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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
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Integrated Hydrogen and Intelligent Transportation Systems Evaluation for the California Department of Transportation

Timothy E. Lipman
Susan Shaheen

California PATH Research Report
UCB-ITS-PRR-2005-34

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Final Report for Task Order 5112

November 2005

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**INTEGRATED HYDROGEN AND INTELLIGENT TRANSPORTATION SYSTEMS
EVALUATION FOR THE CALIFORNIA DEPARTMENT OF TRANSPORTATION**

FINAL REPORT

TASK ORDER 5112

PREPARED FOR CALTRANS AND CALIFORNIA PATH

OCTOBER 17, 2005

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This work was performed as part of the California PATH program of the University of California in cooperation with the State of California Business, Transportation, and Housing Agency; Caltrans; the United States Department of Transportation; and the Federal Highway Administration.

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Executive Summary

This “Integrated Hydrogen/Intelligent Transportation Systems Evaluation for the California Department of Transportation” project was conceived to investigate hydrogen activities in the State and around the U.S. that might impact the California Department of Transportation’s (Caltrans) operations. The project is intended to review these activities and to suggest potential interesting applications of combined hydrogen and intelligent transportation system (ITS) technologies. This project was conducted by researchers at the University of California - Berkeley under California Partners for Advanced Transportation and Highways (PATH) Task Order 5112.

The main theme underlying this study is the potential for synergies between two rapidly evolving areas of advanced transportation and energy technology: hydrogen energy systems and ITS. We hypothesize that concepts and schemes that combine these two types of technologies can help to enable the potential use of hydrogen infrastructure by, first and foremost, allowing communication and mapping/navigation technologies to optimize the access to and operation of initially sparse hydrogen refueling networks. Additional benefits include helping to contend with the potentially limited driving range of initial hydrogen-powered vehicles and exposing consumers to new technologies in ways that do not require purchasing them, such as through fleet/motor pool, transit, and carsharing (i.e., short-term vehicle rentals) organization operations.

This hydrogen and ITS systems evaluation has three primary goals:

- 1) A review of activities in California and in other U.S. states and by the Federal Department of Transportation (DOT) to investigate and demonstrate the use of hydrogen as a transportation fuel;
- 2) A summary of additional concepts that link ITS and/or distributed power generation with transportation systems and that may also link themselves to further integration and enhancement with information technologies; and
- 3) An initial examination of potential hydrogen-fueled vehicle and ITS integrated demonstration/pilot projects.

Based on this initial investigation, we conclude that:

- 1) Several states are competing with California to develop hydrogen plans and to attract the emerging hydrogen and fuel cell industry to their states, including most notably New York and Florida;
- 2) DOTs in these states have for the most part been interested observers to this point but are beginning to be drawn into hydrogen activities in these states, and in some cases have been clearly identified as expected project partners;

- 3) The U.S. DOT is conducting activities at a relatively modest but significant level, particularly with respect to codes and standards development and hydrogen transit buses;
- 4) Hydrogen activities will be continued for FY 2005/2006 at the U.S. DOT under the newly-created Research and Innovation Technology Administration (RITA), taking over from the former Research and Special Projects Administration (RSPA) in most respects;
- 5) The *California Hydrogen Blueprint Plan* contains several references to Caltrans as a potential key partner in hydrogen projects, particularly related to partnering on hydrogen station siting and incorporating hydrogen-powered vehicles in its fleets;
- 6) Many different ITS technologies are applicable to the potential introduction of new alternative fuel vehicle (AFV) types, particularly with regard to the challenges of developing new vehicle refueling networks for hydrogen-powered vehicles and to help enable potential vehicle to grid (V2G) power schemes; and
- 7) Emerging technologies and concepts for the distributed generation of electrical power have potential technological and economic interactions with hydrogen vehicle and refueling systems and ITS.

Finally, we recommend a list of potential concepts to be considered for a field operational test (FOT) along the lines of the technology sets and interactions that we have explored in this study. Of the options, we believe that a “smart hydrogen refueling” FOT is the most attractive based on timing, technology availability, and potential interest for Caltrans, as well as significant national and global interest.

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Acronyms and Abbreviations

AFV = alternative fuel vehicle
APU = auxiliary power unit
AVL = advanced vehicle location
BEV = battery electric vehicle
CAFCP = California Fuel Cell Partnership
CAFE = Corporate Average Fuel Economy
Caltrans = California Department of Transportation
CASFCC = California Stationary Fuel Cell Collaborative
CCEF-FCI = Connecticut Clean Energy Fund Fuel Cell Initiative
CHP = combined heat and power
CNG = compressed natural gas
CTP = California Transportation Plan
DSRC = dedicated Short-range communication
DER = distributed energy resources
EV = electric vehicle
E85 = a fuel blend containing 85 percent ethanol
FDEP = Florida Department of Environmental Protection
FOT = field operational test
FTA = Federal Transit Administration
DC = direct current
DOE = Department of Energy
DOT = Department of Transportation
FCV = fuel cell electric vehicle
FOT = field operational test
HCNG = hydrogen/natural gas blends
HEV = hybrid electric vehicle
ICE = internal combustion engine
ITS = intelligent transportation systems
kW = kilowatt
LNG = liquefied natural gas
LPG = liquefied petroleum gas
MW = Megawatt
NELHA = Natural Energy Lab of Hawaii Authority
NHTSA = National Highway Traffic Safety Administration
NRC = National Research Council
NYSERDA = New York State Energy Research and Development Agency
PEM = insert definition
RITA = Research and Innovation Technology Administration
RSPA = Research and Special Projects Administration
R&D = research and development
SCAQMD = South Coast Air Quality Management District
UC = University of California
U.S. = United States
V2G = vehicle-to-grid power

Note: See references list for additional abbreviations used in citing references.

1.0 Introduction

This “Integrated Hydrogen/Intelligent Transportation Systems Evaluation for the California Department of Transportation” project was conceived to investigate hydrogen activities in California and around the United States (U.S.) that might impact the California Department of Transportation’s (Caltrans) operations. The project is intended to review these activities and to suggest potentially interesting applications of combined hydrogen and intelligent transportation system (ITS) technologies. This project was conducted by researchers at the University of California (UC) - Berkeley under California Partners for Advanced Transportation and Highways (PATH) Task Order 5112.

The main theme underlying this study is the potential for synergies between two rapidly evolving areas of advanced transportation and energy technology: hydrogen energy systems and ITS. We hypothesize that concepts and schemes that combine these two types of technologies can help to enable the potential use of hydrogen infrastructure by, first and foremost, allowing communication and mapping/navigation technologies to optimize the access to and operation of initially sparse hydrogen refueling networks.

Additional benefits include helping to contend with the potentially limited driving range of initial hydrogen-powered vehicles and exposing consumers to new technologies in ways that do not require purchasing them, such as through fleet/motor pool, transit, and carsharing organization operations. We expect additional applications of ITS and alternative fuel vehicle (AFV) technologies to emerge as both of these “technological” streams continue to evolve and interact.

This hydrogen and ITS systems evaluation has three primary goals:

- 1) A review of activities in California and in other U.S. states and by the Federal Department of Transportation (DOT) to investigate and demonstrate the use of hydrogen as a transportation fuel;
- 2) A summary of additional concepts that link ITS and/or distributed power generation with transportation systems and that may also link themselves to further integration and enhancement with information technologies; and
- 3) An initial scoping study of potential hydrogen-fueled vehicle and ITS demonstration/pilot projects.

The overall aim of this study is to provide strategic research and information for Caltrans and to other agencies that can be used to advance State and regional agency goals and the overall public interest. The goal is to complement past, ongoing, and planned future investigations with regard to ITS and AFVs, and particularly those by the authors at UC Berkeley and UC Davis and by investigators at other UC campuses (e.g., Matt Barth at UC Riverside, Scott Samuelsen and Ken Small at UC Irvine, and others).

Background: The California Context

In support of the California Zero Emission Vehicle (ZEV) mandate goals to introduce low- and zero-emission vehicles in California, Governor Schwarzenegger announced his intent to create a “California Hydrogen Highway Network” by signing Executive Order S-7-04 on April 20, 2004. He signed the order at a new hydrogen refueling station at UC Davis, dubbed “Station Number 1” by the California Fuel Cell Partnership (CAFCP) because of its public availability.



Figure 1: Governor Schwarzenegger signing Executive Order S-7-04 at UC Davis.

This initiative is intended to stimulate the development of hydrogen infrastructure in California to remove a key barrier to the introduction of hydrogen-powered vehicles. Among other measures, this order designates the 21 Interstate highways as part of that network and calls for a “California Hydrogen Economy Blueprint Plan” to be developed by January 1, 2005, for the “rapid transition to a hydrogen economy in California.”

The key elements of the Governor’s recent “California Hydrogen Highway Network” Executive Order include:

- Designation of the State’s 21 interstate highways as the “California Hydrogen Highway Network;”
- Development of a “California Hydrogen Economy Blueprint Plan” 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.”

Per the Executive Order, the *California Hydrogen Blueprint Plan* (Blueprint Plan) was developed during the second half of 2004 and released in March 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. Further details of this Blueprint Plan are discussed later in this report.



Figure 2: Various agencies and universities are partnering with DaimlerChrysler and the U.S. Department of Energy to experiment with approximately 25 “F-Cell” hydrogen-powered fuel cell vehicles in California, along with vehicles from other major manufacturers.

The vision of the Schwarzenegger Administration for the increased use of hydrogen is noteworthy given the great potential benefits for California, the U.S., and the world in pushing forward with the development of hydrogen fuel for transportation and stationary power production. The initiation of the California Hydrogen Highway Network represents a unique opportunity for the alignment of government, industry, and academia in California to put the State in the forefront of global developments around the use of hydrogen and fuel cells. These efforts, as the Governor has noted, may be important to both environmental and economic vitality in the State. The development of hydrogen technologies faces key technical hurdles, as noted in a recent report by the National Academy of Sciences / National Research Council (NRC, 2004) and hydrogen should be explored along with other options for making transportation systems more clean and efficient, but it is a particularly promising area of research and development (R&D) activities.

Primary Objectives of Research

The primary objectives of this research are to:

- 1) Investigate the status of hydrogen research activities around the U.S., Federal and state DOTs and the latest California policy initiatives for hydrogen;
- 2) Examine potential hydrogen/ITS technology options and potential field test projects; and
- 3) Help to position Caltrans to participate in additional clean vehicle demonstration and implementation activities, including potential hydrogen infrastructure projects and programs.

This project report concludes with a brief set of recommendations for continued Caltrans research and implementation activities in this area.

This research is expected to contribute primarily to Caltrans' operational goal of improved "stewardship." With further implementation of one or more of the projects suggested in this report, we would expect the "stewardship" and "delivery" goals to be advanced by improving the environmental performance (and ultimately potentially the economic performance) of Caltrans' operations. We further expect these goals to be advanced through Caltrans efforts to assist the State in improving the overall environmental and energy performance of the transportation system more generally through the development and implementation of clean vehicles and energy technologies. This research is also intended to further the California Transportation Plan (CTP) goals of "Enhancing the Environment," "Supporting the State's Economy," and "Promoting Community Values."

2.0 Review of Major Hydrogen Development and Deployment Efforts by the U.S. DOT and at the State Level

The U.S. Federal DOT and various state DOTs are engaged in hydrogen energy research plans and projects. The Federal DOT has created a national “hydrogen portal” worldwide website (see below for details), and California, New York, Michigan, and Florida have been among the leaders in states pursuing hydrogen for transportation applications. States pursuing hydrogen and fuel cell technologies for stationary power applications include Connecticut, Ohio, Colorado, Oregon, Alaska, Hawaii, and (again) California, Florida, and New York (see Lipman *et al.* 2004 for the recent status of these and other “distributed power generation” state initiatives).

We first review the latest hydrogen-related activities by the Federal DOT, and then we review the leading state-related hydrogen activities. These state hydrogen activities are mainly being led by state energy and/or environmental agencies, but to varying degrees the state DOTs are either starting to become involved or expected to become involved as efforts progress further.

2.1 Summary of U.S. Department of Transportation Hydrogen Activities

The U.S. DOT is engaged in a suite of activities related to the potential use of hydrogen in the transportation sector. These activities are concentrated under the DOT’s Research and Special Projects Administration (RSPA) and its Office of Innovation, Research and Education, now under a new organization known as the Research and Innovation Technology Administration (RITA).¹ DOT has also set up a “Hydrogen Fuels Working Group” that includes representatives from all modes of DOT.

The agency considers the potential use of hydrogen as a means to advance the DOT’s goals of safety, mobility, global connectivity, environmental stewardship, and security. The relationship between the potential use of hydrogen and these goals is summarized on the DOT’s “Hydrogen Portal” website:²

Safety: Enhance public health and safety by working toward the elimination of transportation-related deaths and injuries. DOT's operating administrations are working to develop regulations that help ensure the safe design and operation of hydrogen vehicles and infrastructure.

¹ Under a pending departmental reorganization, U.S. DOT hydrogen activities under RSPA are continuing under a new organization known as the Research and Innovation Technology Administration (RITA). This new organization was established under the Norman Y. Mineta Research and Special Programs Improvement Act of 2004.

² Quoted directly from the DOT Hydrogen Portal, which can be found at: <http://www.rspa.dot.gov/dra/hydrogen>.

Mobility: Advance accessible, efficient, intermodal transportation for the movement of people and goods. Hydrogen vehicles offer opportunities to deploy vehicles where air quality restrictions prohibit conventional technology.

Global Connectivity: Facilitate a more efficient domestic and global transportation system that enables economic growth and development. Hydrogen fuel initiatives involve Global Partnerships and international companies that span continents and borders. Transportation and energy are the lifeblood of the global economy. DOT's efforts are helping to make hydrogen a cornerstone of sustainable growth.

Environmental Stewardship: Promote transportation solutions that enhance communities and protect the natural and built environment. Fuel cell buses and heavy-duty vehicles will reduce transportation's impact on the environment.

Security: Balance homeland and national security transportation requirements with the mobility needs of the Nation for personal travel and commerce. Hydrogen offers the potential for the use of domestic distributed resources that are better protected from widespread disruption.

The DOT Hydrogen Portal website notes that the agency has successfully regulated hydrogen transport for decades. The agency thus has significant experience that can be brought to bear to supporting federal initiatives for the expanded use and transport of hydrogen.

Specific actions undertaken by DOT to date include exemptions for use of composite vessels and other hydrogen storage systems, participation in a “Hydrogen and Fuel Cell Bus Initiative” by the Federal Transit Administration (FTA), hydrogen pipeline safety research by RSPA’s Office of Pipeline Safety, and initiation of hydrogen vehicle rulemaking activities by the National Highway Traffic Safety Administration (NHTSA).

The FTA Hydrogen and Fuel Cell Bus Initiative is targeted at demonstrating hydrogen bus technology with a goal of 10 percent of new bus purchases being hydrogen/fuel cell powered by 2015. The program is emphasizing hydrogen transit bus R&D, hydrogen infrastructure development for transit applications, and education and outreach. The program currently is engaged with multiple industry teams for the R&D activities, including Ballard/DaimlerChrysler, United Technologies Corporation Fuel Cells/ISE Research, and Hydrogenics/Enova (Sisson, 2004).

NHTSA is currently engaged in hydrogen codes and standards review activities, outreach to public safety officials, collection of information on the safety record of hydrogen-powered demonstration vehicles, determination of hydrogen to gasoline equivalents for automaker Corporate Average Fuel Economy (CAFE) compliance, and hydrogen vehicle safety research and testing. NHTSA has developed a four-year plan for “Hydrogen, Fuel Cell and Alternative Fuel Vehicle Safety Research,” issued on July 14, 2004, that describes its plans for continued activities in these areas (NHTSA, 2004).

2.2 Summary of State Hydrogen Activities

Hydrogen R&D activities that are primarily being initiated at the state level are discussed below. These efforts in some cases extend to the regional level, and they are therefore grouped regionally. State DOT activities are emphasized where they are present. However, state DOT activities in this area appear to be relatively limited thus far compared to the roles played by other state agencies that are more closely related to energy use and environmental protection.

The backdrop to this section of the report is that in addition to worldwide competition in the global technology and energy economy, there also is competition within the U.S. in the race for hydrogen and fuel cell system development. In addition to California, states such as New York, Florida, Connecticut, Michigan, Ohio, and Texas are 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. 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, California stands to lose much if it does not successfully compete with other states for these resources.

The emphasis of the below discussion is on efforts that relate to the use of hydrogen for transportation uses. For a review of state development activities that focus on hydrogen and fuel cells for stationary applications, see Lipman *et al.* (2004).

2.2.1 California

Under Governor Schwarzenegger, California is charting a bold course forward for the development of hydrogen infrastructure and the introduction of hydrogen-powered vehicles. 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.”

In his speech announcing the California Hydrogen Highway Network on April 20, 2004, Governor Schwarzenegger made the following remarks:

“This starts a new era for clean California transportation. These vehicles produce no emissions and no smog. They will clean the air and get rid of the smog that is hanging over our cities, and reduce the health problems caused by our pollution. Your government will lead by example and start using hydrogen-powered vehicles. And while we invest in a clean California, I will make sure that we get federal funds to support our innovative efforts.

As I have said many times, the choice is not between economic progress and environmental protection. Here in California, growth and protecting our natural beauty go hand in hand. It goes together. A healthy environment leads to a healthy economy and a more productive workforce, and a better quality of life for everyone.”

The *California Hydrogen Blueprint Plan* (California Hydrogen Highway Network, 2005a) 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).

Regarding the specific potential role(s) of Caltrans in the State Hydrogen Highway Network plan, the blueprint plan makes the following specific references. Most notable of these is including Caltrans at the top of the list of potential hydrogen station location partners:

1) California Hydrogen Highway Network “Rollout Report,” Section 6.5.2 on “Target Site Host Partners” (California Hydrogen Highway Network, 2005b, page 6-8)

“Based upon previous experience with alternative fuels and the likelihood for success, potential project partners and station locations include:

1. ***Caltrans locations***
2. State locations
3. Federal fleet locations
4. City/municipal sites
5. Transit properties
6. Existing natural gas sites
7. Existing retail gasoline sites
8. Existing hydrogen facilities (pipelines, production facilities)
9. Auto dealerships
10. Air district locations
11. Airports
12. Refuse fleet facilities
13. Universities
14. Electric and natural gas investor owned utilities
15. Oil refinery locations
16. Port authority locations
17. Other centralized fleet locations
18. Municipal waste plants, landfills
19. Agricultural sites – commercial feedlots, agricultural waste sites”

2) California Hydrogen Highway Network “Rollout Report,” Section 6.7 on “Implementation Plan” also repeated in Section 7.5 on “Sites Report Recommendations” (California Hydrogen Highway Network, 2005b, page 6-11 and 7-11)

“Consider Executive Orders, state requirements, or other methods for phasing in vehicle purchases for gaseous, HCNG (hydrogen/natural gas blends), and hydrogen fuels in the State fleets. For example, ***Caltrans and State fleets could be encouraged to purchase hydrogen, HCNG vehicles*** to help enable development of a wide range of vehicles enticing automakers or small volume manufacturers to bring vehicles to market in this State.”

3) California Hydrogen Highway Network “Public Education Report,” Section 7.2 on “Recommendations” (California Hydrogen Highway Network, 2005c, page 7-3)

“Provide information about location of hydrogen fueling stations to early consumers while expanding awareness of availability of hydrogen products to the public at large:

- **Work with Caltrans to develop and install directional signs for hydrogen fueling locations.**
- Work with industry to ensure that refueling locations are readily identifiable via onboard telematics technologies, such as OnStar.”

The blueprint plan also makes the following additional recommendations regarding “government fleets.” In the first two references, the same language is repeated in both Volumes 1 and 2 of the *California Hydrogen Blueprint Plan* (citations from the Volume 1 summary are provided):

1) California Hydrogen Highway Network “California Hydrogen Blueprint Plan: Volume 1,” Section 3.1 on “Points of Consensus from the Advisory Panel” (California Hydrogen Highway Network, 2005a, page 16)

“**Government fleets**, private fleets, and “early adopters” should be encouraged to purchase hydrogen vehicles based on technology and cost readiness.”

2) California Hydrogen Highway Network “California Hydrogen Blueprint Plan: Volume 1,” Section 3.2.1 on “Description of Phase 1” (California Hydrogen Highway Network, 2005a, page 17)

“**Early Phase 1 hydrogen vehicles are likely to be placed within fleets owned and operated by the State of California**, other government agencies, and private companies and individuals with vested interests in hydrogen vehicles.”

3) California Hydrogen Highway Network “Rollout Report,” Section 2 on “Hydrogen End Use Applications” (California Hydrogen Highway Network, 2005b, page 2-4)

“Encourage the Governor to challenge industry to build, and California residents and **State government** to buy, hydrogen-fueled cars.”

4) California Hydrogen Highway Network “Rollout Report,” Section 2 on “Hydrogen End Use Applications” (California Hydrogen Highway Network, 2005b, page 2-4)

“**Develop projects at government facilities** with a high public visibility profile:

- Stationary fuel cells at government sites
- Purchase hydrogen vehicles for government use.”

5) California Hydrogen Highway Network “Rollout Report,” Section 3 on “Commercialization” (California Hydrogen Highway Network, 2005b, page 3-3)

“**Encourage government to be first customers of technology and fuel.**”

6) California Hydrogen Highway Network “Rollout Report,” Section 6.7 on “Implementation Plan” (California Hydrogen Highway Network, 2005b, page 6-11)

“**Federal, state, and local agencies should work with automakers to develop and**

deploy fuel cell, hydrogen and hydrogen blend ICE vehicles as early as possible. Government entities, transit agencies, environmental organizations, and other early adopters should consider multi-year purchase commitments to reduce the uncertainty of the automakers and fuel providers.”

7) California Hydrogen Highway Network “Rollout Report,” Section 2.5 on “Mandates: Public Resources” (California Hydrogen Highway Network, 2005d, page 2-8)

“2.5.1 State and/or Local Agency Mandates

Require State and/or local agency fleets/garages to purchase hydrogen vehicles and deploy infrastructure that provides public access. Government fleet or fuel procurement standards might be employed.”

These references suggest that governmental agencies at all levels are expected to participate in this California Hydrogen Highway Network effort. The details of the implementation of these directives, to be undertaken through 2010 and beyond, will be guided through the biennial review process where the goals of these plans are periodically (every two years) reviewed and revised accordingly.

2.2.2 New York

The State of New York has been working on a “hydrogen roadmap” in an effort led by the New York State Energy Research and Development Agency (NYSERDA) and its contractor Energetics, Inc. Several “vision” workshops were held around the State during Fall 2004 and Spring 2005, to garner feedback from the public and invited experts. The hydrogen roadmap plan for New York was scheduled for an April 2005 release, but it still has not been unveiled as of June 2005.

Thus far, the New York State DOT has not been a major participant in the hydrogen roadmap activity but does have some involvement and is expected to participate further as the plan is developed and implemented, particularly regarding refueling station siting and permitting. One goal of the roadmap activity is to develop a plan for hydrogen to be available all along the throughway from New York City to Buffalo (Love, 2005).

New York has various hydrogen projects underway and planned, including stationary fuel cell demonstrations on Long Island, a few Honda FCVs that are being leased by the State in Albany, and a plan for six to ten (initially) heavy-duty hydrogen ICE conversion vehicles in Buffalo. The project involves Praxair, the State University of New York (SUNY) Buffalo, and the Niagara Frontier Transit Authority. The vehicles will refuel with by-product hydrogen from chlor-alkali production, as that area benefits from inexpensive hydropower along the Niagara River (Love, 2005).

In addition to the roadmap activity, New York is also engaging in hydrogen and fuel cell codes and standards review, education and outreach (e.g., “teaching the teachers”), and technology R&D activities.

2.2.3 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.

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 streamlined 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 battery? 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).



**Figure 3: Ford “H2ICE” E-450 hydrogen-powered shuttle bus.
Source: Ford Motor Company**

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 non-profit 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.

2.2.4 Michigan

Michigan has been aggressive in 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, non-profit 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; and
- 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 has 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.

2.2.5 Other State Hydrogen Programs

Colorado

The Fuel Cell Research Center has developed a \$12 million fuel cell demonstration program, 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 nine million dollars in funds in 2002, up from five million dollars 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, the two organizations are expecting to collaborate on hardware demonstration and testing activities at the DER Gateway and other locations.

Massachusetts

Massachusetts has a hydrogen roadmap planning activity underway, and several additional new hydrogen and fuel cell-related initiatives. The state is citing a potential demand for fuel cells of \$46 billion by 2011 and its high “density” of over 80 active fuel cell companies in its push to attract fuel cell industrial activity to the state. 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,” greater hydrogen and fuel cell education and outreach, increased 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), and
- 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—one of the nation's first alternative fuels incentives packages (Sullivan, 2005).

3.0 Review of Hydrogen and ITS Technologies for Potential “Integrated Hydrogen Infrastructure”

ITS technologies include a broad array of computer, communication systems, in-vehicle systems, sensors, display and signage, and other technologies. As defined by the Intelligent Transportation Society of America (ITS America, 2002, p. 13):

“Intelligent Transportation Systems (ITS) is the application of computers, communications, and sensor technology to surface transportation.

ITS encompasses technologies that can lead to:

- Better management and operations of the existing highway, public transportation and railroad infrastructure to ease congestion and respond to crises.
- Safer and more convenient travel for people.
- More efficient and secure freight movements.

Used effectively, ITS opens the door to new ways of managing, operating, expanding, refining, reconfiguring and using the transportation system.”

The *National Intelligent Transportation Systems Program Plan: Ten-Year Vision* by ITS America is organized around four “programmatic themes,” and four “enabling themes.” The programmatic themes are:

Programmatic Theme 1: An Integrated Network of Transportation Information,

Programmatic Theme 2: Advanced Crash Avoidance Technologies,

Programmatic Theme 3: Automatic Crash and Incident Detection, Notification and Response, and

Programmatic Theme 4: Advanced Transportation Management.

Programmatic Theme 4 on “Advanced Transportation Management” includes opportunities to reduce emissions through better signalization of arterials and better traffic flow on highways. The goal is to save “a minimum of one billion gallons of gasoline each year and to reduce emissions at least in proportion to this fuel saving” (ITS America, 2002, p. 27).

While not yet explicitly recognized in the plan, ITS technologies that assist in the refueling and operation of alternative fuel vehicles can also contribute to the goals—mentioned in the program and reinforced by various federal, state, and regional initiatives—of reduced gasoline and overall energy use and reduced air pollutant and greenhouse gas emissions.

Potential concepts that link ITS technologies and AFVs include:

- Worldwide web-based refueling location, route mapping, and other information services;

- “Smart refueling” systems that would use in-vehicle navigation systems and communication systems and protocols to locate and query nearby hydrogen refueling stations across a relatively sparse network of early stations;
- “Fuel reservation” systems, potentially linked to “smart refueling” above, whereby fuel could be reserved and paid for over the Internet or cell phone, thereby guaranteeing supply at a particular time and place;
- “Smart parking³” systems whereby alternative fuel vehicles would have prioritized parking rights in some locations as an incentive for vehicle purchase and use and where ITS technologies are used to optimize the parking supply (e.g., by allowing conventional vehicles to access parking spaces reserved for AFVs at transit connection centers after a certain hour in the morning);
- Smart carsharing (i.e., short-term vehicle rentals) services⁴ that incorporate AFVs; and
- Wireless “automatic vehicle locator” and “emergency response” systems that would allow users of AFVs that get stranded due to lack of fuel or vehicle malfunction to receive rapid response to incidents and information on nearby vehicle towing/repair and other helpful services.

These concepts are discussed in more detail below, following a brief review of relevant ITS technologies.

3.1 Brief Review of ITS Technologies Relevant to AFVs

Information technologies of primary interest for AFVs mainly relate the difficulty of locating fuel for some AFV types and identifying facilitates for vehicle refueling. Additional ITS applications include smart parking linked to the use of AFVs, smart carsharing services that use AFVs, and emergency response services for AFV operators who run out of fuel or experience a mechanical problem. The in-vehicle components of these systems are often referred to generally as “telematics” technologies, but in this case they are applied directly to facilitating the operation of, and in the case of carsharing, public exposure to the AFVs.

ITS technologies that can be used for these purposes include:

- 1) In-vehicle navigation systems;
- 2) Carsharing vehicle reservation and locator/mapping services;
- 3) Advanced vehicle location (AVL) systems;
- 4) Real-time reporting of operating performance of initial AFV prototype vehicles; and

³ For more information on smart parking management, see Shaheen *et al.*, 2005a.

⁴ For more information on carsharing services, see Barth and Shaheen, 2002 and Shaheen *et al.*, 1998.

- 5) Additional vehicle-to-station and vehicle-to-vehicle communications systems and protocols.

These technologies can be combined and bundled in various systems, using user interface protocols that include worldwide web interfaces (e.g., 511.org and Travelocity), cellular phone portals (e.g., 511), Bluetooth for short range interfaces, and physical interfaces such as smartcards and electronic key fobs. Additional communications protocols (such as dedicated short range communications or DSRC) also could be employed for certain applications, such as using AFVs in government fleets as “probes” for real-time traffic condition monitoring systems.

3.2 Web-Based Vehicle Fuel Location and Route-Mapping Services

Web-based vehicle fuel location and route mapping services would aid users of AFVs by showing refueling locations on vehicle navigation systems and providing directions to the stations. These systems could be further enhanced with communication systems to provide real-time fuel availability and reservation services (see next section below).

The U.S. Department of Energy (DOE) Alternative Fuels Data Center operates a fueling infrastructure database that includes data on the locations of stations that dispense compressed natural gas (CNG), liquefied petroleum gas (LPG or propane), liquefied natural gas (LNG), 85 percent ethanol (E85), electric, biodiesel, and hydrogen. The database is available through a website that allows users to search for stations, display maps of stations in a region, print tables of stations in a region, and also that includes a route mapping system with driving directions.⁵ Figure 4, below, shows a map that indicates the two hydrogen stations currently located in the Sacramento area.

⁵ The U.S. DOE Alternative Fuels Data Center fueling station website is:
<http://www.eere.energy.gov/cleancities/vbg/fleets/fueling.html>.



[Help](#) [New Station Search](#) [New Route](#)



2 Hydrogen Refueling Station(s) Found
Around: Sacramento, CA
Within Radius: 25 Mile(s)

Figure 4: U.S. DOE alternative fuels data center map showing hydrogen-refueling locations in the Sacramento, California area.

3.3 In-Vehicle Station Identification and Navigation Systems

In-vehicle navigation systems, becoming more popular especially for fleet vehicles and high-end consumer models, can be used to identify refueling locations. Several existing systems include the ability to locate gasoline stations, and this could be extended to refueling locations for other types of fuels.

The first prototype vehicle to include an in-vehicle navigation system that identifies refueling locations is the 2005 Honda FCX vehicle. This system incorporates voice-activation to identify station locations and distances and to provide driving directions. The system currently includes 26 stations in its database, including 17 in California (American Honda Motor Company, 2005).

3.4 Smart Refueling and Fuel Reservation Services

Smart refueling systems would combine information on refueling station locations, such as the database maintained by the U.S. DOE, with the ability to query the station in real-time to assure station operations and adequate fuel supply for refueling at the time required. Since having a more predictable demand is beneficial for the economics of fueling station operation, suppliers may be willing to supply a discount to users who were willing to pre-pay and reserve fuel in advance. This “mutual assurance” on the user- and supply-end could help to smooth the introduction of new alternative fuels, such as hydrogen, which has particularly challenging needs with respect to the economics of fuel storage and compression/liquefaction.

This smart hydrogen refueling concept has been briefly noted, but it was not elaborated upon, in one of the California Hydrogen Highway Network topic team reports:

- California Hydrogen Highway Network “Public Education Report,” Section 7.2 on “Recommendations” (California Hydrogen Highway Network, 2005c, page 7-3)

“Provide information about location of hydrogen fueling stations to early consumers while expanding awareness of availability of hydrogen products to the public at large:

- Work with Caltrans to develop and install directional signs for hydrogen fueling locations.
- *Work with industry to ensure that refueling locations are readily identifiable via onboard telematics technologies, such as OnStar.*

3.5 Smart Parking and AFVs

One mechanism considered to offer an incentive to purchase socially desirable vehicles is preferred parking at transit stations, shopping malls, and other locations. “Smart” parking systems would facilitate this by directing AFVs to available parking resources and making sure they were properly credited with incentives provided in a particular location. The technological and policy-related structures of these arrangements could vary significantly, and they would be tailored to the needs of a particular setting.

3.6 Smart Carsharing and AFVs

Several efforts around the world have combined the use of AFVs with “smart” carsharing, where onboard telematics systems, including AVL services are integrated with user reservation and billing systems to make carsharing operations operate more effectively.

The most notable efforts to combine AFVs with smart carsharing include the Praxitele “station car” experiment in France, and CarLink, Intellishare, and ZEV-NET in California.

The Praxitele experiment used battery electric vehicles (BEVs) in a carsharing arrangement in Paris for two years, from late-1997 through July 1999. This project used 50 BEVs, provided by Renault, in a “dynamic” test of carsharing where users could return a vehicle to a different station (or “carsharing lot”) than they borrowed it from (also known as one-way rental). The electric vehicles were reported to operate quite well with very few breakdowns, but there were a few difficulties with induction charging during the winter months (Massot *et al.*, 1999).

The CarLink I project used 12, 1998 model natural gas-powered vehicles developed by Honda Motor Company, along with a “smart” vehicle reservation system that allowed users to reserve carsharing vehicles when linking to transit on the “home” and “work” end of a trip. The field operational test ran for an initial nine-month period and then a second phase (Carlink II). Data were collected (using surveys and focus groups) on user response to the system and the extent to which use of the system helped people to replace private vehicle use (Shaheen, 1999).

Zero-Emission Vehicle – Network Enabled Transport (ZEV•NET) is a concept developed by Toyota Motor Company and UC Irvine that combines distributed generation of electrical power and shared-use EVs. In the ZEV•NET scheme, EVs are recharged at a commuter train station using a combination of a stationary fuel cell system and solar photovoltaic (PV) panels. The EVs are used by commuters during the day, and also can be taken home by “home side” commuters in the evening where they also can be recharged using home charging stations. ZEV•NET is currently operating under the “corporate model” where companies and other organizations can subscribe to a service where two or four vehicles are made available to employees of the company. The program is being operated by UC Irvine’s National Fuel Cell Research Center and Institute of Transportation Studies (ZEV-NET, 2004).

Finally, similar to the carsharing initiatives, described above, in many respects, UC Riverside’s “Intellishare” system is currently operating approximately a dozen Honda Motor Company BEVs around the campus with three primary stations, including instant rentals (no reservation required), reservations, and one-way rentals. The system includes reservation and real-time (web-based) vehicle locator services. The operators of the system have plans to expand the system to 36 vehicles and five stations in an upcoming phase (UCR CE-CERT, 2005).

3.7 Automatic Vehicle Location Services and AFVs

AVL services may be particularly important for range-limited vehicles such as BEVs and early hydrogen-powered vehicles due to the possibility of running out of fuel or experiencing a failure with these types of vehicles. As discussed above, these services are being recommended for use by fuel cell vehicles in the California hydrogen blueprint plan. Vehicle ranges are expected to increase for hydrogen vehicles with improvements in storage technology, and for battery vehicles with improvements in batteries. However, early generations of these vehicles will be limited to ranges as low as 100 miles in some cases, and therefore may require AVL services more frequently than conventional vehicles. AVL systems for AFVs could have characteristics tailored for those vehicles, such as emergency response providers that have received training in a certain type of response situation (e.g., hydrogen tank rupture or electric system failure).

3.8 Real-Time Reporting of Operational Conditions and Performance of AFVs

Another option for combining ITS technologies with AFVs is the real-time reporting of operational conditions and performance of AFVs that are used in prototype and pre-commercial technology demonstration projects. For example, under its current test program with the U.S. DOE, DaimlerChrysler is collecting information on the operations of the vehicles using computers stationed at each host site.

4.0 Concepts for Linking Transportation and Stationary Power Systems With Potential ITS Enhancements

In addition to concepts through which ITS can be used to enable and enhance the deployment of AFVs, there also are linkages between transportation systems and stationary electrical power that offering interesting potential deployment synergies. These developments are made possible by rapid developments in yet another technology field—electrical power generation—for relatively small-scale (e.g., one kilowatt to ten megawatts) power production. These “distributed energy resource” (DER) or “distributed generation” systems include reciprocating engines, microturbines, stationary fuel cells, photovoltaic and small wind turbine arrays, and energy storage, with the opportunity in some cases for waste heat recovery for “combined heat and power” (CHP). Some of these DER concepts also lend themselves to integration with information technologies to enable communication, enhance functionality, enhance deployment potential, and help to optimize system operation and performance.

This section of the report briefly discusses various distributed power generation systems that may lend themselves to integration with transportation and ITS systems. Also included are some details of a few specific projects that have been conducted or are in progress that have linked stationary power generation and transportation.

Concepts for linking DER and transportation can be classified into two broad categories:

- 1) Concepts that combine DER systems with refueling for advanced technology vehicles, and
- 2) Actually using advanced technology vehicles as DER systems or as part of a larger DER system.

With regard to the first category, concepts include “hydrogen energy stations” that would co-produce electricity for local building loads and/or utility grids along with hydrogen to refuel hydrogen-powered vehicles, and using DER resources to recharge electric vehicle types that require periodic battery recharging. In the second category, electric-drive vehicles themselves (or their powerplants, apart from the vehicles) would act as distributed power generators and/or as providers of utility grid ancillary services.

4.1 DER Systems and Refueling for Advanced Technology Vehicles

Promising advanced vehicle types for addressing energy and environmental concerns associated with transportation include BEVs, hybrid electric vehicles (HEVs), hydrogen-powered internal combustion engine (ICE) vehicles, and hydrogen fuel cell vehicles (FCVs), among others. These vehicle types would in some cases require a different fuel than the gasoline or diesel fuel that has traditionally been used for vehicle refueling. BEVs and some types of HEVs would use electricity to refuel their batteries, and hydrogen-powered vehicles would need to refuel with hydrogen.

Combining refueling systems for AFVs with DER systems could be attractive for several reasons. First, BEVs and “plug-in” HEVs would require grid power for battery recharging, and while recharging these vehicles off-peak would not require additional power generating capacity, any recharging that would occur during grid peak demand periods would require additional capacity to be installed. The additional capacity could be in the form of DG, with the advantages of reduced transmission and distribution losses and the possibility of using renewable DG for electricity production to maximize the environmental benefits of these vehicles. Second, hydrogen-powered vehicles require a hydrogen refueling infrastructure, but there is a “chicken or the egg” problem associated with creating this infrastructure. Consumers will not purchase hydrogen-powered vehicles without reasonable access to refueling locations, but the economic case for developing this infrastructure for what will initially be small numbers of vehicles is a difficult one.

4.2 Hydrogen Energy Stations

One potential solution to this problem is to provide hydrogen refueling in conjunction with distributed electricity production, with what have come to be known as “hydrogen energy stations” (or ‘energy stations’ for short).⁶ These stations would primarily be designed to produce electricity using stationary fuel cells running on hydrogen, but they would also include a hydrogen-vehicle refueling component. By in effect using the electricity cost savings from the DG part of the system to subsidize the hydrogen refueling part, these energy stations can have more attractive economics than dedicated hydrogen refueling stations, particularly for low numbers of vehicles supported (e.g., five to 50 vehicles refueled per day).

California’s Hydrogen Highway Network initiative specifically calls out the possibility for “hydrogen 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 Plan further explores these stations and their potential application, and it suggests (based on estimates provided by the California Stationary Fuel Cell Collaborative) that five energy stations are expected to be deployed in the State by 2010, out of 50 to 100 total hydrogen-dispensing stations.

These energy stations would be either dedicated refueling facilities or a key component of the energy production, use, and management portion of a commercial or industrial facility. The energy station component would consist of a natural gas reformer or other hydrogen generating appliance, a stationary fuel cell integrated into the building with the potential capability for CHP

⁶ Note that here we are distinguishing between “hydrogen energy stations” that co-produce electricity and hydrogen and “hydrogen stations” that dispense hydrogen that is either delivered or produced onsite, but with no electricity co-production as part of the operation.

production and a hydrogen compression, storage, and dispensing facility.

In essence, energy stations would seek to capture synergies between producing hydrogen for a stationary fuel cell electricity generator that provides part or all of the power for the 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.

Many different types of hydrogen energy stations are possible. These stations could be primarily designed to produce hydrogen for vehicles, electricity for local building loads, 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. Table 1, below, presents four potential types of hydrogen energy stations and their basic characteristics. The economics of several of these station types are discussed in Lipman *et al.* (2002) and also are reviewed in the California Hydrogen Highway Network “Economics” Topic Team Report.

Table 1: Four Potential Types of Hydrogen Energy Stations

	Vehicle Refueling Energy Station	DG Energy Station	Utility Support Energy Station	Residential Energy Station
Location	Service station	Commercial or industrial facility	Utility substation	Home or apartment building
Primary Purpose	Hydrogen refueling for vehicles	Electricity production	Local distribution grid support	Hydrogen refueling for vehicles
Vehicles Refueled	5-500 per day	5-50 per day	5-50 per day	1-10 per day
Approximate Fuel Cell Size	25-50 kW	100-1000 kW	100-500 kW	1-50 kW
Key Issues	<ul style="list-style-type: none"> • DG/fuel cell economics with low electrical loads 	<ul style="list-style-type: none"> • Utility tariffs and interconnection rules • Public access for refueling? 	<ul style="list-style-type: none"> • Public access for refueling? 	<ul style="list-style-type: none"> • Natural gas costs • Economics with low electrical loads

A number of energy 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. The following sections discuss the energy stations that have been built or proposed to date, and that have been publicly disclosed.

4.2.1 The Las Vegas Hydrogen Energy Station

The world's first hydrogen 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 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 it is at present using hydrogen that is being delivered from an industrial hydrogen production facility rather than produced onsite. Figure 5 presents a picture of the Las Vegas station.



**Figure 5: The Las Vegas hydrogen energy station.
Source: Air Products and Chemicals, Inc.**

4.2.2 The Toronto Hydrogen Energy Station

The world's second hydrogen 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 Exhibition 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 it will demonstrate the use of fuel cell technology to enhance the productivity and reduce the emissions of work vehicles. In a "Phase 2" in 2004, the system was capable of providing continuous power to the trade center as well as emergency backup power. And in a "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. 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 (City of Toronto, 2004). Figure 6, below, presents a picture of the "Phase 1" Toronto station.



**Figure 6: The Toronto hydrogen energy station.
Source: City of Toronto, 2004**

4.2.3 The Diamond Bar, California Hydrogen Energy Station

The South Coast Air Quality Management District (SCAQMD) partnered with Stuart Energy Systems for construction of an electrolyzer-based hydrogen energy station at SCAQMD's Diamond Bar, California headquarters location. The project, started in 2003 and operational in 2004, uses an electrolyzer to produce hydrogen for hydrogen-powered vehicles as well as a 120-kW hydrogen internal combustion engine generator set to produce electrical power. The power module is being used for peak-shaving and backup power. This is the first permanent energy station (with co-production of electricity and hydrogen) to open in California (Stuart Energy Systems, 2003; 2004).

4.2.4 The Honda/Plug Power Home Energy Station in Torrance, California

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 proton exchange membrane fuel cell, a refiner to purify the hydrogen, a hydrogen compressor, a high-pressure storage tank, and a fuel dispenser. The system is designed to operate on natural gas, provide power for its own operations as well as local electrical loads and/or grid export using the fuel cell, 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. As shown in Figure 7, below, the system is being demonstrated at a Honda office complex in Torrance, California (Plug Power, 2003).



**Figure 7: Demonstration of the Honda/Plug Power hydrogen energy station.
Source: Plug Power, 2003**

Finally, additional hydrogen energy stations have been proposed for Oakland, California (ChevronTexaco and Alameda County Transit), UC Davis (ChevronTexaco and Air Products and Chemicals), and Chino, California (ChevronTexaco and United Technologies Fuel Cells). A more refined energy station design by ChevronTexaco, proposed for the above projects, is presented in Figure 8.



**Figure 8: ChevronTexaco hydrogen energy station design,
Source: ChevronTexaco Technology Ventures**

4.3 Distributed Power Generation for Recharging Battery EVs and Plug-in HEVs

EVs that require electrical power to refuel include battery EVs, plug-in HEVs (which would refuel with both electricity and gasoline or another combustible fuel), and FCVs or other hydrogen vehicles that operate on hydrogen produced from electrolysis.⁷ For all of these vehicle types, significant potential exists to take advantage of off-peak periods for electrical grids and to refuel the vehicles without significant power system capacity additions. However, to the extent that some on-peak electrical use will be required—potentially for hydrogen compression and/or liquefaction as well as actual vehicle refueling—the installation of DG systems in conjunction with vehicle refueling infrastructure could provide the necessary additional peak power without the need to construct additional centralized “peaker” power plants. Furthermore, some DG systems may actually have favorable economics compared with grid power, particularly in some utility service territories in California (and other “high cost” electricity states), and providing the power required to refuel vehicles from DG could then be economically advantageous.

⁷ Electrolysis is a means of producing hydrogen from electricity and water, where the electricity is used to split water molecules into hydrogen and oxygen.

4.4 Another Type of Energy Station – DG Linked to Electric Transit

Another type of “energy station” would involve linking DG resources with electric transit systems to produce power for the transit systems, as well as potentially local loads and/or grid export. Large commuter rail and light-rail systems use considerable amounts of electricity, typically supplied through a high-voltage direct current (DC) “third rail.” Transit systems may find it attractive to install DG systems, particularly where waste heat from the systems could be used (e.g., in train station facilities or adjacent office buildings) for CHP and improved project economics. We note that fuel cell systems and other systems that fundamentally produce DC power could produce power directly for these DC-based transit networks without incurring the costs and efficiency losses of alternating current inverters.

4.5 Electric-Drive Vehicles as DER Sources or Components – “Vehicle-to-Grid” Power

A rather astounding fact is that the gross power generating capabilities of the motor vehicle fleets in California and the rest of the U.S. are enormous, and in fact, they dwarf the power generating capability of stationary powerplant generation. While at present this power is mainly in the form of mechanical rather than electrical power, a hypothetical electrified vehicle fleet in the U.S. would have approximately 14 times as much power generating capacity as all of the stationary power plants in the country.

As the market for various types of EVs continues to develop, the possibilities will emerge for using this power generating capacity in interesting ways. These include V2Gpower, where vehicles produce power and/or grid ancillary services for traditional building electrical loads and utility grids, as well as other potential arrangements where EVs interact with “microgrids” and remote renewable power systems.

Figure 9, below, shows one concept for EVs to produce the utility grid ancillary service of grid frequency regulation, using several novel technologies in combination. These include a vehicle with a battery system or other electrical device capable of producing and/or absorbing electrical energy, a radio frequency signal of local utility grid frequency, global positioning system (GPS)-based vehicle location, a centralized grid operation center, and an Internet-based service aggregation and administration system (AC Propulsion, 2002).

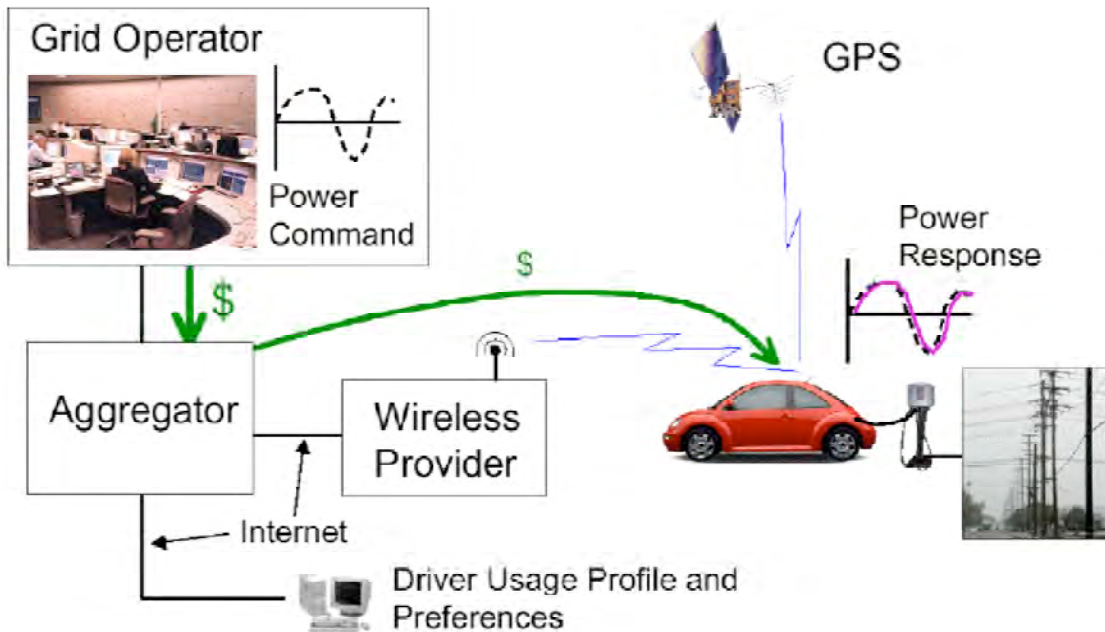


Figure 9: EVs acting as electricity grid frequency regulation service providers.
Source: AC Propulsion, Inc., 2002

Little actual demonstration project activity has yet occurred with regard to V2G power. However, the concept of V2G power appears to be gaining momentum, particularly in the U.S., Germany, and Canada, and we expect more demonstration activity in the near future. The most noteworthy demonstration to date does not use EVs for power *per se*, but rather it uses fuel cell powerplants that have been developed for vehicle applications in a stationary power setting. It is also worth noting that Hydrogenics, Inc., a Toronto, Canada-based fuel cell system and fuel cell test station developer, has recently acquired a fuel cell V2G power patent that was filed several years ago by a New Jersey company, and the company has shown considerable interest in pursuing the V2G concept commercially.

4.5.1 GM and Dow Chemical Vehicle/Stationary Fuel Cell Demonstration

In a notable development with regard to the use of automotive fuel cell systems for distributed power generation, General Motors and Dow Chemical teamed in 2003 to couple the use of GM's fuel cell systems, mounted into tractor trailer trucks, with one of the largest chemical plants in the world. This chemical plant, in Freeport, Texas, covers 30 square miles and produces significant quantities of by-product hydrogen. Under the General Motors/Dow agreement, reportedly worth \$50 million, Dow will provide hydrogen to the General Motors fuel cells and purchase the electricity that is produced for use in its onsite operations (Auto Insider, 2003).

The plan struck by the two companies calls for the initial 75 kW fuel cell system to be accompanied by 12 more, for a total generating capacity of 1 MW. The agreement, reportedly worth \$50 million calls for a potential full-scale level of up to 35 MW over seven years—equivalent to a fleet of 400 FCVs. Since that 35 MW would produce only two percent of the Dow facility’s energy needs, the company expects to reach the 35 MW level ahead of the seven-year scale up plan. In a particularly interesting aspect of the project, the fuel cells will be operated on automotive cycles to mimic use in FCVs, with simulated acceleration and deceleration, rather than typical stationary fuel cell system patterns of operation (Auto Insider, 2003).

4.5.2 AC Propulsion V2G Demonstration

AC Propulsion, Inc., a San Dimas, California manufacturer of electric drive systems for vehicles, demonstrated its V2G system with the company’s “Gen-2” AC150 drivetrain at the Electric Transportation Industry conference in Sacramento in December 2001. This drivetrain has been engineered to allow reverse power flow from EVs that incorporate its controller/inverter. AC Propulsion demonstrated a Volkswagen “Beetle,” which was converted to be a BEV, performing a grid ancillary service dispatched remotely via wireless Internet (AC Propulsion, 2002).

4.6 The Economics of Vehicle-to-Grid (V2G) Power

Vehicles with significant onboard electrical generating capability can generate power and other grid services efficiently and for various uses, many of which have economic value that could translate into reduced ownership costs for these new vehicle types. Kempton *et al.* (2001) conducted the most comprehensive published analysis of the potential for EVs to act as DER system components. This report was prepared for the California Air Resources Board by researchers at the University of Delaware, Green Mountain College, and the University of California. The analysis also involved collaboration with EV drivetrain manufacturer AC Propulsion, Inc., whose “Generation 2” electric motor controller unit allows for bi-directional grid interface that can support V2G connections. The Kempton *et al.* effort examined the economic potential of using various types of EVs to produce power for buildings and the grid, as well as to provide grid “ancillary services,” such as spinning reserves, non-spinning reserves, and grid frequency regulation.

Table 2, below, presents some of the key findings of the Kempton *et al.* 2001 report in terms of the range of annual values that might be expected for different EV types and for three different power generation or ancillary services. The results are highly variable among vehicle types, but they show that annual returns to vehicle owners could amount to as much as a few thousands of dollars per year, depending on the vehicle type and ancillary service provided as well as how much of this potential income would be lost due to the transaction costs associated with bidding these services into electricity markets.

Table 2: Vehicle Owner's Potential Annual Net Profit from V2G

Vehicle Type	Peak Power	Spinning Reserves	Regulation Services
Battery EV (full function)	\$267 (510 – 243)	\$720 (775 – 55)	\$3,162 (4479 – 1317)
Battery EV (city car)	\$75 (230 – 155)	\$311 (349 – 38)	\$2,573 (4479 – 1906)
Fuel Cell EV (on-board H₂)	\$-50 (loss) to \$1,226 (2200 – 974 to 2250)	\$2,430 to \$2,685 (3342 – 657 to 912)	\$-2,984 (loss) to \$811 (2567 – 1756 to 5551)
Hybrid EV (gasoline)	\$322 (1500 – 1178)	\$1,581 (2279 – 698)	\$-759 (loss) (2567 – 3326)

Source: Kempton et al., 2001

Note: The figures represent \$net and (revenue – cost). These are representative mid-range figures extracted from full analysis in the report.

4.7 Advanced Vehicles and “Microgrids”

Additional options for integrating advanced technology vehicles with DER systems include incorporating EVs into designs for “microgrids.” Microgrids are small clusters of DER technologies that act together to supply power and heating/cooling to one or more adjacent buildings, and that would connect with the main grid at one interface point. Microgrids could act as “model citizens” for the grid by supporting it in various ways, and they could also benefit themselves from supplying local generation with grid power at various times (depending on electricity rate schedules and other variables). Battery EVs, plug-in HEVs, and FCVs could play interesting roles in microgrids by supplying electrical storage and/or power generation capability, particularly with the availability of the EV resources coinciding with the arrival of people at various commercial and industrial microgrid locations and their associated energy needs.

4.8 Advanced Vehicles and Renewable Energy Systems

Similarly, EVs could help to provide additional power and “buffering” for small standalone renewable energy systems based on PV and wind power, along with a battery storage system. Small renewable systems that are “off-grid” because of their remote location are becoming increasingly common, but often are of relatively low power to keep costs low. Again, these systems could be bolstered by the use of EVs to provide additional power to operate high-power

equipment for short periods of time, thereby allowing the size of the remote renewable system to be minimized.

4.9 Heavy-Duty Trucks and DER Systems

Finally, another interesting opportunity for combining motor vehicles and distributed energy systems involves efforts to reduce emissions from heavy-duty diesel trucks. Approximately 30% of the fuel use and emissions associated with long-haul diesel trucks is due to the idling that these trucks do when they are stopped, primarily in order to support electronic devices in the truck cabin (refrigerator, microwave, television, climate control, etc.) by operating a generator with the main diesel engine (Brodrick et al., 2002). This is highly inefficient and polluting, and efforts are underway to examine opportunities for reducing these emissions. Furthermore, some diesel powered utility vehicles may be used for construction and maintenance activities that require the engine to be operated to produce electrical energy for power tools and other equipment, using a generator that operates from the shaft power of the engine. There are a variety of options for providing these same services with greater efficiency and lower emissions.

One such option would be to equip trucks with fuel cell auxiliary power units (APUs), running on pure hydrogen or possibly diesel fuel that is converted into a hydrogen-rich gas stream with an onboard fuel reformer. If operated on hydrogen, these heavy-duty truck APU systems could be refueled with hydrogen produced at truck stop hydrogen stations, possibly from one of the energy station designs discussed above. In that case, hydrogen would be used both for truck APU and FCV refueling, as well as to produce electrical power and heat for the truck stop using a stationary fuel cell.

An alternative to using fuel cells as APUs onboard the trucks would simply be to have the trucks “plug in” to electrical outlets when near truck stops, and the electricity could be supplied either by the main utility grid or by a DG system at the truck stop. This would only reduce idling near truck stops, but it would perhaps be easier to implement than the fuel cell option. Also note that both of these types of installations would be good candidate for integration of renewable PV or (if remote sites) wind power to further reduce environmental impacts.

The opportunities for using ITS to enhance the use of these vehicles are similar to those of other AFVs. These include querying nearby fueling locations for availability of hydrogen and possible V2G power or “mobile electricity” applications (e.g., using the APUs for construction site power, backup power, additional power for remote “off-grid” locations, etc.) enhanced by communications and monitoring technologies. For example, for critical power field applications where a power interruption would be disruptive, APUs mounted on construction and maintenance vehicles could be used to provide backup power for a primary power source (e.g., a standalone generator), with a system monitoring and control system that would automatically supply the backup power from the vehicle in the event that it was needed to prevent a power interruption.

5.0 Recommendations and Conclusions

This project has reviewed state and federal DOT activities around the U.S. relating to the use of hydrogen for transportation, existing and emerging ITS technologies and concepts that might be integrated with the use of AFVs, and recent developments in distributed power generation in the electricity sector that have potential linkages with AFVs and ITS.

The primary objectives of this research were to:

- 1) Investigate the status of hydrogen research activities around the U.S. state and federal DOTs;
- 2) Examine potential hydrogen/ITS field test projects; and
- 3) Help to position Caltrans to participate in additional clean vehicle demonstration and implementation activities, including potential hydrogen infrastructure projects and programs.

This project is intended to be the first step in a potentially larger project to demonstrate and test one or more technological systems that combine ITS and AFVs, in a way that is compatible with and potentially able to advance Caltrans' goals. A few ideas for actual deployment/field operational test projects are discussed below, which could be further developed through Caltrans' Division of Research and Innovation.

With further implementation of one or more of the projects of the type suggested in this study, we would expect that Caltrans' stewardship goal to be advanced by improving the environmental performance (and ultimately the economic performance) of Caltrans' operations. We further expect this goal to be advanced through Caltrans' efforts to assist the State in improving the overall environmental and energy performance of the transportation system more generally through the development and implementation of clean vehicles and energy technologies. Further progress in R&D efforts with clean fuel vehicles and ITS can also help to further the CTP goals of "Enhancing the Environment," "Supporting the State's Economy," and "Promoting Community Values."

5.1 Recommendations for an Integrated ITS/Hydrogen Vehicle Field Operational Test

Based on our analysis of the existing status of hydrogen-powered vehicle demonstration programs and potentially complementary ITS technology, we suggest that a particularly promising area for further research is the combination of vehicle mapping and navigation systems with web-based databases of refueling system locations. These systems could then be combined with additional communications protocols (e.g., cell-phone based to add real-time station querying and fuel-reservation capabilities). This system could help to optimize the operation of early hydrogen refueling stations and, at the same time, make hydrogen-powered vehicle use more attractive for State and private fleets, and eventually private consumers as well.

We believe that a “smart hydrogen refueling” demonstration of this sort would be the most attractive idea for further development at this time due to the following factors:

- 1) In-vehicle navigation and telematics systems are becoming widely available on high- and even some mid-range vehicles;
- 2) There is great interest in California for the use of hydrogen for transportation and dozens of prototype vehicles being introduced into the State, but, due to storage limitations, most of the hydrogen vehicles are limited to 100 to 150 miles per fill of hydrogen;
- 3) Communication technologies and protocols exist that would make development of this type of system possible for a near-term demonstration;
- 4) In addition to providing convenience and security on the vehicle-user side, hydrogen fuel reservation systems have the potential to benefit fuel providers who must optimize hydrogen storage, reformer/electrolyzer, compressor, and fuel dispenser operation; and
- 5) Development of vehicle-to-station fuel availability/reservation systems is a new business area that is of interest to both automotive and fuel providers.

The confluence of these factors—combined with the interest that the report’s authors have received based on initial consultations with various parties at Caltrans, other State agencies, and the private sector—suggests that the time is opportune for a real-world demonstration project of this sort.

A longer list of ideas for potential deployment projects involving the use of ITS and hydrogen-powered vehicles includes:

- 1) Smart hydrogen refueling (prioritized here);
- 2) AVL for hydrogen fleet vehicles, with enhancements such as real-time fuel tank status, system operation warnings, etc.;
- 3) Hydrogen-powered vehicles combined with smart carsharing;
- 4) V2G power with one or more FCVs (or plug-in HEVs) that are equipped with ITS-based interfaces for power flow metering and communications with electric grid system operators;
- 5) A “superbus” project where a hydrogen-powered transit bus is also equipped with the latest ITS telematics technology to optimize its operation and potentially to help attract ridership in conjunction with “hot lanes” for transit vehicles at peak times; and
- 6) A full-fledged “microgrid” demonstration⁸ showing a “power park” of the future with DER and CHP and with “plug in” HEVs and/or FCVs acting as

⁸ This would be conducted in a way heavily leveraged with other partners already underway with this proposed effort?, such as the U.S. Department of Energy, the Consortium for Electricity Reliability Solutions or the Distributed Utility Integration Test.

smart and responsive fleet vehicles that double as storage systems to help to optimize the operation of the microgrid and the “macrogrid” to which it is attached.

5.1.1 Potential “Smart Hydrogen Refueling” Field Operational Test

We suggest a field operational test where one or more hydrogen-powered vehicles are equipped with navigation systems that are then configured to display actual and (for research purposes) hypothetical hydrogen refueling networks. Investigations would focus on using various types of information and communications systems with various users and situations and determining what technologies and protocols appear to offer the most useful functionality at the least cost and effort.

As an overall plan, we suggest that a three-stage investigation of these synergistic hydrogen/ITS system concepts be considered, with two additional stages building on this initial assessment. This staged approach could be pursued as follows:

- 1) First, an initial assessment and broad scoping document (such as this report);
- 2) Second, a more detailed feasibility study of a specific scheme with a detailed implementation plan, including technical feasibility, cost estimates, administrative requirements, etc.; and
- 3) Finally, a FOT of an interlinked hydrogen refueling/ITS system in a “smart hydrogen refueling” demonstration project, to be co-funded between industry and governmental partners.

The goal of the FOT would be to experiment with different refinements of the vehicle navigation system with respect to displaying refueling station information, development of protocols for communication between vehicle and station (e.g., to confirm fuel availability), and examination of potential systems for reserving and paying for fuel in advance, among other areas of investigation.

As noted in this report, several UC campuses and other research groups have already partnered with all of the largest automakers and various other groups in conducting various initial investigations that combine AFVs and ITS or AFVs and DER. The efforts that have been the most sophisticated in the first regard have not included DER, while a few initial efforts have begun to bridge all of these areas (e.g., ZEV•NET and *EasyConnect*⁹). This effort would combined AFVs and ITS in a novel way, and that might have further connections with DER through the concepts of “hydrogen energy stations,” “V2G power,” and/or “microgrids.”

We suggest an effort that is leveraged with private sector partnership and support (e.g., from an automaker and/or fuel provider and/or telematics/navigation system company) and that

⁹ *EasyConnect* is an integrated transportation and energy demonstration and educational effort underway by ITS-Berkeley and California PATH as part of a new “transit oriented development” in Northern California. For more information on *EasyConnect*, see Shaheen *et al.*, 2005b.

potentially consists of a “two-pronged” effort that allows for real-world tests to be conducted in two different geographical locations (e.g., Northern and Southern California). This would allow for additional learning from the field tests associated with geographical and demographical differences, different networks of partners and suppliers in the two regions with which Caltrans and the other project partners might wish to interact further in the future, etc. This set of field tests could be leveraged and economized by combining tasks related to common research design but then conducting parallel deployment efforts. Additional project partners might include the CAFCP, the California Environmental Protection Agency (and California Air Resources Board), and/or the California Energy Commission.

5.2 Conclusions

This investigation has examined: 1) state and federal DOT activities around the U.S. relating to the use of hydrogen for transportation (and especially the California Hydrogen Highway Network initiative); 2) existing and emerging ITS technologies and concepts that might be integrated with the use of AFVs; and 3) recent developments in distributed power generation in the electricity sector that have potential linkages with AFVs and ITS.

Based on this initial investigation, we conclude with the following observations:

- 1) Several states are competing with California to develop hydrogen plans and to attract the emerging hydrogen and fuel cell industry to their states, including most notably New York and Florida;
- 2) The DOTs in these states have, for the most part, been interested observers to this point, but they are beginning to be drawn into hydrogen activities in the most active states, and in some cases, they have been clearly identified as expected project partners;
- 3) The U.S. DOT is conducting activities at a relatively modest but significant level, particularly with respect to codes and standards development and with hydrogen transit buses;
- 4) Hydrogen activities will be continued for FY 2005/2006 at the U.S. DOT under the newly created RITA, taking over from the former RSPA in most respects;
- 5) The *California Hydrogen Blueprint Plan* contains several references to Caltrans as potential key partners in hydrogen projects, particularly related to partnering on hydrogen station siting and starting to incorporate hydrogen-powered vehicles in its fleets;
- 6) Many different ITS technologies are applicable to the potential introduction of new AFV types, particularly with regards to the challenges of developing new vehicle refueling networks for hydrogen-powered vehicles and to enabling potential V2G power schemes; and

- 7) Emerging technologies and concepts for distributed generation of electrical power have potential technological and economic interactions with hydrogen vehicle and refueling systems and ITS.

Finally, we recommend a list of potential concepts to be considered for a real-world demonstration along the lines of the technology sets and interactions that we have explored in this study. Of the options, we believe that a “smart hydrogen refueling” field test is the most attractive based on timing, technology availability, and potential interest for Caltrans—but also significant national and global interest as well.

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