VI.A.1 Hydrogen to the Highways - Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project

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Subcontractors:

- DaimlerChrysler AG, Stuttgart, Germany
- BP America, Warrenville, IL
- Mercedes Benz USA LLC, Montvale, NJ
- DTE Energy, Detroit, MI
- NextEnergy, Detroit, MI
- Ballard, Vancouver, BC, Canada

Start Date: December 22, 2004
Projected End Date: December 22, 2009

Objectives

- Record, collect and report data from the fuel cell vehicles and the hydrogen fueling operations to validate 2009 DOE targets:
  - Fuel cell stack durability: 2,000 hours
  - Vehicle range: 250+ miles
  - Hydrogen cost at the station: $3.00/gge
- Demonstrate the safe installation of hydrogen fueling stations and fuel cell service facilities as well as the safe operation of all fuel cell vehicles.
- Raise public awareness of hydrogen technology and fuel cell vehicles.
- Establish an initial hydrogen infrastructure network to support a fuel small fleet of fuel cell vehicles across a metropolitan area.
- Conduct market research that will assist in the development of the next generation vehicles and communication activities.
- Explore cost and commercial feasibility of renewable-based hydrogen generation.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section (3.5.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Lack of Fuel Cell Vehicle Performance and Durability Data

(B) Hydrogen Storage

(C) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

(D) Maintenance and Training Facilities

(E) Codes and Standards

(H) Hydrogen from Renewable Resources

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE Technology Validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 2: Demonstrate FCVs that achieve 50% higher fuel economy than gasoline vehicles (3Q 2005)**. Fuel economy data from DaimlerChrysler's F-Cells have been forwarded to the National Renewable Energy Laboratory (NREL) for analysis. Per NREL's 2006 Annual Report, this milestone has been achieved.
- **Milestone 4: Operate fuel cell vehicle fleets to determine if 1,000 hour vehicle fuel cell durability, using fuel cell degradation data, was achieved by industry (4Q 2006)**. DaimlerChrysler, as well as three other industry teams, has been providing NREL with on-road vehicle data collected from the fuel cell vehicles operated under real world conditions. NREL is analyzing the fuel cell data and publishing the composite data of the four industry teams at web site http://www.nrel.gov/hydrogen/proj_learning_demo.html.
- **Milestone 6: Validate vehicle refueling time of 5 minutes or less (4Q 2006)**. The fuel cell vehicles are refueled on a regular basis at a variety of hydrogen stations. Various technologies are being tested and demonstrated throughout the infrastructure network and results are reported to NREL. The permanent station utilizing electrolysis at the DTE/BP station in Southfield, Michigan

currently provides an average refueling time of less than 5 minutes. Although this refueling time is within the objective, a target of less than 3 minutes is essential for customer friendly operation, even as filling volumes increase. With new technologies including pre-cooling and proper communication between the vehicle and fueling station, it is expected that this refueling time can be maintained or reduced.

- **Milestone 8: Demonstration (on a vehicle) 2.0 kWh/kg and 1.2 kWh/L compressed storage tanks (2Q 2008)**. The F-Cell and Sprinter fuel cell vehicles both utilize a compressed hydrogen storage tank of 5,000 psi with an energy density of 0.58 kWh/l.
- **Milestone 9: Validate FCVs with 250-mile range (by 2008), 2,000-hour fuel cell durability, and a hydrogen cost of $2.00-$3.00/gge (based on volume production) (4Q 2009)**. For this final major milestone of the learning demonstration project, DaimlerChrysler has been and will continue to provide NREL data from daily operation of fuel cell vehicles. NREL plans to assess this milestone in FY 2009.
- **Milestone 22: Five stations and two maintenance facilities constructed with advanced sensor systems and operating procedures (4Q 2006)**
  - **Maintenance Facility:** Not only has DaimlerChrysler established three service stations with detailed safety operating procedure and appropriate safety equipment, but the company was among the first to design and build a cost effective hydrogen safe maintenance facility. This site, which was designed specifically for hydrogen vehicles, is currently servicing hydrogen fuel cell vehicles without having to remove the hydrogen onboard.
  - **Fueling Stations:** The BP hydrogen station located in Southeast Michigan complies with National Fire Protection Association (NFPA) 52 guidelines for fire and gas detection systems. Detailed safety procedures and processes were implemented in the design and construction of the unit. These rigorous safety analysis tools, including third party peer review, were applied for station commissioning.

Accomplishments

- Thirty fuel cell vehicles were operated under real world conditions by 18 customers in three climatic regions.
- Over 45 CDs of vehicle and infrastructure data were submitted to NREL for continuous evaluation of the technology.
- Emergency Response Plan and Training Programs were finalized.
- More than 640 vehicle refills were conducted since the beginning of the project at the PG&E mobile refueler and DTE Energy fueling station.
- Approximately 140 media/outreach events were organized in 2006 to raise public knowledge of hydrogen technology and the demonstration project.
- The development, construction and training for the NextEnergy fueling infrastructure were finalized whereby Michigan external customers are currently operating the hydrogen station.
- The "Customer Perception and Acceptance Study" was completed.

Introduction

The primary goal of this project is to validate fuel cell vehicle and infrastructure technologies as well as assess technology/commercial readiness for the market. DaimlerChrysler, together with its partners, has been testing the technology by operating and fueling hydrogen fuel cell vehicles under real world conditions in varying climate, terrain and driving conditions. Vehicle and infrastructure data have been collected to monitor the progress toward the 2009 hydrogen vehicle and infrastructure performance targets of $3.00-2.50/gge hydrogen production cost, 250-mile range and 2,000-hour fuel cell durability. To prepare the public for a hydrogen economy, outreach activities have been designed to promote awareness and acceptance of hydrogen technology.

Approach

To achieve the project goals, DaimlerChrysler deployed 30 Gen I vehicles into customer hands for real-world operations in three climatic regions of the United States. All vehicles have been equipped with a data acquisition system that automatically collects statistically relevant data for submission to NREL, which monitors the progress of the fuel cell vehicles against the DOE Technology Validation milestones. The energy partners, BP, DTE, and NextEnergy, are installing infrastructure to provide hydrogen to DaimlerChrysler fuel cell vehicles and evaluate the technologies which have the potential to achieve the DOE hydrogen cost targets.

To raise public awareness of hydrogen technology and demonstration projects, DaimlerChrysler aligned its communication activities with the goals of the DOE. In addition, a market research study was conducted to understand the driver's perception, attitudes and usage of fuel cell vehicles with partner organizations in California and Michigan.

Results

Customer Acceptance and Perception Study

DaimlerChrysler and the California Partners for Advanced Transit and Highways (PATH) at University of Berkeley conducted a consumer research study of F-Cell fleet drivers' attitudes and perceptions towards hydrogen and alternative fuel vehicles. Samples were taken from F-Cell partner organizations in California and Michigan consisting of governmental organizations, for-profit, and non-profit entities. The study employed a longitudinal study design with three rounds of surveys in order to examine potential trends in F-Cell driver perceptions over time. The driver assessments, not being represented for the broader U.S. customer base, yielded several key findings:

- Respondents believe the F-Cell was easy to use and did not require much time to learn how to operate.
- Both F-Cell and refueling perceptions were positive. Those who were initially uneducated and cautious with the F-Cell grew to be more comfortable over time. This finding is consistent with the customer driving pattern as they doubled the average weekly mileage from 2005 to 2006 due to their increased driving and fueling experience.
- The limited network of hydrogen which existed during this study placed constraints on participants. Respondents indicated they would be willing to drive approximately 9 miles to find a hydrogen fueling station.
- Range is a crucial point for the acceptance of the technology. This is of particular importance with regard to the switch from 35 MPa to 70 MPa.

Fleet Customers

In 2006, DaimlerChrysler transitioned from vehicle deployment to full vehicle operation. As customers gained driving/fueling experience and the number of vehicles within the operation increased, the average weekly mileage doubled. The scheduled handover of thirty fuel cell vehicles to the 18 external customers was finalized during the second quarter of the year. Of particular note are the customers from the Wayne State University Police Department and Sacramento Metropolitan Fire District that created the first hydrogen fuel cell powered emergency response vehicles by outfitting two F-Cells with sirens, decals and emergency lights (see Figures 1 and 2). These customers are proving to be a valuable asset for promoting the technology both within the fire official and safety communities, as well as to the public at large.

FIGURE 1. F-Cell Operated by Sacramento Metropolitan Fire District

FIGURE 2. F-Cell Utilized by Wayne State University Police Department

Vehicle Operations

Throughout the year, 27 A-Class "F-Cell" and two Sprinter delivery vans were driven under real world conditions in three climatic regions including Michigan, Northern California and Southern California. These selected regions provided a complete breadth of climate conditions, ranging from 3°F in Michigan to 123°F in Sacramento and 93% relative humidity in San Francisco to 51% relative humidity in Michigan. The regions also provided a full range of terrain and traffic conditions, from congested city driving highways in Southern California to rural roads in Michigan.

To ensure that all customer service needs were met and that all vehicle maintenance was performed in a timely fashion, three regional facilities have been servicing the fuel cell vehicles operated in the three locations. The Southern California (Long Beach) facility, which was the first hydrogen safe maintenance site specifically designed with the tools of computational fluid dynamic (CFD) modeling, has been successfully servicing the vehicles with full hydrogen tanks. Prior to the construction of this facility, all fuel cell vehicles had to be completely defueled prior to servicing.

Fueling Stations and Co-Production Facilities

The NextEnergy hydrogen refueling station, located in downtown Detroit, was completed in February of 2007. All BP and NEC safety processes were successfully implemented during construction of the facility and during commissioning of the equipment. DaimlerChrysler and BP performed a number of test refills with and without vehicles. The station is now fully operational and utilized by DaimlerChrysler's external customers (see Figure 3).

Four additional refueling stations are currently in operation and providing hydrogen to DOE customers. The DTE Hydrogen Technology Park and PGE mobile refueler are located respectively in Michigan and Northern California. Although outside of the Demonstration and Validation Project, the California Fuel Cell Partnership (CaFCP) and Los Angeles International Airport (LAX) stations are also fueling F-Cells on a regular basis. No safety incidents or downtime were encountered during the year.

Data Reporting – Fleet Data Acquisition

DaimlerChrysler finalized implementation of the Fleet Data Acquisition (FDA) system that wirelessly transmits data from the fuel cell vehicles to local file servers which then make the data accessible to test engineers via internet. In 2006, the infrastructure for the FDA system was expanded from 13 to 17 local file servers. As a result, all fleet customers are now equipped with the appropriate local file servers. In addition, DaimlerChrysler also completed the semi-annual dynamometer and annual acceleration testing for the three F-Cell vehicles. NREL was provided over 45 CDs of raw data from the FDA server and dynamometer/ acceleration testing.

The data generated from the FDA system verified that the vehicles were operated under the requirements specified by the DOE. The data demonstrates that the vehicles have been driven under real world conditions with the full range of climate, terrain and traffic situations. Figure 4, a graph derived from the FDA system, shows an example of an F-Cell driven under various traffic circumstances, including high speed freeway and stop-and-go conditions.

Outreach and Media

DaimlerChrysler developed a marketing strategy to better align its communication activities with the DOE goals. In order to promote awareness of the hydrogen technology and fuel cell vehicles, DaimlerChrysler and fleet partners participated in over 140 media and outreach events. To raise public knowledge of the hydrogen demonstration project, DaimlerChrysler created new promotional materials,

FIGURE 3. Opening of the NextEnergy Fueling Station

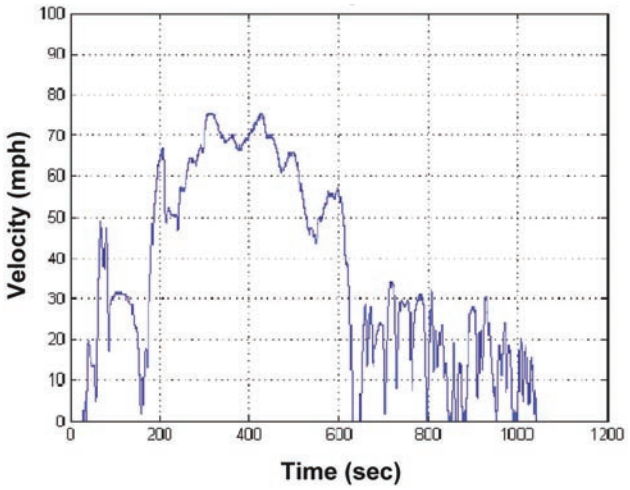

FIGURE 4. Profile of F-Cell Operation on Freeway – High Velocity and Stop-And-Go Traffic

as well as educational tools. These materials included display banners which describe the DOE program and DaimlerChrysler's F-Cell customers, and flyers which highlight the DOE's hydrogen and fuel cell technology efforts and its collaboration with DaimlerChrysler. These materials were displayed and/or were distributed at a variety of on and off-site events.

Safety and Health

DaimlerChrysler, in conjunction with energy partners DTE (Detroit Edison), FTI (Fueling Technology Inc.), and BP completed the failure mode effects analysis (FMEA) of the interface between the vehicle and DTE hydrogen fueling station. In addition, the incident management plan was updated to fine tune the instructions for all employees directly involved in the use of fuel cell vehicles for different levels of incident (high/medium/low).

As the number of vehicles and accumulated mileage of the fleet increases, the probability of accidents also increases. These situations provide opportunity to

demonstrate the efficacy of the vehicle structure and safety systems. Although the F-Cell vehicles incorporate many modifications to their powertrain, they have provided protection equivalent to the production vehicles they are based upon. To date, two minor F-Cell accidents have been reported with no hydrogen release, alarm activation or occupant injury.

Conclusions and Future Directions

Future Work:

- Maintain smooth operation of the fuel cell vehicles with ongoing service, maintenance and customer support.
- Accumulate more miles in the three climatic regions to validate status of DOE performance targets.
- Finalize technical and operational development of the 70 MPa fuel tank upgrade and Gen II activities.
- Continue operations of the DTE, NextEnergy, LAX and CaFCP stations as well as the PG&E mobile unit. Assure safety processes through possibly another safety audit.
- Continue site development of the Los Angeles station. Start site identification and equipment supplier selection for the station.
- Maintain project safety through continued inter-team communication, vehicle and infrastructure training, employee and customer education, "tabletop" incident management drills and emergency responders training.
- Maintain the high quality of technical vehicle and infrastructure data reporting structure to NREL/DOE.
- Pursue novel approaches toward outreach and media events in order to raise public knowledge of hydrogen technology and demonstration projects.

Placing a hydrogen fueling station is a unique experience that breaks new ground. Based on the experiences and lessons learned from the NextEnergy station, the following conclusions and recommendations are made:

- Time to design, manufacture, construct and commission are significantly lengthened with multiple parties involved, primarily due to the many layers of approval that must be managed.
- As-built documentation and associated equipment manuals (at least for life safety systems) need to be available when the authorities having jurisdiction (AHJs) are asked to "clear" their permits and issue a certificate of occupancy.
- Having a "packaged solution" from an equipment supplier limits the creativity of the design in terms of taking advantage of host site features and doesn't lessen the time to deliver or commission the equipment.
- The mandatory gas and flame detection system (per NFPA 52 Vehicular Fuel Systems Code 2006 Edition sec. 9.2.15) for the vehicle fueling station should be designed by the party who is responsible for the overall facility gas and flame/fire monitoring and alarm system.
- There are at least two, and sometimes more, layers of responsibility within the same AHJ and each layer likely has a different set of concerns and needs to be addressed uniquely. The needs of all must be clearly understood and satisfied.
- Early and frequent discussions about the station were entered into with all the stakeholders, including the general public represented by NextEnergy's neighbors. This resulted in no dissention.
- Engaging local contractors, who are familiar with city approval processes, is important. The approval process is the most uncertain aspect of the project to schedule.

FY 2007 Publications/Presentations

1. Kohler, Herbert "The Role of Public-Private-Partnerships for the Commercialisation of Fuel Cell Vehicles", Third General Assembly of the European Hydrogen and Fuel Cell Technology Platform, Brussels, Belgium, October 2006.

2. Mohrdieck, Christian "Well-to-Wheels Visualization", EVS- The 22nd International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Yokohama, Japan, October 2006.

3. Mohrdieck, Christian "Data Analysis of DaimlerChrysler's worldwide Fuel Cell Passenger Car Fleet", EVS- The 22nd International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Yokohama/Japan, October 2006.

4. Bonhoff, Klaus "Data Analysis of DaimlerChrysler's Worldwide Fuel Cell Passenger Car Fleet", NHA Annual Hydrogen Conference, March 2007.