomy, Globetech, Fuel Cell Technologies, **Balance of Plant:** **Heat Mgt:** Porvair (metal foam), Modine, Parker (heat exchangers), MesoScopic Devices **Water Mgt:** Porvair, MesoScopic Devices **Air Mgt:** Vairex **Piping, Fitting, Seals:** Parker **Emission Control:** Johnson Matthey **Afterburners:** Johnson Matthey **Filters:** Donaldson
Fuel Cells-Other	Medis (DLFC), **Regenerative:** Energy Conversion Devices, Hydrogenics, Proton Energy Systems, Giner		Little government R&D support	

_Power Conditioner Overview



Approaches	**Major Player**	**Trends**	**Barriers**	**Suppliers**
Power Conditions	SatCon (Inverpower), Ballard, Magnetek, Xantrex DC-DC: H2 ECOnomy, ABB DC-AC: Abacus Controls, ABB			
Power Conditions-Sensors	Agilent Technologies, City Technology. DCH Technology, fuelcell-sensor.com, Fuel Cell Safety Systems, GE Syprotec, H2scan LLC (formerly DCH), Intelligent Optical Systems, Macurco Gas Detection, RKI Instruments, Sensitor, Synkera Technologies			

Applications Overview



Approaches	Major Player	Trends	Barriers	Suppliers
Portable-Microportable	Toshiba, Hitachi, Motorola, Manhattan Scientifics, Medis, MTI MicroFuel Cells, Casio, Ball Aerospace Minor Players: Neah Power Systems		Cost, Durability, System Miniaturization, Fuel Packaging, Incompatibility of Output (Water) with Electronic Devices	
Portable-Medium Portable	Jadoo, Ball Aerospace			
Stationary	**Premium Power:** UTC, FCE, Avista Labs **Stationary Power:** UTC, FCE, Avista Labs, Giner		Cost, Durability, Fuel Infrastructure, Hydrogen storage	**Gas Purification:** QuestAir **Air Mgt:**Vairex **Fuel Processing:** Chevron-Texaco Technology Ventures, HyRadix, HydrogenSource **Capacitors:** Maxwell Technologies **Power Converters:** Xantrex
Military			Durability, Fuel Infrastructure, Hydrogen storage	
Transportation	Automakers: GM, Honda, Toyota, Daimler-Benz, BMW **Minor Players:** Anuvu, Esoro AG, Hino Motors Ltd., Other vehicles (scooters, fork lifts, etc): Vectrix	Bus demos	Cost, Durability, Fuel Infrastructure, Hydrogen storage. Long start-up times (target=30 seconds)	**Fuel Storage**: Impco, Texaco Ovonic Hydrogen Systems **Safety/Sensors**: Impco, Boeing **Fuel Cells**: Nuvera, Mitsubishi, Ballard **Fuel Processing**: Nuvera, Catalytica, HydrogenSource **Graphite Plates**: GrafTech International Ltd. **Heat Management**: Modine **Gas Purification:** QuestAir **Air Mgt:**Vairex **Electric Drive Trains:** Enova, Ballard Power Systems **Catalyst:** BASF

System Integration	**Major Players:** Anuvu Inc, Aperion Energy Ltd., Fuel Cell Technologies, Ballard, Hydrogenics, H2-Interpower, IdaTech, ISE Research, Mosaic Energy, ITM Power, ReGentech **Minor Players:** Third Orbit Power Systems			

Other: Investors

Major Players: DQE (9% of Satcon), DCH, DTE Energy (23% of PLUG), Enbridge (Cdn $25 in Global Thermo), New Energy Partners (long list of VCs)
Trends: Hedging

Other: Safety Services

Major Players: Air Products, BlazeTech , FuelCellStore.com, Hydrogen Safety LLC, ioMosaic, REB Research and Consulting, TISE

Appendix V: Science and Technology Assets in New Mexico

Los Alamos National Laboratory

Los Alamos National Laboratory (LANL) has one of the oldest and largest fuel-cell R&D programs in the country. Located in the Materials Science Division, this program has been active for over 27 years and has a portfolio of 25 active patents of which 16 are currently licensed. In the early 1980s LANL scientists pioneered polymer electrolyte membrane (PEM) fuel cells focusing on reducing the amount of precious metal catalysts while improving efficiency. The entire fuel-cell program is currently funded at $8 million per year and has totaled more than $50 million over the past 10 years. The diverse research team consists of 10 Ph.D. scientists in disciplines including materials science and engineering, mechanical engineering, chemistry, theoretical physics, electrochemistry, and chemical engineering. Unique capabilities available to scientists include:

- Advanced Fuel Processor Diagnostics
- Fuel Processor-Stack Durability Testing
- Stack Environmental Testing
- Direct Catalyst Imaging
- Hydrogen Purification

The technical capabilities housed at the Laboratory will continue to mature as a result of the 2003 President's budget calls for the establishment of a Fuel Cell National Resource Center at Los Alamos. This new Center will provide a national focus and an integrated approach to addressing technical barriers to PEM fuel cell commercialization. This center will considerably enhance collaborative R&D efforts with private companies and facilitate commercialization. Los Alamos also expects to develop a new program in hydrogen storage technology.

Ongoing projects

- Electrodes for Reformate-Air Fuel Cells
- Development of New High-Temperature Membranes
- Stack Durability - Hydrogen, Real (not synthetic) Reformate, Air-Borne Impurity Effects
- Reformate Clean-Up – Technology Transfer
- Fuel Constituent Effects on Hydrogen Generation
- Solid-State Sensors for Fuel Cell Applications
- Direct Methanol Fuel Cell R&D
- Diesel Reforming for SOFC APU Applications
- Methanol Steam Reforming for Portable Power Applications
- Technical Assistance to Developers (at DOE direction)
- Small Hydrogen Fuel Cells for Battery Replacement

Applications

- Portable Power (battery replacement)
- Residential (distributed power)
- Transportation
- Military/Space
- Utilities

Sandia National Laboratories

Sandia possesses a slightly smaller fuel-cell program with an annual budget of $6 million. The core team consists of 15 researchers, the majority of whom are Ph.D.s with degrees in chemistry, chemical engineering, economics, and physics. Scientists have active projects in the following areas:

- Micro Fuel Cells and Reformers
- Bio Fuel Cells
- H2 Science and Technology
- H2 Systems Engineering
- Renewable Energy Sources
- Nuclear Energy
- Combustion Research
- Novel Separations Technologies

In hydrogen production Sandia has projects in nuclear (thermochemical cycles), renewable sources of hydrogen, reformers, catalyst development and testing, and gas separation (membranes). In hydrogen infrastructure Sandia's program in safety and surety is a growth area. In hydrogen storage Sandia is the world leader in metal hydride synthesis and testing. In utilization of hydrogen, Sandia has a variety of programs in fuel-cell systems and is a leader in systems integration, sensors, and IC engine technology. A strong capability in dynamic modeling and simulation underlies all programs at Sandia.

Sandia also has a strong industrial collaboration and commercialization program ranging from basic to applied to production technology. This program includes relationships with industrial partners in the form of cooperative R&D agreements (CRADAs) to expedite transfer of novel technology to the marketplace. Sandia also participates in another program with New Mexico Tech to support a Graduate Fellowship Program in fuel-cell research. The classes are taught at NM Tech while Fellows conduct their thesis research at Sandia National Laboratories.

White Sands Test Facility

The Lyndon B. Johnson White Sands Test Facility (WSTF) is supported by NASA and has been actively involved in resolving hydrogen safety issues in the U.S. Space Program for over 25 years. Their areas of expertise include the following:

- Standards Development – WSTF has been involved in the development of National and International Standards for hydrogen the past 10 years;
- Training – WSTF is the lead center for the training of NASA personnel in the safe use of hydrogen. Courses have been developed for the design of systems and for operators and system operators;
- Hazard Analysis – WSTF has developed a rigorous hazards analysis protocol to look systematically at the hazards involved in hydrogen systems;
- Hazard Analysis – WSTF has developed a rigorous hazards analysis protocol to look systematically at the hazards involved in hydrogen systems;
- Technology Transfer; and
- Testing in the following areas:
    - Materials testing
    - High energy blast testing
    - Combustion testing
    - High gas flow testing
    - Liquid pumping testing

WSTF is recognized for several notable achievements the fields of safety and standards during its history:

- ISO Standard 15916 "Basic Concern for Hydrogen Safety"
- NASA NSS 1740.16 "Safety Standard for Hydrogen and Hydrogen System"
- AIAA G-095-2003 "Guide for Safety of Hydrogen and Hydrogen System"
- Support of National Hydrogen Association (NHA) standards development activities
- Hydrogen Design and Safety Course
- Hydrogen Handlers and Safety Course
- 1998—Developed hazard analysis protocol
- Performed hazard analysis for the following:
  - EPA National Vehicle and Fuel Emissions Laboratory hydrogen fueling station siting support
  - NASA International Space Station, Advanced Launch Systems, Helios, and Facility Siting Issues
  - Large Scale Hydrogen and Oxygen Explosion program to support siting for accident scenarios
  - GASL hydrogen incident investigation.

New Mexico Institute of Mining and Technology

The fuel-cell research and education programs at NM Tech reside in the Chemical Engineering and Materials Engineering Departments. The core team of 4 PhDs, assisted by a number of graduate and undergraduate students, pursues research in the following areas:

- catalytic membranes for hydrogen production;
- electrochemical processes in fuel cells and membrane electrode assembly (MEA) performance;
- purification processes;
- solid-oxide fuel-cell ceramic thin film deposition techniques;
- catalytic layer deposition methods;
- thin-film deposition;
- chemical and ionic transport processes in membranes;
- plasma deposition of "nafion-like" thin films; and
- mass and heat transfer.

Supporting these research programs are the following facilities and assets:

- Proton Exchange Membrane and Fuel Cell Stack Testing Stand
- Thin Film Conductivity Test Facility (temperature and %rh control)
- Hot Press for PEMFC MEA fabrication
- Complete LabView instrumentation and expertise for continuous MEA evaluation
- Surface Characterization: SEM w/ XED, AFM, FTIR-ATR, profilometer, etc.
- Membrane Permeability Apparatus (both pure and mixed gas/vapor transport)

As noted above NM Tech has partnered with Sandia to develop a fuel-cell graduate fellowship program and would like to expand the program to include Los Alamos. The curriculum under development is to include the following specializations and majors:

- PEM performance section in senior chemical engineering laboratory section
- Fuel Cell Technology option or minor as part of Mat Eng or Chem Eng degree program (to be offered)
- Mobile PEM fuel-cell test stand taken as demonstration to junior and senior high schools around the state

New Mexico State University and WERC

WERC, a Consortium for the Environmental Education and Technology Development, was established in 1990 through a cooperative agreement with the U.S. DOE. Partner institutions include New Mexico State University (WERC headquarters), the University of New Mexico, New Mexico Institute of Mining and Technology, and Dine College, in collaboration with Los Alamos and Sandia National Laboratories.

WERC's initiatives in fuel cell, related technologies, and supporting activities are captured under the formation of the Center for Energy, Environment and Economics at New Mexico State University. The Center includes the following:

- Fuel Cell Laboratory—Targeted completion date 2004. The laboratory will be the foundation for the education, research, and development efforts in the fuel-cell development program.
- Water Quality Laboratory—This operational laboratory is a joint effort with the Civil Engineering Department
- Biomass Laboratory—This operational laboratory is a joint effort with Civil Engineering and College of Agriculture. Additional capabilities are targeted for completion by 2004.
- Education and public outreach
- Fuel-Cell Fundamentals was offered Fall 2003, 3 credit hours
- Numerical Modeling and Analysis

Additional capabilities at NMSU are located in various departments and institutes:

- Chemical Engineering—Energy Storage and Delivery
- Mechanical Engineering—Advanced Interconnection Laboratory
- Chemistry—Catalyst and Conversion Research
- Southwest Technical Development Institute—Fuel Alternatives
- Biology—Pathogen Survival in Animal Waste
- College of Agriculture—Biomass for Energy Production Research

Another activity of WERC is the Distributed Energy Systems for Energy and Sustainability. This research initiative is a collaborative effort between the U.S. DOE's National Border Technology Partnership Program, LANL, University of Texas at El Paso, U.S./MX Materials Corridor Initiative, Border Health Commission, and Centro de Investigacion en Materiales Avanzados in Ciudad Chihuahua, Chihuahua, Mexico.

Undergraduate Courses:

WERC and designated engineering faculty members will build on the existing undergraduate courses currently being taught and will develop new or modify existing courses so that students can earn a WERC certificate or a minor in fuel-cell technology in either Chemical Engineering or Mechanical Engineering.

The current courses being offered in Mechanical Engineering that support this initiative include applied thermodynamics, heat transfer, introduction to automation and control system design, polymers, and product development. Courses currently being offered in Chemical Engineering include chemical engineering thermodynamics, engineering materials, air pollution monitoring, chemical kinetics and reactor engineering, and advanced chemical process simulation.

In addition to the above courses, two new undergraduate courses are being developed. The courses will be listed as WERC courses and will be jointly listed in Mechanical Engineering and Chemical Engineering. The courses, and a brief description of their content, follow:

- Fuel Cell Fundamentals
  - Fuel-cell system design and operation. Electrochemistry, fuel reforming, cell degradation, electrodes, and electrolytes

- Fuel Cell Design Laboratory
  - Students will be required to address a fuel-cell design problem. Solution of the problem will require applications of thermal science, kinetics, electrochemistry and numerical modeling.

As the program matures, additional courses will be developed and offered. These courses will be developed in close cooperation with our industrial and national laboratory advisors.

Graduate Courses:

WERC and designated engineering faculty members who are members of the graduate faculty will build on the existing graduate courses currently being taught and will develop new or modify existing courses so that students can earn a WERC certificate or specialize in fuel-cell technology at the Master of Science degree or at the Doctor of Philosophy level in either Chemical Engineering or Mechanical Engineering.

The current graduate level courses being taught in Mechanical Engineering that support this effort include advanced composite materials, product development, computer aided design, control of mechanical systems, conduction and convection heat transfer, environmental management seminar, engineering analysis, and advanced computational methods. Graduate level courses currently being taught in Chemical Engineering that support the effort include advanced chemical process simulation, intermediate thermodynamics and transport properties, air pollution modeling, and advanced topics in applied mathematics.

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In addition to the graduate level courses that complement the fuel-cell technology program, two new graduate level courses will be developed. The courses will be listed as WERC courses and will be jointly listed in Mechanical Engineering and Chemical Engineering. The courses and a brief description of their content follows:

- Alternative and Renewable Energy
  - Basic principles, design, and operation of alternative and renewable energy sources. Included will be solar, wind, biomass, and biogas. Topics will include power generation, energy storage, and use of renewable fuels for transportation and stationary power generation.

- Advanced Fuel Cell Systems
    - Continuation of the undergraduate fuel-cell fundamentals course. An advanced fuel-cell system will be analyzed and designed.

Students interested in numerical modeling will have the opportunity to enroll in existing courses in either department and concentrate on fuel-cell modeling. The graduate student research efforts will be conducted in either the Fuel Cell Laboratory or the students' respective departments.

University of New Mexico

The research and education programs at UNM are based in the Department of Chemical and Nuclear Engineering. Their core research team consists of 5 staff (PhD, MS, and BS), 3 post docs, 15 graduate students and 10 undergraduates, involved in research in the following areas:

- Development of non-platinum electrocatalysts for PEMFC and DMFC;
- Spray pyrolysis routes for electrocatalyst synthesis;
- Bioelectrocatalysis and biofuel cells;
- Biomimetic approaches for fuel-cell materials' synthesis;
- Nano-structured materials for micro-fuel-cell applications (power-on-a-chip);
- Enabling technologies based on nano-structured functionalized materials;
- Super-hydrophobic coatings and nano-porous materials;
- Reforming catalysis and catalysts for hydrogen generation;
- Micro-reformers for portable fuel cells;
- Fuel cells as system components for space applications;
- Heat transfer effects on system design and integration of fuel cells;
- Surface composition of complex materials;
- Structure and functionality of composites;
- Development of SOFC materials;
- Ceramics interconnects durability and corrosion;
- Functional and stimuli-responsive polymers;
- Nanostructured smart materials with active transport characteristics;
- Bio-gas and microbial hydrogen generation;
- Biomimetic nanostructured materials for power sources applications;
- Plasma torch synthesis of catalysts;
- Cost-effective routes for nano-tube synthesis;
- Inorganic membranes for hydrogen separation;
- Spray-pyrolysis synthesis of inorganic nano-composites.

UNM has several joint appointments with Sandia and LANL researchers serving as professors in the department.

Appendix VI: Companies by Geographic Region

ALABAMA	
CFD Research Corporation (Huntsville) PEI Electronics (Huntsville)	Southern Company (Birmingham)
ALASKA	
Solar Hydrogen Systems, Inc. (Anchorage)	
ARIZONA	
American Hydrogen Association (Mesa) Architekton (Tempe) Intertec Southwest, Inc. (Tucson) Materials & Electrochemical Research Corporation (Tucson)	Motorola, Inc. (Tempe) Refrac Systems (Chandler) Rhombic Corporation (Phoenix) TTT, Inc. (Tucson)
CALIFORNIA	
Advance: Solar, Hydro, Wind Power Company (Calpella) Advanced Material Sciences, Inc. (Pasadena) AeroVironment, Inc. (Monrovia) AESC, Inc. (Carlsbad) Alternative Energy Systems Consulting, Inc. (Carlsbad) American Association for Fuel Cells (Daly City) AMREL/American Reliance (Arcadia) Anuvu Incorporated (Sacramento) ARCADIS Geraghty & Miller, Inc. (Fullerton) Asia Pacific Fuel Cell Technologies, Ltd. (Anaheim) BAT International (Chula Vista) Bechtel Corporation (San Fransisco) Bourns College of Enginnering -Bourns College of Engineering - Center for Enviromental (Riverside) C2i, Ltd. (Aptos) California Air Resources Board (Sacramento) California Energy Commission (Sacramento) California Fuel Cell Partnership (West Sacramento) California Hydrogen Business Council (Los Alamitos) CALSTART (Pasadena) Catalytica Energy Systems (Mountain View) Circle Seal Controls Division Circor International (Corona) City of Chula Vista (Chula Vista) Coval Partners (Desert Hot Spring) Down Stream Systems, Inc.(Folsom) EHG Technology, LLC (Los Angeles) Electric Power Research Institute (Palo Alto) Electric Vehicle Information Services (Moraga) Enova Systems (Torrance) Fluor Daniel (Aliso Viejo) Fuel Cell Buyers Consortium (Los Angeles) Fuel Cell Infrastructure, Inc. (Carmicheal) FuelSell Technologies (San Fransisco) Fusion Dynamicsm Inc. (Lemon Grove) GE EER Corporation (Irvine) GE Energy & Environmental Research Corporation (Irvine) General Atomics (San Diego) General Motors - Advanced Technology Vehicles (Torrance) Glacier Bay, Inc. (Oakland)	Independent Energy Partners (Englewood) ISE Research Corporation (San Diego) Jet Propulsion Laboratory (Pasadena) John B. O'Sullivan, Consultant (Mountain View) John Nimmons & Associates, Inc. (Mill Valley) L-3 Communications/Power Paragon, Inc. (Anaheim) Lawerence Berkeley National Laboratory (Berkeley) Lawrence Livermore National Laboratory (Livermore) Mazda R&D of North America, Inc. (Irvine) Mechanology, LLC (Palo Alto) Merit Academy (Soquel) Meruit, Inc. (Santa Monica) Metallic Power, Inc. (Carlsbad) National Fuel Cell Education Program (Tustin) National Fuel Cell Research Center (Irvine) Nexant, Inc. (San Fransisco) Panasonic Technologies, Inc. (Cupertino) PFG Energy Capital (Pasadena) Polyfuel, Inc. (Menlo Park) Power Correction Systems, Inc. (Los Angeles) Power Point International (San Jose) Powerzinc Electric, Inc. (City of Industry) Procyon Power Systems, Inc. (Alameda) QUANTUM Fuel Systems Technologies Worldwide, Inc. (Irvine) RealEnergy, Inc. (Sacramento) RIX Industries (Benicia) Sacramento Municipal Utility District (Sacramento) San Diego Miramar College (San Diego) Saratoga Technology Associates (Saratoga) SolarEn International Corporation (Glendale) South Coast Air Quality Management District (Diamond Bar) Southern California Edison (Rosemead) Southern California Gas (Los Angeles) Stuart Energy USA (Van Nuys) SunLine Services Group (Thousand Palms) Symyx Technologies, Inc. (Santa Clara) Technip USA Corporation (San Dimas) Telaire (Goleta) Toray Carbon Fibers America (Santa Ana) University of California, Davis (Davis)

Global Fuel Cell Corporation (Chula Vista) H2 Solutions Inc. (Holloster) H2 ECOnomy (Glendale) Harvest Energy Technology, Inc. (Sun Valley) Honda R&D Americas, Inc. (Torrance) Honeywell (Torrance) Humbolt State University Foundation (Arcata) Hydrogen Ventures, LLC (Santa Monica) HyGen Industries, LLC (Marina Del Rey) IMPCO Technologies, Inc. (Irvine)	University of California, Irvine (Irvine) University of California, White Mountain Research Station (Bishop) Valley Environmental Associates (Yorba Linda) W.J. Schafer Associates (Livermore) Wesgo Metals (San Carlos) XCELLSIS Corporation (Poway)
COLORADO	
Ball Aerospace & Technologies Corporation (Boulder) BekkTech LLC (Loveland) Blue Star Sustainable Technologies Corporation (Arvada) Colorado School of Mines (Golden) Comer & Associates, LLC (Boulder) Draeger Safety (Durango) ESOURCE (Boulder) Energy Alliance Group (Boulder) Fuelcell Propulsion Institute (Denver) FuelCellStore.com (Boulder) Institute of Ecolonomics (Ridgeway) ITN Energy Systems, Inc. (Littleton) J.F. Hurlbut Company (Golden) JFH Distributing (Golden)	Merrick & Company (Denver) National Renewable Energy Laboratory (Golden) NextGen Power Systems (Greenwood Village) NextWave Energy, Inc. (Denver) Protonetics International Inc. (Golden) PureVision Technology, Inc. (Fort Lupton) Rentech, Inc. (Denver) Rocky Mountain Institute (Snowmass) TDA Research (Wheat Ridge) UQM Technologies (Golden) Vairex Corporation (Boulder) Webcom Communications (Greenwood Village) Woodward Industrial Controls (Fort Collins)
CONNECTICUT	
Bloomy Controls Inc. (Windsor) Delker Corporation (Branford) Design By Analysis, Inc. (New Britain) Digatron/Firing Circuits (Norwalk) Exmet Corporation (Naugatuck) Farmington Engineering (Madison) Fuel Cell Design & Development (Newington) Fuel Cell Technologies, Inc. (New Milford) FuelCell Energy, Inc. (Danbury) GenCell Corporation (Southbury) Habco, Inc (Glastonbury) HydrogenSource (South Windsor) Jet Process Corporation (New Haven) Loctite (Rocky Hill)	Maricle Consulting, LLC (Glastonbury) Praxair, Inc. (Danbury) Proton Energy Systems, Inc. (Rocky Hill) Rhodia Electronics & Catalysis (Shelton) RJS Associates, Inc. (Hartford) Robert Sanderson & Associates (Wethersfield) Sure Power Corporation (Danbury) Teleflex Fluid Systems, Inc. (Suffield) Ulbrich Stainless Steels & Special Metals, Inc. (North Haven) United Technologies Research Center (East Hartford) University of Connectict (Storrs) Updike, Kelly & Spellacy, P.C. (Hartford) UTC Fuel Cells (South Windsor)
DELAWARE	
C. G. Processing, Inc.(Rockland) DuPont Fluoroproducts (Wilmington) Ion Power, Inc. (Bear)	Rath Performance Fibers (Wilmington) APEX Piping Systems, Inc. (Newport)
DISTRICT OF COLUMBIA	
American Council for an Energy-Efficient Economy American Gas Association Breakthrough Technologies Institute DaimlerChrysler North American Direct Fuelcell Group Distributed Power Coalition of America Electric Vehicle Association of the Americas Energy Resources International, Inc. Fuel Cell Institute Fuel Cells 2000 FuelCell Energy, Inc. (Government Affairs) Georgetown University Global Environment Facility	havePOWER, LLC Methanol Institute National Hydrogen Association Propane Education & Research Council Renewable Fuels Association SAE International Technology Transition Corporation U.S. Fuel Cell Council United States Department of Energy (Office of Advanced Automotive Technologies) United States Department of Energy (Office of Energy Efficiency and Renewable Energy) United States Department of Energy (Office of

	Transportation Technologies) United States Department of Transportation
FLORIDA	
APTEC Corporation (Ormond Beach) AquaLux Corporation (Clearwater) Bruderly Engineering Associates, Inc. (Gainesville) Concept Communiques, Inc. (Fort Lauderdale) Dais-Analytic Corporation (Odessa) DynEco Corporation (Rockledge) Electric Auto Corporation (Fort Lauderdale) FCP Associates (Boynton Beach) Fisher Electric Technology, Inc. (St. Petersburg) Florida Solar Energy Center (Cocoa)	Global Business Solutions International (Plantation) Hall Company (Cape Coral) Jansen Controls (Stuart) Motorfuelers, Inc. (Clearwater) Saminco, Inc. (Fort Myers) Shaw Aero Devices (Naples) Technetics (Deland) University of Florida (Gainesville) University of Miami (Coral Gables) U.S. Global, LLC (Hillsboro)
GEORGIA	
Burns & McDonnell (Atlanta) ChemEnergy, Inc. (Chamblee) Emprise Corporation (Marietta) Flint Energies (Warner Robins)	Fuel Cell Resources, Inc. (Atlanta) LOGANEnergy Corp. (Roswell) MicroCoating Technologies, Inc. (Atlanta) Thermal Ceramics, Inc. (Augusta)
HAWAII	
Hoku Scientific (Honolulu) Hydrogen Fuel Cell Institute (Lahaina)	University of Hawaii at Manoa (Honolulu)
IDAHO	
Idaho National Engineering & Environmental Laboratory (Idaho Falls)	
ILLINOIS	
Argonne National Laboratory (Argonne) Avery Dennison (Niles) Chicago Bridge & Iron Company N.V. (Plainfield) Chicago Transit Authority (Chicago) Coleman Powermate (Aurora) Energy & International Development, Inc. (Chicago) Gas Technology Institute (Des Plains) General Motors - Electro-Motive Division (La Grange) GRI (Chicago) HyRadix (Des Plaines) Illinois Institute of Technology (Chicago) Intercon Research (Lincolnwood) Invest in France Agency (Chicago)	Misra, Inc. (Wheaton) Mosaic Energy, LLC (Des Plaines) Northwestern University (Evanston) Nuveen Investments (Chicago) Parkview Metal Products (Chicago) Product Concepts Ltd. (Sleepy Hollow) Swift Enterprises, Ltd. (West Lafayette) Technologix Corporation (Naperville) Tenneco Automotive (Lake Foresy) Underwriters Laboratories, Inc. (Northbrook) United States Army Construction Engineering Research Labs (Champaign) Wangtec, Inc. (Woodbridge)
INDIANA	
Citizen Gas & Coke Utility (Indianapolis) Downstream Alternatives, Inc. (South Bend)	NiSource (Merrillville) Purdue University (West Lafayette)
IOWA	
Iowa State University (Ames)	
KANSAS	
High Plains Corporation (Wichita) Propane Resources (Shawnee Mission)	TVN Systems, Inc. (Lawrence) University of Kansas (Lawrence)
KENTUCKY	
Sud-Chemie, Inc. (Louisville)	United Catalysts, Inc. (Louisville)
LOUISIANA	
Southern States Power (Shreveport)	
MARYLAND	
Aperion Energy Systems (Jefferson City) D&R International, Ltd. (Silver Spring) EA Engineering, Science & Technology (Hunt Valley) National Joint Apprenticeship & Training Committee (Upper Marlboro) Parsons Corporation (Gaithersburg)	Sentech, Inc. (Bethesda) Teledyne Energy Systems, Inc. (Hunt Valley) United States Army Research Laboratory (Adelphi) W.L. Gore & Associates, Inc. (Elkton)
MAINE	

Hydrogen Energy Center (Cape Elizabeth)	
MASSACHUSETTS	
Alfa Aesar (Ward Hill) Aspen Technology, Inc. (Cambridge) Ballard Material Products (Lowell) Beacon Power Corporation (Wilmington) Cabot Corporation (Billerica) Cape Cod Research (East Falmouth) ElectroChem, Inc. (Woburn) EnGen Group, Inc. (Boston) Environmental Futures, Inc. (Boston) E-TEK (Ashland) Exergy, Inc. (Hanson) Extrication.Com, LLC (Plymouth) Film Microelectronics, Inc. (North Andover) Foster-Miller, Inc. (Waltham) Fucellco, Inc. (Boston) Full Circle Energy Project, Inc. (Wilbraham) The Gillette Company (Needham) Giner, Inc. & Giner Electrochemical Systems, LLC (Newton) Hyperion Catalysis (Cambridge) ICET, Inc. (Norwood) Industrial Ecology Consultants (Newton) Ionics, Inc. (Watertown) Ion-Optics, Inc. (Waltham) Iwaki Walchem Corporation (Holliston) Magmotor (Worcester)	Massachusetts Institute of Technology (Cambridge) Massachusetts Technology Collaborative (Westborough) Mechanology, LLC (Attleboro) National Coating Corporation (Rockland) New Energy Solutions, Inc. (Pittsfield) Northeast Advanced Vehicle Consortium (Boston) Northeastern University (Boston) Nuvera Fuel Cells (Cambridge) Phoenix Innovation, Inc. (West Wareham) Photofabrication Engineering, Inc. (Milford) Precix, Inc. (New Bedford) Protonex Technology Corporations (Marlboro) Safe Hydrogen LLC (Lexington) SatCon Technology Corporation (Cambridge) Schaefer, Inc. (Ashland) Solectria Corporation (Wilmington) Spectracorp (Lawrence) Texas Instruments Automotive Sensors (Attleboro) TIAX, LLC (Cambridge) Venture Development Corporation (Natick) Walter Juda Associates, Inc (Medford) Worcester Polytechnic Institute (Worcester) Wyman-Gordon (North Gafton) ZTEK Corporation (Woburn)
MICHIGAN	
3-Dimensional Services (Rochester Hills) Bulk Molding Compounds, Inc. (Southfield) CHEMAC (Sterling Height) Convergence, LLC (Howell) DaimlerChrysler (Madison Height) Dana Corporation (Rochester Hills) Delphi Automotive Systems (Flint) DENSO International America, Inc. (Southfield) Dow Corning Corporation (Midland) Eaton Corporation Innovation Center (Southfield) Ecostar Electric Powertrain & Power Conversion Systems (Dearborn) Energy Conversion Devices, Inc. (Troy) Ford Motor Company (Dearborn) Freudenberg-NOK General Partnership (Plymouth) Fuel Cell Safety Systems (Grandville) Futuristic Design International Corporation (Troy) Gast Manufacturing (Benton Harbor)	International Business Development Services, LLC (Southfield) Isuzu Motors America, Inc. (Plymouth) National Automotive Center (Warren) NextEnergyZone (Lansing) OMG Corporation (Auburn Hills) PowerQuest Partners, LP (Bloomfield Hills) Quantum Composites, Inc. (Bay City) REB Research & Consulting (Ferndale) Ricardo, Inc. (Belleville) SPX/Valley Forge Technical Information Services (Allen Park) T/J Technologies, Inc. (Ann Arbor) Toyota Technical Center USA, Inc. (Ann Arbor) Transportation Design & Manufacturing Company (Lavonia) U.S. Council for Automotive Research (Southfield) Universal Parametrics (Ann Arbor) University of Michigan (Ann Arbor)
MINNESOTA	
3M Fuel Cell Components (St. Paul) Donaldson Company, Inc. (Minneapolis) Dyneon, LLC - A 3M Company (Oakdale) Imperial Custom Molding (Rodgers)	R4 Energy, Inc. (White Bear Lake) TESCOM Corporation (Elk River) TSI Incorporated (Shoreview)
MISSISSIPPI	
University of Southern Mississippi (Hattiesburg)	
MISSOURI	
Aperion Energy Systems (Jefferson City) FP&C Consultants, Inc. (Kansas City)	Therminol Heat Transfer Fluids (St. Louis) University of Missouri - Rolla (Rolla)

Intoximeters, Inc. (St. Louis) Sigma-Aldrich Fine Chemicals (St. Louis)	Utilicorp United (Kansas City) Zoltek Corporation (St. Louis
MONTANA	
Big Sky Economic Development Authority (Billings)	Center for Applied Economic Research (Billings)
NEBRASKA	
Tenaska, Inc. (Omaha)	
NORTH CAROLINA	
Duke Energy (Charlotte) Greenhouse Gas Technology Center (Research Triangle Park) JMC (USA), Inc. (Research Triangle Park)	Penn Compression Moulding, Inc. (Garner) Porvair Fuel Cell Technology (Hendersonville) Scribner Associates, Inc. (Southern Pines)
NEVADA	
Desert Research Institute (Reno)	Hydro Environment Resources Corporation (Las Vegas)
NEW HAMPSHIRE	
FuelCell-info Publishing Incorporated (Nashua) Lydall Filtration Separation Inc. (Rochester)	Perros & Associates (Amherst) Youtility, Inc. (Hudson)
NEW JERSEY	
Abacus Controls (Somerville) Asbury Carbons (Asbury) Ausimont (Thorofare) BOC Gases - Americas (Murray Hill) Conti Enterprises, Inc. (South Plainfield) De Nora North America, Inc. (Somerset) Dynaload Division of TDI (Randolph) Ergenics, Inc. (Ringwood) Institute of Electrical & Electronics Engineers, Inc. (Piscataway) Johnson Matthey (West Deptford) Johnson Matthey Catalysts & Chemicals (West Deptford) Krupp VDM Technologies Corporation (Florham Park) McBride Energy Services Co., LLC (Edison) Metcon Industries (Mount Laurel) M.E. Watanabe Consulting, Inc. (Patterson)	Mihama Corporation (Cliffside Park) Millennium Cell (Eatontown) Nanodyne, Inc. (New Brunswick) New Jersey Department of Transportation (Trenton) NUI Ventures (Union) Parsons Brinckerhoff, Inc. (Newark) Patrick Grimes Associates (Scotch Plains) Perma Pure, Inc. (Toms River) Princeton University (Princeton) Rutgers University (Piscataway) Sensor Products, Inc. (East Hanover) Ticona (Summit) Tosoh Ceramics Division (Bound Brook) Transistor Devices, Inc. (Randolph)
NEW MEXICO	
Energy Related Devices (Los Alamos) Los Alamos National Laboratory (Los Alamos) Manhattan Scientifics, Inc. (Los Alamos) MesoFuel, Inc. (Albuquerque)	Sandia National Laboratory (Albuquerque) Superior MicroPowders (Albuquerque) TPL, Inc. (Albuquerque)
NEW YORK	
Advanced Refractory Technologies, Inc. (Buffalo) Albany NanoTech (Albany) Allied Business Intelligence (Oyster Bay) Blasch Precision Ceramics (Albany) Brookhaven National Laboratory (Upton) Burnham Polymeric (Glen Falls) Cogeneration Systems of L.I. (Hicksville) Cooper Industries (Olean) Corning, Inc. (Corning) Environmental Advocates (Albany) Fox & Fowle Architects (New York) Fuel Cell Components & Integrators, Inc. (Hauppauge) Fuel Cell Industry Report (New York) GE Fuel Cell Systems (Schenectady) GE MicroGen (Latham) General Motors Global Research & Development (Honeoye Falls) Harbec Plastics, Inc. (Ontario)	KeySpan Energy (Hicksville) Main-Care Energy (Waterford) Mechanical Technology, Inc. (Albany) Medis Technologies, Ltd. (New York) Mitsubishi Heavy Industries America, Inc. (New York) Mitsui & Co. (USA), Inc. (New York) MTI Micro Fuel Cells (Albany) National Military Academy (Kings Point) New York Power Authority (White Plains) New York State Energy Research & Development Authority (Albany) Nextek Power Systems, Inc. (Ronkonkoma) Niagara Mohawk Energy, Inc. (Syracuse) Niagara Mohawk Power Corporation (Syracuse) Nissho Iwai American Corporation (New York) Piller, Inc. (Middletown) Plug Power, Inc. (Latham) Scientific American: Fuel Cell Industry Report Newsletter

Hofstra University (Hempstead) Hydrogen & Fuel Cell Letter (Rhinecliff) Institute for Fuel Cell Science & Technology (Albany)	(New York) Tyco Electronics M/A-COM (Buffalo) Viewpoint Systems (Rochester) Zircar Zirconia, Inc. (Florida)
NORTH CAROLINA	
Duke Energy (Charlotte) Greenhouse Gas Technology Center (Research Triangle Park) JMC (USA), Inc. (Research Triangle Park)	Penn Compression Moulding, Inc. (Garner) Porvair Fuel Cell Technology (Hendersonville) Scribner Associates, Inc. (Southern Pines)
OHIO	
Advanced Elastomer Systems, L.P. (Akron) AMETEK Rotron Technical and Industrial Products (Kent) Battelle (Columbus) Brewer-Garrett Company (Middleburg Heights) Case Western Reserve University (Cleveland) Cinergy Technology, Inc. (Cincinnati) CSA America, Inc. (Cleveland) Dana Commercial Credit (Toledo) Die-Matic Corporation (Brooklyn Heights) Edison Materials Technology Center (Dayton) Graftech, Inc. (Cleveland) IGR Enterprises, Inc. (Beachwood) McAfee & Associates (Pepper Pike) McDermott Technology, Inc. (Alliance)	Michael A. Cobb & Company (Akron) NexTech Materials, Ltd. (Worthington) Ohio Department of Development - Technology Division (Columbus) Parker Hannifin Corporation (Mentor) PME Energy, Ltd. (Maumee) Premix, Inc./Quantum Composites (North Kingsville) Sensotec, Inc. (Columbus) Shepherd Chemical Company (Cincinnati) Swagelok Company (Solon) Technology Management, Inc. (Cleveland) The American Ceramic Society (Watersville) UCAR Carbon Company, Inc. (Cleveland) University of Cincinnati (Cincinnati) Wellman Friction Products (Medina)
OKLAHOMA	
Badger Meter Research Control Valves (Tulsa) Fuel Cell Power Systems, Inc. (Tulsa)	Syntroleum Corporation (Tulsa)
OREGON	
Bonneville Power Administration (Portland) IdaTech (Bend)	Portland General Electric (Portland)
PENNSYLVANIA	
Air Products & Chemicals, Inc. (Allentown) Alfa Laval, Inc. (Warminister) Allegheny Power (Greensburg) Allegheny Technologies Inc. (ATI) (Pittsburgh) ATOFINA Chemicals, Inc. (Philadelphia) Concurrent Technologies Corporation (Johnstown) Energy Signature Associates, Inc. (Pittsburgh) Foamex International (Eddystone) FuelCell Corporation of America (Large) Gerard Daniel Worldwide (Hanover) Hobbs & Towne, Inc. (Valley Forge) JLG Industries (McConnellsburg) Johnson Matthey Fuel Cells (Wayne Johnson Matthey Fuel Cells Gas Processing Technology (West Chester) Metropolitan-Edison Sustainable Energy Fund - A Fund of Berks County Community Foundation (Reading) Morgan Advanced Materials & Technology (St. Marys)	Motors & Controls International (Hazelton) Pdc Machines, Inc. (Warminster) Pennsylvania State University (University Park) Power Conversion Technologies, Inc. (Harmony) Pressure Products Industries, Inc. (Warminster) SGL Carbon Corporation - SGL Carbon, LLC (Short Hills) SiemensWestinghouse Power Corporation (Pittsburgh) Silicon Power Corporation (Frackville) SKF USA, Inc. (Norristown) Snap-tite Components Inc. - Solenoid Valve Division (Erie) SOCA (Pittsburg) Solid Oxide Fuel Cell Commercialization Association (Pittsburgh) Solution Technology (Mendenhall) United States Department of the Navy (Philadelphia) University of Pennsylvania (Philadelphia)
RHODE ISLAND	
Alternate Energy Corporation (Cumberland) Technical Materials, Inc (Lincoln)	Thames & Kosmos (Newport)
TENNESSEE	
Bethlehem Advanced Materials Corporation (Knoxville) EPRI PEAC Corporation (Knoxville) JE/Sverdrup Technology, Inc. (Tullahoma)	Oak Ridge National Laboratory (Oak Ridge) Tennessee Valley Authority (Chattanooga) Vanderbilt University (Nashville)
TEXAS	

Arbin Instruments (College Station) BCS Technology, Inc. (Bryan) Dyna-Therm Corporation (Houston) Exeltech (Fort Worth) Fuel Cells Texas (Austin) Garland Power & Light (Nevada) Houston Advanced Research Center (The Woodland) Howe-Baker Engineers, Ltd. (Tyler) Hunt International Energy Services, LC (Houston) Intellimotive Systems (Austin) Lynntech, Inc. (College Station) Poco Graphite, Inc. (Decatur)	Reliant Energy Power Systems, Inc. (Houston) Rice University (Houston) SAIC Assurance Engineering Services Group (Houston) Shah Smith & Associates (Houston) Shell Hydrogen (Houston) Southwest Research Institute (San Antonio) Stewart & Stevenson Services, Inc. (Houston) Texaco Energy Systems, Inc. (Houston) Texas A&M University (College Station) Texas Fuel Cell Partnership (Austin) Texas Propane Gas Association (Austin) Tyco Electronics Power Systems (Mesquite)
VIRGINIA	
Ball Aerospace & Technologies Corporation (Arlington) Directed Technologies, Inc. (Arlington) Electrical Equipment Company (Richmond) Energia, Ltd. (Alexandria) Energy Co-Opportunity (Herndon) H2Gen Innovations, Inc. (Alexandria) ICRC Energy, Inc. (Alexandria) Kausar, Inc. (Annandale) National Evaluation Service, Inc. (Falls Church)	National Rural Electric Cooperative Association (Arlington) Navy Office of Installations & Environment (Arlington) Newport News Shipbuilding (Newport News) Rolls-Royce North America, Inc. (Chantilly) Schrader-Bridgeporrt International, Inc. (Altavista) Technology & Market Solutions, LLC (Fairfax Station) Virginia Polytechnic Institute & State University (Blacksburg) W. Alton Jones Foundation (Charlottesville) Winrock International (Arlington)
WASHINGTON	
Avista Labs, Inc. (Spokane) CryoFuel Systems, Inc. (Monroe) H2fuel, LLC (Spokane) Information Technologies, Inc. (Spokane) InnovaTek, Inc. (Richland) King County Fuel Cell Demonstration Project (Seattle) Logan Industries, Inc. (Spokane) MarkeTech International, Inc. (Port Townsend)	Northern Technologies, Inc. (Liberty Lake) Pacific Aerospace & Electronics, Inc. (Wenatchee) Pacific Energy Ventures, LLC (Seattle) Pacific Northwest National Laboratory (Richland) Permagas, Inc. (Lake Stevens) Spokane Intercollegiate Research & Technology Institute (Spokane) Toray Composites (American), Inc (Tacoma) University of Washington (Seattle
WEST VIRGINIA	
National Energy Technology Laboratory (Morgantown)	
UTAH	
Ceramatec, Inc. (Salt Lake City) Materials & Systems Research, Inc. (Salt Lake City) PacifiCorp (Salt Lake City) Powerball Technologies, LLC (West Valley City) SOFCo (Salt Lake City)	Thiokol Corporation (Brigham City) University of Utah (Salt Lake City) Utah State University (Logan) VIA-TEK, Inc. (Brigham City)

Appendix VII: Entrepreneurial Support Programs

Technology Venture Corporation (TVC)
TVC was founded by Lockheed Martin as a non-profit, 501(c)(3) tax-exempt corporation to commercialize technologies and to create jobs. TVC identifies technologies with commercial potential, coordinates the development of business and management capabilities and seeks sources of capital investment for businesses. TVC also assists defense-dependent enterprises with commercializing technologies. TVC is not a funding institution, but a bridge between technology and investment. TVC offers services to both investors and entrepreneurs. Technology Ventures Corporation does not charge for its services.

Kauffman Proposal
The University of New Mexico in Albuquerque and other U.S. universities will vie for as much as $5 million each in grants from the Missouri-based Ewing Marion Kauffman Foundation, which works to improve entrepreneurship education. The foundation will award the grants to between five and seven universities in December. The Kauffman Foundation picked 15 universities in June from 30 schools it had asked to develop preliminary concepts to compete in the Kauffman Campuses initiative. Each of the 15 universities picked received a $50,000 planning grant to help develop a comprehensive proposal for presentation in December, 2003.

The Experimental Program to Stimulate Competitive Research (EPSCoR)
EPSCoR is a joint program of the National Science Foundation (NSF) and several U.S. states and territories. EPSCoR operates on the principle that aiding researchers and institutions in securing Federal R&D funding will develop a state's research infrastructure and advance economic growth. New Mexico entered EPSCoR in FY 2001. In addition to NSF EPSCoR, New Mexico participates in the EPSCoR or EPSCoR-like programs of the DoD, the DOE, the EPA, and the National Institutes of Health, New Mexico institutions participating in NSF EPSCoR include the University of New Mexico, New Mexico State University, New Mexico Institute of Mining and Technology, Western New Mexico University, Eastern New Mexico University, and New Mexico Highlands University. The Los Alamos and Sandia National Laboratories are also represented on the New Mexico EPSCoR Committee.

Regional Development Corporation (RDC)
The RDC is a private, non-profit economic development organization, established in 1996, as a Section 3161 Community Reuse Organization. Funded by the U.S. DOE, the RDC is the successor organization to the Defense Adjustment Task Force, established in 1994 to mitigate the economic impact of Los Alamos National Laboratory's 1994–95 downsizing. Through collaborative partnerships, the RDC furthers regional economic development policy and economic diversification by facilitating the development of sustainable commercial activities that maximize utilization of DOE resources, support on-going DOE missions, expand non-government opportunities, and add long-term value to the regional economy. The RDC's vision is to foster a sustainable economically diverse region through collaboration and communication, achieving such objectives as developing a highly trained workforce, building a comprehensive infrastructure that supports business development and workforce retention, and encouraging proactive community leadership.

Space Alliance Technology Outreach Program (SATOP)
SATOP is a cooperative program between the states of Florida, New Mexico, New York, and Texas. SATOP is a free service designed to provide engineering assistance and speed the transfer of space technology to the private sector. By giving free technological assistance to small businesses, SATOP helps

them solve their challenges and increase their chances of succeeding. The goal of SATOP is to help small businesses apply the technical expertise derived from the U.S. Space Program. Made up of an alliance group of 30 space industries, universities, colleges, and NASA centers (Johnson Space Center, Texas; Kennedy Space Center, Florida; and White Sands Test Facility, New Mexico), SATOP finds professionals within these companies who volunteer their time and expertise to solve the challenges brought forth by the inquiring businesses.

State Investment Council (SIC)

SIC is a non-cabinet level agency reporting to the governor. SIC was established by an act of the 23rd Legislature, which was approved on March 28, 1957 and subsequently ratified by a constitutional amendment adopted by the citizens of New Mexico in the general election of 1958. According to the terms of the legislation, responsibility for the investment of the Land Grant Permanent Fund (LGPF) was transferred to the State Investment Officer subject to the policy direction of the SIC. SIC was assigned the responsibility for managing the Severance Tax Permanent Fund (STPF) in 1983. In 1991 the Legislature authorized the SIC to provide investment management services for other state agencies. The 1997 legislature further expanded this client authorization to include all political subdivisions of New Mexico and the New Mexico Finance Authority.

Invest New Mexico

New Mexico is committed to helping businesses by providing many options for funding and incentives to relocate or expand businesses. Recently, Governor Bill Richardson created the Governor's Finance Council, which consolidates all financial state agencies and offices under one umbrella creating a one-stop-shop for businesses seeking financing. Managed by the state's Economic Development Department, this new entity is authorized to offer more than $1 billion to fund businesses and local governments for the purpose of creating high-wage jobs. Another goal of Invest New Mexico is to increase the number of public and private partnerships in the state.

Next Generation Economy, Inc. (NextGen)

A collaboration between the public and private sectors, Next Generation Economy, Inc. (NextGen) helps Metro New Mexico establish its unique position in the changing global economy. Utilizing the region's unique assets, NextGen seeks to diversify the regional economy, keep the region competitive, increase the number of quality jobs and reduce the dependence on the federal government within the state. Specifically, it works to maximize the growth of technology clusters by

- analyzing specific needs and strengths of each cluster;
- identifying cross-cutting issues among clusters; and
- initiating efforts to address these needs and issues.

Appendix VIII: New Mexico Renewable Energy Incentives

Mainstay Energy Rewards Program—Green Tag Purchase Program

Mainstay Energy is a private company offering customers who install, or have installed, renewable energy systems the opportunity to sell the green tags (also known as renewable energy credits, or RECs) associated with the energy generated by these systems. These green tags will be brought to market as Green-e™ certified products. Through the Mainstay Energy Rewards Program, participating customers receive regular, recurring payments. The amount of the payments depends on the type of renewable energy technology, the production of electricity by that system, and the length of the contract period. Mainstay offers 3-, 5-, and 10-year purchase contracts. The longer the contract period, the greater the incentive payment on a cost per kilowatt-hour basis.

Renewable Energy Production Tax Credit

Enacted in 2002, and amended in 2003, the New Mexico Renewable Energy Production Tax Credit provides a tax credit against the corporate income tax of one cent per kilowatt-hour for companies that generate electricity from wind, solar, or biomass. The credit is applicable only to the first 400,000 megawatt-hours of electricity in each of 10 consecutive years. To qualify, an energy generator must use a zero-emissions generation technology and have capacity of at least 10 megawatts.

ConservationSmart from Xcel EnergySM—Windsource®

ConservationSmart from Xcel EnergySM supports the Windsource® program in Colorado, Minnesota and New Mexico. All residential, commercial, and industrial electric customers are invited to participate in this program which supports grid-connected wind turbines. Residential customers can sign up for one year periods and buy wind energy at $3.00/month for 100 kWh blocks; commercial customers can sign up for three year periods and either choose the "Leader" plan, buying all their energy from renewable resources, or the "Supporter" plan, buying in blocks similar to residential customers.

El Paso Electric Company—Renewable Energy Tariff

El Paso Electric's Renewable Energy Tariff Program enables its customers in Texas and New Mexico to support the development of wind energy resources through the purchase of one or more 100-kWh blocks sold at premiums that vary by customer class. Premiums vary by state. In Texas, residential customers pay $1.92 per 100-kWh block per month; commercial customers pay $3.04 per 100-kWh block per month; and transmission level 1 customers pay $5.61 per 100-kWh block per month. In New Mexico, residential customers pay $3.19 per 100-kWh block per month; commercial customers pay $2.69 per 100-kWh block per month; and transmission level 1 customers pay $3.05 per 100-kWh block per month. By signing up to purchase blocks, customers are committed to a one-year program subscription. The power will be generated at the El Paso Electric Hueco Mountain Wind Ranch located near the Hueco Mountains, east of Horizon City, Texas.

New Mexico Million Solar Roofs Partnership

The New Mexico Million Solar Roofs Initiative is led by the Energy Conservation and Management Division of the New Mexico Energy, Minerals and Natural Resources Department. The goal is to install 600 solar systems by the year 2010.

Interconnection Standards

Distributed generation (DG) and renewables interconnection in New Mexico is governed by New Mexico Public Regulation Commission (PRC) Rule 570, for large PURPA class systems, and Rule 571, for small cogeneration and renewable systems up to 10 kW. Rule 571, which was established September 1999, specifies the net metering provisions for small systems and provides guidance on interconnection. The rule also includes a standard interconnection agreement. Systems must comply with all local and national standards (National Electrical Code, Institute of Electrical and Electronic Engineers, and Underwriters Laboratories), and must also meet any additional requirements that a utility files and the PRC approves.

Line Extension

Due to New Mexico Public Utility Commission Case Number 2476, electric utilities in the state are required to provide information on alternative energy systems to remote customers with less than a 25-kW load who request line extensions. This requirement applies when the cost of the requested line extension is greater than 15 times the estimated annual revenue from the line extension. In such cases, utilities must provide customers with information on suppliers of alternative energy systems.

Mandatory Utility Green Power Option

On December 17, 2002, the New Mexico Public Regulation Commission (NMPRC) unanimously approved an expansive new renewable energy rule. The rule requires investor owned utilities and electric cooperatives to offer a voluntary renewable energy tariff (green pricing program) for those customers who want the option to purchase additional renewable energy. These utilities must also develop an educational program to communicate the benefits and availability of their voluntary renewable energy programs. The renewable energy tariffs must be filed with the NMPRC by the end of August 2003. The rule also requires public utility companies to produce 5% of all energy they generate for New Mexico customers from solar, wind, hydropower, biomass, or geothermal sources by 2006. Generation from renewables must increase by at least 1% per year until the renewable portfolio standard (RPS) of 10% is attained in the year 2011.

Net Metering

On September 30, 1999, the NMPRC issued a rule requiring all utilities regulated by the NMPRC to offer net metering for cogeneration facilities and small power producers with systems of 10 kW or less. Municipal utilities are exempt because they are not regulated by the NMPRC. There is no statewide cap on the number of systems eligible for net metering.

Renewables Portfolio Standard

On December 17, 2002, the New Mexico Public Regulation Commission unanimously approved an expansive new renewable energy rule requiring public utility companies to produce 5% of all energy they generate for New Mexico customers from solar, wind, hydropower, biomass, or geothermal sources by 2006. Generation from renewables must increase by at least 1% per year until the portfolio standard (RPS) of 10% is attained in the year 2011.

Solar Rights Act of 1978

New Mexico's Solar Rights Act of 1978, like those in many other states, allows property owners to create solar easements for the purpose of protecting and maintaining proper access to sunlight. The New Mexico Energy Conservation and Management Division reports that three to five solar easements are granted each year. The Solar Rights Act also includes provisions allowing local governments to create their own ordinances or zoning rules pertaining to the protection of solar rights.

Appendix IX: Other State Initiatives

California	
Supplier Incentives	Emerging Renewables Buydown Program—Fuel cells operating on renewable fuels are eligible for a state-funded rebate; can receive up to $1,000 for the Honda hybrid electrical vehicles and up to $3,000 for vehicles powered by natural gas.
	Energy Financing Industrial Development Bond Program—Offers below-market loans to manufacturing companies that will use the land for the purchase and installation of renewable energy systems (including fuels cells); $30M in funding available.
Buyer Incentives	Solar or Wind Energy System Credit—Provides personal and corporate income tax credit for the purchase and installation of solar energy systems. Efficient Vehicle Incentive—Provides rebate at the time of purchase of vehicle using alternative fuel.
University Involvement	UC Davis and UCLA receiving state money for fuel-cell program.
	Toyota has delivered first six fuel-cell vehicles to UC Davis and UC Irvine for research. Toyota has provided more than $2 million to the University of California for research in advanced transportation systems, including fuel-cell vehicles, since 1997. National Fuel Cell Research Center at the University of California Irvine—Offers master of science (M.S.) and doctoral (Ph.D.) degrees in fuel-cell studies.
Organized Partnerships	California Fuel Cell Partnership—A collaboration of auto companies, fuel providers, fuel-cell technology companies and government agencies that is demonstrating fuel-cell electric vehicles and exploring an alternate fuel infrastructure.
	California Fuel Cell Stationary Collaborative—Joint initiative of federal, state and non-governmental organizations interested in the acceleration of stationary fuel-cell commercialization.
	California Hydrogen Business Council—Non-profit organization focused on developing business partnerships in the hydrogen area.
	California Clean Fuel Infrastructure Program—Provides cost-share funds to assist public agencies to establish alternative fuel dispensing facility projects in California.
General Grant Programs	Zero Emission Vehicle Incentive Program—Provides grants to individuals, public agencies, nonprofit organizations and private businesses for the purchase of zero emission vehicles; maximum of $5,000 per vehicle.
	Energy Innovations Small Grant Program—Provides up to $75,000 to small business, nonprofits, individuals and academic institutions to conduct research that establishes the feasibility of innovation energy concepts, including fuel cells.
	California Public Interest Research Program (PIER)—Five to ten percent of $6.5M budget is allocated for stationary fuel-cell activities.
Funds Available for Initiatives	
Demo Sites	Shell Hydrogen is involved in hydrogen demonstration projects in California. Demonstrations are conducted by industry.
	50,000 square foot state-of-the-art testing and demonstration facility in West Sacramento.

Connecticut	
Supplier Incentives	Local Option for Property Tax—Allows municipalities the option of offering property tax exemptions for certain renewable energy systems (including fuel cells); amount varies.
Buyer Incentives	Sales Tax Exemption—The purchase of new vehicles that are exclusively powered by natural gas, LPG, hydrogen or electricity as well as the storage, use or other consumption of such a vehicle, are exempt from sales tax until July 1, 2004.

Fuel Cell Center	Connecticut Global Fuel Cell Center—Partnership between University of Connecticut, The Connecticut Clean Energy Fund and Connecticut industry
University Involvement	University of Connecticut's school of engineering houses the Connecticut Global Fuel Cell Center.
Organized Partnerships	Connecticut Innovations—Manages Connecticut participation
Clean Energy Fund.	The Connecticut Clean Energy Fund (CT CEF) was established in January 2000 to invest in enterprises and other initiatives that promote and develop sustainable markets for energy from renewables and fuel cells that will benefit the ratepayers of Connecticut.
Funds Available for Initiatives	Funds used to stimulate the state's clean energy industry come from a surcharge on Connecticut ratepayers' utility bills. The fund is expected to aggregate to over $100 million in 5 years.
Demo Sites	Clean Energy Fund recently solicited a Request for Proposals for commercial fuel-cell demonstration projects.
Hawaii	
Supplier Incentives	High Technology Business Investment Credit—Any taxpayer making a high-technology business investment is eligible for a 100% tax credit.
Buyer Incentives	Income Tax Deduction—The state provides income tax deductions of $2,000 to $50,000 for the installation of clean-fuel refueling property as provided in the Energy Policy Act of 1992.
Fuel Cell Technology Centers/Technology Park	Hydrogen Power Park—Three-phase project with the goal of taking to market hydrogen-based fuel cells. Began build out in November 2002.
University Involvement	University of Hawaii is a partner of the Hawaii Energy and Environmental Technology Initiative. The Hawaii Natural Energy Institute is located at the University of Hawaii. Along with The Naval Research Laboratory, it established the Hawaii Energy and Environmental Technology Initiative.
Organized Partnerships	Hawaii Natural Energy Institute (HNEI)—At the University of Hawaii in partnership with the Naval Research Laboratory. Established to seek new forms of energy to alleviate the nation's dependence on fossil fuels.
	Hawaii Energy and Environmental Technology Initiative—Initiated in July 2001, addresses the development and testing of advanced fuel-cell systems including fuels processing, and the characterization and development of sea-floor based methane hydrates. The initiative is funded through the Office of Naval Research and managed by the Hawaii Natural Energy Institute.
General Grant Programs	In Process?
Funds Available for Initiatives	
Demo Sites	Hydrogen Fuel Cell Test Facility—A 4,000 sq ft facility that was dedicated in April 2003 and is now operational. The test facility currently houses three test stands designed to characterize full-size, single-cell proton exchange membrane (PEM) fuel cells, and a host of supporting equipment including on-site hydrogen generation and storage. The Institute is seeking other commercial and public sector partners to participate in this program.
	Would like to form a consortium that would favor Hawaii as a test site.[60]
Massachusetts	
Supplier Incentives	Local Property Tax Exemption—Hydropower facilities are exempt from local property tax for a period of 20 years from the date of completion of the facility if construction commences after January 1, 1979.

[60] "State Launches Drive for Fuel-Cell Money," *Pacific Business News*, June 2, 2003

	Green Building Initiative—Provides competitive awards to fund the planning and construction of renewable technologies in all types of green buildings.
Buyer Incentives	Alternative Energy and Energy Conservation Patent Exemption—Offers both corporate and personal income tax deductions for any income received from the sale of or royalty income from a patent that is deemed beneficial for energy conservation or alternative energy development.
University Involvement	Fuel Cell Program at Massachusetts Institute of Technology (MIT)
	Renewable Energy Research Laboratory—Located within University of Massachusetts and exists to promote education and research in renewable energy technologies.
	Renewable Energy Trust is in the process of developing a university consortium to provide R&D and a skilled workforce in the area.
Organized Partnerships	The Renewable Energy Trust—Created in 1998 as a component of efforts to restructure the electric utility industry and to promote the development of renewable energy in the Massachusetts. The trust has launched a fuel-cell initiative whose primary objective is to promote the use of commercially available fuel cells in applications that require high reliability and/or power quality. Total funding is more than $3.5M.
General Grant Programs	Fuel Cell Feasibility Grant—Provides up to $150,000 per project, on a cost-shared basis, to examine the feasibility of using fuel cells to provide high quality power at various sites in Massachusetts.
	Premium Power Installation Grant—This grant will provide financial assistance, up to twenty-five percent of the total capital costs of a premium power system to a maximum of $2,000,000 per project, in the purchase and installation of fuel cells as part of systems to provide high quality power at various sites in Massachusetts. Funding is available only for capital cost, not technical services related to feasibility studies. A total of $5,000,000 is available through this grant.
Funds Available for Initiative	Between 1999 and 2003, the fund is expected to collect roughly $150 million through a charge to all customers at a rate of $6 per year.
Demo Sites	MIT developed cars for demonstrations of alternative fuel-cell vehicles.
Michigan	
Supplier Incentives	NextEnergy Tax Incentives—Exemptions from the SBT and personal property tax for companies, whose primary focus is alternative energy R&D or manufacturing.
Buyer Incentives	Sales Tax Exemption—Includes an exemption from the sales and use tax of any purchases of stationary and vehicular devices using alternative energy technologies.
Fuel Cell Technology Centers/Technology Park	Research and Technology Park—This urban Detroit location has been designated an Alternative Energy Renaissance Zone by the City of Detroit and offers a 20-year state and local tax exemption for companies that locate and perform AET research, development, and manufacturing.
	NextEnergy Center—A 40,000 square-foot facility affiliated with the Wayne State University's Technology Park in Detroit. The facility's power grid will include the use of fuel cells, advanced combustion engines, clean burning Sterling engines, as well as photovoltaics and advanced solar systems.
University Involvement	NextEnergy is within Wayne State University.
	Other universities in Michigan participate in fuel-cell demonstration projects.
Organized Partnerships	NextEnergy—Announced in April 2002 by Governor Engler, NextEnergy is a comprehensive set of actions and incentives designed to position Michigan as the world's leading center for alternative energy technology, research and development, education and manufacturing. Technologies for both mobile and stationary applications using renewable and distributed energy solutions will be supported; $50M in funds.
	Michigan NextEnergy Zone – a 700-acre, state-owned site being designated a tax-free Renaissance Zone. NextEnergy will build the NextEnergy Center in the Wayne State University
	National Alternative Energy Program –a type of Underwriters Laboratory
	NextEnergy Leadership Council

General Grant Programs	Energy Efficiency Grant—Offers grants to support energy efficiency projects, including fuel-cell installations.
	Michigan Biomass Energy Program Grants—Provides funding for state bioenergy and biofuel projects maximum of $50,000 per project.
Funds Available for Initiatives	NextEnergy, Michigan's alternative energy research, development and education program received a $2M earmark in the fiscal year 2003 Energy and Water appropriations bill signed by President Bush last month. This is in addition to the $50M in funds for NextEnergy.
Demo Sites	Henry Ford Community College in Dearborn and the MTEC facility at Macomb Community College in Warren were also selected as demonstration sites for fuel-cell technology.
	The NextEnergy Center will also house a laboratory, conference room, product demonstration area, office space and exhibition area.
New York	
Supplier Incentives	Solar and Wind Energy Systems Exemption—Provides a 15-year property tax exemption for solar and wind energy systems constructed in New York.
Buyer Incentives	Green Building Tax Credit—Tax credits for owners and tenants of eligible building and tenant spaces, which meet certain "green" standards.
	New York Alternative-Fuel Vehicle Tax—Provides tax credits and a tax exemption for people who purchase alternative fuel vehicles.
University Involvement	New York State Energy Research and Development Authority has partnered with Syracuse University to improve energy efficiency on campus.
Organized Partnerships	New York State Energy Research and Development Authority (NYSERDA)- a public benefit corporation created in 1975 by the New York State Legislature.
	NYSERDA administers the New York Energy $mart^{SM} program, which is designed to support certain public benefit programs during the transition to a more competitive electricity market. Since 1990, NYSERDA has successfully developed and brought into use more than 125 innovative, energy-efficient, and environmentally beneficial products, processes, and services. Some 2,700 projects in more than 30 programs are funded by a charge on the electricity transmitted and distributed by the state's investor-owned utilities. Additional research dollars come from limited corporate funds.
General Grant Program	Power Systems, Distributed Generation and CHP Grants—NYSERA has $10M in funding to support the following categories: demonstration of DG/CHP systems at industrial/institutional/commercial/residential facilities, feasibility studies, technology transfer studies, and product development.
	Renewables R&D Grant Program—Assists companies in the development, testing, and commercialization of renewable energy technologies that will be manufactured in New York.
	New York State Clean Cities Challenge—Awards fund up to 75% of the proposed project including the incremental cost of purchasing alternative fuel vehicles.
Funds Available for Initiative	Contributions to the state's economic growth and environmental protection are made at a cost of about $0.70 per New York resident per year.
Demo Sites	Supports demonstration projects.
Ohio	
Supplier Incentives	Conversion Facilities Property Tax Exemption—Exempts certain equipment from property taxation, Ohio's sales tax and use tax and Ohio's franchise tax.
	Renewable Energy Loan—Reduces the interest rate by approximately half on standard bank loans for those qualifying Ohio residents and businesses that borrow money to implement energy efficiency or renewable energy projects.

Buyer Incentives	Ethanol Investment Tax Credit-tax credit against corporation franchise or personal income tax liability for investments in ethanol plants whose business plans have been approved by the board.
Fuel-cell Technology Center/Technology Park	Ohio awards $2M in Wright Capital Project Funds to Stark State College of Technology for new Fuel Cell Prototyping Center.
University Involvement	Stark State College of Technology will support the research, development and commercialization of fuel cells by establishing the Fuel Cell Prototyping Center.
	Ohio Fuel Initiative plans to expand on work being done by Case Western Reserve University and The Ohio State University.
Organized Partnerships	Ohio Fuel Cell Coalition—A consortium of industry, academia, and government leaders from throughout the state of Ohio who are dedicated to developing a forward looking plan to advance a fuel-cell industry in Ohio.
	Third Frontier Project—A 10-year $1.6 billion plan to create high-tech, high-paying jobs through the expansion of the state's high-tech research sector and promotion of start-up companies.
General Grant Programs	Fuel Cell Grant Program—Three-year $100M dollar initiative to invest in research, project demonstration, and job creation.
	Distributed Energy Resources Grant—Ohio Department of Development is offering matching grants ranging from $25,00–$75, 000 to support distributed energy resources. Renewable technologies and clean burning technologies are eligible.
Funds Available for Initiatives	The state of Ohio proposed a $100M initiative.
	Financing–$75M—The Ohio Department of Development will set aside up to $15M to help Ohio's fuel cell companies make new strategic capital investments that will create or retain jobs for Ohio citizens. Up to $60M ($20M per year) in federal volume cap for tax exempt financing of qualified, small issue projects over the next three years. Loan program to provide interest reduction up to 50% of the market rate on the eligible energy efficiency costs (max $250,000 per project).
	Research, Development, & Demonstration—$25 million allocation of up to $13 million over three years of oil overcharge monies to help with fuel-cell research and development.
	Training—$3M to assist Ohio's fuel-cell companies upgrade the skills of workers over the next three years.

Texas

Supplier Incentives	Texas Emission Reduction Program—Provides incentives for individuals and businesses to encourage them to purchase alternative fuel vehicles. (Funding limited to $33M, 20% targeted to fuel cells.)
Buyer Incentives	Solar Energy Device Franchise Tax Deduction—Allows a corporation to deduct cost of a solar energy device.
Fuel Cell Technology Centers/Technology Park	Recently awarded funding to develop the Texas Energy Center ($33M for total project).
University Involvement	Texas Consortium for Advanced Fuel Cells Research—Organization includes seven universities and two private research institutions.
	Energy Center located within the University of Texas at El Paso; includes energy efficiency and renewable energy research.
Organized Partnerships	Fuel Cells Texas—Seeks to accelerate the broad commercialization and deployment of fuel cells in the state of Texas through public education, policy alignment and development of state-sponsored initiatives.
	Houston Advanced Research Center—Private research and development center that has a fuel-cell commercialization program. Promotes demonstration projects as well as policy development in Texas.
	Texas Council on Environmental Technology—Oversees Fuel Cell Initiative.
General Grant Programs	Texas Emission Reduction Program—In addition to rebates, includes grants to reduce emissions of heavy-duty vehicles.

Funds Available for Initiatives	Recently funded a total of $31.1M in state matching funds for the development of the state initiative.
Demo Sites	Houston Advanced Research Center was recently awarded a $200,000 grant to manage a demonstration project at the Port of Houston intended to test electrochemical fuel-cell technology on a fuel-cell vehicle.

Glossary

Acronym	Definition
AFC	alkaline fuel cell
CHP	combined heat and power
CT CEF	Connecticut Clean Energy Fund
DG	distributed generation
DMFC	direct methanol fuel cell
DOE	Department of Energy
DoD	Department of Defense
EDD	Economic Development Department
EPA	Environmental Protection Agency
EPScoR	Experimental Program to Stimulate Competitive Research
FCV	fuel cell vehicle
GM	General Motors
GSP	gross state product
ICE	internal combustion engine
LANL	Los Alamos National Laboratory
MCFC	molten carbonate fuel cell
MEA	membrane electrode assembly
MISER	Massachusetts Institute of Social & Economic Research
MTI	Mechanical Technology Incorporated
NMEDD	New Mexico Economic Development Department
NMPRC	New Mexico Publications Regulation Commission
NSF	National Science Foundation
PAFC	phosphoric acid fuel cell
PEMFC	proton exchange membrane fuel cell
PNM	Public Service Company of New Mexico
PURPA	Public Utility Regulatory Policies Act of 1978
RDC	Regional Development Corporation
RPS	Renewable Portfolio Standard
SATOP	Space Alliance Technology Outreach Program
SIC	State Investment Council
SMR	steam methane reforming
SOFC	solid oxide fuel cells
TERP	Texas Emission Reduction Plan
TVC	Technology Ventures Corporation