INTEGRATED HYDROGEN FUEL INFRASTRUCTURE RESEARCH AND TECHNOLOGY DEVELOPMENT

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Abstract

The task seeks to establish an integrated hydrogen fuel infrastructure research and technology development effort. The long-term goal is to establish an initial hydrogen fueling infrastructure in several key locations, beginning with California, that will lead to development of a national infrastructure required to meet market demand by hydrogen-fueled vehicles. The task also seeks to establish integrated hydrogen safety codes and to establish a rationale for long-term hydrogen RD&D investments through scenario planning and analysis.

Introduction

The major objectives this year are to establish a comprehensive government industry approach to hydrogen infrastructure research and technology development. The rationale is to establish the framework and process for R&D and for government-industry guidance for this comprehensive approach. This approach includes preparation of an overall approach to infrastructure R&D (the Blueprint) and a government-industry team (the Core Team) to provide overall guidance. For codes and standards, a proposal was submitted to the Executive Committee of the International Code Council (ICC) to establish an ad hoc committee of code officials and hydrogen experts to consider establishing a comprehensive code for hydrogen safety under the ICC's model code format and process. The task also provides technical support to the DOE Hydrogen Technical Advisory Panel (HTAP), especially in the areas of scenario planning and fuel choice, to facilitate strategic guidance by the HTAP on RD&D priorities and interagency coordination at the federal and state levels.

Results

Hydrogen Infrastructure Activities

In October 1999, the U.S. Department of Energy (DOE), the California Air Resources Board (CARB), and the California Energy Commission (CEC) co-sponsored a workshop to answer the question: *What has to be done, beginning today, to implement a hydrogen fuel infrastructure so that when hydrogen vehicles become market-ready in 3-5 years, the infrastructure needed for on-board direct use of hydrogen will be available?*

The workshop did not specifically address the issue a fuel choice (direct hydrogen versus on-board reforming of a liquid fuel). Although the participants acknowledged that fuel choice is an open issue, the workshop focused on near -term direct hydrogen systems with on-board hydrogen storage. This near-term focus does not preclude longer-term concerns, such as climate change and the sustainable use of resources.

As a result of the workshop, the *Blueprint for Hydrogen Fuel Infrastructure Development* was formulated. The objective of the *Blueprint* is to outline a five-year action plan to develop a hydrogen fuel infrastructure needed by the 2003 - 2004 timeframe for both heavy-duty and light-duty vehicles. The *Blueprin*t is based on a consensus among the workshop participants on the desirable attributes of a hydrogen fuel infrastructure, as well as on an estimate of the number, type, and uses of hydrogen vehicles anticipated in the 2000-2005 time. The *Blueprint* also explores how addressing near term requirements and barriers will facilitate establishment of a commercial-scale hydrogen fuel infrastructure.

Collaboration with DOE Office of Transportation Technologies (OTT), and Other Efforts

Subsequent to an initial *Blueprint* planning meeting held in February 2000, a second *Blueprint* meeting was held in May 2000. The primary purpose of this meeting was to develop better coordination and collaboration with the Gas Research Institute's Natural Gas Vehicle Infrastructure Industry Working Group (IWG), with the DOE Office of Transportation Technologies' (OTT) Fuels for Fuel Cells Plan, and with the California Fuel Cell Partnership. Due to the overlapping areas of interest, the *Blueprint* will focus considerable attention toward coordinating with these activities and others. Excellent opportunities exist to leverage skills and experience among all applicable programs.

Blueprint Roadmapping

The *Blueprint* is structured into four technical areas: Standardized Dispensing Station Design; Test and Certify Hydrogen Containers; Integrate Codes and Standards; and Safety RD&D for Public use of Hydrogen. In order to identify tasks within each technical area, and to develop associated action plans for their completion, a meeting will be held in August 2000 to roadmap the activities. Four sub-working groups will be established according to technical area, and include representation from hydrogen fueling companies and hands-on expertise from both the fueling station and advanced vehicle areas. Natural gas industry experience will also be represented by the natural gas IWG.

The products of the *Blueprint* roadmapping meeting will delineate activities that will be undertaken by industry, by government, and by collaborative efforts of government and industry. It will also aim at outlining a pre-competitive collaborative process for auto, energy, and government organizations to meet near term market needs for hydrogen fuel infrastructure. The *Blueprint* roadmap, when completed, will be available on the DOE Hydrogen Information Network web site.

Hydrogen Bus Data Acquisition Plan

Since 1993, NREL's Alternative Fuel Transit Bus Program has performed extensive data collection and fleet studies on alternative fuel buses around the country. The program, designed to evaluate early commercial products, has studied the reliability, fuel economy, repairs and maintenance, cost and emissions of buses operating on compressed natural gas, liquefied natural gas, methanol, ethanol, and biodiesel.

The data collection, analysis and reporting for this project cost approximately $100k per site per year. An additional $80k to $200k per site was used for chassis dynamometer emissions testing. Although this level of effort is not appropriate for the hydrogen bus sites which are employing uncertified prototype technology in very low numbers, some lessons learned from the Alternative Fuel Transit Bus Program are appropriate for the hydrogen bus projects:

- It is critical to have control vehicles at the same site as the test vehicles for comparison.
- Consistency of data collection and analysis protocol between sites is important for comparing technologies.
- Sites must have high quality existing data systems to obtain reliable operational data.
- For emissions testing, data from several vehicles is necessary due to significant vehicle-to-vehicle variability.
- Lessons learned by sites implementing new technologies can be very helpful to other sites attempting to implement similar technology.

In addition to these fleet studies, NREL manages an On-Road Prototype Development Project aimed at moving alternative fuel engine technology from the laboratory to the road on the path to commercialization. This program places one to four vehicles with prototype engines into revenue service in existing fleets to reveal the weaknesses of the new technology and develop solutions that can be incorporated into the commercial version of the engine. These projects are executed in close cooperation with the engine manufacturer.

Since the California hydrogen bus projects fall somewhere between the existing NREL alternative fuel vehicle programs, the data and information collected on the hydrogen buses will be a hybrid of the types of information collected in the existing programs.

Three hydrogen bus development projects in California have been funded by FTA/DOE and the California Energy Commissions (CEC). The DOE has also provided support for hydrogen buses in Las Vegas, NV. An additional site will operate hydrogen buses as part of the California Fuel Cell Partnership. These sites are summarized in the table below.

Site	Number of Fuel Cell Buses Planned	Number of H_2/Natural Gas Buses Planned	Number of Hydrogen Hybrid Buses Planned	Expected Date for First Bus
SunLine Transit, Palm Desert	1*	2	0	March 2000
UC Davis, Sacramento	2	3	0	August 2000
City of Chula Vista	1	0	0	2003
AC Transit, Oakland	4*	0	0	4Q 2001
City of Las Vegas, NV	0	4	1	March 2001
Totals	**8**	**9**	**1**	

*The CA Fuel Cell Partnership plans to put five buses in service at SunLine Transit and AC Transit, the split between the sites may be different than shown here.

NREL applied its previous experience in evaluating alternative fuel transit bus fleets to design a draft Data Acquisition Plan for these hydrogen buses. Operational data on the hydrogen buses will be collected and analyzed to benchmark the state of development of the technologies and to identify areas in need of improvement. The questions to be answered by collecting operational data on the hydrogen buses are as follows:

1. Did the hydrogen buses meet the needs of the transit agencies?
2. What was the availability (or "up-time") of the prototype buses during the demonstration?
3. What problems were encountered with the prototype buses and what solutions were developed?
4. Were there any safety incidents? If so, what changes have been implemented to avoid similar incidents?
5. What is the fuel efficiency of the hydrogen buses?
6. What was the cost of the prototype buses?
7. What lessons were learned that would be of use to other transit agencies implementing hydrogen bus technology?

At each site, one or more diesel and/or CNG buses will be designated as control vehicles. The diesel or CNG buses that are as similar as possible to the program buses, and are dispatched on the same or similar service routes will be used. All data collected for the program buses will also be collected for the control buses.

Vehicle specifications of interest include:

- Vehicle use patterns
- Fuel economy
- Bus availability and reliability
- Capital and fuel costs
- Maintenance and repairs issues encountered
- Safety Incidents
- Emissions of hydrogen/natural gas buses

In addition to the data acquisition and analysis activity, a "Hydrogen Bus Information Exchange" website is also planned. The homepage for the Exchange will include publicly accessible background information on the projects as well as the results of the data acquisition effort as they become available. A password-protected area of this website will contain space for each of the bus sites and a threaded chatroom. Project members can post information they wish to share with other bus project participants but not with the public on their area of the protected site. In the chatroom section, project members can discuss issues that arise at the sites and learn from one another's experiences. These conversations can be archived and the experiences distilled into a written report that will be reviewed by the project members before being released on the public site and in hardcopy.

Codes and Standards

Incorporation of Hydrogen Technologies and Safe Engineering Practices into the National and International Safety Codes

One of the near-term objectives of the Hydrogen Program is to incorporate hydrogen safety into existing and proposed national/international building, fire and other applicable codes, in order to facilitate market acceptance and deployment of the hydrogen technologies. All interested parties (i.e., government, private industry and prospective users) would be best served if the International Code Council (ICC) faced the hydrogen issue directly and adopted a separate section specifically dealing with hydrogen fuel issues in either the International Building Code (IBC) or the International Fuel Gas Code (IFGC). In April 2000, the ICC Board of Directors approved the appointment of an Ad Hoc Committee to address the subject of hydrogen used as in fuel cells in vehicular or portable technology. The ICC concluded that the subject of stationary fuel cell power plants is already being well addressed in the International Codes. The ICC Board decided to establish a nine-member Ad Hoc Committee consisting of three code officials, three industry representatives and three design professionals. The Committee is scheduled to have its first meeting in late July 2000. NREL will participate as an *ex officio* member.

Generation of a Document for Building Code and Fire Safety Officials that Describes the Hydrogen Technologies and Safety Issues

One of the milestones in the FY2000 Hydrogen Program is generation of a “Draft Sourcebook for Building and Fire Code Officials.” The objective of the draft is to be an abridged version of the “Sourcebook for Hydrogen Applications” that addresses the specific concerns of building and fire safety officials relating to the hydrogen technologies. The Program completed a draft report entitled ***“The Hydrogen Primer for Building Codes and Fire Safety Codes Officials (Current and Emerging Uses of Hydrogen as an Energy Resource and Properties of Hydrogen Compared to Other Fuels).”*** The draft, when finalized, is intended to be a professional-quality, visually-pleasing, non-technical report that familiarizes building code and fire safety officials with the following:

- Hydrogen as a fuel
- Current and emerging applications of hydrogen

- Properties of hydrogen (with respect to safety issues) compared to "conventional" fuels such as natural gas and propane
- Examples of successfully operating projects
- Status of standards and codes development
- Where to go to obtain detailed information.

NREL is using the review comments to generate a revised draft document. The revised draft will be disseminated to the ICC Hydrogen Ad Hoc Committee at its kickoff meeting in late July 2000.

HTAP Scenario Planning Committee Support

Thirty-three HTAP members and invited experts on scenario planning and hydrogen energy attended the Hydrogen Technical Advisory Panel (HTAP) Scenario Planning Workshop in Sacramento, California on October 21-22, 1999. The Workshop's genesis was an HTAP recommendation in its Report to Congress. HTAP recommended that the Hydrogen Program host scenario development workshops to develop compelling visions and scenarios of a hydrogen energy future to advance the concept of hydrogen energy to senior DOE management, the Congress, and the public. The scenarios—which are tools to provide a context to explore planning for the DOE Hydrogen Program's RD&D portfolio—are intended to help link HTAP's overarching vision in the 21st Century with the portfolio by providing a rationale for the Program. The scenario planning approach was chosen over a more traditional strategic planning process because of the great numbers of uncertainties and variety of outcomes possible for the time frame to be examined.

The Workshop was structured so as to expose participants to selected existing future global scenarios to provide a thought-provoking context for developing focused scenarios by drawing out implications for energy in general and hydrogen in particular. The approach involved developing storylines that are compelling, plausible, and interesting to DOE and to key constituencies. Results can be used to explore the role that hydrogen energy can play in continuing and accentuating the positive trends evidence in the 21st Century.

As part of the discussion on ***drivers***, participants pointed to the finite supply of fossil fuels, the potential for energy disruption, and tension between the developed and developing countries around such issues as growth, energy needs, and trade.

The ***sociopolitical and economic trends*** identified by participants included:
- The structure of population growth
- Economic output
- Energy consumption/energy demand
- Human attitudes and behavior
- Conflict between the "haves" and "have-nots" concerning energy
- Energy market developments
- Energy subsidies

The ***environmental trends*** identified by participants included:

- Changing environmental objectives and policies concerning emissions and hazardous wastes
- Improved data concerning environmental effects of energy alternatives, including climate change
- Economic valuation of clean environment
- Policies regarding greenhouse gases and climate change
- Policies regarding pollution credits and trading
- Hazardous energy-related events (such as oil spills or nuclear accidents)

The ***technical trends*** identified by participants included:

- The nature and rate of technological change
- Energy supply, including disruptions and limitations
- Fossil fuel supplies and extraction costs (including natural gas and petroleum)
- Improving technologies for fossil fuel production and consumption
- Improving hydrogen technologies
- Improving renewable technologies
- New technology inventions
- Carbon dioxide sequestration breakthroughs.

Emerging themes that participants identified included:

- A cataclysm results in breakdown of energy system
- Discontinuity leads to massive social breakdown and reduced population
- Investment results in massive technology efforts
- Social-political-technical solutions are found.
- A technological breakthrough in hydrogen technology occurs.

Markets affect the result through customer demand (market pull), regulation (policy push), manufacturer investments, and balancing business and environmental growth.

Participants discussed ***how quickly change could occur***. It could be evolutionary, revolutionary, or discontinuous. Change could result from an epic event, a series of small crises, or market pull. Examples were given.

In summary, participants said the key driving forces that will determine the role of hydrogen in plausible energy futures are (1) the rate of hydrogen technology development and (2) the interplay between market forces and social concerns. The key uncertainties are (1) the nature and rate of hydrogen technology development, and (2) how social concerns about, for example, environmental quality and energy security, affect competitive market forces that determine fuel choice and commercial success of advanced technologies.