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Hydrogen Energy Stations: Poly-Production of Electricity, Hydrogen, and Thermal Energy

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Innovation in Finance, Technology & Policy

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The findings and conclusions expressed in this paper are those of the authors alone.

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Preface

We are entering a period of new opportunities for clean energy. A confluence of events in the past year has highlighted a new role for sustainable energy strategies. The ratification of the Kyoto Protocol and regional greenhouse gas emission reduction efforts in the United States have spawned new markets and price signals for carbon dioxide and other greenhouse gases. Major announcements from institutional investors and the financial community have brought renewed interest in the sector. Sustained high oil prices have brought about discussion of "peak oil" and the potential inability of oil production to meet the pressures of steadily growing demand.

It is into this context that many are looking to hydrogen technologies as part of a sustainable energy solution. As has been the trend with clean energy innovation, state-based efforts are leading the way. California, New York, and other states have promoted bold "Hydrogen Highway" initiatives. Florida has championed hydrogen in a recently revised energy plan. A cluster of states in the Upper Midwest are collaborating on a roadmap for hydrogen technology deployment.

Still, much of the focus in these efforts has been on hydrogen applications in the transportation sector. Relatively little attention has been given to developing strategies for incorporating hydrogen into our stationary power and electricity infrastructure, and even less attention has been paid to strategies that might bring these two sectors together to seek synergies and combined opportunities for research and development. These strategies should be compared with other long-term options for making large gains in efficiency and achieving reductions in greenhouse gases, while also improving other environmental and health impacts of the U.S. energy system.

One innovative new strategy that is emerging is the development of hydrogen "energy stations" or "power parks." These energy stations would use fuel cells to produce electricity with a slipstream of purified hydrogen that could satisfy refueling demands for hydrogen vehicles. In order to better understand the technology and implications of the energy station concept, Clean Energy Group commissioned this report.

This report is intended to provide:

1) a review of the current state of the commercial and technical status of "hydrogen energy stations" for combined production of electricity, hydrogen, and thermal energy;

2) a survey of notable energy station projects; and

3) policy recommendations for further exploring and advancing the potential of hydrogen energy stations as a source of clean fuel for stationary power and transportation applications.

This report on energy stations has been prepared in conjunction with a companion report on renewable hydrogen production. We hope that you find both of these reports useful and that they can serve to advance the development of new strategies to promote the deployment of fuel cells and hydrogen technologies in innovative settings.

Executive Summary

The "hydrogen energy station" is one method of hydrogen production at small and medium scales. Unlike more conventional hydrogen station designs where hydrogen is simply delivered or produced on-site with a fuel "reformer" or water electrolyzer and then compressed and dispensed, energy stations would provide multiple functions in the same facility. They would integrate systems for production of electricity for 1) local uses and/or the utility grid, 2) re-use of thermal energy "waste heat" for building heating/cooling needs, and 3) purified hydrogen for refueling vehicles.

Hydrogen energy stations can be of various types and configurations. Most designs to date are based around some type of fuel cell power plant for electricity production, with co-production of hydrogen either by splitting the stream of hydrogen from a fuel reformer or electrolyzer (to power the fuel cell and provide electricity with one stream and to refuel vehicles with the other) or by using excess hydrogen from the fuel side of the fuel cell system to provide vehicle fuel.

A few hydrogen energy station demonstration projects have been conducted in the past few years, and additional projects are anticipated as part of the California Hydrogen Highway Network initiative and other regional distributed power and hydrogen fuel efforts. We suggest that the interest in hydrogen as a transportation fuel offers opportunities for the development of additional hydrogen energy station projects, as we are beginning to see in California. Promoting new projects such as these will allow for the more complete exploration of the varying potential of different designs, configurations, and locations/settings for the energy station concept.

Clean Energy Group (CEG) commissioned this report in order to support the Public Fuel Cell Alliance project (PFCA) and to more fully explore the potential for hydrogen energy stations to play an important role in advancing the development of clean and efficient technologies for both stationary and transportation applications.

The following are several recommendations for consideration by key stakeholders that have an interest in developing strategies for promoting these new technologies and projects. These recommendations are intended initially for consideration by state clean energy funds. While it is clear that there is no simple, one-size-fits-all program for state action, these are intended to serve as a starting point for in-depth discussions that can lead to state-specific action plans and stakeholder engagement processes.

Specific recommendations include:

- **Integrate Energy Stations Into State Hydrogen Plans:** Many states have completed or are undertaking to develop hydrogen "roadmaps." These state-specific plans, which have been completed in California, Ohio, New York and Florida, provide recommendations to capture new economic development opportunities related to hydrogen and fuel cell technologies. Other states, such as Massachusetts and Connecticut, are embarking on similar planning exercises. The energy station concept should be integrated into these existing and emerging hydrogen plans. California, for example, is emphasizing the inclusion of energy station projects in early hydrogen stations for its Hydrogen Highway effort. We believe this is a strategy that can be replicated in other states.

- **Explore Fleet-Based Opportunities to Deploy Energy Stations:** In many settings, there likely exist opportunities for states to deploy energy stations in conjunction with a specific, clustered vehicle fleet. Fleet-based opportunities reduce the need to develop regional networks of refueling stations as envisioned in many "hydrogen highway" proposals and could be implemented in partnership with military, industrial and delivery organizations. In these settings, a single energy station could support the refueling demands of a significant vehicle fleet. Initially, in order to advance these opportunities, state clean energy funds and economic development offices could support and conduct opportunity assessment studies that identify specific fleets, partners and electricity demands.

- **Foster Public-Private Partnership Development:** Energy stations, in order to be successful, require significant partnerships with technology providers and host facilities. These partnerships can be fostered through public support from state clean energy funds, economic development offices and other key players. In particular, funding and support of coalition-building processes can have cross-cutting benefits for other hydrogen-related priorities in specific states.

- **Proactively Address Regulatory Incentives:** Advanced energy technologies require advanced regulatory policies. Many states have implemented regulatory preferences and incentives (such as standby charge exemptions and net metering policies) that recognize and accommodate the public preference for and benefits from fuel cell, hydrogen and clean energy technologies. The regulatory strategies used by these early leaders can be replicated in other states. This kind of support is especially important for energy stations where a key component of the project is providing distributed electricity for the electric grid. Currently, many regulatory barriers prevent the wide-scale adoption of clean distributed generation and limit the ability to quickly site energy stations. State clean energy funds and others can assist by facilitating information-sharing about the best model regulations that can overcome barriers to distributed generation facilities.

- **Develop Compelling Communications Strategies:** The concept of using hydrogen in consumer settings has been plagued with public misperceptions and lack of awareness of the significant potential benefits and remaining challenges. In recent years, many states have conducted sophisticated consumer and stakeholder research that has resulted in new communications campaigns to increase public understanding and support for clean energy technologies. Many states, for example, recently joined together to develop and fund a "Clean Energy: It's Real, It's Here, It's Working. Let's Make More" branding campaign. This kind of proactive communications strategy would yield tremendous results for the hydrogen sector, helping to organize currently disparate enthusiasm for hydrogen with a single, compelling message while also helping to manage expectations regarding the types and timing of hydrogen technologies that are likely to be introduced.

INTRODUCTION

The "hydrogen energy station" is one method of hydrogen production at small and medium scales. Unlike more conventional hydrogen station designs where hydrogen is simply delivered or produced on-site and dispensed, energy stations would include a system for production of electricity and thermal energy "waste heat," as well as purified hydrogen for refueling vehicles.

The unique combination of electricity generation, thermal energy and hydrogen production provided by an energy station design allows a single energy facility to leverage several objectives. As with other co-generation or combined heat and power (CHP) facilities, the utilization of electrical and thermal energy provides a much greater efficiency in energy conversion. This translates into lower fuel costs, improved economics, as well as reduced pressure on the increasing demands for energy services.

Energy stations can be of various types and configurations. Most designs to date are based around some type of fuel cell power plant for electricity production, with co-production of hydrogen. This hydrogen production occurs either by splitting the stream of hydrogen from a fuel reformer or electrolyzer (to power the fuel cell and provide electricity with one stream and to refuel vehicles with the other) or by using excess hydrogen "tail gas" from the fuel side of the fuel cell system to then be purified and compressed for vehicle fueling.

Thus, the value of energy stations is that they combine distributed generation (DG) of electrical power with a hydrogen dispensing station for vehicles. This is one potential avenue for mitigating the "chicken or egg" problem with hydrogen infrastructure development. That is, the demand for either electricity or refueling may not be sufficient to support a facility dedicated to either independent application. But the combination of applications results in a facility that is more fully utilized for all applications—electricity, heat and refueling. Through the use of an energy station, significant capital that could be "stranded" in the early years of hydrogen vehicle introduction due to low utilization of capacity can be more fully utilized, thereby reducing the "start-up costs" of deploying hydrogen infrastructure.

HYDROGEN ENERGY STATIONS—THE CONCEPT

The hydrogen energy station concept combines a refueling facility for hydrogen vehicles with the capability for onsite power production, creating synergies between these two types of systems. The energy station fundamentally consists of a natural gas reformer or other hydrogen generating appliance, a stationary fuel cell integrated into the building with the potential capability for CHP production, and a hydrogen compression, storage, and dispensing facility. However, many different arrangements are possible, both in terms of the technologies used and the setting and primary purpose of the station.

Energy stations seek to capture synergies between producing hydrogen for a stationary fuel cell electricity generator that provides part or all of the power for local building load (as well as the capability to supply excess electricity to the grid) and refueling hydrogen-powered vehicles with additional high-purity hydrogen that is produced through the same hydrogen-generation system. Particularly where electricity costs are high and significant savings can be realized through distributed generation (or "onsite power"), energy stations offer a potentially more economically attractive opportunities to deploy hydrogen-refueling infrastructure for vehicles.

The energy station concept was originally developed by Air Products and Chemicals, Inc. (APCI) in the late 1990s when efforts started under U.S. Department of Energy (DOE) to develop the power center for hydrogen "power parks." APCI is a leading commercial gas supplier, including hydrogen, and the company has participated in a few energy station demonstration efforts to date (discussed below). The company has experimented with low temperature fuel cell-based energy station designs but is currently developing an energy station design that employs a high temperature molten-carbonate fuel cell system as its core technology (Keenan, 2006).

THE CONTEXT FOR HYDROGEN FUELING STATIONS AND DISTRIBUTED POWER GENERATION

A few hydrogen energy station demonstration projects have been conducted in the past few years, and additional projects are anticipated especially as part of the California Hydrogen Highway Network initiative and other regional initiatives for distributed power generation and/or hydrogen. In addition to California, such efforts are underway in New York, Connecticut, Florida, Texas, Michigan, and Ohio, among other states.

California's recently announced "Hydrogen Highways" initiative specifically identifies the possibility for energy stations to be used as part of the state's future hydrogen refueling network in the preamble of the key executive order:

"Whereas, the economic feasibility of a hydrogen infrastructure is enhanced by building hydrogen energy stations that power vehicles as well as supply electricity for California's power needs." (State of California Executive Order S-7-04)

The "blueprint reports" that have been developed in response to the California executive order further detail the potential role of hydrogen energy stations in the state's plans to develop an initial hydrogen infrastructure. The California Hydrogen Blueprint Plan summary report states that "the California Stationary Fuel Cell Collaborative estimates that five 'energy stations' with stationary fuel cells will be deployed during Phase 1 (California Enviromental Protection Agency, 2005a). The prospects for deploying stationary fuel cell based energy stations as part of the initiative are discussed in greater detail in Volume II of the Blueprint Plan and are summarized in a later section of this paper.

The increasing interest in hydrogen as a transportation fuel offers opportunities for the development of additional hydrogen energy station projects, as is beginning to occur in California. In addition to the California effort, a number of other U.S. states are pursuing hydrogen vehicle commercialization plans. These states include New York, Michigan, Ohio, and Florida. Further details of these state efforts for hydrogen vehicles are discussed below, along with the most noteworthy state efforts to promote distributed power generation and stationary fuel cells.

Furthermore, there are many public benefits from advancing distributed generation and the development of a new generation of advanced power technologies. These technologies hold the potential for dramatic end-user efficiency improvements. They can ease transmission constraints and provide an alternative to development of expensive and difficult to site new power plants. Distributed generation technologies include conventional gas turbines and reciprocating engines, microturbines, and solar photovoltaic systems, as well as fuel cell systems.

Distributed generation also frequently involves a "combined heat and power" (CHP) or "cogeneration" component, where heat exchangers are used to capture waste heat for productive purposes. Use of this waste heat for local thermal energy needs can dramatically improve the overall thermal efficiency of power generation. Typical uses of waste heat include heating water to reduce boiler usage, generating steam for building heating and other uses, and providing cooling using absorption or adsorption cooling systems, thereby reducing electrical chiller or air conditioner use.

States that are engaged in efforts to promote hydrogen, fuel cells and advanced energy technologies include California, Connecticut, Massachusetts, Michigan, New Jersey, New York, Ohio and others. The Public Fuel Cell Alliance (PFCA), of which many of these states are members, provides a multi-state platform for information sharing, support and joint action by these (and other) states to advance fuel cell and hydrogen technologies. The PFCA is a project of the Clean Energy States Alliance (see *www.cleanenergystates.org*).

WHY ARE ENERGY STATIONS INNOVATIVE?

Energy stations have several benefits. First, they simultaneously advance clean technology development in the transportation and stationary power sectors. These stations represent an innovative design concept for linking transportation and stationary energy applications of hydrogen and fuel cell technologies. They enable fuel cell systems to satisfy an immediate demand for electricity production while advancing the gradual scale-up of hydrogen refueling capacity. This application helps to bridge a fundamental timing mismatch—fuel cells and hydrogen transportation are long-term solutions; distributed energy production demands are near-term concerns.

Second, because most fleets are urban-based, siting energy stations with fuel cell systems provides air quality advantages in comparison to power systems with higher pollution levels in urban and air quality-impacted areas.

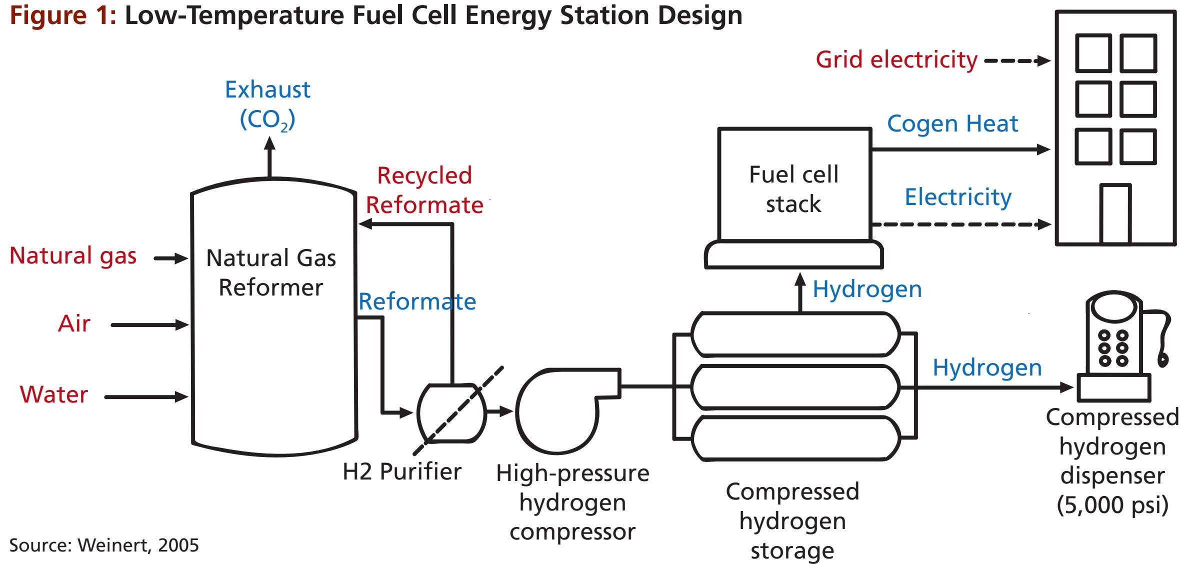
Third, energy stations offer a bridge between dual state objectives: advancing both stationary and transportation uses of hydrogen. Today, most state fuel cell programs focus on stationary fuel cells, while most hydrogen initiatives focus on transportation. Energy stations provide a solution to the problem of how to link these similar state initiatives to advance the emergence of a hydrogen economy and bridge this programmatic gap.

ENERGY STATION TYPES

Many different types of energy stations are possible. These stations can be primarily designed to produce hydrogen for vehicles, electricity for local building loads (commercial, industrial, or residential), electricity for export to the utility grid, or support for local electricity distribution grids.

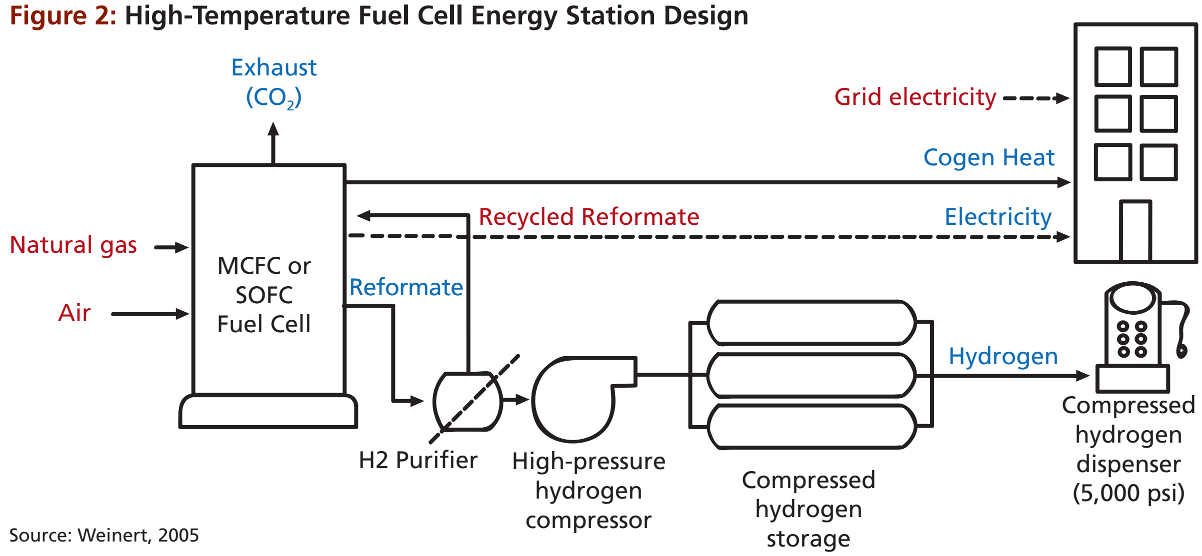
The most obvious near-term arrangement would be to combine a stationary fuel cell system that operates on hydrogen produced onsite (e.g. a proton-exchange membrane or phosphoric acid fuel cell system) from natural gas, with a hydrogen purification, compression, storage, and dispensing system for vehicle refueling. However, configurations using other fuel cell types and hydrogen generation systems are also possible. Figures 1 and 2 below, present designs for both low and high temperature based energy stations.

Figure 1: Low-Temperature Fuel Cell Energy Station Design



Source: Weinert, 2005

Figure 2: High-Temperature Fuel Cell Energy Station Design



Source: Weinert, 2005

Table 1: **Technical and Economic Characteristics of Energy Station Power Technologies**

	Low/Medium Temperature Fuel Cell Design			High Temperature Fuel Cell Design		Hydrogen Engine Gen-Set
Tech. Type	**PEM**[2]	**Alkaline**	**Phos. Acid**[3]	**Molten Carb.**	**Solid Oxide**	**ICE/Generator**
Typical Electrical Efficiency[4]	35-50% (NG) 50-60% (H_2)	35-50% (NG) 50-60% (H_2)	37-42%	45-60%	45-60%[5]	25-35%
Operating Temperature	~80°C	65°C–250°C	150-220°C	650°C	600°C-1,000°C	>1,000°C
Waste Heat Grade	Low	Low-Medium	Medium	High	High	High
Waste Heat Use (typical)	Hot water	Hot water	Hot water, steam, process heat	Steam, process heat, abs. cooling	Steam, process heat, abs. cooling	Steam, process heat, abs. cooling
Capital cost (current est.)	$3,000-4,000/kW	$2,500-3,000/kW	$3,000-4,000/kW	$3,000-4,000/kW	Pre-comm.	Early comm. no cost avail.
Capital cost (future goal)	$400-600/kW[5]	$250-500/kW	$1,000-1,500/kW	<$1,000/kW	$250-500/kW	$500/kW
Hydrogen co-production source	Split reformer / electrolyzer / pipeline stream	Split reformer / electrolyzer / pipeline stream	Split reformer / electrolyzer / pipeline stream	Anode tail gas	Anode tail gas	Split reformer / electrolyzer / pipeline stream

Source: Technical and economic specifications are primary from U.S. DOE, 2002, along with other various sources.

Decisions about selection of the various types of fuel cell based energy station designs, whether a high or low temperature system and potential or incorporation of another power generation technology, involve key engineering and economic trade-offs. In fact, there are important trade-offs even between different types of low temperature fuel cells and high temperature fuel cells. Table 1, below, presents some of the key engineering and economic tradeoffs among these options for the electrical power production and waste heat recovery components of the energy station. In addition to these options, energy stations can also be built around phosphoric acid fuel cell systems, such as those commercialized by United Technologies Corporation—an intermediate temperature option.

High temperature fuel cell systems can also be "hybridized" with combustion turbines to improve overall efficiency. However, this would represent a competing use for the extra "anode tail gas" hydrogen and may not be a useful option when this un-reacted hydrogen is also of interest for purification and compression as a vehicle fuel.

With regard to determining the location and primary purpose of the hydrogen energy station, the possibilities are many. Some of the main options include:

1. **Service station location**—mostly focused on vehicle refueling with small power production capability to offset local electrical loads

2. **DG energy station at industrial or commercial facility location**—mostly focused on meeting local electrical loads with additional capacity for vehicle refueling

3. **Utility substation location**—mostly focused on providing grid power and ancillary services support to the grid, with additional capacity for vehicle refueling

4. **Home or apartment building**—provides power and thermal energy for residences as well as small capacity for refueling vehicles

5. **Electric transportation network**—mostly focused on providing power for the electric transportation (e.g. light rail) system with additional capacity for vehicle refueling (possibly focused on hydrogen transit buses and/or taxi cabs)

Table 2, below, presents some basic characteristics of these five potential types of hydrogen energy stations.

Table 2: Five Potential Types of Hydrogen Energy Stations

	Service Station	Distributed Generation	Utility Support	Residential	Electric Transp. Network
Location	Service station	Commercial or industrial facility	Utility substation	Home or apartment building	Electric transportation system
Primary Purpose	Hydrogen refueling for vehicles	Electricity production	Local distribution grid support	Hydrogen refueling for vehicles	Local distribution grid support
Vehicles Refueled	5-500 per day	5-50 per day	5-50 per day	1-10 per day	5-100 per day
Approximate Fuel Cell Size	25-50 kW	100-1,000 kW	100-500 kW	1-50 kW	100-1,000 kW
Key Issues	• DG/fuel cell economics with low electrical loads	• Utility tariffs and interconnection rules • Public access for refueling?	• Public access for refueling?	• Natural gas costs • Economics with low electrical loads	• Public access for refueling?

HYDROGEN ENERGY STATION ECONOMICS

Recent analysis of the economics of several potential hydrogen energy designs shows that in locations where prevailing commercial and residential electricity rates are high these stations have the potential to be relatively economically attractive ways of supplying vehicles with hydrogen. This is particularly true where small numbers of fuel cell vehicles (FCVs) or other hydrogen-powered vehicles are being supported, in comparison with other options where a facility is dedicated solely to refueling applications and therefore can be more economically cumbersome.

In general, hydrogen energy stations can be more attractive economically than dedicated hydrogen refueling stations, especially for low numbers of vehicles supported per day. However, the economics depend significantly on several variables including natural gas and electricity prices, capital equipment costs, the hydrogen sales price, and fuel cell maintenance and stack refurbishment costs. In order for energy station economics to be favorable, the business case for the distributed generation aspect of the station has to be favorable. With current fuel cell system prices, this would typically require significant state and/or federal incentives to reduce capital costs of station construction. However, detailed analysis shows that future projected costs of hydrogen fuel cells can lead to attractive economics in the absence of incentives, again also based on other key assumptions regarding fuel prices and fuel cell system operation and maintenance costs. In the early years of hydrogen vehicle introduction, energy station designs could reduce the losses associated with operation of the initial, lightly-used hydrogen station network, and then eventually could make the stations more profitable when they do start to turn a profit (Lipman et al., 2002).

EXISTING ENERGY STATION PROJECTS

A number of H2E-Station concepts are being explored by various industrial groups; two actual stations have been constructed (plus one residential-scale demonstration), and a few others are in the planning stage. This section discusses the energy stations that have been built or proposed to date and that have been publicly disclosed.

The Las Vegas Hydrogen Energy Station

The world's first energy station was dedicated in Las Vegas, Nevada on November 15, 2002. The $10.8 million, five-year demonstration project includes research, development of new technology, and the manufacturing and installation of equipment at the energy station. The project costs have been split equally under a cooperative agreement between Air Products and Chemicals Inc. and the U.S. DOE. The team also includes Plug Power, a New York-based fuel cell manufacturer, and the city of Las Vegas. These last two partners were responsible for the research, development, design, and construction of the station and are responsible for its operation. The station is capable of dispensing pure hydrogen for vehicle refueling and compressed natural gas (CNG) for CNG vehicles, as well as CNG/hydrogen blends (City of Las Vegas, 2002).

The station has reportedly experienced problems with its fuel cell system and is at present using hydrogen that is being delivered from an industrial hydrogen production facility rather than produced onsite. Figure 3 presents a picture of the Las Vegas station.

The Toronto Hydrogen Energy Station

The world's second energy station was installed in Toronto, Canada and unveiled at the city's Exhibition Place during the annual 'Green Day' activities at the Canadian National Exhibition on August 27, 2003. The demonstration at the exhibition is the first phase of a three-year initiative undertaken by Hydrogenics, Inc., the City of Toronto and Exhi-

Figure 3: **The Las Vegas Energy Station**

Source: Air Products and Chemicals, Inc.

bition Place. Electrical power generated by a Hydrogenics "HySTAT" fuel cell generator will be used to provide electrical demand "peak shaving" for the National Trade Center during periods of high electricity consumption when power is more expensive. In addition, a John Deere "Pro Gator" demonstrator FCV will be refueled with hydrogen produced by steam reformation of natural gas at the same site and will demonstrate the use of fuel cell technology to enhance the productivity and reduce the emissions of work vehicles.

The station uses pressure-swing adsorption hydrogen purification technology from QuestAir Technologies, Inc. Funding support for installation of the fuel cell and vehicle fueling systems was provided by the Canadian Transportation Fuel Cell Alliance and Natural Resources Canada (QuestAir Technologies, Inc., 2003; City of Toronto, 2004).

In a "Phase 2" component of the project added in 2004, the system was made to be capable of providing continuous power to the trade center as well as emergency backup power. And in a planned "Phase 3" of the project, a renewable wind turbine/ electrolyzer hydrogen generator will be added to the site, along with a 40-foot, fuel cell-powered passenger bus. Figure 4 presents a picture of the "Phase 1" Toronto station.

The Diamond Bar, California Hydrogen Energy Station

The South Coast Air Quality Management District (SCAQMD) has contracted with Stuart Energy Systems for construction of an electrolyzer-based H2E-Station at SCAQMD's Diamond Bar, California headquarters location. This station will use an electrolyzer to produce hydrogen for hydrogen-powered vehicles as well as a 120-kW hydrogen internal combustion

Figure 4: The Toronto Energy Station

Source: City of Toronto, 2004

engine generator set. The power module will be used for peak-shaving and backup power, and the station is expected to open early in 2004. This will represent the first electrolyzer-based energy station to open in California (Stuart Energy Systems, 2003).

The Honda/Plug Power Home Energy Station

In late 2003, Honda Motor Company and Plug Power announced an integrated "home energy station" system that was co-developed by the two companies. The system incorporates a fuel reformer, a stationary PEM fuel cell, a refiner to purify the hydrogen, a hydrogen compressor, high-pressure tank storage, and a fuel dispenser. The system is designed to operate on natural gas, provide power for its own operation as well as local electrical loads and/or grid export, and produce enough additional hydrogen to refuel one vehicle per day. The system also includes the capability for "combined heat and power" and can provide space heating and/or hot water using waste heat from the operation of the system (Plug Power, 2003).

Planned Energy Station Projects

The most noteworthy energy station project currently in the planning and development stage is an effort being led by APCI, along with MCFC manufacturer FuelCell Energy (Air Products and Chemicals Inc., 2005). These companies are working on a high-temperature fuel cell based energy station design, under an effort that started with initial funding provided by the U.S. DOE in 2001 to develop "power parks." The FuelCell Energy system was chosen for the electricity production component of the energy station because the system is commercially available and has been proven to be reliable under real

Figure 5: **Demonstration of the Honda/Plug Power Home Energy Station**

Source: Plug Power, 2003

world conditions (Keenan, 2006). Advantages of the MCFC system, compared with lower temperature PEM or PAFC systems, include the ability to dedicate part of the fuel cell stack to "internally reform" input fuel into hydrogen (obviating the need for a separate reformer system and reducing costs), as well as to provide typically higher electrical efficiencies.

APCI and FuelCell Energy are currently in the "Phase II" system design portion of the energy station project. Phase III will consist of procuring the equipment needed for the project and validating the system design. Phase IV will consist of actually operating the system. The companies plan to use the standard "DFC 300" FuelCell Energy product, with a nominal power rating of 250 kW, without significant modifications to the system. This will mean that the system will primarily be designed for electricity production, with relatively little hydrogen production. This contrasts with APCI's Las Vegas energy station that has a lower electricity to hydrogen production ratio (Keenan, 2006).

Purification of the hydrogen from the MCFC anode "tail gas" is a key aspect of the hydrogen production part of the energy station design. APCI evaluated over 20 potential purification systems and strategies and has settled on a pressure-swing adsorption (PSA) purification system for this project. The anode tail gas is approximately 10% hydrogen by volume, with the remainder being primarily carbon dioxide. APCI initially expected to be able to recover and purify about 65% of the hydrogen for vehicle refueling purposes, but due to better than expected performance of the advanced PSA system, the company now expects to realize recovery rates in the 85–90% range (Keenan, 2006). These recovery rates affect the heat balance of the overall energy station system, particularly with regard to the waste heat, with higher hydrogen recovery and purification rates coming at the expense of waste heat production.

Another significant energy station effort in the planning and development stage is by ChevronTexaco in conjunction with Alameda-Contra Costa Transit District (AC Transit). These organizations have collaborated to construct a natural gas reformer-based hydrogen station at AC Transit's bus maintenance yard in Oakland, California for purpose of refueling AC Transit's fleet of 3 fuel cell buses and 10 light-duty fuel cell vehicles. The station had its opening ceremony on March 13, 2006 and is currently capable of dispensing up to 150 kilograms of hydrogen per day. The station has been specifically designed to accommodate future inclusion of a stationary fuel cell for electricity production in order to make it into a "full blown" energy station. Press information released in conjunction with the opening event reports that the station includes "co-generation capability to power a stationary fuel cell that would provide electricity to the facility" (Alameda-Contra Costa Transit District, 2006, p. 1)

FUTURE OPPORTUNITIES FOR HYDROGEN ENERGY STATIONS

Hydrogen energy station research, development, demonstration, and incentive activities that are primarily being initiated at the state level are discussed below. Some efforts focus primarily on hydrogen energy (discussed first) and others focus mainly on stationary fuel cells and distributed power generation. Since the hydrogen energy station concept spans both the realms of hydrogen energy and distributed power, both types of programs are relevant to the future prospects of energy station development.

State Level Hydrogen and Stationary Fuel Cell Initiatives

In addition to the well known "California Hydrogen Highway Network Initiative" effort, New York, Florida, Connecticut, Michigan, Ohio, and Texas are also enacting bold initiatives, such as the "New York Hydrogen Highway," "H2 Florida," "NextEnergy" in Michigan, "Fuel Cells Texas," and the "Ohio Fuel Cell Coalition" to garner private sector and federal investment for the development of these industries. In addition, other states (notably Connecticut and Massachusetts) are preparing to embark on similar "roadmapping" exercises. With significant federal funding now being allocated for hydrogen and other clean energy system development, and with venture capital markets taking large positions in the clean energy sector, states are competing vigorously to position themselves to compete for these resources.

California

Under Governor Schwarzenegger, California is charting a bold course for the development of hydrogen infrastructure and the introduction of hydrogen-powered vehicles with the "California Hydrogen Highway Network Initiative." Building on the state's low-emission vehicle program and "zero-emission vehicle mandate," Governor Schwarzenegger adopted an Executive Order in 2004 that provides considerable momentum for hydrogen R&D activities in California, with a strong emphasis toward expanded deployment efforts in the near- and medium-term. The California Fuel Cell Partnership (CAFCP) and California Stationary Fuel Cell Collaborative (CASFCC) are key organizations that are expected to take part in hydrogen activities in California, along with state and regional agencies, universities and governmental laboratories, and other groups.

The main elements of the Governor's recent "California Hydrogen Highway Network" Executive Order include (State of California, 2004):

- Designation of the state's 21 Interstate highways as the "California Hydrogen Highway Network;"
- Development of a "California Hydrogen Economy Blueprint Plan" by January 1, 2005, for the "rapid transition to a hydrogen economy in California" (to be updated biannually);
- Negotiations with automakers and fuel cell manufacturers to "ensure that hydrogen-powered cars, buses, trucks, and generators become commercially available for purchase by California consumers, businesses and agencies;"
- Purchase of an increasing number of hydrogen powered vehicles "when possible" for use in California's state vehicle fleets;
- Development of safety standards, building codes, and emergency response procedures for hydrogen fueling stations and vehicles;
- Provision of incentives to encourage hydrogen vehicle purchase and the development of renewable sources of energy for hydrogen production; and
- Ultimately planning and building a significant level of hydrogen infrastructure in California by 2010, so that "every Californian will have access to hydrogen fuel, with a significant and increasing percentage produced from clean, renewable sources."

The California Hydrogen Blueprint Plan was developed during the second half of 2004 and released in March of 2005. The plan calls for the implementation of the "California Hydrogen Highway Network" per the Governor's Executive Order. The plan and associated reports represent several months of effort by a senior review committee, the Governor's executive officers team, an implementation advisory panel, five "topic teams" each composed of 30 to 50 industry, academic, and governmental experts, and additional consultant work. The topic teams addressed the following topics: "Public Education," "Economy," "Societal Benefits," "Implementation," and "Blueprint and Rollout Strategy." Each team produced an extensive report that was then used in compiling the final blueprint plan.

The plan calls for a phased approach, whereby 50 to 100 hydrogen stations would be in place during Phase 1, along with approximately 2,000 vehicles. Phase 1 is a five-year time period from 2005 to 2010. Phase 2 would be marked by an increase in hydrogen refueling stations to 250, along with up to 10,000 hydrogen-powered vehicles. Finally, Phase 3 would entail an expansion of the vehicle fleet to 20,000 as the last precursor to full-scale commercialization. The timing of Phases 2 and 3 would depend upon technological developments and the outcome of biennial reviews. The blueprint emphasizes the following benefits associated with the pursuit of this plan: energy diversity, security, environmental, economic development, and education (California Hydrogen Highway Network, 2005a).

The role of incorporating hydrogen energy stations in the California Hydrogen Highway Network has recently been addressed through a request for proposals (RFP) issued by the California Air Resources Board for three new hydrogen stations in California. These are to be funded partly under Senate Bill 76, which is providing $5.5 million for California

Hydrogen Highway Network hydrogen station development activities in fiscal year 2005-06 on a 50/50 basis. This RFP 05-609 allows hydrogen stations that use the energy station concept to avoid the 20% renewable energy requirement for the stations. The RFP emphasizes high temperature MCFC energy station designs but appears to allow for other types of systems.

The role of hydrogen energy stations is also specifically addressed in the Blueprint Plan. In Volume II of the Blueprint Plan summary report, Section 3.2.4 "Stationary Fuel Cells on the CA H2 Net" briefly discusses the hydrogen energy station concept and the difference between low and high temperature fuel cell based designs. The report summarizes a statement by the CASFCC that high-temperature based energy station designs are "viewed as potentially the most efficient, cost-effective, and environmentally sensitive means (to generate) hydrogen from natural gas" (California Hydrogen Highway Network, 2005b, p. 26). Section 6.2 of the Volume II report titled "How to Deploy the Network" states that California should "work with the CASFCC and trade associations to advance the use of energy stations" (California Hydrogen Highway Network, 2005b, p. 76).

Finally, the "Rollout Strategy Topic Team Report" discusses in general terms the role of stationary fuel cells in energy station applications in Section 2.4 titled "Stationary Applications." The report then discusses the specific role that these systems might play in Phase I of the plan in Section 7.3 "Specific Recommendations for Phase I, II, and III." This section states that "while focusing on the development of Hydrogen Highways, the use of hydrogen and fuel cells should be promoted in stationary power production…for hydrogen refueling of vehicles but also for electricity generation in fuel cells" (California Hydrogen Highway Network, 2005c, p. 7–6).

New York

The State of New York has developed a "hydrogen roadmap" in an effort led by the New York State Energy Research and Development Agency (NYSERDA), the New York Power Authority, and the Long Island Power Authority, along with contractual support from Energetics Inc., Albany Nanotech, and the National Hydrogen Association. Several "vision" workshops were held around the State during Fall 2004 and Spring 2005 to garner feedback from the public and to invite experts to review early drafts of the roadmap plan. The final version of the "New York State Hydrogen Energy Roadmap" was released in October of 2005.

The New York roadmap plan is similar to the California plan in that it calls for a multi-phase approach to usher in the beginnings of a hydrogen economy in the state and addresses both transportation and stationary power applications of hydrogen and fuel cell technologies. Phase I of the plan consists of "high profile demonstrations," designed to further R&D, raise public awareness, and establish codes and standards and supportive policies. Phase II would consist of "market entry" and would focus on "the three C's: cities, clusters, and corridors." Phase II would focus on reducing costs and developing the basic elements of the New York hydrogen network. Finally, Phase III would be a full commercialization phase where various clusters of activity would be linked in to a statewide network and where the government role could be stepped back (NYSERDA, 2005).

The New York roadmap plan contains specific mention of hydrogen energy stations, but unlike most other efforts, it puts energy stations specifically in a renewable fuel context. During Phase I of the plan, a renewable energy station project would be scoped and sited, and one or more stations would be deployed during Phase II. The detailed part of the plan references the potential project as an "energy center" that might be connected to an airport or municipal bus project with hydrogen vehicles (NYSERDA, 2005).

Florida

In Florida, Governor Jeb Bush launched the "H2 Florida" initiative in July 2003, and in March 2005 he "broke ground" on a "Hydrogen Highway" initiative similar to California's. Approximately $15 million in state funds for hydrogen projects has been proposed. The focus of the Florida program appears to be heavily geared toward the use of hydrogen in the transportation sector, rather than for stationary fuel cells.

Florida's statewide programs are intended to accelerate the development and deployment of hydrogen technologies in Florida, with multiple goals in mind. These goals include:

- Diversifying Florida's economy by stimulating corporate investment;
- Demonstrating hydrogen energy technologies;
- Establishing public-private partnerships;
- Recruiting and supporting hydrogen technology companies in Florida;
- Demonstrating new business models for corporate revenue and profit;
- Increasing energy security and independence; and
- Keeping Florida's air clean.

As part of this initiative, Florida has launched the "Florida Hydrogen Business Partnership," composed of over 20 companies. This is an effort to "establish Florida as the center of hydrogen technology commercialization in the Americas." The partnership currently lists 22 member companies that include fuel cell companies, hydrogen gas suppliers, large energy companies, and electric utilities (Florida Energy Office, 2005).

The Partnership finalized the "Florida Hydrogen Energy Roadmap" on March 23, 2005, which supports a "Florida Hydrogen Energy Technologies Act" proposed by Gov. Bush at a recent hydrogen station groundbreaking. This legislation calls for financial incentives, expanded demonstration projects, and a uniform siting standard for businesses that invest in hydrogen in Florida (FDEP, 2005a).

The Florida Hydrogen Energy Roadmap calls for many of the familiar measures that are being discussed by state and federal governments in the U.S. and abroad:

1) A portfolio of demonstration projects across sectors;
2) Tax and financial incentives for both demonstration and commercial activities;
3) Public-private partnerships to share risks;
4) Governmental incentive (rather than regulation) policies;
5) State and local technology procurement programs;
6) Targeted infrastructure development and stream-lined siting procedures;
7) Coordinated academic research in collaboration with industry; and
8) Public education and outreach programs.

The plan goes as far as to suggest specific tax incentives and measures, and it reports that five hydrogen refueling stations are expected in metropolitan Orlando by 2007, with fuel cell-based electrical generation capacity on-line "to exceed 500 kW" (FDEP, 2005b).

In terms of demonstration and pilot project activities to-date, Florida's efforts are concentrated in the Orlando area. Five Ford Focus FCVs will be demonstrated in North Orlando with refueling infrastructure provided by BP in a program funded under the U.S. Department of Energy's "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project" (Barber, 2005). In a second project, eight Ford E-450 shuttle vehicles will be deployed at the Orlando airport starting in 2006. These hydrogen combustion vehicles use a 6.8-liter V-10 engine and about 26 kilograms of hydrogen, stored at 5,000 pounds per square inch of pressure, to produce a driving range of about 150 miles (McCormick, 2005).

Finally, two airport "tug" vehicles will be converted to combust hydrogen and then will be tested at the Orlando International airport in 2006. The Florida Department of Environmental Protection, Delta Airlines, Ford Motor Company, and TUG Technologies are involved in the project. The vehicles will initially be refueled using a mobile refueling unit and possibly with a more permanent station, especially if additional hydrogen-powered tugs are deployed (Barber, 2005; Hydrogen Now, 2005).

The Florida Energy Office and the Florida Department of Environmental Protection are the state agencies most involved in the H2 Florida initiative. The energy office coordinates hydrogen research and demonstration activities in the state and manages the "Florida Hydrogen Initiative, Inc." This nonprofit organization has been developed to broker demonstration projects and to sponsor research in hydrogen production, storage, and use. At present, the Florida Department of Transportation is apparently not playing an active role in the H2 Florida initiative, but the agency may become more involved as demonstration project activities become more extensive.

Michigan

Michigan has been aggressive trying to attract existing fuel cell and other clean energy companies from outside the state. The organization heading this effort is "NextEnergy," a state-funded, nonprofit entity authorized to stimulate the development of advanced power systems with a strong focus on fuel cells. NextEnergy's stated mission is to "make Michigan a world center of excellence for alternative energy technology education, research, development, and manufacturing." Within this broad mandate, there are two main priorities at present:

- Construction of the NextEnergy Center
- Educational programs—$1 million has been set aside to disburse to several Michigan universities to create curricula in alternative energy technologies to help produce the "engineer of the future."

Industry recruitment is another priority and will likely rise in importance once the building nears completion. NextEnergy had a goal of creating five new advanced power technology companies within the state during 2003. They expect to work with existing companies both outside Michigan and outside the country in recruiting companies and partnerships (Michigan NextEnergy, 2003).

Although the scope of NextEnergy includes all advanced power technologies, fuel cell commercialization and deployment will be its primary focus. The NextEnergy Program is intentionally broad and will include efforts for both stationary and transportation-related fuel cells. The Center itself will be powered by a stationary fuel cell system. However, with the automobile industry located nearby, there is a strong long-term interest in fuel cells for transportation.

Other State Hydrogen and Fuel Cell Programs

Colorado

The Fuel Cell Research Center has developed a $12 million fuel cell demonstration program that is leveraged from $2 million in public funding from a petroleum violation escrow account. The center was launched in 2004 at the Colorado School of Mines in Golden, Colorado (U.S. DOE, 2004).

Connecticut

The Connecticut Clean Energy Fund has a five-year budget of $100 million to support renewable energy and fuel cells. This included $22 million in 2002 and a somewhat scaled-back 2003 budget of $16 million. Within this program, the Fuel Cell Initiative (CCEF-FCI) provides loans, grants, and equity investment for the demonstration and commercialization of fuel cells. The CCEF-FCI disbursed $9 million in funds in 2002, up from $5 million in 2001, demonstrating the attention that fuel cell industry development is receiving under this program. The primary focus of this program is fuel cells for stationary applications (Connecticut Clean Energy Fund, 2004).

Hawaii

Hawaii has received several million dollars in federal funding for hydrogen research, development, and demonstration projects. Much of this funding has been directed toward the Hawaii Natural Energy Institute at the University of Hawaii Manoa campus (Honolulu, Oahu) and the Natural Energy Lab of Hawaii Authority (NELHA in Kailua-Kona, Hawaii). A "DER Gateway" has been constructed at the NELHA site near the Kona airport on the Big Island, and the two organizations are expecting to collaborate on hardware demonstration and testing activities at the DER Gateway and other locations around the islands.

Massachusetts

Massachusetts has a hydrogen roadmap planning activity underway and several additional new hydrogen and fuel cell-related initiatives. In its push to attract fuel cell industrial activity to the state, Massachuetts is citing a potential demand for fuel cells of $46 billion by 2011 and its high "density" of over 80 active fuel cell companies The Massachusetts Hydrogen Coalition is leading this effort. The Coalition lists "job creation," "energy security," "clean transportation," and "high mobility power" as primary drivers for the state to lead these efforts.

On June 14, 2005, the Coalition proposed seven initiatives to significantly expand the hydrogen and fuel cell industry in Massachusetts. These initiatives include developing the Massachusetts "Clean Energy Corridor," establishing a "Hydrogen and Fuel Cell Center," establishing a "Clean Energy Export Program," increasing hydrogen and fuel cell education and outreach, increasing state resource allocation and procurement, and establishing appropriate tax and financial incentives. As a first step, the Coalition will work collaboratively with representatives from state agencies, institutions, universities, and industry leaders to develop the Massachusetts Hydrogen Roadmap (AIADA, 2005).

Ohio

The Ohio Fuel Cell Initiative is a $103 million program that is part of Ohio's $1.6 billion "Third Frontier Project" aimed at supporting high-tech sectors in Ohio. Launched on May 9, 2003, there are two main components to the initiative:

1) Financing for company expansion ($75 million budget over three years)

2) R&D support ($25 million budget over three years).

There is also a fund of $3 million dedicated to retraining workers. The Ohio program stands out from other states in its ambitious plan to dedicate 75 percent of its resources to provide financing for fuel cell companies to expand their manufacturing operations. The program goal is economic development for Ohio. A few years ago, a study by Battelle found that there was already a core of high tech companies, universities, and government labs in Ohio. This study resulted in the decision to launch the Third Frontier program to grow high-tech industry in Ohio where there are as many automotive suppliers (McKay, 2003).

Washington

Efforts in Washington are highlighted by a recent effort to pass three bills with implications for hydrogen/fuel cells and other alternative fuels, building on initial alternative fuel legislation passed in 2003. Three bills co-sponsored by Representatives Brian Sullivan and Jeff Morris passed by the Washington State House Technology, Energy and Communications Committee on February 22, 2005, and they proceeded to fiscal committees for funding appropriation. These include:

1) House Bill 1645 that would exempt school districts from the state's 28-cent-per-gallon special fuel tax on the bio-fuel portion of the fuel in their school buses, if they use more than a 20 percent blend;

2) House Bill 1646 that would encourage the alternative fuels industry through tax exemptions on sales and use tax, business and occupation (B&O), and property taxes for six years after building manufacturing facilities; and

3) House Bill 1647 would provide tax incentives for using and purchasing alternative fuel vehicles, alternative fuel refueling equipment, and alternative fuel.

All three bills have benchmarks to assess effectiveness. They also build on legislation passed two years ago in one of the nation's first state-level alternative fuels incentives packages (Sullivan, 2005).

Regional Level Hydrogen and Distributed Generation Initiatives

In addition to the above state-level efforts to promote the use of hydrogen and fuel cells, there also are a few noteworthy regional efforts that are banding states together to leverage their activities. These efforts include the Public Fuel Cell Alliance (PFCA) and a new effort that has been launched in the Northern Plains region known as the Upper Midwest Hydrogen Initiative.

The Public Fuel Cell Alliance

The PFCA is a coalition of state and federal agencies working together to accelerate the development and deployment of fuel cell and hydrogen infrastructure development. It is the only nonprofit organization in the U.S. that coordinates public funding of fuel cells and hydrogen technologies at the state and regional level. The PFCA was officially organized by its members in 2003 as a project of the Clean Energy States Alliance (CESA). CESA is a fourteen-state consortium of clean energy funds dedicated to supporting renewable power technology development.

As with many other clean energy technologies, state-based initiatives are leading the way to commercialization of these technologies. In particular, many states have promulgated renewable portfolio standards (RPS), creating new opportunities for fuel cells and distributed generation. States are funding demonstration projects for hydrogen production from renewable energy sources and are leading efforts to promote hydrogen fuel cells in security applications, providing reliable power supplies to critical telecommunications and emergency infrastructure.

The founding members of the PFCA include:

➤ **Federal**
DOD: US Army Corps of Engineers, Construction Engineering Research Laboratory
DOE: National Energy Technology Laboratory
Bonneville Power Association

➤ **State**
CT: Connecticut Clean Energy Fund
DE: Delaware Economic Development Office
MA: Massachusetts Technology Collaborative Renewable Energy Trust
NJ: New Jersey BPU
OH: Ohio Fuel Cell Initiative
PA: Sustainable Development Fund and 3 PA-based community funds
RI: Renewable Energy Fund

➤ **Supporting Private**
FuelCell Energy

PFCA's mission is to bring together and align state and federal programs with industry partners to accelerate the commercialization of fuel cell and hydrogen technologies. Current activities are designed to further the PFCA's objectives to:

- Foster increased public collaboration by expanding the existing network of state, federal and local funding agencies to more states and agencies;
- Encourage additional state and regional commitments of public funding streams and to create new public funding mechanisms for these technologies;
- Develop and support regional strategies in various parts of the country to accelerate technology adoption and economic development (particularly for impacted communities);
- Devise more effective programs to explore renewable sources of hydrogen production, homeland security applications and linkages between stationary power and transportation; and
- Engage leading academic strategists on new approaches to technology innovation and deployment in order to develop alternative energy sources and energy infrastructure.

The Upper Midwest Hydrogen Initiative

The Upper Midwest Hydrogen Initiative is a recently announced effort to develop up to twelve "energy stations" throughout the Northern Plains states (and potentially extending into Canada) that would demonstrate a range of hydrogen production systems. The program is in its initial startup and fundraising stage. The initiative is seeking partners to develop a network of hydrogen stations approximately every 150 miles along a network in Iowa, Michigan, Minnesota, South Dakota, North Dakota, Wisconsin, and the Canadian province of Manitoba. The project hopes to complete the first three stations by 2007 and the full network of twelve stations by 2012 (Great Plains Institute, 2006).

The specific projects mentioned include:

- ethanol-to-hydrogen using onsite ethanol reforming;
- wind-to-hydrogen using electrolysis;
- methane-to-hydrogen using anaerobic digestion of organic wastes;
- coal-to-hydrogen with carbon sequestration at the Dakota gasification facility in Beulah, North Dakota;
- byproduct hydrogen from an industrial process; and
- ammonia-to-hydrogen.

The effort makes specific reference to developing hydrogen energy stations that include electricity production as well as hydrogen for vehicles, and that also potentially use waste heat for cogeneration or "combined heat and power" (Great Plains Institute, 2006).

International Programs

Outside the U.S., major hydrogen and distributed power generation programs include those in the United Kingdom (U.K. government along with groups such as the UK Carbon Trust and the Renewable Power Association), Germany (with a primary focus on wind power but also with major hydrogen initiatives), Australia, Japan, China, Iceland, Denmark and Singapore. See Lipman et al. (2004) for a summary of various recent international programs for distributed power generation.

RECOMMENDATIONS

The Clean Energy Group commissioned this report to support the PFCA project and to more fully explore the potential for hydrogen energy stations to advance the development of clean and efficient technologies for both stationary and transportation applications. In addition, to the observations in the body of the report, we have assembled several recommendations for consideration by those key stakeholders that have an interest in developing strategies for promoting these new technologies and projects.

These recommendations are intended initially for consideration by state clean energy funds. However, there are other key stakeholders such as economic development offices, transportation authorities and other public-sector agencies that may have similar commitments to fostering the adoption of advanced energy technologies; they may consider these recommendations and incorporate them into upcoming planning processes. It is clear that there is no simple, one-size-fits-all program for state action, and these recommendations are intended to serve as a starting point for in-depth discussions that can lead to state-specific action plans and stakeholder engagement processes.

These recommendations include:

- **Integrate Energy Stations Into State Hydrogen Plans:** Many states have completed or are undertaking to develop hydrogen "roadmaps." These state-specific plans, which have been completed in California, Ohio, New York and Florida, provide recommendations to capture new economic development opportunities related to hydrogen and fuel cell technologies. Other states, such as Massachusetts and Connecticut, are embarking on similar planning exercises. The energy station concept should be integrated into these existing and emerging hydrogen plans. California, for example, is emphasizing the inclusion of energy station projects in early hydrogen stations for its Hydrogen Highway effort. We believe this is a strategy that can be replicated in other states.
- **Explore Fleet-Based Opportunities to Deploy Energy Stations:** In many settings, there likely exist opportunities for states to deploy energy stations in conjunction with a specific, clustered vehicle fleet. Fleet-based opportunities reduce the need to develop regional networks of refueling stations as envisioned in many "hydrogen

highway" proposals and could be implemented in partnership with military, industrial and delivery organizations. In these settings, a single energy station could support the refueling demands of a significant vehicle fleet. Initially, in order to advance these opportunities, state clean energy funds and economic development offices could support and conduct opportunity assessment studies to identify specific fleets, partners and electricity demands.

- **Foster Public-Private Partnership Development:** Energy stations, in order to be successful, require significant partnerships with technology providers and host facilities. These partnerships can be fostered through public support from state clean energy funds, economic development offices and other key players. In particular, funding and support of coalition-building processes can have cross-cutting benefits for other hydrogen-related priorities in specific states.

- **Proactively Address Regulatory Incentives:** Advanced energy technologies require forward-thinking regulatory policies. Many states have implemented regulatory preferences and incentives (such as standby charge exemptions and net metering policies) that recognize and accommodate the public preference for and benefits from fuel cell, hydrogen and clean energy technologies. The regulatory strategies used by these early leaders can be replicated in other states. This kind of support is especially important for energy stations, where a key component of the project is providing distributed electricity for the electric grid. Currently, many regulatory barriers prevent the wide-scale adoption of clean distributed generation and limit the ability to quickly site energy stations. State clean energy funds and others can assist by facilitating information-sharing about the best model regulations that can overcome barriers to distributed generation facilities.

- **Develop Compelling Communications Strategies:** Hydrogen has been plagued with public misperceptions and lack of awareness of its significant benefits. In recent years, many states have conducted sophisticated consumer and stakeholder research that has resulted in new communications campaigns to increase public understanding and support for clean energy technologies. Many states, for example, recently joined together to develop and fund a "Clean Energy: It's Real, It's Here, It's Working. Let's Make More" branding campaign. This kind of proactive communications strategy would yield tremendous results for the hydrogen sector, helping to organize currently disparate enthusiasm for hydrogen with a single, compelling message.

CONCLUSIONS

Energy stations are an innovative approach to satisfying multiple demands for limited resources and objectives to advance hydrogen and clean energy technologies. This report was prepared as an educational resource for state clean energy funds and state-level hydrogen advocates. We believe that there are opportunities to replicate from state-to-state these emerging strategies to advance deployment of clean energy resources and accelerate the transition to a hydrogen economy.

We hope that the information and recommendations offered in this report can serve to advance discussions intended to promote further action by state clean energy funds and other regional partners.

Through the efforts of the Public Fuel Cell Alliance, Clean Energy States Alliance and other multi-state collaborative efforts, we anticipate that the topic of developing energy stations and incorporating this design concept into upcoming planning processes will continue to receive significant attention. In that context, we hope that this report will serve to inform and advance those discussions.

ENDNOTES

1 Phase 1 of the California Hydrogen Highway Network Initiative extends through 2010, when 50 to 100 hydrogen-refueling stations are expected to be in place to support up to 2,000 hydrogen-powered vehicles (California Environmental Protection Agency, 2005).

2 PEM is proton exchange membrane

3 Phos. Acid is phosphoric acid.

4 For PEM and alkaline, efficiencies are quoted for operation on natural gas (NG) that is reformed to hydrogen and on hydrogen (H2) directly.

5 Up to ~60-65% w/turbine hybrid design

6 Cost targets for automotive PEM systems (with lower operational durability) are as low as $60-100/kW

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Clean Energy Group (CEG) is a nonprofit organization established in January 1998 to increase the use of cleaner energy technologies in the U.S. and abroad through creative financing, business partnerships, public policy and advocacy.

CEG works with state and nonprofit officials from around the U.S. that are responsible for over $4 billion in new clean energy funds. CEG manages the Clean Energy States Alliance (CESA), a new nonprofit organization assisting these funds in multi-state strategies. A key project of CESA is the Public Fuel Cell Alliance, a state and federal fuel cell and hydrogen infrastructure collaboration. CEG also works with public officials in Europe interested in trans-Atlantic efforts to build clean energy markets.

CEG, including its related work through CESA, is supported by the state funds, and by major foundations including Oak Foundation, Surdna Foundation, Citigroup Foundation, Rockefeller Brothers Fund, New York Com-munity Trust, Educational Foundation of America, and others.

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