VIII.1 Controlled Hydrogen Fleet and Infrastructure Analysis

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Start Date: October 2003
Projected End Date: September 2010

Objectives

- By 2008, validate that hydrogen vehicles have greater than a 250-mile range without impacting passenger or cargo compartments.
- By 2009, validate 2,000-hour fuel cell durability in vehicles and hydrogen infrastructure that results in a hydrogen production cost of less than $3.00/gasoline gallon equivalent (gge) (untaxed) delivered, and safe and convenient refueling by drivers (with training).
- Assist DOE in demonstrating the use of fuel cell vehicles (FCVs) and hydrogen infrastructure under real-world conditions, using multiple sites, varying climates, and a variety of sources for hydrogen.
- Analyze detailed fuel cell and hydrogen data from vehicles and infrastructure to obtain maximum value for DOE and industry from this "learning demonstration."
- Identify the current status of the technology and its evolution over the project duration; generate composite data products (CDPs) for public dissemination.
- Provide feedback and recommendations to DOE to assist hydrogen and fuel cell research and development (R&D) activities and assess progress toward technology readiness.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section (3.6.4) of the Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) 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
(I) Hydrogen and Electricity Co-Production

Contribution to Achievement of DOE Technology Validation Milestones

Over a five-year period, researchers in this project are gathering data and providing technical analysis that is contributing to achieving the following DOE technology validation milestones from the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development, and Demonstration Plan (MYRDDP):

- **Milestone 2: Demonstrate FCVs that achieve 50% higher fuel economy than gasoline vehicles (Q3, FY 2005).** Vehicle chassis dynamometer testing was completed on 11 vehicles to obtain accurate fuel economy data from the four industry teams. While some of the Learning Demonstration vehicles are not sold in the United States, and therefore don't have a benchmark U.S. fuel economy to compare to, data show that the fuel economy of the FCVs was >50% higher than the equivalent conventional gasoline vehicles. This milestone has been achieved.
- **Milestone 3: Decision for purchase of additional vehicles based on projected vehicle performance and durability, and hydrogen cost criteria (Q4, FY 2006).** At the end of Fiscal Year 2006, NREL used all available fuel cell data to analyze performance against DOE 2006 targets. Based on high fuel cell system efficiency results, good refueling times, and fuel cell voltage degradation that straddled DOE's 1,000-hour target, we recommended that DOE proceed with purchasing 2nd generation FCVs to validate the 2009 targets. This milestone has been achieved.
- **Milestone 4: Operate fuel cell vehicle fleets to determine if 1,000 hour fuel cell durability, using fuel cell degradation data, was achieved by industry (Q4, FY 2006).** In September 2006, NREL analyzed the fuel cell data to date and made projections about fuel cell durability to a 10% voltage degradation. These results were then compared to the 1,000-hour target and formed the basis for a public CDP. At the time of the milestone,

the highest projected team average was 950 hours with a four-team average of just over 700 hours. After two and a half years of additional on-road data (through December 2008), the latest results show the highest projected team average of 1,977 hours with the four-team average of 828 hours. This milestone has been achieved.

- **Milestone 5: Validate vehicle refueling time of 5 minutes or less for a 5 kg tank [1kg/min] (Q4, FY 2006).** NREL used all available project refueling data to compare the refueling rate to the DOE target of 5 kg in five minutes (1 kg/min). At the time of the milestone, we analyzed over 2,000 vehicle refueling events and calculated an average rate of 0.69 kg/min and median rate of 0.72 kg/min, with 18% of the events exceeding the 1 kg/min target. Updates 2.5 years later using over 16,000 refueling events showed improved results with an average rate of 0.78 kg/min with 24% of refueling events exceeding 1 kg/min. This milestone has been achieved.
- **Milestone 7: Validate refueling time of 5 minutes or less for 5 kg of hydrogen (1 kg/min) at 5,000 psi through the use of advanced communication technology (Q4, FY 2007).** While similar to Milestone 5, this milestone specifically addresses communication fills. At the time of the milestone, we calculated an average rate of 0.76 kg/min based on all refueling events, with 23% of the events exceeding the 1 kg/min target. As mentioned in Milestone 5 above, refueling rates have continued to improve since then. We also analyzed the difference in refueling rates of communication and non-communication fills; the data show that communication fills can refuel at a higher rate (up to 1.8 kg/min) and have an average fill rate 35% higher than non-communication fills (0.88 kg/min vs. 0.65 kg/min). This milestone has been achieved.
- **Milestone 8: Fuel cell vehicles demonstrate the ability to achieve 250-mile range without impacting passenger cargo compartment (Q4, FY 2008).** We analyzed the driving range of second-generation FCVs utilizing 700 bar high-pressure hydrogen tanks and compared it to DOE's 2008 target of 250 miles using the window-sticker results which are more realistic than the raw dynamometer test results. The Learning Demonstration results indicate that hydrogen stored on-board vehicles at 700 bar can significantly increase driving range (to between 196–254 miles), however in some cases it still does so at the expense of passenger or cargo volume. In June 2009, an on-road driving range evaluation was performed in collaboration with Toyota and Savannah River National Laboratory, with the results indicating a 431 mile on-road range was possible in southern California from their FCV. No cargo or passenger space was compromised in that vehicle, but they did give up the spare tire in the packaging of the hydrogen tanks under the rear floor. This milestone has been achieved.
- **Milestone 10: Validate FCVs 2,000 hour fuel cell durability, using fuel cell degradation data (Q4, FY 2009).** On-road fuel cell voltage data from 2nd generation fuel cell systems will be analyzed in a manner similar to the 2006 analysis (including any improvements to the methodology) to evaluate durability and compare it to the 2,000-hour target for the Fall 2009 CDP results.
- **Milestone 11: Decision to proceed with Phase 2 of the Learning Demonstration (Q2, FY 2010).** Based on the progress made between first- and second-generation FCV technologies, NREL will support DOE in the decision to proceed with Phase 2 of the Learning Demonstration.
- **Milestone 23: Total of 10 stations constructed with advanced sensor systems and operating procedures (Q1, FY 2008).** This milestone has been achieved.
- **Milestone 24: Validate a hydrogen cost of $3.00/gge (based on volume production) (Q4, FY 2009).** We will estimate hydrogen costs at volume using the hydrogen analysis (H2A) tool with support from industry. The results will be included in the Fall 2009 CDPs.

Accomplishments

- Received and processed data from a total of 395,000 individual vehicle trips, amounting to over 88 gigabyte (GB) of on-road data, since inception of the project.
- Created and published 60 CDPs (the seventh such set of public results) representing results from analyzing almost four years of Learning Demonstration data.
- Completed implementation for producing detailed data results and CDPs at the same time for easier industry and internal review.
- Documented and archived each quarter's analysis results in the Fleet Analysis Toolkit (FAT) graphical user interface.
- Presented project results publicly at EVS-24, the Fuel Cell Seminar, the National Hydrogen Association conference, and the 2009 DOE Hydrogen Program Merit Review meeting.
- Kept NREL's Web page up-to-date at http://www.nrel.gov/hydrogen/cdp_topic.html to allow direct public access to the latest CDPs organized by topic, date, and CDP number. This also allowed the results to be indexed directly by Web search engines.
- Made major improvements to NREL's FAT, the tool that automatically processes and analyzes every

vehicle trip file and refueling event and presents the results graphically in an interactive manner.

- Further developed a collaborative technical relationship with all four industry teams by giving presentations to each team, including detailed results on every stack in their fleet.
- Provided presentations of results to key stakeholders, including two FreedomCAR and Fuel technical teams (storage and fuel cells), the US Fuel Cell Council Transportation Working Group, the Joint Hydrogen Quality Working Group, and both the Vehicle Technologies Program and the HFCIT Program.

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Introduction

The primary goal of this project is to validate vehicle/infrastructure systems using hydrogen as a transportation fuel for light-duty vehicles. This means validating the use of FCVs and hydrogen refueling infrastructure under real-world conditions using multiple sites, varying climates, and a variety of sources for hydrogen (see Figure 1 for photographs representing the four types of hydrogen refueling stations). Specifically, in 2009 we are validating hydrogen vehicles with greater than 250-mile range, 2,000-hour fuel cell durability, and $3/gge hydrogen production cost (based on modeling for volume production). We are identifying the current status of the technology and tracking its evolution over the five-year project duration, particularly between the first- and second-generation FCVs. NREL's role in this project is to provide maximum value for DOE and industry from the data produced by this "learning demonstration." We seek to understand the progress toward the technical targets, and provide information to help move the HFCIT R&D activities more quickly toward cost-effective, reliable hydrogen FCVs and supporting refueling infrastructure.

Approach

Our approach to accomplishing the project's objectives is structured around a highly collaborative relationship with each of the four industry teams, including Chevron/Hyundai-Kia, Chrysler/BP, Ford/BP, and GM/Shell. We are receiving raw technical data from both the hydrogen vehicles and refueling infrastructure that allows us to perform unique and valuable analyses across all four teams. Our primary objectives are to feed the current technical challenges and opportunities back into the DOE Hydrogen R&D Program and assess the current status and progress toward targets.

To protect the commercial value of these data for each company, we established the Hydrogen Secure Data Center (HSDC) to house the data and perform our analysis. To ensure value is fed back to the hydrogen community, we publish CDPs twice a year at technical conferences to report on the progress of the technology and the project, focusing on the

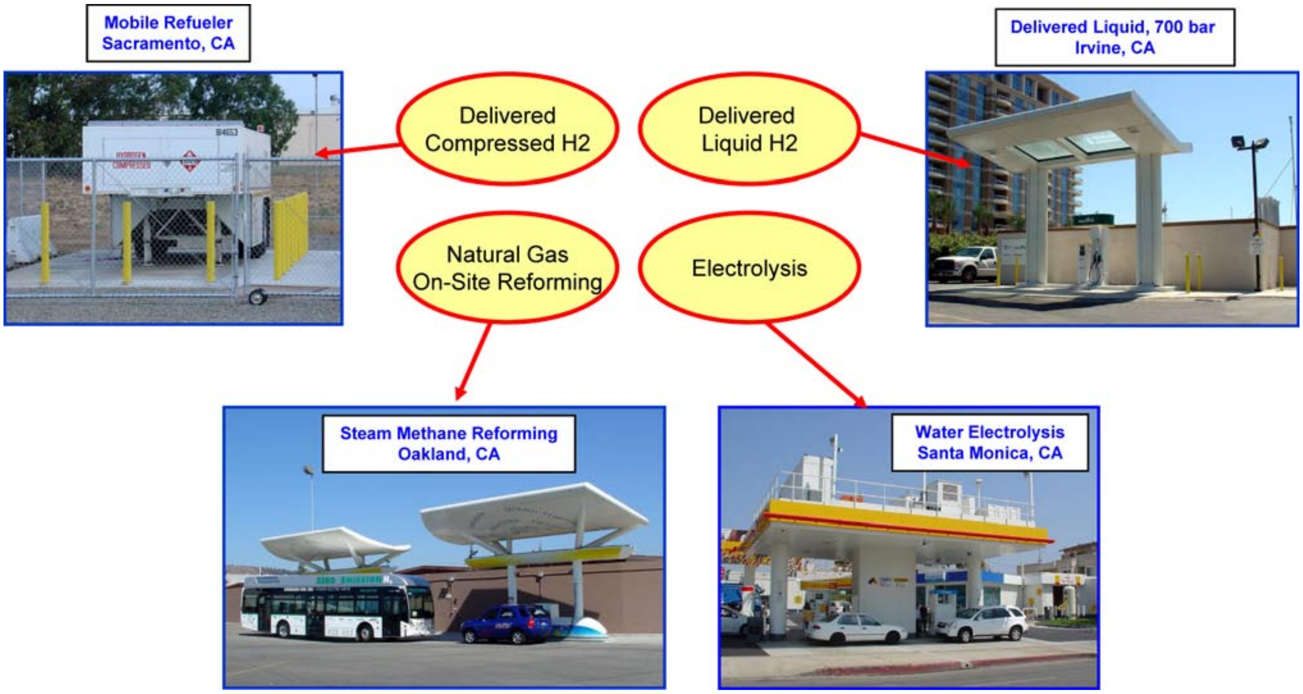

FIGURE 1. Four Types of Hydrogen Refueling Stations are being Tested

most significant results. Figure 2 shows the periodic publication of CDP sets relative to the inflow of vehicle data to NREL. Additional CDPs are being conceived as additional trends and results of interest are identified, and as we receive requests from DOE, industry, and codes and standards committees. We also provide our detailed analytical results (not public) on each individual company's data back to them to maximize the industry benefit of NREL's analysis work and obtain feedback on our methodologies.

Results

The results in FY 2009 came from analyzing an additional year of data (January – December 2008), creating a total of 60 new or updated CDPs, and presenting these results at five technical conferences. To accomplish this, we continued to improve and revise our in-house analysis tool, FAT. Since there are now so many technical results from the project, they cannot all be listed here or be fully presented during brief conference presentations. Therefore, in 2007 NREL launched a new Web page at http://www.nrel.gov/hydrogen/cdp_topic.html to provide the public with direct access to the results. Portions of these results have also been presented publicly at the Fuel Cell Seminar (10/08), the Electrochemical Society conference (10/08), the 2009 National Hydrogen Association meeting (3/09), the EVS-24 conference (04/09), and the Society of Automotive Engineers (SAE) Congress (04/09) as two distinct sets of results (labeled "Fall 2008" and "Spring 2009"). Since all 60 of the results are available now on the Web site, this report will just include some of the highlights over the last year.

- **Vehicle Fuel Economy:** Vehicle fuel economy was measured using city and highway drive-cycle tests on a chassis dynamometer using draft SAE J2572. These raw test results were then adjusted according to U.S. Environmental Protection Agency (EPA) methods to create the "window-sticker" fuel economy that consumers see when purchasing the vehicles (0.78 x Hwy, 0.9 x City). Generation 1 vehicles had an adjusted fuel-economy range of 42 to 57 miles/kg hydrogen for the four teams, and generation 2 vehicles showed a slight improvement in fuel economy to 43 to 58 miles/kg.
- **Vehicle Driving Range:** Vehicle driving range was calculated using the fuel economy results discussed above and multiplying them by the usable hydrogen stored onboard each vehicle. New for this year was the comparison between the two generations of vehicles. Generation 1 vehicles had a range from just over 100 miles up to 190 miles from the four teams, whereas generation 2 vehicles using 700 bar pressure hydrogen tanks showed a significantly improved window-sticker driving range of 196 to 254 miles (Figure 3). This demonstrated that DOE's September 2008 MYRDDP Milestone 8 target of 250 miles was achieved. Note that all of the Learning Demonstration vehicles are based on existing platforms, and higher driving ranges are expected when the vehicles are designed around hydrogen.
- **Fuel Cell Efficiency:** The baseline fuel cell system efficiency was measured from selected vehicles on a vehicle chassis dynamometer at several steady-state points of operation. DOE's technical target for net system efficiency at ¼-power is 60%. Data from the four Learning Demonstration teams showed a range of net system efficiencies from 52.5% to 58.1%, which is very close to the target. These results have not changed since they were first published because they are baseline results for first-generation vehicles, but the teams have tested second-generation systems and these will be evaluated for any efficiency

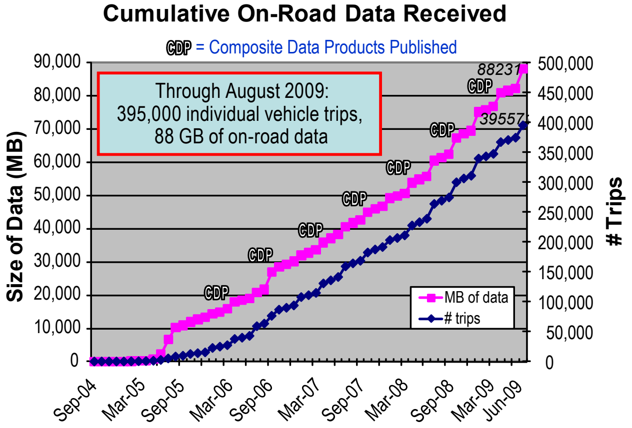

FIGURE 2. CDPs are Published at Six-Month Intervals

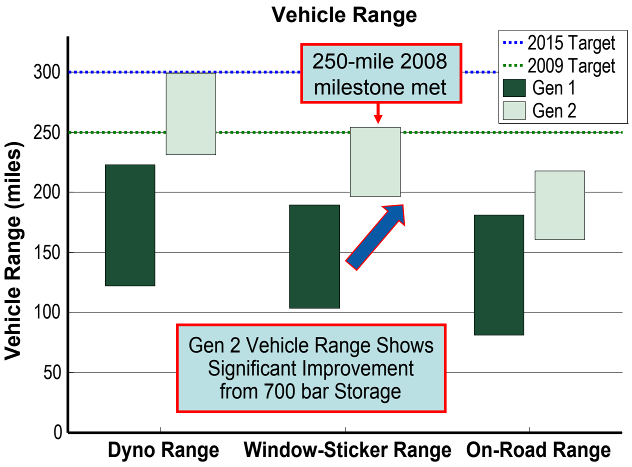

FIGURE 3. Driving Range for Gen 1 and Gen 2 Vehicles, based on Fuel Economy and Usable H_2

changes as the systems get closer to technology readiness. We anticipate including the range of efficiency curves (idle to full power) in the Fall 2009 results, in addition to just the ¼ power point described here.

- **Fuel Cell System Specific Power and Power Density:** Data were received on the total fuel cell system mass, volume, and power. Both the specific power (W/kg) and the power density (W/L) were evaluated for generation 1 and compared with generation 2 fuel cell systems. We found that while the fuel cell system power density stayed about the same between the two generations (ranging from 300 to 400 W/L) there were significant improvements in fuel cell system specific power, improving from generation 1 results of 200–300 W/kg up to generation 2 results of 300–400 W/kg. It appears as though it may take another generation or two before the fuel cell systems achieve DOE's 2010 and 2015 MYRDDP target of 650 W/kg. For the Fall 2009 results we will add a new CDP that includes hydrogen storage as part of the system to allow comparisons with other energy and power systems such as batteries.
- **Fuel Cell Durability:** Fuel cell stacks will need roughly a 5,000 hour life to enter the market for light-duty vehicles. Preliminary durability estimates were first published in the fall of 2006 because most stacks at that time only had a few hundred hours of operation or less accumulated on-road. NREL developed a methodology for projecting the gradual degradation of the voltage based on the data received to date. This involved creating periodic fuel cell polarization curve fits from the on-road stack voltage and current data, and calculating the voltage under high current. This enabled us to track the gradual degradation of the stacks with time and do a linear fit through each team's data. We then compared these results to the first-generation target of 1,000 hours for 2006.

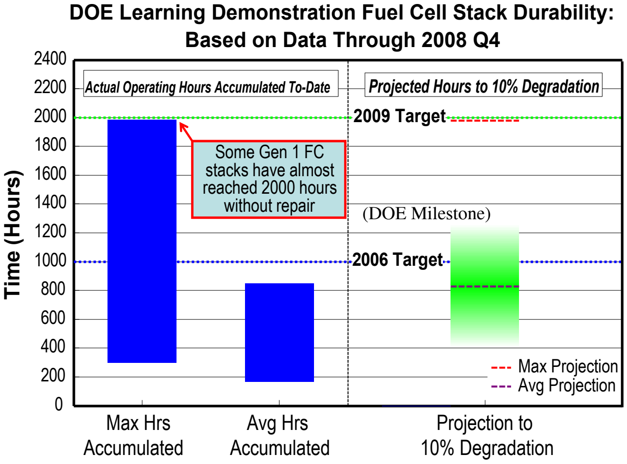

FIGURE 4. Gen 1 Stack Operating Hours and Projected Time to 10% Voltage Drop

In the past two and a half years, many more hours have been accumulated on the fuel cell stacks, and the range of fleet averages is now ~200 to 850 hours, with the range of fleet maximums spanning ~300 to 1,987 hours (Figure 4). This is the first time, to our knowledge, that a light-duty passenger fuel cell car has accumulated almost 2,000 hours in real-world operation without repair to the fuel cell stack, which is a significant project accomplishment. The amount of data extrapolation we have to make using the slope of the linear voltage degradation method (10% voltage drop target divided by the mV/hour slope) continues to decrease as we receive additional data. However, with the additional data we have also found that the accuracy of the 10% voltage degradation projection could be improved by using a non-linear fit to account for the more rapid degradation that occurs within the first few hundred hours. Fuel cell stack degradation results for this project in the Fall 2008 began using a two-segment linear fit and also used a weighting algorithm to come up with a more robust fleet average. The projected times to 10% fuel cell stack voltage degradation from the four teams using this new technique had an average of 828 hours. Note that the 10% criterion, which is used for assessing progress toward DOE targets, may differ from the vehicle manufacturer's end-of-life criterion and does not address "catastrophic" failures such as membrane failure. The second-generation stacks introduced in this project beginning in late 2007 will be compared to the 2,000-hour target in September 2009, and we will also add additional CDPs relating to acceptable power degradation and stack longevity.

- **Factors Affecting Fuel Cell Durability:** We continued investigating factors that are affecting the rates of fuel cell stack degradation. Two of these factors that our industry partners asked us to examine were the amount of time the fuel cell spends at various voltage levels and the average number of trips per operating hour. We found that about 15% of the time was spent at roughly the open-circuit voltage and very low current, while only 17% of the time was spent at <70% of the maximum voltage (corresponding to high load). In looking at the average number of trips per hour (Figure 5), we found a normal distribution around the median of roughly four trips per hour. This information was also provided to a fuel cell durability task force that was formulating durability test protocols, as they wanted to make sure they knew what the actual average trips per operating hour was from real stacks in everyday use. We also examined whether there was a trend of average trips

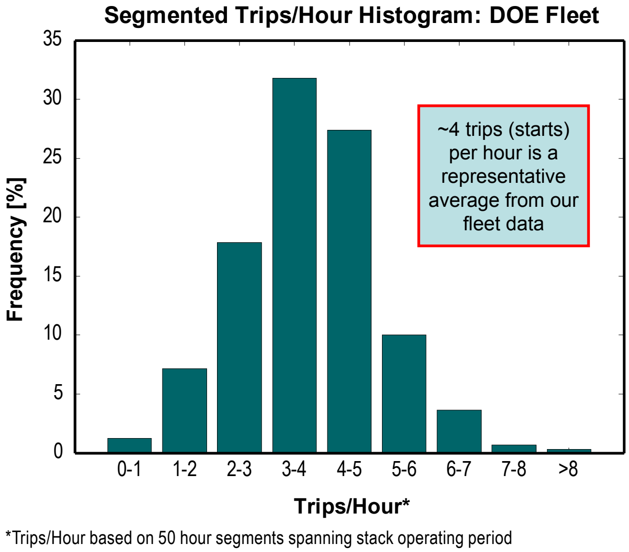

FIGURE 5. Fuel Cell Stack Trips per Hour Histogram

per hour as a function of stack operating hours, and we found that the stacks that have demonstrated long hours (to date) show lower average trips per hour. We will have to accumulate more data before we can attribute a causal relationship between the two.

- **Vehicle Maintenance:** Over the four years of vehicle operation, there has been a large set of data collected on all of the vehicle maintenance events. There were a total of 9,357 maintenance events consuming 10,216 hours. We found that 34% of the vehicle maintenance events were due to the fuel cell system, consuming 49% of the maintenance labor. Over half (57%) of the vehicle maintenance events were non-powertrain related. Breaking down the details of the fuel cell system into all of its parts, we found a surprising result: only 11% of the fuel cell system events were due to the fuel cell stack, while the most frequently serviced parts of the fuel cell system were the thermal management system (36%), the air system (26%), controls/electronics/sensors (14%), the fuel system (11%), and then the fuel cell stack (5th down the list). This indicates that the other components in the fuel cell system beside the fuel cell stack itself need more attention and potentially R&D before these vehicles reach the point of commercialization.
- **Infrastructure Maintenance:** Like vehicle maintenance, the hydrogen fueling station maintenance data were also analyzed. There were a total of 1,860 infrastructure maintenance events, requiring 9,093 hours. While we assumed that one of the production components would top the list, it was actually the system control and safety systems that accounted for the most maintenance events (22%) and labor (22%). The four major components of the system including the compressor, electrolyzer, reformer, and dispenser were roughly equal in terms of their maintenance requirements. The hydrogen storage system required the least maintenance at just a couple percent.
- **Vehicle Refueling Rates:** Over 16,000 refueling events have been analyzed to date, and the refueling amount, time, and rate have been quantified. The average time to refuel was 3.30 minutes with 87% of the refueling events taking less than five minutes. The average amount per fill was 2.18 kg, reflecting both the limited storage capacity of these vehicles (~4 kg max) and peoples' comfort level with letting the fuel gauge get close to empty. DOE's target refueling rate is 1 kg/minute, and these Learning Demonstration results indicate an average of 0.78 kg/min, with 24% of the refueling events exceeding 1 kg/minute.
- **Fueling Rate Comparison Between 350 and 700 bar Fills:** The previously discussed refueling rates included all types of refueling events. There has been much interest from industry and from the codes and standards community on the effect of communication vs. non-communication and 350 bar vs. 700 bar pressure on fill rates. A communication fill means that the vehicle communicates data about the state of its hydrogen storage tank(s), such as tank temperature, pressure, and max pressure rating, to the refueling station. We previously showed that communication fills are capable of having higher average fill rates (0.88 kg/min) than non-communication fills (0.65 kg/min). This year, we also examined the difference in fill rates based on fill pressure (Figure 6), and found that 700 bar fills were currently 27% slower than 350 bar fills. The average 350 bar fill rate was 0.81 kg/min while the average 700 bar fill rate was only 0.59 kg/min.
- **On-Site Production Efficiency from Natural Gas Reformation and Electrolysis:** Detailed data on all of the energy inputs required to produce hydrogen on-site were gathered and analyzed and compared to DOE's program targets for 2010 for natural gas reformation and 2012 for water electrolysis. The results indicate that natural gas reformation efficiency was demonstrated close to the 2010 target of 72% through achieving a best quarterly efficiency of 67.1% and a best monthly efficiency of 69.8%. The best quarterly efficiency for water electrolysis was 57.4% with a best monthly efficiency of 60.3% (compared to the 2012 target of 69%). Note that targets for both of these technologies are for future years (2010 and 2012) and results from 2005-2008 were not yet expected to have achieved future targets. Additionally, the targets are set for significantly larger stations (1,500 kg/day of hydroge) and higher utilization

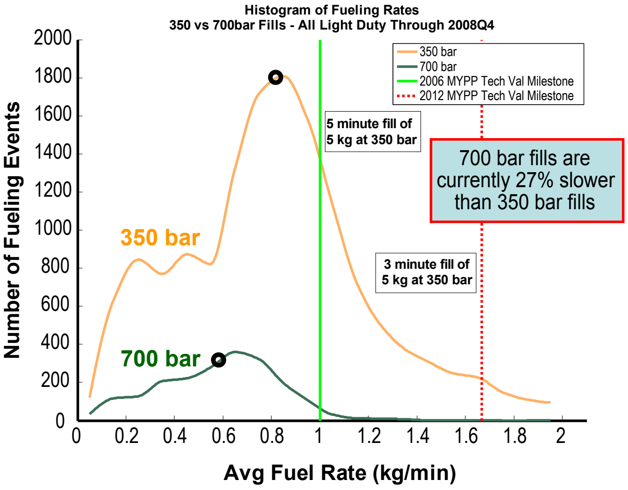

FIGURE 6. Comparison of Fueling Rates for 350 and 700 bar Pressure Fueling Events

(70% capacity factor) than we have in the Learning Demonstration. The purpose of comparing our actual results to these future targets is to benchmark demonstrated progress toward the targets while technical R&D development continues to improve the state-of-the-art.

- **Vehicle Greenhouse Gas Emissions (GHGs):** GHGs from the Learning Demonstration fleet have been assessed and compared to greenhouse gas emission estimates of conventional gasoline vehicles. The results indicate that when using hydrogen produced on-site via either natural gas reformation or water electrolysis, Learning Demonstration hydrogen FCVs offer significant reductions of GHGs relative to conventional gasoline vehicles (Figure 7). Conventional gasoline mid-sized passenger vehicles emit 484 g CO_2-eq/mile (grams CO_2-equivalent per mile) on a well-to-wheels (WTW) basis and conventional mid-size sport utility vehicles (SUVs) emit 612 g CO_2-eq/mile on a WTW basis. WTW GHGs for the Learning Demonstration FCV fleet (which includes both passenger cars and SUVs) were analyzed based on the window sticker fuel economy of the Learning Demonstration fleet and the actual distribution of hydrogen production conversion efficiencies from on-site hydrogen production. Average WTW GHGs for the Learning Demonstration fleet operating on hydrogen produced from on-site natural gas reformation were 356 g CO_2-eq/mile and the lowest WTW GHG emissions for on-site natural gas reformation were 237 g CO_2-eq/mile. For the Learning Demonstration fleet operating on hydrogen produced from on-site water electrolysis (including some renewable sources of electricity), average WTW GHG emissions were 380 g CO_2-eq/mile, with the lowest emissions estimated to be 222 g CO_2-eq/mile for the month with the best electrolysis production conversion efficiency.

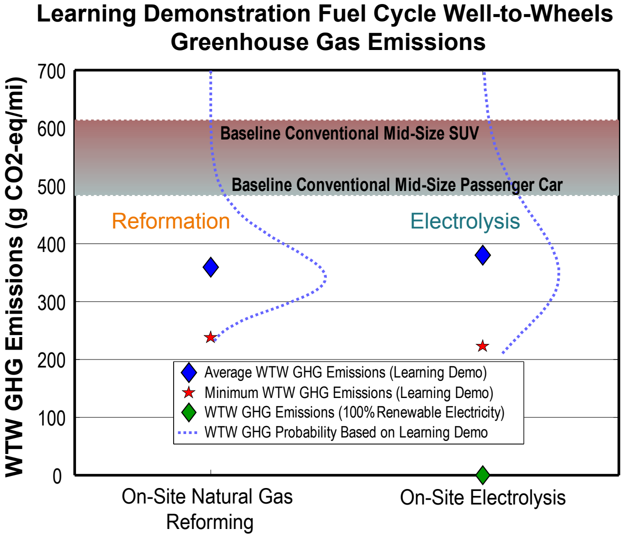

FIGURE 7. Learning Demonstration Vehicle GHGs Using Actual Production Efficiencies and Fuel Economies

Conclusions and Future Directions

- Completed the first four years of the five-year project with 140 vehicles now in fleet operation, 20 project refueling stations in use, and no major safety problems encountered.
- Analyzed data from 395,000 individual vehicle trips covering 1.9 million miles traveled and 90,000 kg H_2 produced or dispensed.
- Analyzed fuel cell system efficiency at ¼-power and compared it to DOE target of 60%: system efficiency results from the four teams ranged between 52.5% and 58.1%.
- Published 60 CDPs to date and made them directly accessible to the public from a NREL's Web site.
- Continued to examine individual fuel cell stack degradation with each team to understand the results and refine both the inputs and the analysis performed.
- We will create new and updated CDPs based on data through June 2009 (Fall 2009 CDPs) and present results for publication at 2009 Fuel Cell Seminar.
- NREL will support key September 2009 DOE MYRDDP and Joule milestones on:
  - Hydrogen production cost from project compared to $3/gge target.
  - Generation 2 stack voltage degradation time to 10% compared to target of 2,000 hours.

  - Generation 2 vehicle freeze capability and start-up energy requirements compared to targets.
- We will support vehicle manufacturers, energy companies, and state organizations in California in coordinating early infrastructure plans.
- NREL will continue to identify opportunities to feed findings from the project back into Vehicle Technologies and Hydrogen Programs and industry R&D activities to maintain the project as a "learning demonstration."
- We will publish the Spring 2010 and Fall 2010 composite data products as the last two sets of anticipated analysis results from the project.
- As the last deliverable from this project, we will write a final comprehensive summary report for publication.

Special Recognitions & Awards/Patents Issued

1. Nominated for "Best Dialogue Presentation Award" at the EVS-24 international vehicle conference in Stavanger Norway, April 2009 (one of only five posters nominated for this award out of hundreds).

2. Received 2009 DOE Hydrogen Program R&D Award, "In Recognition of Outstanding Contributions to the National Hydrogen Learning Demonstration," May 2009.

FY 2009 Publications/Presentations

1. Kurtz, J., Wipke, K., Sprik, S., "Fuel Cell Vehicle Learning Demonstration: Study of Factors Affecting Fuel Cell Degradation," Sixth International Fuel Cell Science, Engineering and Technology Conference (ASME Fuel Cell Conference), Denver, CO, June 2008. (paper and presentation).

2. Wipke, K., presentation of Learning Demonstration results to FreedomCAR Fuel Cell Tech Team, July 2008.

3. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., "Composite Data Products for the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project, Fall 2008" Golden, CO: National Renewable Energy Laboratory, September 2008.

4. Wipke, K., Sprik, S., Kurtz, J., Garbak, J., "Fuel Cell Vehicle Infrastructure Learning Demonstration: Status and Results," *ECS Transactions: Proton Exchange Membrane Fuel Cells 8*, September 2008.

5. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Fuel Cell Vehicle Infrastructure Learning Demonstration: Status and Results," Electrochemical Society Meeting, Honolulu, Hawaii, October, 2008.

6. Wipke, K., presentation of Learning Demonstration results to FreedomCAR H2 Storage Tech Team, October 2008.

7. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Fuel Cell Vehicle Learning Demonstration: Early Second-Generation Vehicle Results and Hydrogen Production Efficiency," 2008 Fuel Cell Seminar & Exposition, Phoenix, AZ, October, 2008. (presentation)

8. Wipke, K., Sprik, S., Kurtz, J., Thomas, H., Garbak, J., "FCV Learning Demonstration: Project Midpoint Status and First-Generation Vehicle Results," *The World Electric Vehicle Journal*, Vol 2, Issue 3. NREL/JA-560-45468, November 2008. (paper)

9. Wipke, K, Sprik, S., Kurtz, J., 2008 Annual Progress Report for NREL's "Controlled Hydrogen Fleet and Infrastructure Analysis Project," Section VII.12, November 2008. (paper)

10. Wipke, K., Sprik, S., Kurtz, J., Garbak, J., "Field Experience with Fuel Cell Vehicles," *Handbook of Fuel Cells – Fundamentals, Technology, and Applications, Volume 6: Advances in Electrocatalysis, Materials, Diagnostics and Durability*, chapter 60, John Wiley & Sons, Ltd. ISBN: 978-0-470-72311-1. NREL/CH-560-43589, March 2009. (paper)

11. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project–Spring 2009 Composite Data Products, Final Version," March 2009. (presentation)

12. Wipke, K., Kurtz, J., presentation of FC stack usage statistics to the FCCJ-DOE-USFCC Testing Protocol Harmonization meeting, March 2009. (presentation)

13. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "National Fuel Cell Vehicle Learning Demonstration Nears Full Deployment," 2009 National Hydrogen Association Conference, Columbia, South Carolina, April 2009. (presentation)

14. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "National Fuel Cell Vehicle Learning Demonstrations: Status and Results," 2009 Society of Automotive Engineers World Congress, Detroit, Michigan, April 2009. (presentation)

15. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "National Fuel Cell Vehicle Learning Demonstration Nears Full Deployment," Joint FreedomCAR & Fuels Hydrogen Storage and Fuel Cell Tech Team meeting, Detroit, Michigan, April 2009. (presentation)

16. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T, Garbak, J., "U.S. Fuel Cell Vehicle Learning Demonstration: Status Update and Early Second-Generation Vehicle Results," 24th International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Stavanger, Norway, May 2009. (paper and poster presentation)

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