Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project

DOE Cooperative Agreement No. DE-FC36-04GO14284

General Motors, LLC

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DOE Final Technical Report

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Hydrogen Vehicle and Infrastructure Demonstration and Validation

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U.S. Army, Ft. Belvoir, VA
Quantum Technologies, Inc., Irvine, CA
Viewpoint Systems Inc., Rochester, NY
NextEnergy, Detroit, MI
U. S. Environmental Protection Agency, Washington, D.C.
District of Columbia Department of Transportation, Washington, D.C.
State of Virginia Department of Environmental Quality, Richmond, VA
U.S. Postal Service, Washington, D.C. and Irvine, CA

Phase 2 Partners:
Project Driveway drivers composed of media, policy makers, general public, businesses, and government

Project Start Date: **October 1, 2004**
Report Date: **October 30, 2011**

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1. Project Objectives

General Motors, LLC (GM) and energy partner Shell Hydrogen, LLC (Shell), deployed a system of hydrogen fuel cell electric vehicles (FCEVs) integrated with a hydrogen fueling station (HFS) infrastructure to operate under real world conditions. Project objectives included demonstration of progressive generations of vehicle fuel cell system technology, demonstration of multiple approaches to hydrogen generation and delivery for vehicle fueling, and the collection and reporting of operating data.

This project was initiated to support the resolution of technical barriers such as the lack of performance and durability data for fuel cell electric vehicles, the lack of performance and availability data for hydrogen fueling infrastructure, the need for maintenance and training facilities, and experience with related codes and standards.

2. Executive Summary

The Hydrogen Vehicle and Infrastructure Demonstration and Validation project has delivered the learnings needed to enable the DOE and industry to assess the current state of FCEV and HFS approaches and help make decisions regarding commercialization timelines and next steps along the path to a hydrogen economy.

This project has progressed over a five year period with an additional 2-year learning cycle and has made progress in support of the long term goals of DOE's Technical Validation Program. General Motors completed the deployment of eight of its commercially developed Phase 1 FCEVs according to plan for the DOE Learning Demonstration. Phase 1 vehicles are referred to as Gen1 in this document. Phase 2 FCEVs were launched in 4Q07 in the Eastern and Western regions. All 42 Phase 2 vehicles were deployed by the end of 3Q08. . The Phase 2 vehicles are referred to as Gen2 in this document. 32 of these Phase 2 vehicles completed their deployment at the end of 3Q2009, and 10 Baseline Phase 2 vehicles continued to report data thru 3Q2011. The purpose of the Gen2 Baseline vehicles was to demonstrate long stack durability with extended vehicle operating hours. In addition, 10 Phase 2 FCEVs were retrofitted with the most recent technology advances in order to extend learnings. These 10 vehicles are referred to as Technology Insertion vehicles in this document. All 10 Technology Insertion vehicles were deployed by the end of 2Q10. These Technology Insertion vehicles were deployed and data was submitted according to the NREL Data Reporting Templates.

Three maintenance and training hubs were used to support the fleet. Many fueling stations were used to support this fleet, however, eight initially and then three towards the end of the program were part of this demonstration project. Shell Hydrogen ended its participation in the Demo program (per our updated SOPO for Alteration 018) in 3Q09. General Motors continued to utilize the Shell Hydrogen stations and other hydrogen refueling stations outside of the Demo program to support operation of the Demo program vehicles.

Beginning-of-life chassis dynamometer testing was conducted for Phase 2 Chevrolet Equinox FCEVs, which included cold weather tests. Dynamometer testing was completed on one Phase 2 vehicle in September 2009 and on one Technology Insertion vehicle in June 2010. Another round of dynamometer testing was completed in December 2010 on one Technology Insertion vehicle so the results can be compared to previous testing. End-of-test dynamometer testing was conducted on the same Technology Insertion vehicle in 3Q11 so all of the results can be compared.

In order to accelerate the learnings on the most recent technology stack design, three fuel cell systems were instrumented with the same hardware as the Technology Insertion vehicles. These fuel cell systems operated under a stressful, accelerated durability protocol in order to capture additional early learnings. This laboratory durability data was reported following the NREL data reporting templates.

From April, 2005 to September, 2011, 56,617 miles of Gen1 data and 1,155,048 miles of Gen2 data was generated and submitted according to the NREL data reporting templates. In addition, 1,757 Gen1 and 12,629 Gen2 refueling events were submitted according to NREL data reporting templates.

A large part of this project was to provide ample outreach opportunities to educate and demonstrate the fuel cell vehicle to the general public. A recent outreach activity was a demonstration of the extent of existing Hydrogen vehicle fueling infrastructure in the northeastern US where a Gen2 vehicle was driven across 10 states and 1 Canadian province, using 12 hydrogen refueling stations. The objective of this outreach activity was to support and encourage hydrogen infrastructure development by demonstrating the network already connecting 10 states and to provide continued visibility and demand for the existing stations during the ramp-up to commercialization of fuel cell electric vehicles. An overview of the activity is shown in ***Figure 1***. Likewise a “24 hour marathon” FCEV drive in southern California highlighted the current capability of FCEVs not only to serve a large geographical area, but to operate in both conditions of changing altitude (Sea Level to over 4000 feet) and changing temperatures (60°F to 110°F) during a single day. An overview is shown in ***Figure 2.***

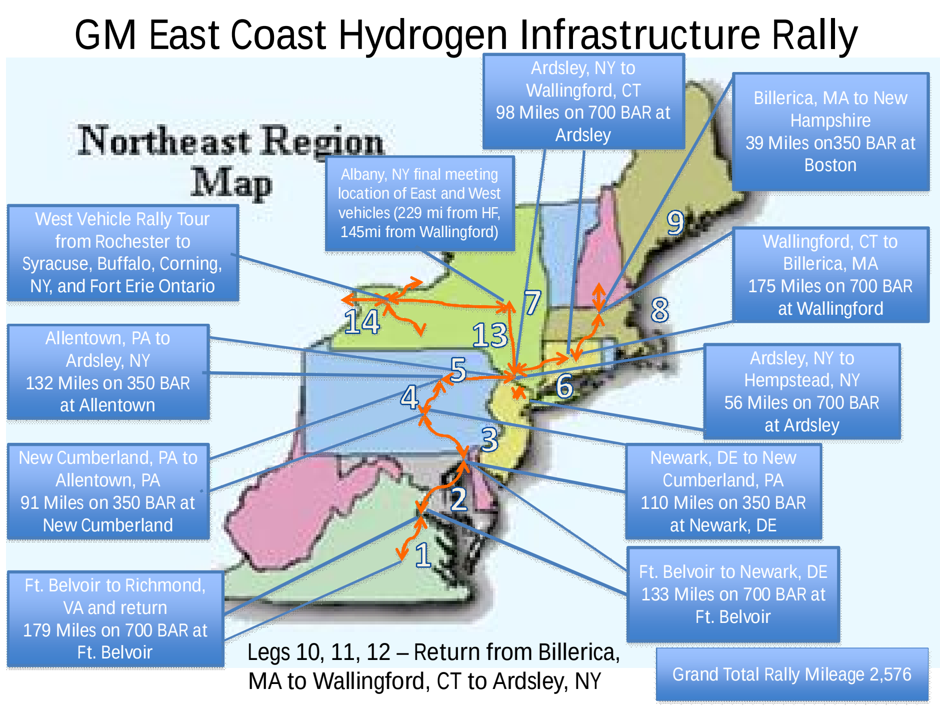

Figure 1 – Route travelled during the Hydrogen Infrastructure Rally

GM 24 Hour Fuel Cell Marathon

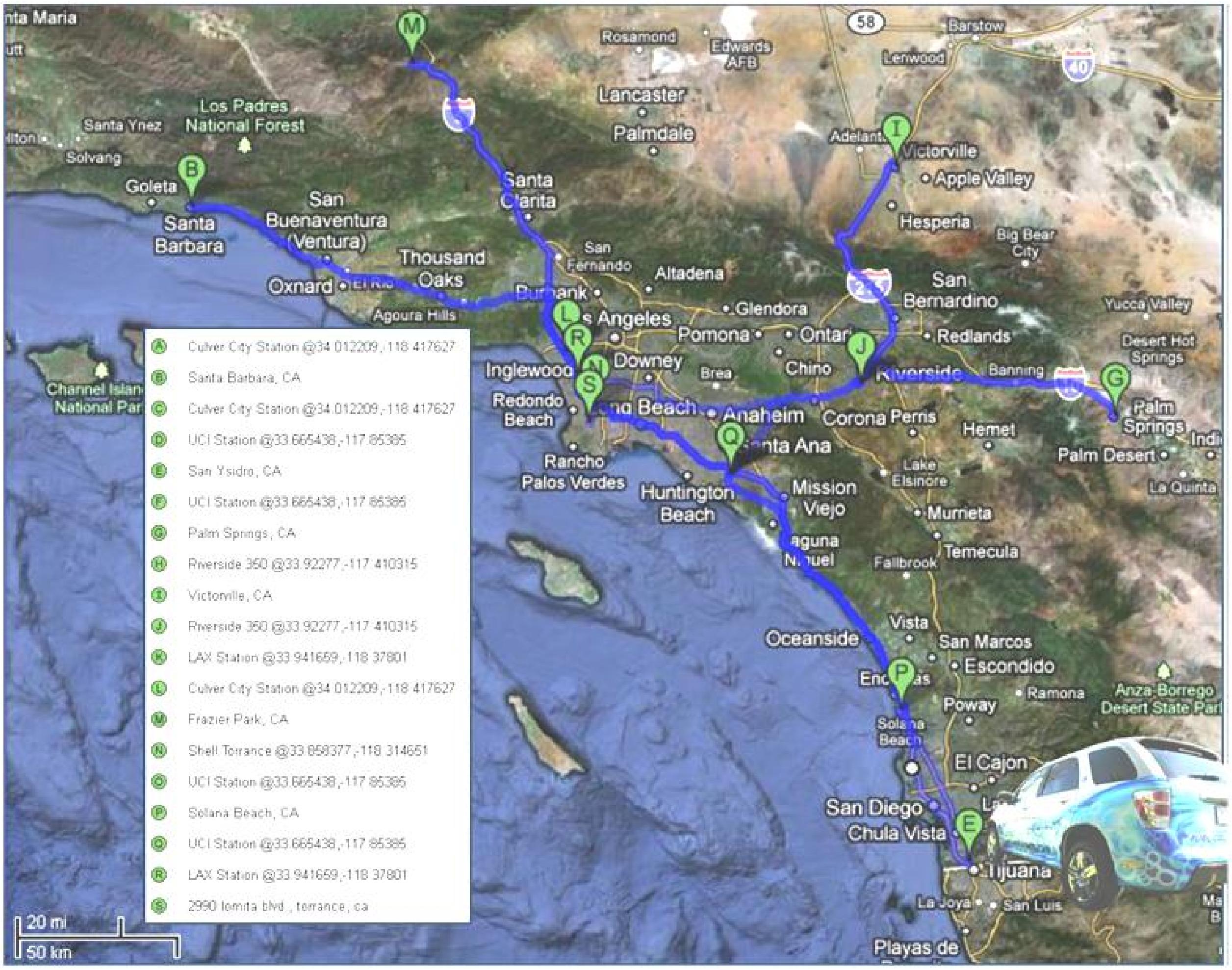

Figure 2 – Route travelled during the 24 Hour Fuel Cell Marathon

This report summarizes the accomplishments, activities, lessons learned, and recommendations resulting from the data and conclusions gathered from October 2004 through September 2011 concerning both the FCEV and the HFS. Shell Hydrogen provided data per the DOE data templates but didn't accept DOE funding. This report is the final technical summary of the GM and Shell Hydrogen partnership in this Hydrogen Vehicle and Infrastructure Demonstration and Validation project.

3. Accomplishments

There were multiple objectives that had to be met in this demonstration project. The objectives are stated below followed by the description of the accomplishments supported with pictures, tables, and/or lessons learned as appropriate. The text was written to give the reader a good understanding of the technologies demonstrated in this project.

3.1 Objective: Demonstrate progressive generations of fuel cell system technology

3.1.1 Overview

GM's participation in the Hydrogen Vehicle and Infrastructure Demonstration project covered two generations of vehicles deployed in two primary geographic regions.

The first generation vehicles, Gen1, were based on the Opel Zafira, a five passenger vehicle from the Opel division in Germany as shown in ***Figure 3***. The Gen1 vehicles utilized GM's 2nd generation fuel cell. There were 8 vehicles in the Gen1 project. 4 of the vehicles utilized liquid hydrogen storage and 4 utilized compressed hydrogen storage. The Gen1 eastern region deployment covered the Washington, D.C. metropolitan area with a service hub located on the military base in Fort Belvoir, Virginia. The Gen1 western region deployment covered the Los Angeles metropolitan area and was supported by a service hub in Lake Forest, California. There were 6 Gen1 vehicles in the eastern region and 2 Gen1 vehicles in the western region.

Figure 3 – Gen1 Opel Zafira Fuel Cell Electric Vehicle

Gen1 vehicles were deployed to various drivers including the U.S. Postal Service, Department of Transportation, media, congressional representatives and staff, and internal GM drivers. The 8 Gen1 vehicles where retired in the fall of 2007 to coincide with the introduction of the Gen2 vehicles.

For Gen2, GM's 4th generation fuel cell was integrated into the Chevrolet Equinox as shown in ***Figure 4***. Approximately 100 Equinox FCEVs were produced and participated in "Project Driveway", including the 42 vehicles in the Gen2 demonstration. "Project Driveway" was a focused effort to get a variety of drivers to experience the Chevrolet Equinox Fuel Cell Electric Vehicle. The types of drivers included were media, policy-makers, general public, business-to-business and celebrity drivers. "Project Driveway" allowed GM to receive comprehensive feedback on all elements of the customer experience and vehicle performance to guide future fuel cell vehicle and infrastructure development. "Project Driveway" constituted the first meaningful market test of fuel cell vehicles anywhere.

Figure 4 – Gen2 Chevrolet Equinox Fuel Cell Electric Vehicle

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The major design differences between the Gen1 and Gen2 vehicles highlight the transition from an experimental vehicle requiring substantial engineering support for fleet operation to a pre-production vehicle that could be deployed to customers. The Gen1 vehicles were highly instrumented to allow for increased understanding of vehicle operations. In contrast, the software controls for Gen2 vehicles replaced many physical sensors with model based sensing and added diagnostic logic and troubleshooting codes to allow for vehicle deployment to customers. Enhanced software logic allowed the Gen2 vehicles to start and operate in sub-freezing temperature conditions and enabled customer deployment in cold weather regions.

The Gen1 vehicles met all the propulsion power requirements using a fully dynamic fuel cell system as shown in ***Figure 5***. The Gen2 vehicles, as shown in ***Figure 6***, utilized a hybrid system, combining a dynamic fuel cell along with a charge-sustaining nickel-metal hydride high voltage battery which also accommodated regenerative braking.

Figure 5 – Gen1 Vehicle Overview

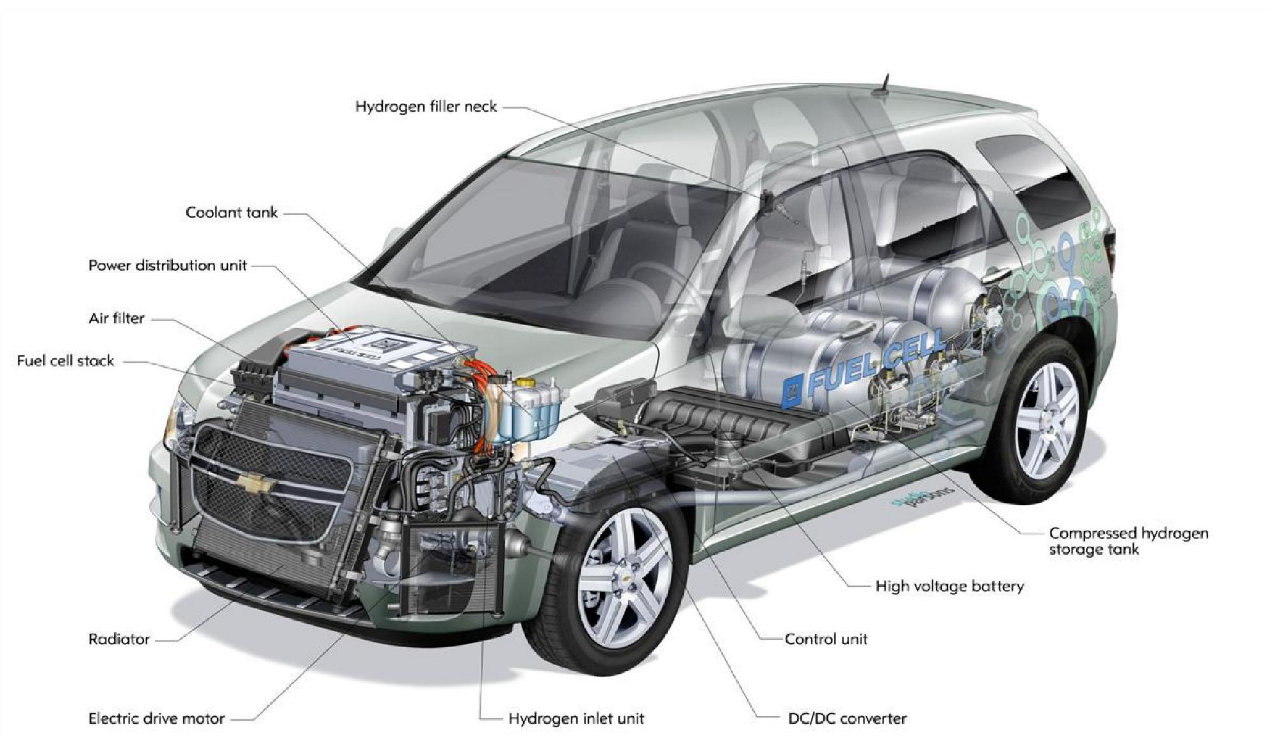


Figure 6 – Gen2 Vehicle Overview

The Gen1 vehicles consisted of four vehicles with liquid hydrogen storage and four vehicles with compressed hydrogen storage. The process of fueling vehicles with cryogenic liquid hydrogen proved complex and would require additional development to improve customer ease of use. Another difficulty experienced with the liquid hydrogen was that it would boil off resulting in a loss of hydrogen. The Gen1 vehicles utilizing compressed hydrogen storage incorporated 700 bar tank capacity, however due to limited fueling options at 700 bar, most fueling was limited to 350 bar. All of the Gen2 vehicles were equipped with 700 bar compressed hydrogen tanks. This was supported by infrastructure upgrades to allow for 700 bar fueling which helped increase the vehicle range.

*Gen2 (Chevrolet Equinox Fuel Cell Electric Vehicle) details***:**

The Chevrolet Equinox Fuel Cell Electric Vehicle is a zero-gas, zero-emissions vehicle that makes no compromises, achieving 0 to 60 mph in 12 seconds, 236 lb.-ft. (320 Nm) of instant torque and a top speed of about 100 miles per hour. It seats four, sports 32 cubic feet of cargo volume for everybody's gear, and has a range of approximately 158 miles per fill-up based on the 2008 EPA adjusted measurement.

The Equinox Fuel Cell also features full four-wheel ABS for controlled, confident stopping and, unlike early fuel cell vehicles, starts and operates in sub-freezing temperatures.

Aside from its dramatically different propulsion system, the Equinox Fuel Cell looks and drives much like a production Chevy Equinox crossover. The fuel cell system fits within the space of the conventional engine compartment. The nickel-metal hydride battery pack, which stores energy from the regenerative braking system to increase operating efficiency and boost acceleration when needed, sits under the floor in the middle of the vehicle. Three compressed hydrogen storage tanks, made of carbon fiber for strength and pressurized to 700 bar or 10,000 pounds per square inch (psi), are located under the rear seats and cargo area. They contain roughly nine pounds (4.2 kg) of hydrogen.

Outside, the Chevrolet Equinox Fuel Cell fascia sports Chevy's horizontally split grille, along with extra cooling air inlets in the lower front corners. At the rear, the new fascia under the bumper has four thin vertical slits in place of the exhaust pipe; they release the clean water vapor emissions. This patented design lets onlookers know that this is no ordinary internal combustion engine vehicle.

Exterior graphics, including special badging on the liftgate, also call out the Equinox Fuel Cell, finished in either a premium tri-coat Glacier Gold or White. Under the hood, a special trim cover on the fuel cell system also sets the Equinox Fuel Cell apart from its conventional sibling.

The plush interior includes a touch screen display in the center stack for the navigation system and power flow display. Instead of a tachometer, a power indicator is integrated into the instrument panel to show the actual power being delivered to the system in kilowatts (kW). The Equinox Fuel Cell shifter also includes an emblem signifying it's a hydrogen fuel cell-electric vehicle.

SPECIFICATIONS: CHEVROLET EQUINOX FUEL CELL

General

Vehicle type:	5-door, front-wheel-drive crossover SUV
Chassis:	Independent McPherson struts front, independent 4-link trailing arm rear, disc brakes front and rear, friction brake blending to maximize energy capture, electric power assist steering
Seating capacity:	4

Dimensions

Wheelbase (in / mm):	112.5 / 2858
Length (in / mm):	188.8 / 4796
Width (in / mm):	71.4 / 1814
Height (in / mm):	69.3 / 1760
Curb weight (lb / kg):	4431 / 2010
Cargo volume (cu ft / L):	32.0 / 906.24

Fuel storage system

Type:	3 carbon fiber fuel tanks, compressed gas
Service pressure (psi / bar):	10,000 / 700 or 5,000/350
Storage capacity (lb / kg):	9.24 / 4.2

Fuel cell system

Power (kW):	93

Battery system

Type:	Nickel-metal hydride battery pack; regenerative braking
Power (kW):	35

Electric traction system

Front system:	3-phase asynchronous electric motor, FWD
Power (kW):	73 continuous, 94 maximum
Torque (lb-ft / Nm):	236 / 320

Performance

Acceleration 0-60 mph / 0-100 km/h (sec):	12
Top speed (mph / km/h):	100 / 160
Operating range (miles / km):	150 / 240 based on the new EPA 2008 adjusted measurement
Payload (lb / kg):	800 / 362

Exterior

Colors:	White, and premium tri-coat Glacier Gold
Styling:	Differentiated front and rear fascia, exhaust outlets, chrome accents, graphics
Tire size:	P225/60R17, 17-inch aluminum wheels

Interior

Content:	Premium cloth (leather free) seats and trim, 2-passenger rear bench with center console
Color & styling:	Glacier Gold theme with fabric and trim, unique floor mats and shift lever graphics
Instrument panel:	kW meter, fuel cell energy display

Fuel cell propulsion system

Freeze capacity:	Freeze capable without grid heater
Operating temperature (F / C):	5 to +113 / -15 to +45

Gen2 Technology Insertion Vehicles

In order to demonstrate the progress made in the program to date, 10 Gen2 vehicles were upgraded with the most recent materials and controls technology. These Technology Insertion vehicles shown in ***Figure 7*** were deployed and they accumulated miles.

Figure 7 –Technology Insertion vehicle

The Technology Insertion vehicles were upgraded with both revised components and materials and advanced software controls.

Many of the fuel cell system software upgrades included enhancement to the vehicle controls strategy to increase stack durability. These included a modified vehicle start/stop strategy, a strategy to reduce the effects of voltage cycling, and strategies to maintain a more constant stack humidification. Software upgrades to the vehicle propulsion system provided opportunities to address fuel economy and vehicle range improvements. These improvements focused on improving vehicle start-up and shut-down, reductions in parasitic draw from the balance of plant components in the vehicle, and a modified hybridization strategy.

Hardware upgrades included a redesigned coolant pump and other components to reduce power draw, wiring changes to support a new start/stop strategy, an updated coolant heater, and a rerouting of the hydrogen exhaust hose. The fuel cell stack was upgraded with new material as well to extend durability.

3.1.2 Cold Weather Performance

The Gen2 vehicles were designed to start and operate under sub-freezing conditions. Gen2 cold weather testing at -20 degree Celsius was done at GM's Cold Weather Development Centre in Kapuskasing, Ontario Canada as shown in **Figure 8**. The Gen2 vehicles met the freeze start and drive away DOE metrics. GM places considerable emphasis on the capability of the FCEV to operate under the same set of environmental temperature conditions as vehicles with internal combustion engines.

Figure 8 – Gen2 Vehicle Driven in Snow

Besides the testing site at Kapuskasing, the Ardsley, New York location, just north of New York City, provided ample opportunity to test the freeze capability of the Gen2 vehicles while in the hands of customers. As noted in ***Figure 9***, the vehicles in the eastern region performed over 3100 starts when the ambient temperature was less than 0˚ C without any issues.

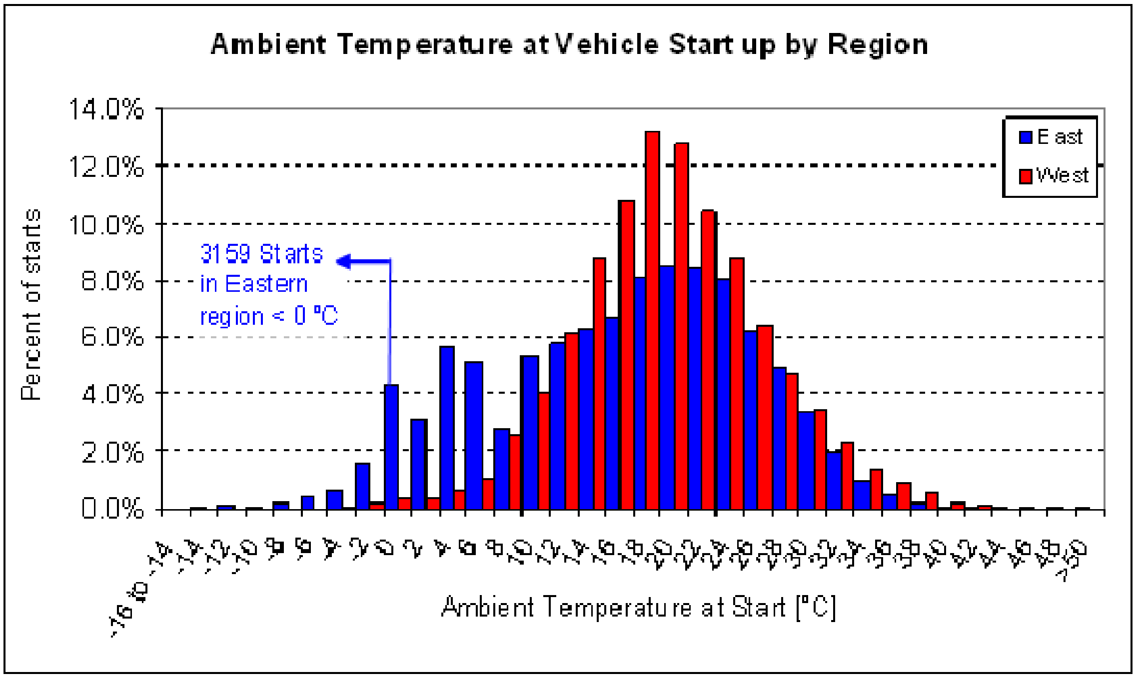


Figure 9 – Number of starts at various ambient temperatures for the Gen2 DOE vehicle fleet

Inherent features of a PEM fuel cell present unique challenges during operation in temperatures below freezing. For example, comparing a fuel cell stack to the piston/valve power generation of a typical internal combustion engine, the stack:

- has a heavy reliance on catalyst activity that prefers temperatures well above freezing
- uses a membrane that relies on humidification
- requires humidified gas streams to go through much smaller channels, making it more susceptible to ice blockage
- has a softer material set than the metal of an IC engine, so it's at a higher risk of damage from expanding ice

Part of the fleet operates in cold climates to prove that the technology is reliable, despite the cold weather challenges. There were no hardware or software modifications required for the northern climates–the vehicles were of the same specification whether in Southern California, Michigan, or New York. To further prove cold weather capability, there were no provisions available to plug in heaters during cold soaks.

The fleet answered a very important question about this technology: Climates with freezing temperatures do not limit the use of PEM fuel cell vehicles. The systems performed extremely well due to careful water management using a combination of hardware design and operational controls. There were five areas of operation that where studied: Startup, drive-away performance, run performance once up to temperature, shutdown, and cabin/windshield heat.

- Startup (prior to drive-away): The system reliably starts and warms up, but there is an additional wait compared to typical gasoline engines. In very cold temperatures (below

15F or -10C), a wait of up to one minute is required before the vehicle may be driven away. Reducing this wait time remains an area of system development.

- Drive-away performance: It is important to avoid a significant reduction in vehicle performance as the fuel cell system warms up. The vehicle meets the targeted 0 to 100 kph acceleration in 14 seconds immediately upon drive-away, so for example, a driver pulling out of the driveway into heavy traffic can get up to speed safely even when the system is cold.

- Run Performance: Performance once the vehicle reaches normal operating temperature is virtually indistinguishable from performance in warm weather.

- Shutdown: At cold temperature, the system has a longer shutdown than an IC engine to purge water from the system. This does not inconvenience the driver since it automatically completes as the driver walks away from the vehicle.

- Performance for cabin heat and windshield defrost meets the applicable FMVSS standards. Fuel consumption (power demand) can increase modestly during cold weather due to high cabin/windshield heat demand. At normal operating temperature, the majority of heat is provided from fuel cell waste heat, so additional power demand for heating is primarily seen during the warm-up period.

In summary, the Gen2 vehicle has proven to be a very capable winter vehicle. Multiple Gen2 vehicles were successfully operated through 4 winters in the New York City and New York State areas.

3.1.3 Fuel Economy and Vehicle Range

Various performance testing was conducted using a vehicle chassis dynamometer at GM's Milford Proving Grounds test facility in Milford, Michigan. ***Figure 10*** shows a Gen2 vehicle undergoing performance and fuel economy testing at the facility.

Figure 10 – Performance Testing on a Dynamometer

The fuel economy test results from the dynamometer testing are displayed in ***Figure 11***. The beginning of project fuel economy results for Gen1 and Gen2 vehicles are similar. The difference in the fuel economy is more noticeable during the end of project testing. The Gen1 vehicles exhibit a decline in fuel economy as the vehicle and stack aged. In contrast, the Gen2 vehicles exhibit an increase in fuel economy. There is a seventeen percent (17%) improvement in dynamometer fuel economy from beginning to end of project. This is mainly attributed to engineering advances made to the software controls over the course of the vehicle deployment as described previously. It is important to note that the Gen2 end of project fuel economy was tested with an aged vehicle and an aged stack whereas the Gen2 beginning of project testing was conducted using a new vehicle and a new stack.

The tested Technology Insertion vehicle exhibited a small decline in fuel economy as the vehicle and stack aged over approximately 30,000 miles. In this case, the same vehicle and fuel cell stack with the same control software/calibration was tested both at the beginning and the end of the project. The end-of-project Technology Insertion vehicle continued to demonstrate fuel economy significantly better that the beginning-of-project economy of the Baseline vehicle.

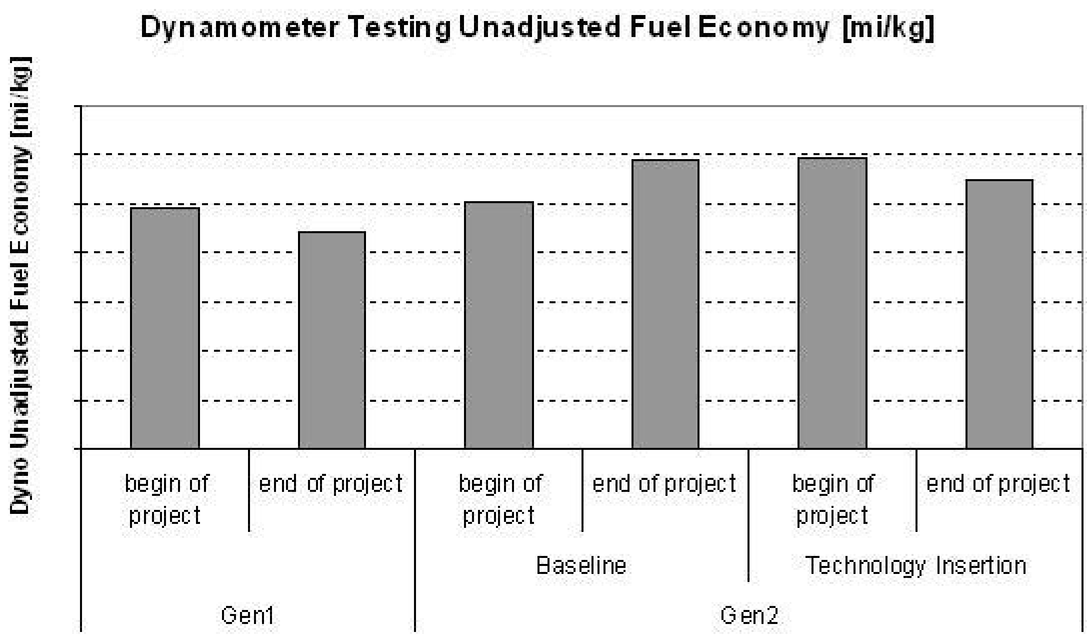


Figure 11 – Fuel Economy for Gen1, Gen2, and Technology Insertion shown at beginning and end of project

The fuel economy improvements over the duration of the project as seen on the dynamometer also translated to improvements seen for on-road fuel economy. ***Figure 12*** shows quarterly on-road fuel economy for the DOE fleet vehicles.

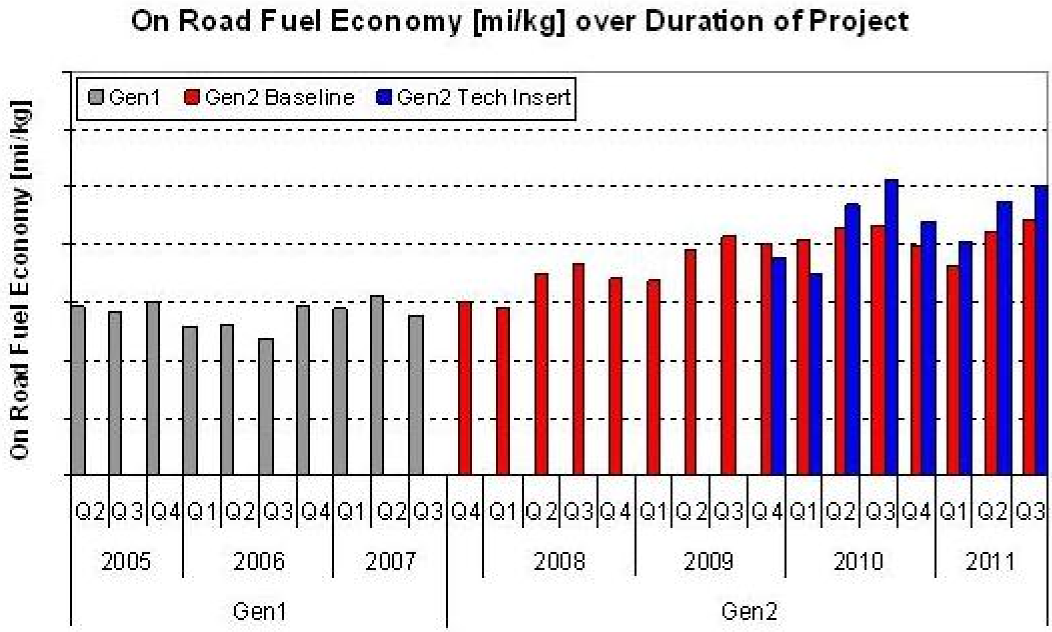


Figure 12 – On-road fuel economy over the life of the project

Improvements to the vehicle range can be seen between Gen1 and Gen2 vehicles in ***Figure 13***. This increase in range is due to the addition of 700 bar fueling capacity in addition to the improvements in fuel economy.

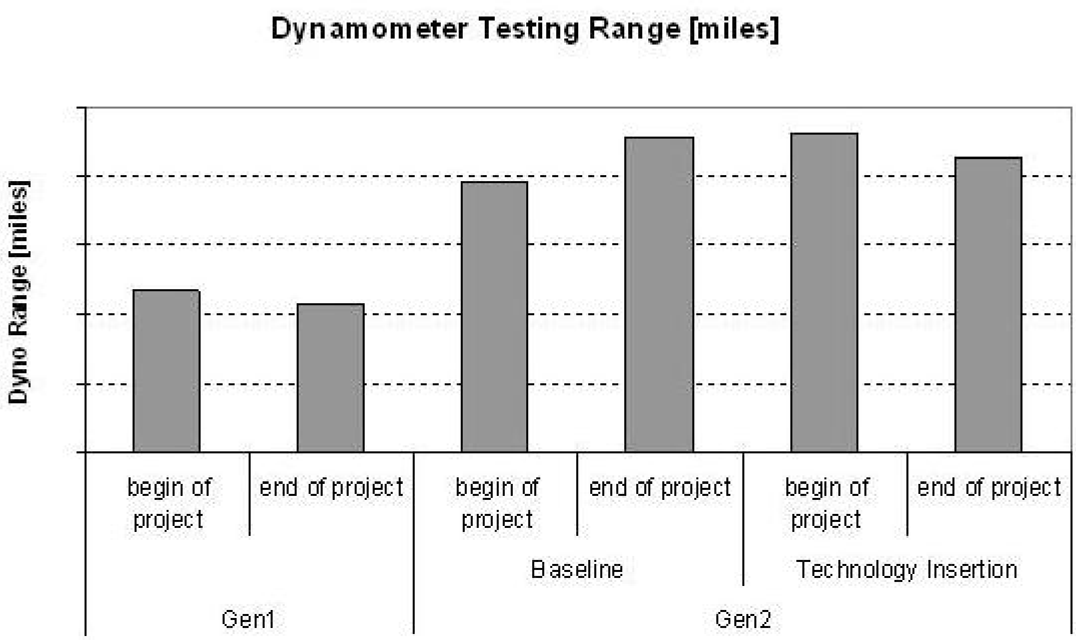


Figure 13 – Vehicle Range for Gen1, Gen2 and Technology Insertion

A histogram of distance traveled between fueling for Gen2 DOE fleet is shown in ***Figure 14***. The drivers refueled the vehicles after ninety miles on average.

700 bar fueling capability is a key enabler for providing vehicle range that is acceptable to customers, particularly during the early stages of hydrogen fueling station infrastructure roll out when the number of fueling stations may be limited.

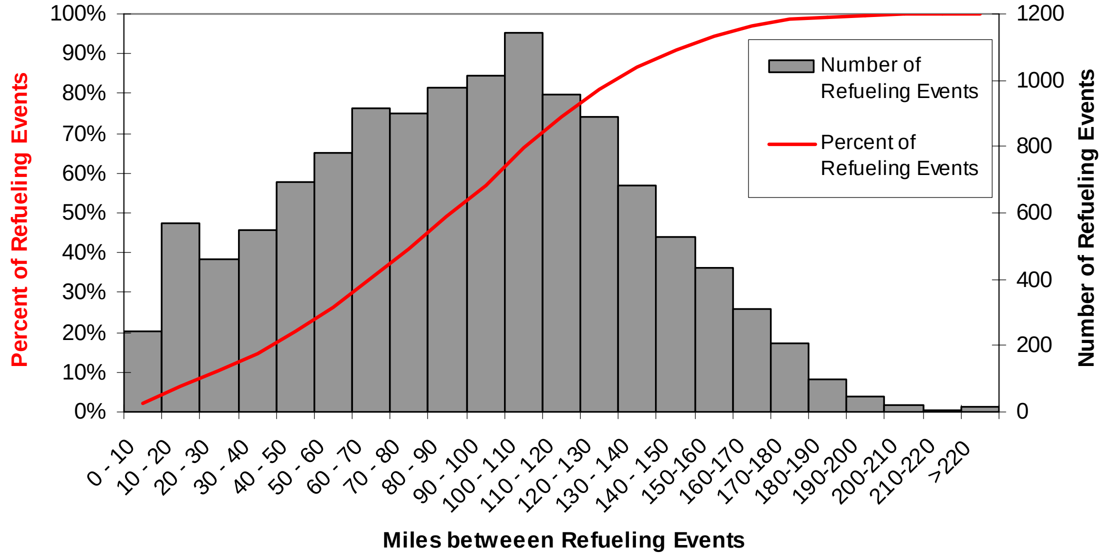


Figure 14 – Gen2 Fueling Events

3.1.4 <u>Fuel Cell Stack Durability</u>

Demonstrating that fuel cell stack durability is on track to meet targets for commercial usage was a major focus of this project. Multiple approaches based on continuous learning were used to demonstrate ongoing improvements in fuel cell stack durability. The multiple approaches used in this project included demonstration of multiple generations of fuel cell hardware, multiple types of membrane and catalyst material, multiple configurations of controls, accelerated durability testing, and vehicle deployment in real world applications.

The initial fuel cell stack durability measure that NREL used was time to stack voltage loss of 10%. As the project progressed, additional stack durability performance measures were added to reflect that fuel cell stacks can have a useful life well beyond a 10% drop in initial voltage. GM has demonstrated steadily increasing fuel cell stack durability as the project has progressed, demonstrating that the electrode durability goals outlined by DOE can be achieved.

During the Gen1 phase of the project, twenty stacks were replaced for non-repairable failures as shown in ***Figure 15***. Global low performance (loss of stack voltage) was the primary failure mode for the Gen1 vehicle stacks. This failure mode was caused by rapid degradation of the cathode performance of the stack. Multiple improvements to the stack operating conditions under various modes of vehicle use were implemented in the Gen2 vehicles to mitigate this degradation.

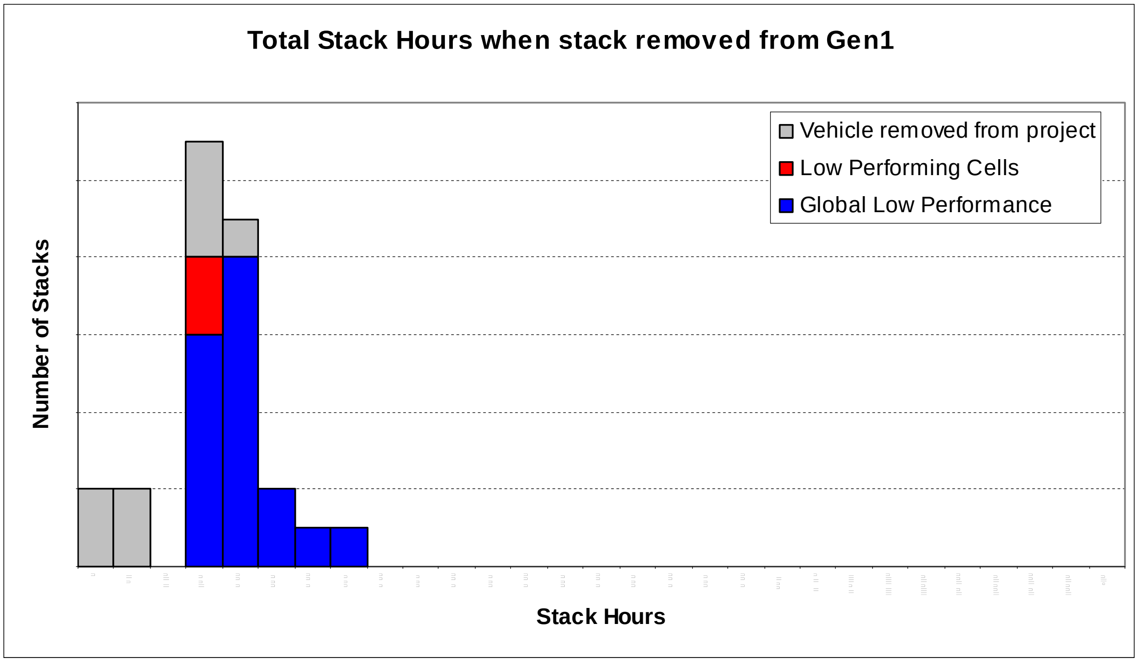


Figure 15 – Fuel Cell Stack Removal Data in Gen1 Vehicles

In addition, Gen1 stacks occasionally experienced a "low performing cell" failure mode resulting from failures of individual cells. For the Gen2 stacks, improvements to the cell materials and design helped mitigate this failure mode. The Gen2 operating conditions were also modified to reduce stresses on the cell materials.

The Gen1 stacks had 20 non-repairable failures. The stacks in the Gen2 project have accumulated more than four times the operating hours of Gen1 stacks as shown in ***Figure 16***.

Early in the Gen2 phase, a problem was discovered in the fuel cell system shutdown logic that had not previously been observed in the test stand durability trials. This problem caused the fuel cell stacks to have premature catalyst deterioration on a few end cells. Initially software controls were used to extend the time before this deterioration occurred. Subsequently, hardware upgrades were also implemented which eliminated this failure mode. These "low performing cells" were replaced and the stacks were returned to the vehicles to continue operating. This test-fail-analysis-design-test sequence within Gen2 has allowed rapid advances in fuel cell stack durability in real-world use as a direct result of this demonstration project.

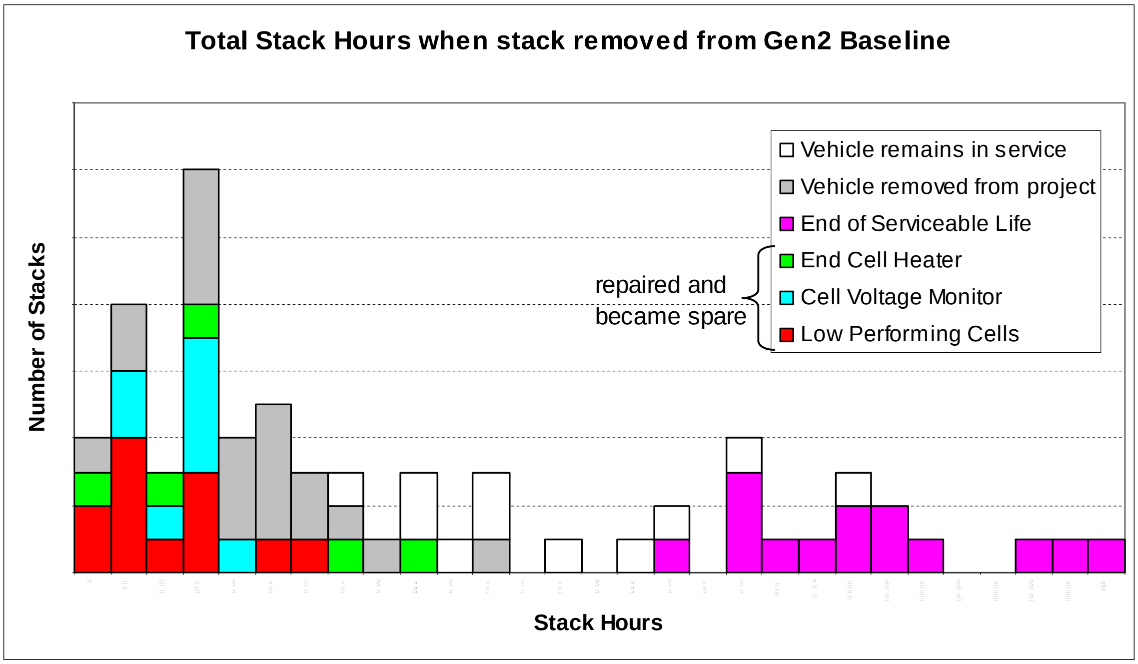


Figure 16 - Fuel Cell Stack Removal Data in Gen2 Vehicles

Two additional repairable failure modes (end cell heater and cell voltage monitor) were observed in Gen2 stacks. Both required the replacement of electrical devices that require removal of the stack from the vehicle in order to repair or replace the device. There are multiple causes for these hardware failures as shown in ***Figure 17***: bad solder connections, breach in conformal coating, bad components and loose connections related to non-production processing.

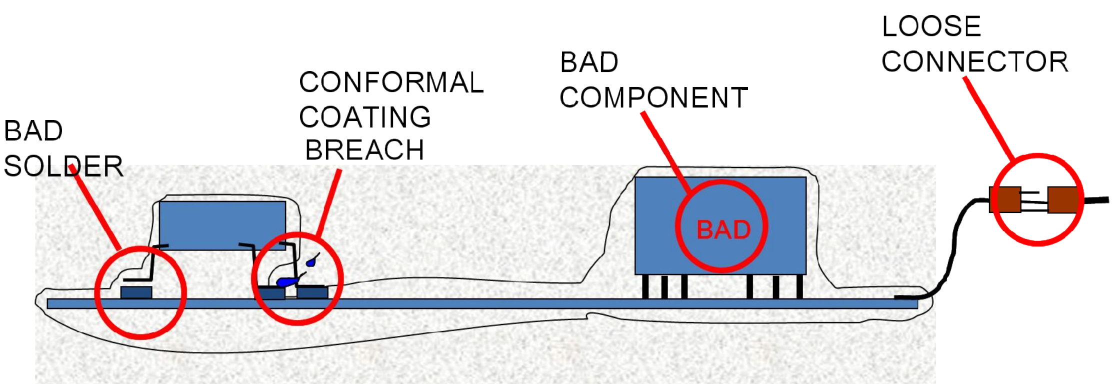


Figure 17 - Electrical Support Hardware Failures

As part of the design of the fuel cell system to meet the overall product performance requirements of the vehicles, trade-offs were made between optimum stack voltage/durability performance and robust vehicle performance. For example, the vehicle software controls were optimized to allow rapid power transients to improve acceleration performance. In addition, stack operating conditions were selected to enable consistent startups from potentially sub-freezing conditions. These conservative trade-offs were thoroughly evaluated during the project and in some cases analysis of the vehicle data from the project confirmed that changes could be made to improve stack durability without compromising the performance and reliability of the Gen2 vehicles.

The stacks in the Gen2 Baseline vehicles operated under several software levels in order to implement the improvements noted above. Stack performance over time varied significantly based on operating conditions, even though the stack itself was not permanently influenced. ***Figure 18*** shows a single stack as it was operated thru various software levels. This stack was not removed from the vehicle during the entire project. The data in blue shows the voltage decay early in the project. By implementing software B, the rate of decay was slowed down. Software C introduced a change in operating conditions which reset the stack voltage. Learnings from these iterations were incorporated into the software for Gen2 Technology Insertion vehicles.

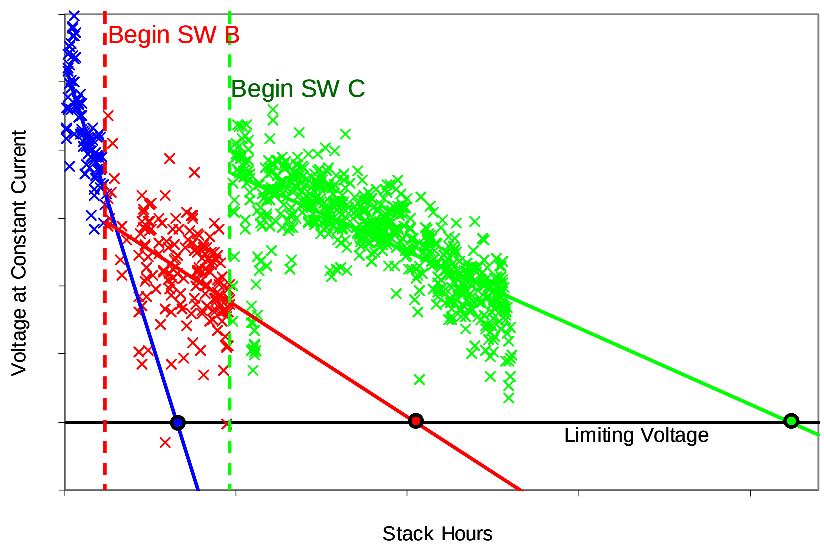


Figure 18 - Stack Voltage Degradation for Baseline Stack with Software Changes

The software changes made evaluating the voltage degradation metrics a bit more challenging. In order to evaluate the stack, the time until the stack meets a limiting voltage is estimated for each software level. ***Figure 19*** shows the progression of improvements made in time to voltage limit through the successive project phases. This metric is a projection of when the stack is expected to decay to a voltage level at which the vehicle performance requirements can no longer be met. Zero Gen2 stacks were removed from service due to global voltage decay; that is, none have reached a voltage level which cannot meet the vehicle performance requirements.

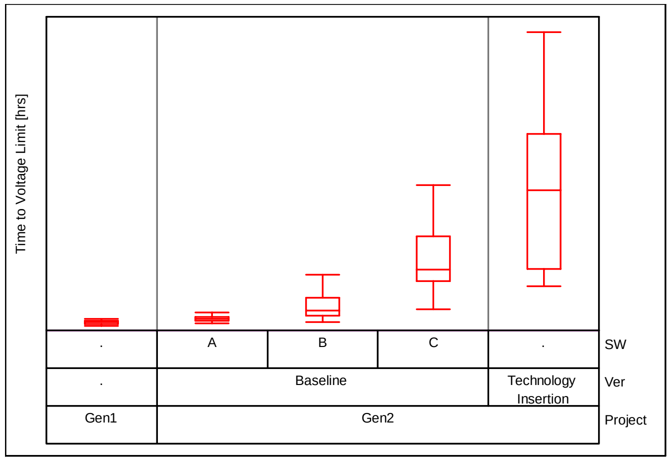


Figure 19 - Time to Voltage Limitation with Successive Project Phases

A total of fourteen Gen2 Baseline stacks experienced non-repairable failures before reaching a global voltage limitation as shown in ***Figure 16***. For these stacks, the control system limits the power requested of the stack in order to prevent the stack from shutting down with the result that the customer experiences reduced vehicle performance. This gradual power reduction was coupled with a warning message displayed to the driver to assure that the customer would not experience a complete loss of propulsion. Each stack removed from a vehicle was carefully evaluated in order to determine the root cause of any failure modes to feed back learnings into both improvements in the current vehicles and into future designs. The failure mode observed in the Gen2 Baseline stacks was related to a localized chemical deterioration of the membrane in multiple cells in each stack which resulted in a loss of voltage for the cells affected.

The Technology Insertion vehicles benefitted from the learnings of the initial phase of the Gen2 project in both the hardware selections and modified operating conditions. The Technology Insertion vehicles also allowed evaluation of stacks produced with components that utilized manufacturing techniques being developed for high-volume production. The controls for Technology Insertion added features to further mitigate disturbances that can impact stack durability. The ability to quickly incorporate designs based on vehicle learning and laboratory work into the vehicles on the road in this project accelerated learning and reveals failure modes that were not easily identified in the lab.

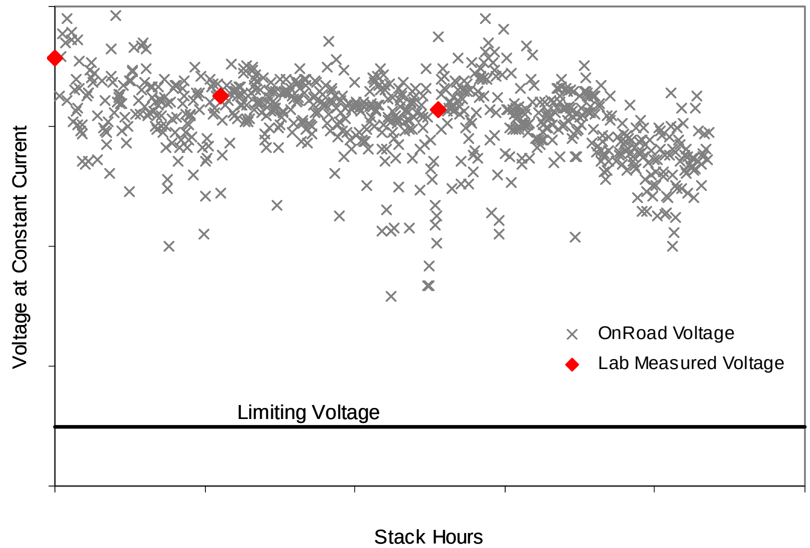


Fig 20 - Technology Insertion Stack Voltage Degradation with Lab Measurements

Evaluating stack performance from on-road vehicle data can be challenging because the varying drive conditions and drive environment can impact polarization curve results derived from dynamic conditions. During the Technology Insertion phase of the project, the stacks from five vehicles were removed at regular intervals to measure the polarization curve under the controlled laboratory conditions that are used in product development. An example from one of these stacks is shown in ***Figure 20***. The voltage decay as seen by controlled laboratory conditions in red corresponds to the noisier on-road evaluation of voltage decay in grey. This example also demonstrates that the steep decline in stack voltage early in the life of the stack has been eliminated with Technology Insertion.

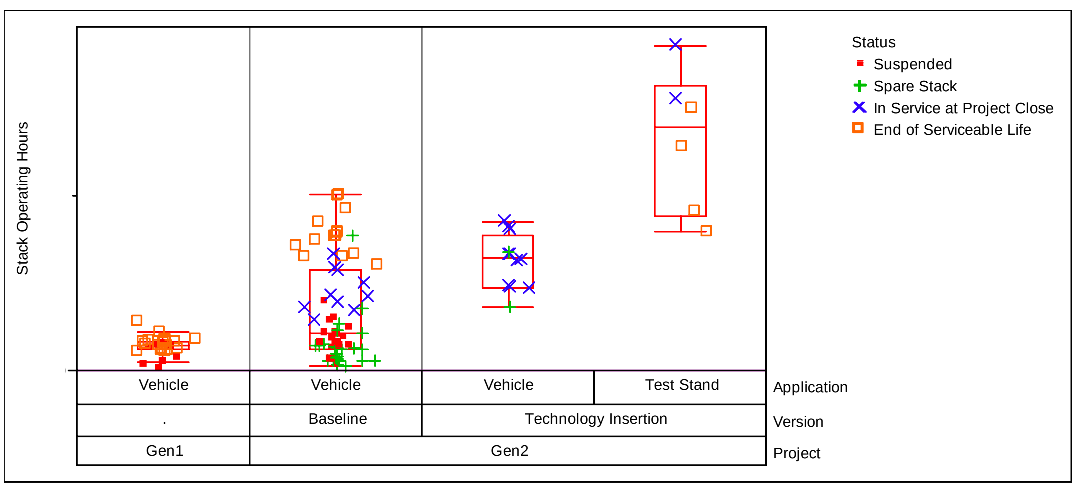


Figure 21 - Total Stack Operating Hours across Project Phases

While ***Figure 19*** showed the expected time until global voltage decay by project phases, ***Figure 21*** shows the elapsed total time of test for stacks across project phases. The data reflects the fact that many vehicles and stacks were retired from the project before reaching the end of their serviceable life. Had all stacks been run to end of serviceable life, the distributions would shift higher. Even with the suspension of testing prior to failure in many cases, it is clear that the total stack life achieved during each project phase increased significantly.

The Technology Insertion and Baseline vehicles accumulated mileage more rapidly than the initial Gen2 vehicles in order to validate stack durability improvements. While none of the Technology Insertion stacks reached the end of its serviceable life during the project, certain characteristics could be confirmed. The shallow degradation slope seen with the most mature software version in the Baseline vehicles is also a characteristic of the Technology Insertion vehicles. The steep initial slope seen with the early Gen2 vehicles has been eliminated in Technology Insertion.

The Technology Insertion phase introduced technology to allow the fuel cell stack to operate only when the driver or vehicle call for a high level of current. At other times the fuel cell stack is placed in a "stand-by" status which reduces fuel consumption and reduces the impact of stressful events on stack health thus increasing the useful life of the stack. Incorporating the stand-by strategy and associated controls into an on-road vehicle gave experience for future fuel cell programs.

The Technology Insertion stack components utilized manufacturing techniques being developed for high-volume production. After approximately a year of operation, the Technology Insertion vehicles exhibited a repairable failure mode that has been confirmed to be a problem with the high-volume production process. This finding again highlights the value of the project for revealing both design and process issues with Fuel Cell Stack technology. ***Figures 19 and 21*** illustrate how the vehicle demonstration project has allowed rapid cycles of learning to improve the durability of fuel cell stacks during the project.

As part of the Technology Insertion project, the same stack design and controls technology was implemented in three durability test stands for accelerated testing. The intent of the accelerated testing was to increase the stresses on the stack related to specific failure modes so that fixes and design improvements can be evaluated more quickly. The Fuel Cell Research Center designed the accelerated durability test protocol to include specific events experienced in real world fuel cell and internal combustion automotive use. These events are known to be damaging to a fuel cell stack. A critical goal of the test protocol was to increase the frequency of damaging events per hour of exposure while not exceeding the maximum magnitude of these damaging events beyond that seen in the field. Two specific failure modes were targeted in the protocol: the first related to membrane degradation and the second related to electrode degradation.

In the first round of testing, all three stacks failed (see ***Figure 21***) due to membrane issues. An investigation into the root cause of the cell failures identified brief periods of poor humidification control as the cause.

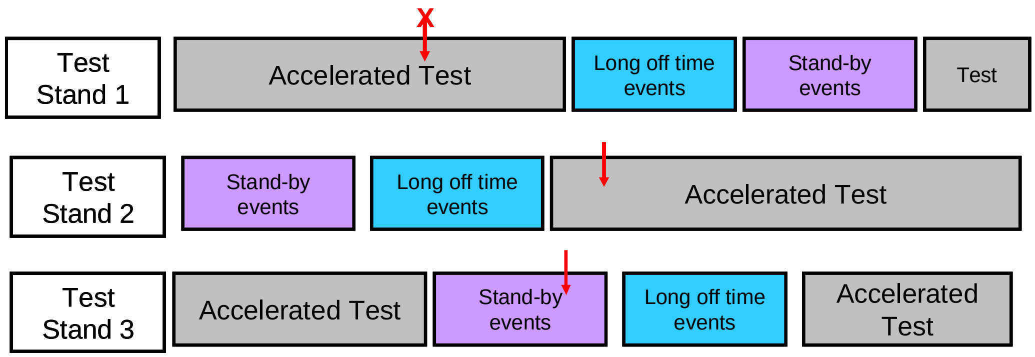


Figure 22 - Second round of Accelerated Testing with additional stressors

A second round of accelerated testing quickly resolved the initial issues and also expanded the testing to incorporate additional stress factors. The accelerated run protocol in the first round of the testing was supplemented with blocks targeting long duration off-time events and stand-by condition events as seen in ***Figure 22***. At the time of project closure, one stack had reached the end of its serviceable life and two were still on test (see ***Figure 21***).

3.2 Objective: Demonstrate multiple approaches to hydrogen generation and delivery for vehicle refueling:

In order to support the demonstration project GM vehicles, the following stations were used:

- Shell DOE project stations: Benning Rd. station in Washington D.C., White Plains station in NY, West LA station in CA, Culver City station in CA, JFK station in NY, Bronx station in NY
- GM DOE project stations: LAX station in CA, Ardsley station in NY
- GM non-DOE stations: Burbank station in CA, Ft. Belvoir station in WDC, Honeoye Falls station in New York, West Point station in NY, Lake Forest station in CA
- GM also supported and utilized the following stations: In California - UC Irvine, Camp Pendleton, South Coast AQMD, City of Burbank (AQMD), City of Riverside (AQMD), and CaFCP. In New York - City of Hempstead, Monroe County, and Rochester Institute of Technology.

Specific to this demonstration project, five (5) Shell and two (2) GM hydrogen fueling stations were successfully permitted and constructed, providing experience for industry and local permitting authorities on how to work with this type of new facility. (It should be noted that Culver City is considered a 70 MPa extension of West Los Angeles, not a sixth station).

Our partner Shell Hydrogen operated hydrogen refueling stations that GM FCVs and other companies' FCVs utilized. Shell Hydrogen participated and provided data per the required data templates without any DOE funding. Shell Hydrogen stopped its participating in the Demo project in 2009 but General Motors continued to utilize the Shell stations at JFK, Culver City, West LA, Torrance and the new opening of Newport Beach, CA in 2011. General Motors continued to submit refueling data for the Ardsley NY station, LAX station, and the Culver City station according to the DOE data templates. In addition, the fuel cell vehicles refueled at any of the non-project refueling stations including Honeoye Falls, Rochester Institute of Technology, Monroe County, Fort Belvoir, White Plains, UC Irvine, Santa Monica Blvd, Camp Pendleton, UC Irvine, Shell Torrance.

Unfortunately, four of the refueling stations mentioned above are now closed. General Motors feels that it is critical for DOE to support continued operation of existing fueling points by assuring that FCEVs continue to operate in order to both promote futher development of fuel cells for commercialization and to maintain and expand the number of hydrogen fueling points during the “bridge” period between now and the commercial introduction of FCEVs in less than 5 years. there is a need for all the stations and without them the ability to get fuel for the fleet is reduced. General Motors would like the participation of more energy companies and government to add additional refueling stations to the infrastructure so that fuel cell vehicle customers have access to fuel.

General Motors is also anticipating the opening of numerous hydrogen stations in California over the next 18 months, which are supported by the California Air Resources Board (CARB) and California Energy Commission (CEC) grants. In total, 18 new and upgraded stations ,mostly located in the Los Angeles metropolitan area, will be able to support the fuel cell vehicle fleet.

Shell Hydrogen Perspective

In conjunction with and support of GM’s fuel cell vehicle demonstration, Shell Hydrogen collaborated with GM to build and operate five (5) hydrogen refueling stations (HRS). The HRS were located generally on the east and west coasts (primarily New York and Los Angeles metropolitan areas) with local siting determined by available property and vehicle user geographies. All stations were delivered within the project timeframe; however, two in New York were commissioned only weeks before the end of project. Two stations were built with visitor centers to help engage local audiences as well as visitors from around the world.

The HFS format chosen varied depending upon site host properties and includes facilities ranging from gasoline station retail-like to private behind-the-fence configurations. Additionally, the technology deployed varied to include examples of renewable production, trucked-in liquid hydrogen, and trucked-in gaseous hydrogen. Operational experiences were realized over several years on some stations and included general technical challenges, functional/mechanical issues, one fire, and several thousand fuelings.

While all the stations in this demonstration project were entered into and designed as “demonstrations” even at small scale and low utilization they provided insights into future commercialization considerations.

- On-site hydrogen production via electrolysis will be limited to specific regions/areas that can offer renewable power and somewhat lower fueling demands. Production capacity of on-site electrolyzers is not expected to be practical for refueling stations beyond 500 kg/day due to footprint and power requirements.

- On-site production via natural gas reformation is more likely to reach wider usage due to its smaller footprint and relatively lower cost compared to electrolysis. No reformer based stations were included in this demonstration project, but Shell is aware of the systems and technology.

- While Shell expects delivered hydrogen to become the most widespread application in commercial hydrogen refueling, it expects to see this accomplished with liquid hydrogen and ultimately pipelines rather than gaseous tube trailers. From a commercial deployment perspective, tube trailer logistical costs appear to be a major challenge, even with doubling or tripling of the carrying capacity of today's trailers. Liquid hydrogen can nearly match equivalent gasoline logistics in energy content per mile driven and can be stored in large quantity. Pipelines may come into play at high volume, and boosting to high pressure at the station seems doable at a commercial scale, even with pre-cooling requirements added.

A common link however across all station types is the cost of compression and storage – even for pipeline supplied stations. Shell's efforts in this demonstration project have elevated its interest to work toward better systems to increase reliability, lower costs, and deliver more cost-effective infrastructure and fueling capabilities.

Two of the stations were constructed as "one of a kind in the world" involving the use of below grade liquid hydrogen storage in Washington, D.C. and aerial placement of the entire electrolyzer, compression and storage system on top of a canopy in West Los Angeles to show the extent of options available for HFS deployment and to help further develop codes and standards.

The following table in ***Figure 23*** summarizes key HFS attributes by station within this demonstration project (Includes both Shell Hydrogen and GM owned stations in the DOE project):

ID	Location	Open	Setting	Technology	Scale	Daily Capcty	Pressure (MPa)	Cost* (1,000 USD)
SH01	Washington, DC	Oct 2004	Retail w/ Gasoline	Liquid H2 Delivery	300 kg storage	30 kg	35 & 70 Liquid***	3,500*
SH02	White Plains, NY	Sep 2007	Private	On-site Electrolyzer	12 kg/day production	12 kg	35 & 70	3,000*
SH03	West Los Angeles, CA	Jun 2008	Retail w/ Gasoline	On-site Electrolyzer	30 kg/day production	30 kg	35	4,500*
SH03A	Culver City, CA**	Sep 2009	Private	Gas Tube Trailer	100 kg storage	28 kg****	70	2,500*
SH04	Bronx, NY	Sep 2009	Private	Gas Tube Trailer	300 kg storage	28 kg****	70	2,500*
SH05	JFK Airport, NY	Jul 2009	Private	Gas Tube Trailer	300 kg storage	30 kg	35 & 70	2,500*
GMAL01	Ardsley, NY	Apr 2008	Private	Gas Tube Trailer	300 kg storage	28 kg****	70	1,250
GMAL03	LAX, CA Clean Energy	Oct 2009	Retail	Gas Tube Trailer	300 kg storage	28 kg****	70	1,750

Figure 23 – Demonstration Project Fueling Station Details

* Approximate costs are shown and may include other facility costs such as visitor centers, etc.
** Culver City is considered a 70 MPa extension of West Los Angeles, not a sixth station
*** Liquid dispensing was discontinued in early 2008.
**** Design capacity is noted as 28 kg/d; the system is capable of delivering as high as 50 kg/d

The following section contains a description of the technology and the usage demonstrated at each of the fueling stations mentioned in ***Figure 23.***

3.2.1 SH-01: 3355 Benning Road, Washington, DC

"The First US Hydrogen Station in a Retail Setting"

Project Months of Operation	Total Fuelings Conducted	Hydrogen Dispensed (kg)	Maintenance (approx. hours)	Other Comments
60	1,726	2,471	1,297	- Visitor Center - LH2 Storage

Figure 24 - Benning Road Station in Washington, D.C.

Figure 25 - Below-grade LH2 storage

The Washington, D.C. station was opened just prior to the beginning of this demonstration project and therefore was able to operate for the entire 60 months of the project. The station was originally built to dispense both gaseous and liquid hydrogen. Additionally both 35 and 70 MPa gaseous pressures were accommodated in the original design, though 70 MPa was not commissioned until 2008. The station setting is within a mixed-use area that includes residential and industrial/light commercial along Benning Road as shown in ***Figure 24***. The specific site selected for the hydrogen station was an existing Shell affiliated gasoline station with capacity to allow the inclusion of a Hydrogen Visitor Center as well. The Visitor Center, adjacent to the convenience store, welcomes and educates the general public, local residents, hydrogen stakeholders, and local, national and global dignitaries. In 2005 President George W. Bush visited the station and conducted a hydrogen fueling of a GM Fuel Cell Electric Vehicle during a DOE organized event.

Technically the station provided very good uptime – above 90% - over the 5 years of operation with the originally installed equipment. Regular preventive maintenance was conducted on a monthly basis. However, about half the total maintenance hours were non-scheduled for various reasons, most often due to compressor-related issues. The station utilizes two compressors to accommodate the two dispensing pressures.

The facility provided liquid hydrogen dispensing from 2005 through 2007 to fuel the GM Gen1 vehicles operating with liquid on-board storage. Liquid hydrogen dispensing provided many technical and operational challenges to become fully functional for routine use by GM drivers. Due to the relatively small scale of the station there were significant levels of boil-off during vehicle fuelings which would be reduced if scale and use were multiplied. The liquid dispenser was removed from the station after GM discontinued operation of the Gen1 liquid vehicles.

This station delivered several "firsts" for Shell, this demonstration project, and the industry. The station was the first US-based retail-type hydrogen fueling station successfully commissioned. This "uniqueness factor" brought challenges during permitting and community engagement due to concerns and misconceptions about the safety of hydrogen systems. In addition, the station was the first in the world to utilize below-grade liquid hydrogen storage as shown in ***Figure 25***. A seemingly simple change, but here-to-fore liquid hydrogen had always been stored in above ground vessels, and codes and standards did not formally address this application. Similar to the retail-type application, utilizing below-grade storage helped establish new code and standard direction and provided a real-world example, which is fundamental to the development of codes and standards. Other firsts include the publicly accessible Hydrogen Visitor Center, the first hydrogen station visit by a sitting US President, and emergency responder training sessions.

The station was suitable for a demonstration project of small scale. However, a commercial-scale station of this type (liquid hydrogen storage) could utilize advanced cryo-compression / cryo-pump techniques to replace conventional vaporization / gaseous compression systems and greatly improve efficiency. Larger below-grade storage vessels similar in volume to typical gasoline underground storage tanks will need to be developed for economic logistics. Liquid hydrogen based stations offer benefits of large storage volumes, ultra-pure hydrogen, and the ability to leverage large-scale production economics off-site.

3.2.2 SH-02: 39 Brockway Place, White Plains, NY

"A Key Learning for the Industry"

Project Months of Operation	Total Fuelings Conducted	Hydrogen dispensed (kg)	Maintenance (approx. hours)	Other Comments
25 - calendar 18 - functional	843	1,268	274	- Green power - Fire incident

Figure 26 - White Plains, NY Hydrogen Station

Figure 27 - Adding 70 MPa Capability

Figure 28 - Gen1 Vehicle Fueling at White Plains

The White Plains, NY station consisted of an electrolyzer-based system connected to New York Power Authority utilities with a significant green component of hydro-sourced electricity. A picture of the station is shown in ***Figure 26***. One of the objectives in the Project was to deliver a station with renewable capability, and Shell worked with New York Power Authority and the City of White Plains to ensure this was incorporated. The electrolyzer was small at only 12 kg/day production capacity, but the station was part of a three-station cluster in the New York City metropolitan area where the other two stations could take on more demand due to larger scale. The site selected was the maintenance and fueling depot for the Public Works Commission of the City of White Plains, which already provided gasoline, diesel and natural gas fueling. The hydrogen station was built apart from the existing fueling systems, but the hydrogen dispenser was placed on the same fueling island used by the Public Works vehicle fleet. While the station was technically behind-the-fence, access was available to any GM fuel cell vehicle driver during regular working hours.

The electrolyzer design utilized a PEM system providing very good uptime and very reliable high-quality hydrogen. The footprint of this production system was compact by most measures and is expected to be the type of system that can be scaled up for larger electrolysis type station applications. Performance was consistent and maintenance was minimal and very manageable.

The station first opened in late 2007 with 35 MPa only and in early 2008 70 MPa compression and dispensing was added ***(Figure 27 and Figure 28)***. Unfortunately, after about 4 months of operating with the 70 MPa addition, a failure resulted in a fire that significantly damaged the newly added equipment and caused the station to be temporarily decommissioned for about seven months. No injuries were involved. Following a lengthy investigation involving Shell, Air Products and DOE, the station was rebuilt and reopened in 2009 – first with 35 MPa and later with 70 MPa. The fire was determined to have resulted from a pressure switch that catastrophically failed within the 70 MPa compression skid. The resulting hydrogen high-pressure leak was quickly ignited (exact ignition source unknown) resulting in a cascading failure of impinged piping and additional hydrogen jet fires within the skid.

Some of the key learnings from the incident include the following:

- discontinue use of pressure switches and only use pressure transmitters

- employ redundant automatic shut-off valves at the storage vessels in case skid valves are compromised

- modify skid designs to protect sensitive hydrogen piping and other elements with shields and revised routing

- employ linear heat detection systems in addition to optical/UV/IR flame sensors

The learnings above have been incorporated in the station rebuild and also at all other Shell stations as applicable. The emergency response systems worked well. With the escalating scenario, first responders were able to control the situation and within less than 30 minutes the fire had burned itself out as all hydrogen was depleted. The situation was nearly a worst-case scenario and does provide evidence that hydrogen can be adequately managed even in a fire condition. Shell and Air Products have presented on this incident at various DOE and industry conferences to help share learnings and improve industry practice.

Station permitting was largely facilitated by the City Public Works Department, resulting in a very efficient and comprehensive three month permitting process. The fast-paced process and strong support from the Commission of Public Works, the Mayor of White Plains, and the White Plains City Council helped deliver the project in a relatively short timeframe.

3.2.3 SH-03: 11576 Santa Monica Blvd, Los Angeles, CA

"The *World's First Hydrogen "Canopy" Station"*

Project Months of Operation	Total Fuelings Conducted	Hydrogen Dispensed (kg)	Maintenance (approx. hours)	Other Comments
15	1,398	2,193	446	- Visitor Center - Canopy Use

Figure 29 - Canopy at the West Los Angeles Station

Figure 30 - Visitor Center at West Los Angeles

Figure 31 - Conducting educational outreach

The Los Angeles, CA area has become the focal point for fuel cell vehicles, and therefore it is not surprising that the Shell station in West L.A. was the busiest of the Shell Project stations. Within 12 months the station reached 1,000 fuelings and played host to dozens of area school children as part of an outreach effort by Shell ***(Figure 31)***. Additionally, notable site visitors included California Governor Arnold Schwarzenegger, State Air Resources Board staff, numerous technical and industry experts from locations around the world, and several TV and movie celebrities driving FCVs from various automakers. Similar to the Shell Washington, D.C. project, this station was located at a Shell branded gasoline station and also includes a Hydrogen Visitor Center adjacent to the convenience store as shown in ***Figure 30*** It is located along the busy Santa Monica Blvd just off I-405.

The most unique aspect and "world first" was the approach of designing and installing the entire hydrogen system to sit on top of a specially designed canopy over the fuel dispensing island as shown in ***Figure 29***. This approach had never been done before and Shell was also instrumental in getting the codes written to accommodate such an approach in 2006. The effort to build the world's first canopy mounted hydrogen system was challenging and more expensive than building on the ground level. However, Shell's purpose was to show that it could be done and that it could help further develop the governing codes.

The system is similar to that of the White Plains, NY station in that it utilizes an on-site electrolyzer to produce hydrogen from renewably sourced grid electricity. However, the electrolyzer utilized at W. LA was an alkaline-type system rather than a PEM based system. The alkaline system was chosen because it was available in larger scale (which was needed) and because there was a desire by Shell to field test two different types of electrolyzer systems. The alkaline unit was a bit more complex to install and does require more ancillary systems, but it did operate very well over the term of this demonstration project and was provided exceptional technical support from the manufacturer. The compression and storage, along with the electrolyzer, were installed on the canopy. This required the overall canopy structure to support a load of approximately 50,000 pounds. The original design intent included the use of carbon fiber composite storage vessels to reduce weight, but these were not able to be included in the permit package, resulting in the use of the heavier steel vessels. The compressor system was to be expanded later to provide for 70 MPa dispensing, but the steel vessel mass prohibited any additional weight on the canopy. The station provided 35 MPa dispensing with the "extension" station in Culver City, CA providing the 70 MPa dispensing.

Permitting for this station was the longest of this demonstration project's stations requiring approximately 12 months to receive all permits after initial application. The project was permitted within the City of Los Angeles municipal jurisdiction which is somewhat more complex and involved than other areas where projects were pursued.

3.2.4 SH-03A: 1124 Venice Blvd, Culver City, CA

"Utilized Fast-Fill Technology to support Los Angeles Deployments"

Project Months of Operation	Total Fuelings Conducted	Hydrogen dispensed (kg)	Maintenance (approx. hours)	Other Comments
<1	No official counts	No official counts	N/A	- 70 MPa extension to W. LA

Figure 32 - Culver City Hydrogen Station

Figure 33 - Shell Hydrogen Signage

Figure 34 - Hydrogen Compression Skid

As discussed previously, the Culver City, CA station was conceived out of the need to bring 70 MPa dispensing into this demonstration project and the LA market after the W. LA station was not able to incorporate the additional compression system. Shell and GM collaborated to deliver the Culver City project as shown in ***Figure 32***. Shell was able to provide an existing vacant parcel to the project and GM was able to provide fueling hardware ***(Figure 33)***. Shell conducted the overall site design, permitting, construction and start-up, while GM and Shell collaborated on testing and final commissioning. The station equipment provides only 70 MPa dispensing from a containerized compression system fed with gaseous hydrogen from a tube trailer, with liquid nitrogen for pre-cooling the compressed gas when dispensing into a vehicle ***(shown in Figure 34)***.

Some start-up challenges did surface regarding the flow control valve used for managing the hydrogen dispensed to the vehicle. The station experienced several months of delay in final commissioning due to flow control valve redesign efforts and trouble-shooting. As with many early technologies, a limited supply network contributed significantly to the delay as the team worked with a supplier from Europe and had to wait on shipping and testing. The valve was finally resolved and commissioning occurred, but only during the final month of the project.

While the project site consisted of a vacant parcel adjacent to a Shell branded gasoline station, there were still challenges in meeting local requirements for ingress/egress of the fuel cell vehicles and hydrogen tube trailer deliveries. Due to the surrounding roadways and alleys it was not possible to bring full sized tube trailers to the site, so shorter trailers with lower capacity were employed. Originally the City required hydrogen deliveries to be made only during night-time hours. However, after discussing on-site and conducting demonstration deliveries the City did later allow restricted day-time deliveries as well.

3.2.5 SH-04: East 233rd Street, Bronx, NY

"The First Hydrogen Station within the City of New York"

Project Months of Operation	Total Fuelings Conducted	Hydrogen dispensed (kg)	Maintenance (approx. hours)	Other Comments
<1	No official counts	No official counts	N/A	- First NYC H2

Figure 35 - Bronx, NY Hydrogen Station at DSNY Facility Showing Existing Retaining Wall

Each hydrogen station in the project had its unique challenges, and the Bronx, NY station was no exception. Never before had anyone attempted to permit and build a hydrogen fueling station within the jurisdiction of the City of New York, and for good reason – the City had intentionally removed all hydrogen station codes from the latest International Code Council (ICC) issue, requiring all projects to be specially reviewed by the Fire Department of New York (FDNY). The State of New York had also not had the most receptive approach to hydrogen station permitting, though Shell had successfully permitted the private White Plains, NY station earlier. Shell and GM agreed to pursue the project in concert with a City agency to help ensure permitting success and to site the project on City property and operate the station as a private facility (i.e. not at a retail gasoline station, ***Figure 35***). The New York Department of Sanitation (DSNY) was willing to provide space at its facility in the Bronx and to help satisfy some of the FDNY requirements.

Shell and GM worked with the City and FDNY over the course of about a year to successfully permit the project. This collaborative effort included FDNY tours of the White Plains and private GM Ardsley, NY facilities, and also several design review meetings.

The equipment and system for the project was identical to that installed at the previously described Culver City, CA station. As with the Culver City station equipment, issues with the flow control valve delayed the final commissioning of the station, and commissioning was not completed until the last month of the Program term. The valve issue was resolved and dispensing was able to commence.

Unique aspects to the project also included the permitting of each hydrogen tube trailer as it entered the jurisdiction of the City of New York. The requirement was only encountered in New York City and its purpose was to ensure proper routing and awareness by necessary entities whenever a hydrogen carrying transport entered the city limits. A seemingly troublesome requirement, but overall the City does execute the permitting of trailers quite efficiently.

Another hurdle was with having all systems UL approved or certified by a third-party engineer. Many hydrogen systems were not approved or certified by a Nationally Recognized Testing Laboratory (NRTL) at the time of their initial production, requiring field certifications to be coordinated with laboratories such as UL. A field certification is only applicable to the specific equipment at the specific site but can be accomplished with fewer complications than seeking model approval for blanket certification purposes. The City of New York may not have been the only jurisdiction requiring such certifications for hydrogen systems, but it was the only one faced by Shell during the Project. NRTL certifications, while appropriate for commercial systems, pose challenges for new technologies and suppliers if demanded too early in the demonstration process. Certifications are costly, and without an established market many manufacturers of equipment are unlikely to seek these approvals. Subsequent requirement by permitting authorities results in project delay and/or added expense.

3.2.6 SH-05: Federal Circle, JFK Airport, New York City, NY

"Created a Hydrogen Fueling "Network" for New York City"

Project Months of Operation	Total Fuelings Conducted	Hydrogen dispensed (kg)	Maintenance (approx. hours)	Other Comments
<1	No official counts	No official counts	N/A	- Part of 3 station NYC cluster

Figure 36 - JFK Airport Hydrogen Station

Figure 37 - First Test Fuelings of Thirsty Gen2 Vehicles

Shell and GM reconsidered the notion of pursuing an "east coast corridor" running between Washington, D.C. and New York City in favor of developing a New York City cluster concept to better mimic what was developing in California. The corridor concept would have connected the Shell station in Washington DC with the Shell project in White Plains, NY by placing two additional stations along the route. After further reflection, the concept was abandoned due to the need for more local fueling in the NYC metropolitan area. Shell and GM therefore embarked upon the Bronx station (described earlier) and the JFK Airport station shown in ***Figure 36***. Unfortunately, the decision to pursue a cluster over a corridor approach was arrived upon somewhat late in this demonstration project and contributed to the two final stations not being fully operating during the demonstration project timeframe.

The JFK station did conduct an "opening event" in mid-July 2009 and allowed the supporters of the project to speak and share common interests ***Figure 37***. The JFK station site host and FCEV vehicle operator was the Port Authority of New York and New Jersey (PANYNJ), the official authority of the JFK Airport property. The property provided by the PANYNJ was a vacant area along Federal Circle which Shell improved by adding grading, concrete, asphalt and utilities to support the installation and operation of a hydrogen station. After the opening event the station underwent final performance testing, and unfortunately several technical problems delayed the kick-off of regular dispensing operations for several months.

All stations with 70 MPa fast-fill (<5 minutes) dispensing require pre-cooling of the high-pressure hydrogen to avoid overheating the fuel cell vehicle hydrogen storage system. Additionally, some automakers require electronic communications to be utilized when dispensing 70 MPa hydrogen, and the industry-standard infrared (IR) communication was employed at this station. Both the pre-cooling system and the communication device failed to function properly for more than a day or two without needing attention. The pre-cooling system was finally resolved and the temperature was raised to reduce the impact on the dispensing hose and nozzle systems. It should be noted that the communication technology was one of the first IR systems installed in the US, along with several of the other demonstration stations noted in this report. As with many new technologies deployed in the field for the first time, problems encountered were not completely unexpected, and the teams are working closely with the manufacturer to make improvements. In this case, the IR communication device was eventually resolved by redesigning its mounting to the dispenser to eliminate torsion and wiring disconnects. Various other issues presented themselves during the ensuing two months, but the pre-cooling and communication issues were the most notable.

GM Perspective

As the launch of this demonstration project approached, GM determined that additional hydrogen infrastructure would be necessary to support the network necessary for drivers to be comfortable getting around each of the deployment regions. GM also believed this would enable far greater usage of the vehicles, as Shell and GM Infrastructure would complement each other. In addition, GM believed it was critical for each of the deployment facilities to have hydrogen - both as a means to fuel drivers' vehicles and for vehicle maintenance purposes. Therefore, GM purchased an additional eight (8) pieces of fueling equipment to support its drivers—three of which were included under the DOE Demonstration Project. The three stations that were part of this demonstration project were located at Ardsley, NY, LAX, CA, and Culver City (as noted above).

The critical goal of these systems was to easily deploy hydrogen infrastructure in each of the regions—therefore, low cost (including taking advantage of scale economies), low power requirements, and transportability of the systems were key elements of the project's execution. The eight fueling stations were purchased from two different manufacturers, Air Liquide and Quantum.

- The Air Liquide hydrogen technology enabled fast-fills (<5 minutes) and offered the ability to fuel three vehicles back-to-back without losing such performance. It also offered robust hydrogen chiller technology in a package which could be easily transportable.

- The Quantum technology had been known and proven with previous GM projects. Their base system offered an ability to easily transport and place fueling equipment with virtually zero site preparation. While this system would not meet customer expectations in terms of fast-fill performance, it was key to getting fueling established quickly. Quantum offered complementary equipment on a "plug-and-play" basis to improve system performance—adding buffers in different configurations as well as a chiller—all with minimal impact to the system's footprint. These systems provided a fill closer to customer expectations— about ten (10) minutes.

Descriptions of the two GM owned stations are described below.

3.2.7 GMAL01: 425 Saw Mill River Road, Ardsley, NY

"The First Step in Fast-Fill/Retail-Performance Technology"

Project Months of Operation	Total Fuelings Conducted	Hydrogen dispensed (kg)	Maintenance (approx. hours)	Other Comments
17	2,836	4,964	170	70 MPa fast fill station

Figure 38 - Ardsley, NY Refueling Station

The GM Ardsley location is the 'East Coast Service Hub' in New York (Photo of station shown in ***Figure 38***). The GM Ardsley station was the first (of four) commissionings of the Air Liquide hydrogen fueling equipment and demonstrated the advantage of automaker and equipment provider working very closely to create a high-performance fueling system. Taking advantage of high pressure storage and a robust pre-cooling system, vehicles could easily be filled in less than five (5) minutes. The station could also perform three back-to-back fills with such a performance.

The GM team's approach also provided some unique insight into improving permitting norms. The planning of the project focused on its simplicity—an 'equipment placement effort' meeting all the safety elements of any fueling installation. While the system was placed in a private setting, the team worked closely with local authorities to bring in temporary fueling beforehand—both as a means to bridge the gap before the Air Liquide system was commissioned, and also as a means to introduce local authorities to the technology. The local jurisdiction quickly became comfortable with the technology (and associated layers of safety) as well as the project.

This piece of equipment proved to be one of the busiest fueling locations for GM as the team worked to complete installations in the three additional New York City locations (Bronx, JFK, and White Plains). Since the Air Liquide system included several unproven pieces of equipment, there have been significant learnings and subsequent improvements to major components—including compressors, flow control, and software controls. These improvements were closely coordinated by GM, Air Liquide, and each of the component suppliers.

3.2.8 GMAL03: LAX (Clean Energy), 7450 World Way West, Los Angeles, CA

"An *Example of Retail-Like Execution of Permitting and Construction'*

Project Months of Operation	Total Fuelings Conducted	Hydrogen dispensed (kg)	Maintenance (approx. hours)	Other Comments
11	395	909	100	Open 24 hrs to public

Figure 39 - LAX, CA station

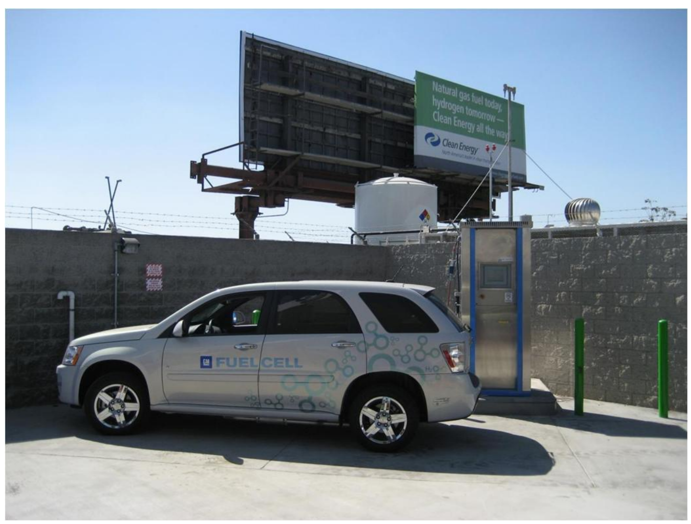


Figure 40 - Gen2 vehicle refueling at LAX

The GM team took a different perspective with the execution of the Clean Energy LAX, CA site. GM was installing Quantum technology at its 'West Coast Service Hub' and was looking for a practical and complementary location for its additional fueling equipment. The identified area needed to serve as an important connector location for drivers and as an important deployment base for GM's business-to-business partners. The chosen location was an existing natural gas fueling station operated by Clean Energy Fuels, whose experience with compressed natural gas fueling was seen as complementary to hydrogen ***Figure 39 and Figure 40***. Clean Energy's experience as also proved to be an important enabler to quickly and easily deploy the fueling equipment.

Design, permitting, and construction became a key focus of the team—it was imperative to quickly deploy the fueling equipment to support the vehicle deployment needs. The team chose to take a design-build approach, which greatly improved the timing of the entire project. Moreover, the team worked closely with the City of Los Angeles permitting officials to provide clear overview of project designs as well as the codes and standards associated with such an installation. Because we were able to take advantage of the existing site--compressed natural gas fueling station—the team was able to execute permitting in less than six weeks, and overall 'handshake-to-first fill' took only five months. This project succeeded in demonstrating that hydrogen fueling stations can be installed in a comparable timeframe to gasoline stations.

The operational phase of LAX was very important for the GM team and our drivers. While the LAX location was the second installation of the Air Liquide equipment, the team appreciated that this was the first time the equipment would be placed into a 24-hour setting for real-world drivers to use. A key element to GM's infrastructure efforts was ensuring equipment uptime for driver support and convenience. Significant effort and resources were expended to maintain and quickly repair the system should it be necessary. GM collaborated closely with the existing Clean Energy technical team to maintain the system and was well prepared with a spare parts inventory and rapid technical support response time.

The station proved to be a valuable asset for many Project Driveway participants—providing hydrogen fuel 24/7 in a safe, retail setting. Moreover, the station allowed for a significant amount of outreach to local, California, and Federal officials, from the California Energy Commission to a ranking member of the House of Representatives. Routine visits by technology providers, industry pundits, media outlets and celebrity users confirmed the significant progress being made on the fuel cell vehicles and their fueling station infrastructure.

3.3 Objective: Hydrogen infrastructure with cost of less than $3.00/gge

Commercially acceptable hydrogen costs to support consumer retail uptake and promote a transition to fuel cell vehicles was not physically demonstrated within this project; however, insights to reaching the $3.00/gge milestone were developed because of the activities of this demonstration project.

While the focus of this demonstration project was technical feasibility and real-world deployment of existing and available technologies, the following efforts show where the most promising approaches exist with respect to developing a hydrogen fueling infrastructure.

- Comparisons with well established methods and technologies for gasoline infrastructure highlight the need for greater emphasis on resolving hydrogen station equipment and processes to reduce costs and complexity. A typical gasoline system at a state-of-the-art retail station might cost approximately $800,000 to $1,000,000 USD and can accommodate up to 500 vehicles per day. This demonstration project, as implemented by Shell, has resulted in costs several times higher than a gasoline station, with capacity several times lower. It was not expected that demonstrations of field R&D would approach commercial-scale economics; however, this demonstration project did shine a light on the need for new approaches to compression and storage of hydrogen to get costs on track for commercial success.

- Hydrogen stations built during this demonstration project employed existing and conventional technology adapted to a new application. The focus was on permitting, building, and operating, not on development of new technology or approaches. Shell stretched its ability to pilot various station configurations, including several industry firsts, but realized all projects still had to be "buildable," meaning successful permitting and dependable operations were key. Next generation hydrogen station technology could be a separate focus of the DOE to ensure that development in this area matched the pace of fuel cell vehicle research and development.

- GM's execution of hydrogen infrastructure also provided additional learnings on the cost of hydrogen—including the ability to obtain scale economies with equipment providers. Next generation technologies should take advantage of further cost reductions with movement towards common fueling components, such as fueling dispensers (rather than unique designs by each equipment provider) and hydrogen storage techniques.

It is possible to reach the $3.00/gge for consumer retail hydrogen fueling, but to do so requires more R&D for the hydrogen station systems. Commercially viable hydrogen production exists today as does commercial-scale liquefaction and large-scale gaseous pipeline delivery. R&D in these areas is important, but a greatly increased effort on hydrogen station technologies is the real key to commercial success of hydrogen as a retail vehicle fuel. Hydrogen station performance lagged fuel cell vehicle performance in this project, and this gap must be closed for fuel cell vehicles to successfully enter the market.

3.4 Objective: Safe and convenient fueling by trained drivers

All stations developed and operated by Shell as part of the project were utilized by any approved automaker and by any trained vehicle driver. Whether the station was retail-like at a gasoline station or private behind-the-fence, all were self-serve with controlled access (i.e. use of a PIN) and operated successfully in this manner.

Training of drivers to fuel FCEVs was a collaborative effort between Shell and GM and other automakers. Shell initially conducted all hydrogen station fueling training for all drivers but soon found this to be unmanageable as the number of drivers increased. Shell developed specific fueling training programs for each station and trained each automaker representative in a "train-the-trainer" model. The automaker then provided training to the specific vehicle drivers and communicated/issued Personal Identification Numbers (PINs) to allow use of the station. The fueling process was intuitive, and most drivers were quick to understand it. There were several cases where user actions uncovered the need for additional fool-proofing of the dispensers, and these learnings were used to improve the designs or operating controls strategies.

Shell and GM continue work to improve consumer dynamics at the dispenser. A key component to future station deployment will be the customer-friendliness of the user-interface. While most attention was provided to the overall technology execution, the demonstration revealed the shortfalls of 'designed by engineers for engineers.' At all stations, the team has worked to develop a more user-friendly experience. Soon it is expected that all dispensing will be conducted without any training needed.

Shell's demonstration project stations did not require payment for hydrogen for several reasons, even though transactions were experimented with in Washington, D.C. early on. There are few, if any, regulations or rules for handling the transaction of hydrogen as a fuel. Additionally, it was difficult to get transaction systems and hydrogen dispensing systems to "talk" to one another without more development and participation from traditional gasoline dispenser manufacturers.

Past drivers of FCEVs have not been "typical" drivers, since they were specially selected and trained. This demonstration project brought many common drivers into the FCEV experience for the first time and was able to provide GM with real-world regular consumer input. Shell conducted some survey sampling of various FCEV drivers as well as gasoline consumers to better understand what today's consumer might say about the future consumers' needs. A brief synopsis of the research conducted by Shell and supported by GM's participation is included as Attachment 1: "Future Fuels – confronting consumer perceptions with market reality."

Shell's work in this demonstration project related to the consumer was deepened by virtue of the two stations incorporating Hydrogen Visitor Centers. The center in Washington, DC attracted several media events, countless visitors, and literally hundreds of school children brought to the station through Shell's collaboration with the local school districts. All who visited the center left knowing more about hydrogen, fuel cell vehicles, and the possibilities that lie ahead.

All GM stations, except those at each of the Service Hubs, could be considered self-serve. A key element to making most stations self-serve is the belief that filling a vehicle with hydrogen is not much different than filling a gasoline vehicle. This perspective was important to GM's hydrogen safety and fueling training. Drivers were provided key background information on hydrogen basics shown how to fuel, much the way a family member would train a new driver in the household. This background information made drivers feel more comfortable with hydrogen and allowed them to easily answer most questions they were asked by friends and family.

Since nearly every hydrogen station is different—different look, different dispenser, different steps to complete a fill, all drivers completed a short station walk-through and demonstration. At the end of this short training, drivers were encouraged to use the station of their choice at their convenience at any hour on any day. *[In some cases, drivers were also provided short "cheat sheets" to complement training and act as an easy reference for questions].* Several drivers took advantage of 24/7 access fueling during off-hours such as midnight to 5:00am. If a driver requested access to a new station, the GM team would meet the individual at the station and perform a similar walk-through.

The decision to make fueling at the GM Service Hubs "attendant" fueling was related to a couple of different factors: (1) ensuring a positive customer experience and (2) the site traffic presented an additional obstacle to drivers fueling themselves. This time also allowed a GM engineer or technician to ensure data was properly transferred and to check the vehicle for any minor maintenance items. Over time, it also provided interesting informal opportunities for GM team members to obtain feedback from drivers about their experiences.

In addition, the service hubs, such as GM Ardsley, were open during normal business hours and also accommodated drivers after-hours and on weekends as needed. In particular, the Ardsley location was open routinely on the weekend to support drivers' needs for fuel, as the New York area did not have 24/7 fueling access.

3.5 Objective: Collect and report operating data

Both vehicle operation data and fueling station operation data were recorded and submitted quarterly according to the NREL data reporting templates. The vehicle operation data was uploaded to the RADO server either while the vehicle was at a refueling station or manually updated. Data files from the vehicle transferred to the RADO server while the driver was refueling (***Figure 41***). Once the data was captured at the RADO server, the data was then processed for reporting ***(Figure 42).***

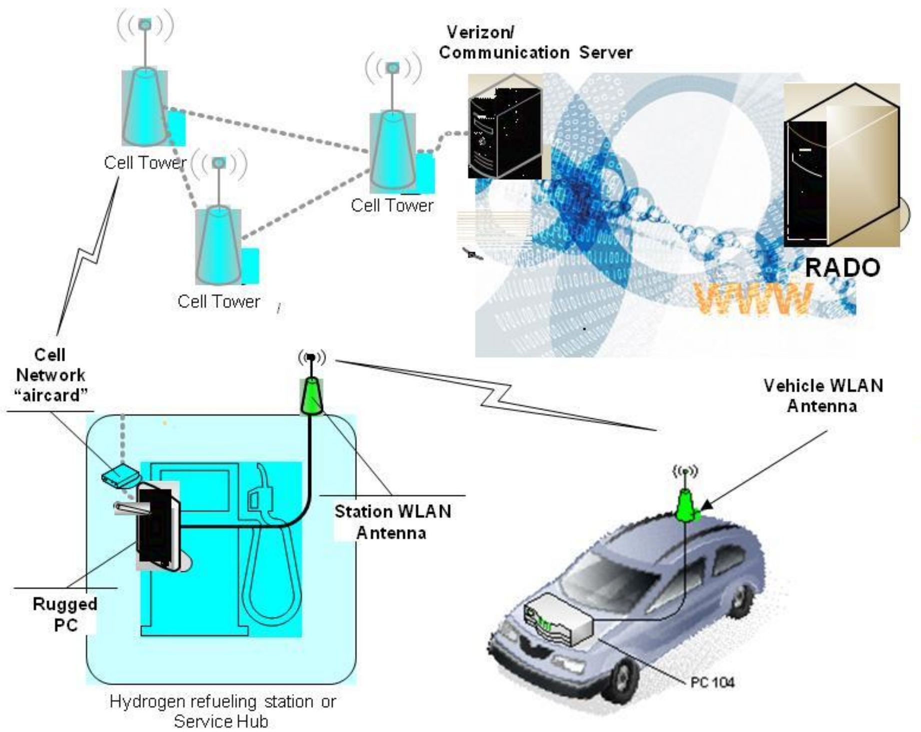


Figure 41 – Data from the vehicle uploaded to RADO server during refueling.

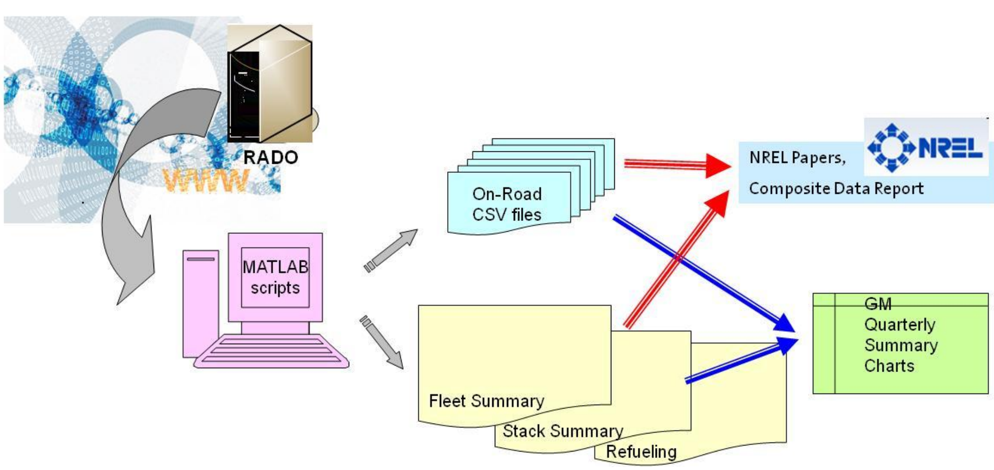


Figure 42 - Post Data Processing Flow

FCEV dynamometer test performance data was submitted according to the NREL data reporting templates, at the beginning and end of project.

Hydrogen quality testing was completed in both the western and eastern regions. Shell and GM stations were among the first in the US to be tested at 70 MPa at the dispenser. All stations achieved a high quality reading.

4. Activities

Below is a listing of the Work Breakdown Structure (WBS) for this demonstration project and a description of the work performed.

4.1 FCEV Systems Startup

Training manuals were developed for each station within the Project and covered the following:

- Operations (Technical and Maintenance);
- Training (Vehicle Driver and First Responder);
- Emergency Response (including fire and other).

GM University designed and delivered Vehicle Service Engineer training. Training was delivered on site or via Distance Learning system. All service engineers have completed this training:

10 day class covers key areas:

- Theory of operation
- Procedures
- Hands on Exercises
- Troubleshooting Exercises
- Abbreviated list of topics:
- Safety
- Diagnostic Tools
- Fuel Cell Stack
- Fuel Cell Support Systems
- High Voltage / Low Voltage Battery
- Tank System
- Fueling / Purge Procedures
- Regenerative Braking

Training of vehicle drivers was conducted largely by GM and each of the other automakers and several hundreds of drivers were trained in total. First Responder Training was implemented by Shell at the completion of each station and averaged 100 participants for each of five stations, including over 200 in Washington, D.C. First Responder Training was also completed by GM at various levels—(1) at the launch of Project Driveway (Q3/Q4 2007), (2) at events requested by various organizations (such as California Fuel Cell Partnership), and (3) at station openings (in conjunction with Shell, for example), and (4) at GM's own station openings (such as LAX). GM has trained over 300 drivers for fueling and over 1,500 first responders ***Figure 43.*** The material is available at www.gmstc.com.

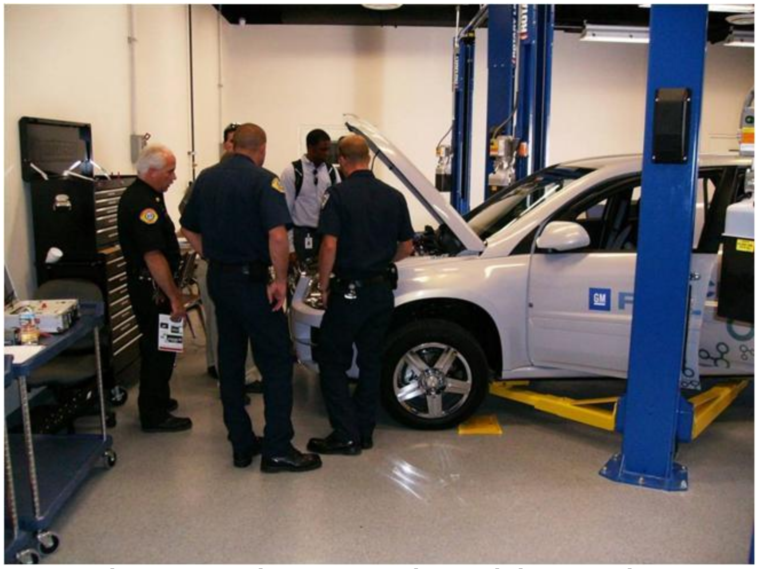


Figure 43 – First Responder Training Session

4.2 FCEV Operation and Maintenance

The service engineers completed a ten day class in "Fuel Cell Vehicle Operation and Maintenance" which was designed and delivered by GM University. The class was a combination of theory, procedures and hands on exercises and troubleshooting. An abbreviated list of class topics included:

- Safety
- Diagnostic Tools
- Fuel Cell Stack
- Fuel Cell Support Systems
- High Voltage / Low Voltage Battery
- Tank System
- Fueling / Purge Procedures
- Regenerative Braking

Screenshots of various applications used for vehicle operation and maintenance can be found in the Appendix, under ***Attachment 2***.

At the start of the project, the six Gen1 vehicles deployed in Washington, D.C. were supported from the Fort Belvoir, VA facility. Likewise, the two Gen1 vehicles in the Los Angeles area were supported from the Lake Forest, CA facility. The eastern region expanded when Gen2 vehicles were deployed in the New York City metropolitan area. The NYC fuel cell vehicle maintenance was supported from an existing GM training facility located in Ardsley, NY. The Los Angeles region relocated primary fuel cell vehicle maintenance support to an existing GM training facility in Burbank, CA while retaining the Lake Forest facility for satellite support.

The vehicle maintenance records for the Gen1 vehicles were stored in electronic workbooks. For Gen2 vehicles, the maintenance system was integrated into a web based field service database. In addition to tracking vehicle maintenance, the web based field service database includes: work instructions for completing fuel cell specific service tasks, fuel cell vehicle service bulletins, engineering change requests, fuel cell vehicle diagnostic tool, and vehicle software updates.

The type of vehicle maintenance as well as the number of maintenance items changed with the two generations of vehicles as shown in ***Figure 44***. The Gen1 vehicles averaged twelve hours of maintenance per vehicle each month with the primary time spent on routine and specialized diagnostic tests as well as work on fuel cell stacks. The Gen2 vehicles had refined diagnostics added to the controls and averaged four hours of maintenance per vehicle each month. The nature of the maintenance for the Gen2 vehicles was spread more evenly across the categories of H2 fuel tank, electrical components, fuel cell stack and software upgrades.

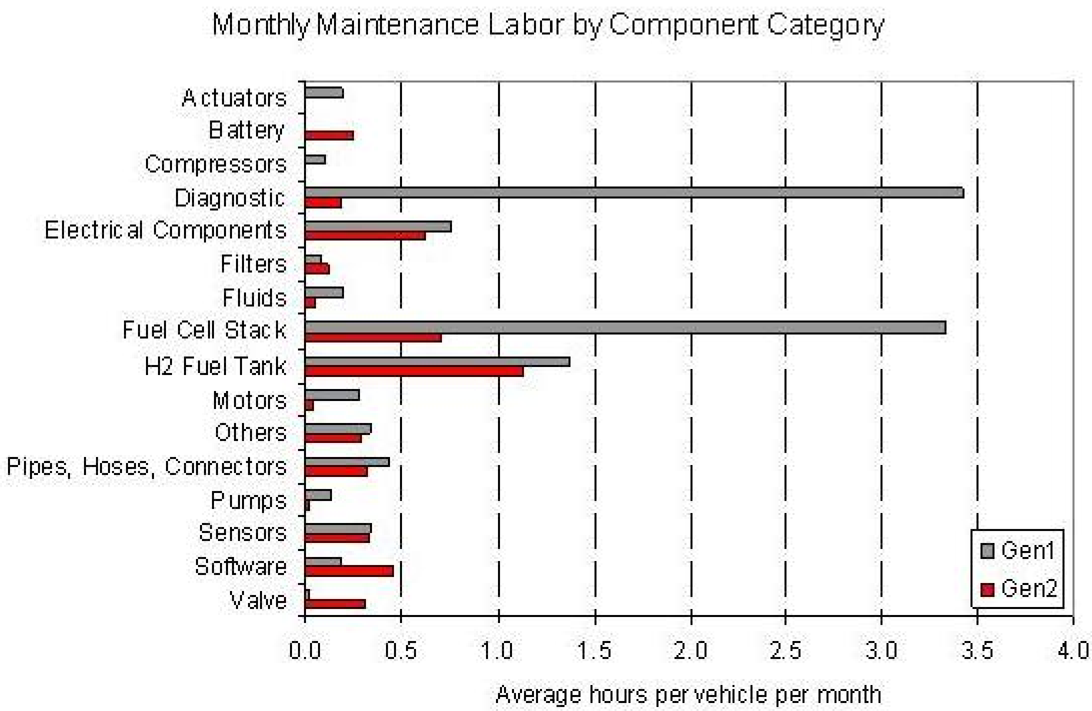


Figure 44 – Maintenance Labor Hours Breakdown

As the project transitioned from the Gen1 vehicles to Gen2, vehicle usage dramatically increased. This was partly due to the fact that there was less maintenance labor hours associated with the Gen2 vehicles so these vehicles spent more time on the road accumulating miles. ***Figure 45*** shows the change in vehicle maintenance as the project progressed.

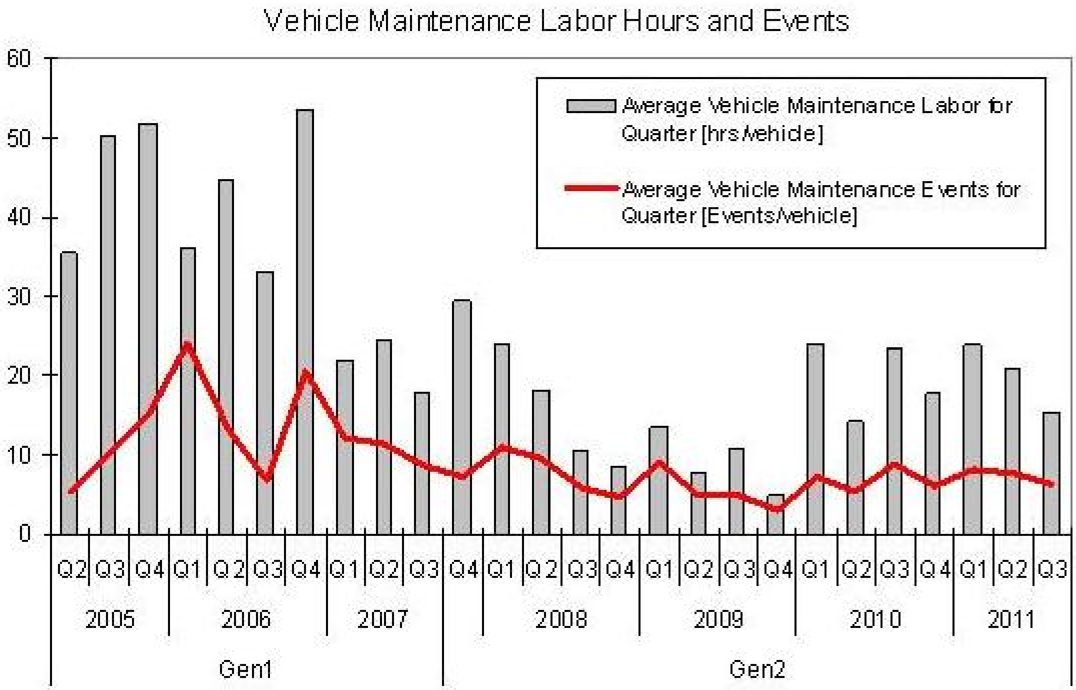


Figure 45 – Maintenance Labor Hours and Events

Figure 46 shows that along with an increase in the number of vehicles deployed, there was a change in vehicle usage between Gen1 and Gen2. The vehicles in Gen2 had more consumer-like drive cycles as shown by an increase in the average vehicle speed.

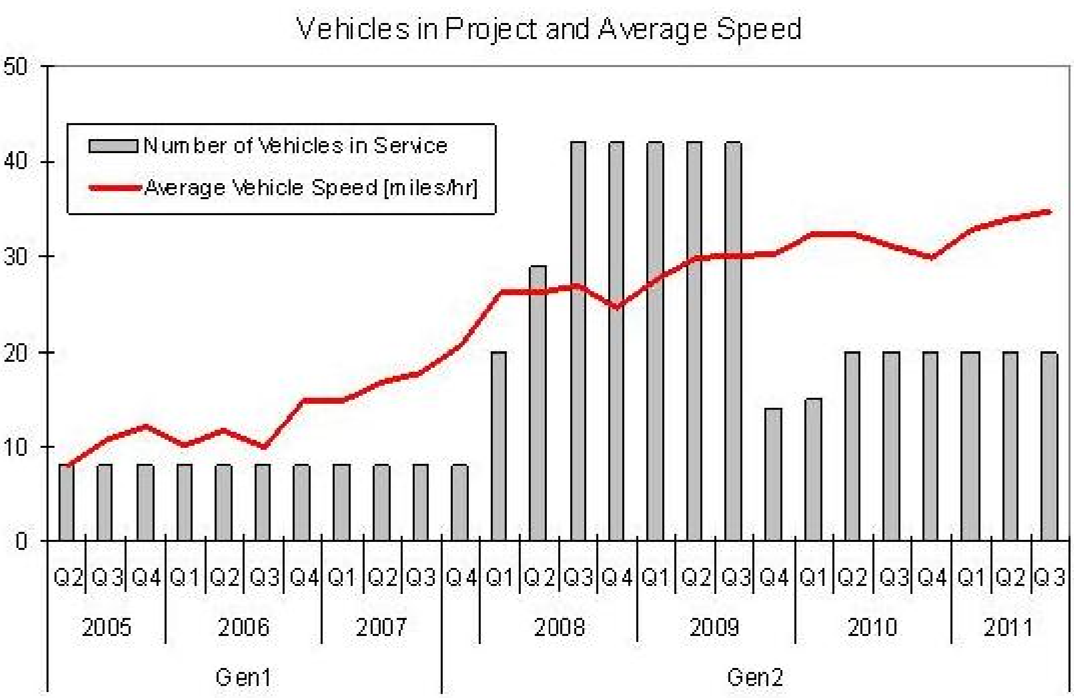


Figure 46 – Vehicle Count in Project and Average Speed

Along with an increase in the total number of deployed vehicles, the total drive distance and operating hours also increased with Gen2 as shown in ***Figure 47***.

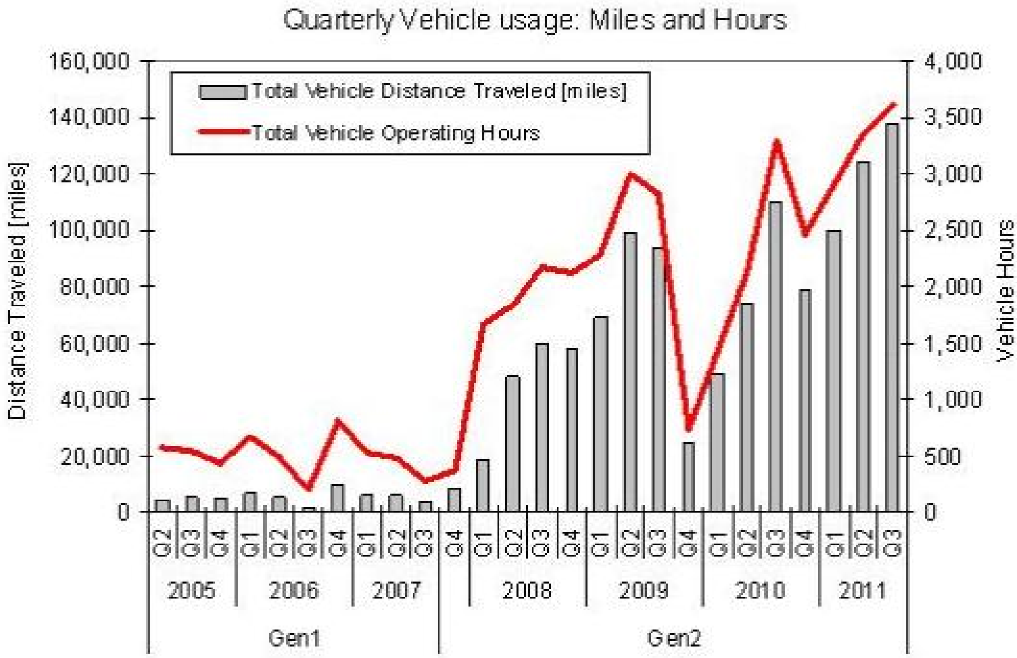


Figure 47 – Vehicle Usage in Mileage and Hours

Another measure of vehicle usage is shown by the total hydrogen used as shown in ***Figure 48***. The hydrogen usage increased as the project progressed.

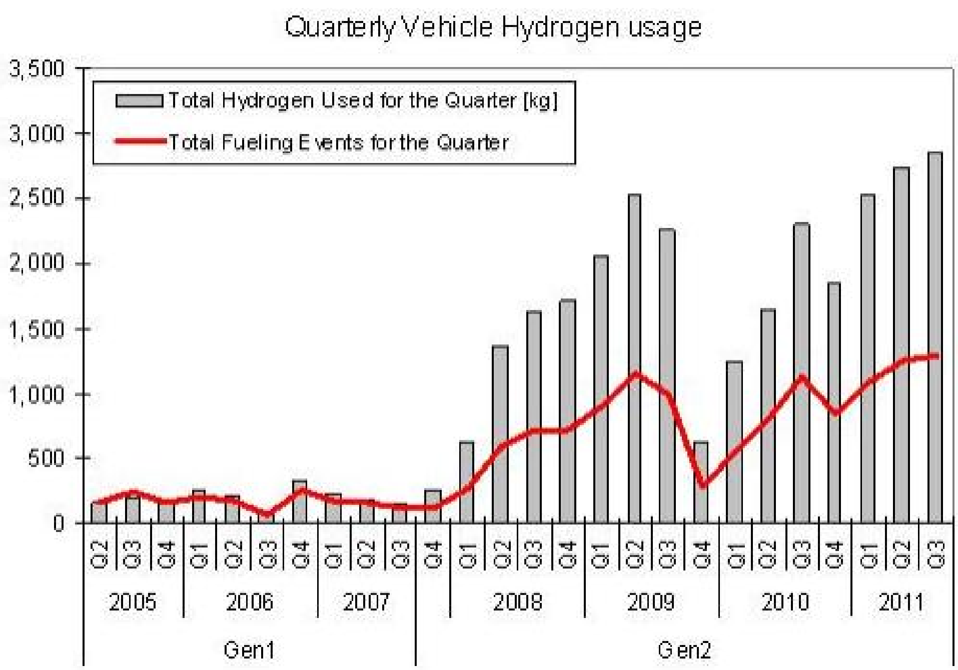


Figure 48 – Vehicle Hydrogen Usage

4.3 Hydrogen FCEV Codes & Standards

Shell was successful in advancing development in codes and standards as a part of this demonstration project through its pursuit of industry firsts and in its collaboration with the ICC, NFPA, and other CDOs and SDOs. Shell presented at the International Code Council (ICC) final hearings to incorporate aerial or canopy mounted hydrogen systems into the building code. After personal presentations and discussion with several state and regional fire chiefs, text was added to the ICC code in 2006. Shell was also the first to apply the code in the W. LA station project where the entire hydrogen system (electrolyzer, compressor, storage) was placed 14 feet overhead on a canopy over a combined gasoline/hydrogen dispensing island.

Shell was also instrumental, along with Air Products, in having the code modified by ICC and NFPA to recognize the application of below-grade storage of liquid hydrogen. Prior to Shell and Air Products developing the Washington, D.C. station there had never been a need to pursue such an approach, and therefore the code had not recognized this application. For hydrogen retail stations below grade storage is important to reduce footprint, while industrial hydrogen uses are not typically confronted with the same type of constraints. Because of this project, the code now permits others to pursue similar approaches to underground storage.

Not specifically a part of this demonstration project but worth including herein, Shell is a full-time supporter and participant in the FreedomCAR and Fuel Partnership. Shell was the first industry co-lead for the Codes and Standards Technical Team and held that position for two years.

NextEnergy is our Codes and Standards partner for the Learning Demo. They have launched their Permitting website and held their annual Codes & Standards conference in September 30, 2009.

Database

NextEnergy successfully transferred hydrogen permitting database tools to a new website. They coordinated with DOE and other partners to transfer the databases layout and functionality to DOE ownership, for public benefit and use.

The hydrogen permitting database function is to help identify the key decision makers throughout Michigan who will make the "yes" or "no" decision for the permitting of a hydrogen station in their respective municipalities.

The permitting experiences database function is to help identify common issues encountered during the permitting process among several hydrogen stations across the country. Due to limited overall participation, the overall template of this database tool is what can bring the most value.

Annual Conference September 30, 2009

The conference held by NextEnergy attracted many diverse individuals from the national codes and standards organizations, as well as local officials and permitting authorities. The conference promoted education by exposing the community to the internet tools available today, as well as the most up-to-date progress on hydrogen regulations.

Code Development

NextEnergy participated in quality control task groups for the new revision of the NFPA 2 Hydrogen Technologies Code and participated in the NFPA board review meeting in Pittsburgh, PA on August 19th, 2009. By September 30 2009, both Task Groups completed their review of the latest NFPA.

4.4 Site Management

Each hydrogen station within this demonstration project executed a similar but tailored operating plan. All site plans included regular inspections, preventive maintenance programs, and response capability to resolve unplanned maintenance issues safely and promptly. Additionally, training for various persons and audits at certain intervals were managed. Sites with Visitor Centers also included some form of regular outreach to either the surrounding community/residents or the larger region. These engagement efforts were managed by third-party contractors to Shell and overseen by Shell staff.

Shell's most significant outreach involved local school children in the Washington, D.C. school system, where organized tours and field trips were executed multiple times per week in some cases. During the tours students listened to trained speakers about hydrogen, watched educational videos and often were able to see or even ride in a GM fuel cell vehicle.

4.5 Public Outreach

Throughout this demonstration and Project Driveway, GM has placed significant emphasis on the opportunity to engage in public outreach activities to introduce FCEV and the hydrogen technology to consumers, students, government agencies and representatives at local, state, and national levels, and to various other stakeholders. A high level of interest has been identified amongst these groups in learning about new technology and in being involved in "green" focused activities.

Vehicles were deployed to various broadcast, print and online media as shown in ***Figure 49***.

Figure 49 – Media Outreach

Vehicles were deployed to governmental agencies and also used for Capital Hill rides as shown in ***Figure 50***.

Figure 50 - John Mizroch, Principal Deputy Assistant Secretary Office of Energy Efficiency and Renewable Energy

Vehicles were deployed to many businesses as shown in ***Figure 51***.

Figure 51 – Business to Business Outreach

Vehicles were deployed to celebrities as shown in ***Figure 52***.

Figure 52 – Jay Leno with Gen2 Fuel Cell Vehicle

Many school outreaches were done with the vehicle as shown in ***Figure 53***.

Figure 53 - School Outreach Activity

Figures 54, 55, 56, and 57 were photos taken at various public outreach initiatives.

Figure 54 - Vehicle demonstration at Times Square

Figure 55 - Vehicle outreach with young professionals (YPE) NY chapter

Figure 56 - Photos taken during the Infrastructure rally

Figure 57 - Photos taken during the Infrastructure rally

4.6 Hydrogen Infrastructure

The approach to implementing the HFS generally involved three major elements: Siting, Development, and Operation; each further described in the Appendices, ***Attachment 4***. The table shown in ***Figure 58*** highlights some of the unique attributes for each of the HFS.

ID	Location	Apprx Sites Rvwd	Setting	Technology	Key Supplier	System Design	Const. Time (mos)	Local MIST*
SH01	Washington, DC	50	Retail w/ Gasoline	Liquid H2 Delivery	Air Products (APCI)	APCI	4	DeLuca
SH02	White Plains, NY	5	Private	On-site Electrolyzer	Proton	APCI	3	IP&T
SH03	West Los Angeles, CA	15	Retail w/ Gasoline	On-site Electrolyzer	Hydrogenics (HG)	HG	10	IDECO
SH03A	Culver City, CA**	5	Private	Gas Tube Trailer	Air Liquide (AL)	AL	6	IDECO
SH04	Bronx, NY	10	Private	Gas Tube Trailer	Air Liquide (AL)	AL	5	IP&T

SH05	JFK Airport, NY	10	Private	Gas Tube Trailer	Quantum	Bertin Assoc.	6	IP&T
GMAL01	Ardsley, NY	0	Private	Gas Tube Trailer	Air Liquide (AL)	AL	1	GM
GMAL03	LAX, CA	5	Retail w/ CNG	Gas Tube Trailer	Air Liquide (AL)	AL	3	Clean Energy, GM

Figure 58 – Demonstration Project Fueling Station Details

* Local MIST (Maintenance Inspection Service Technicians) include : Deluca & Sons, Island Pump & Tank (IP&T), and Industrial Design & Engineering Company (IDECO).

The GM Demonstration Stations performed relatively well, meeting or outperforming initial expectations. However, GM believes noteworthy efforts are still necessary for system performance to meet commercial expectations in terms of availability and individual component performance.

4.7 Driver Feedback

A critical part of the Gen2 vehicle deployment was gaining feedback from real world drivers. Drivers were expected to drive the vehicles in their everyday driving routines. Part of the agreement with the drivers was that they would provide feedback on a weekly basis on their experiences with the vehicle. The drivers were selected to drive the Gen2 vehicles for a period of two to three months. They were chosen on the basis of their sincere interest in the environment and the future of the automobile. There was no shortage of people interested in participating in the project as a driver. Over 100,000 people applied online at Chevrolet.com to be part of the market test. The feedback from the drivers was collected on an internet community blog site over the course of the two years.

4.7.1 Positive Feedback

The top positive driver comments were in the areas of driver support, vehicle performance, fuel economy and vehicle range. Driver support received the highest number of positive comments. As part of the experience, each driver was assigned a Driver Relationship Manager (DRM) who was the driver's single point of contact on all opportunities and issues for the duration of the drive period. The DRM was available to the driver on a 24 hour / 7 days a week basis.

One driver commented:

> "I hope when these vehicles become available to the public they offer a similar service [DRM] (at additional cost) that we as drivers are privileged to have. Tech support with a phone call, at home or work service calls, and pick-up and delivery. I for one would pay the additional fee for such coverage in a heartbeat."

The next top area of positive driver feedback concerned the vehicle performance in the areas of acceleration, responsiveness and smoothness. There were consistent positive comments concerning the vehicle performance. Here is a sample of the driver comments:

> "First and foremost, the car is INCREDIBLE! I love the quiet, comfort, power, and joy of the ride. It's such a pleasure to drive, that it's a highlight every time I get into the car…

The car simply stands out as incredible. All my passengers revel in the power and smoothness of the ride. Good stuff!!!"

The next top area of positive feedback was the fuel economy and range of the vehicle. The drivers were advised that the vehicle range was anticipated to be about 150 miles on a full tank of 4.2 kilograms of hydrogen. What happened was that the drivers quickly tried to exceed the expected range and an informal competition occurred between the drivers blogging and bragging about their own fuel economy and range. Here is a sample of one of the driver's comments:

> "The first couple of weeks I was driving I was getting an average of 49.7 m/kg. I thought that was fantastic! Considering my gas guzzler gets about 14 m/gal. Last week I finally broke that barrier and hit 50.7 m/kg. At my last fill up on Wednesday I was averaging 51.9!! I don't know why or how, maybe it's the wonderful job the guys from Shell are doing tweaking the system in White Plains or the engineers in Ardsley that have had my car in a couple of times to "go over it" or maybe its ME! I don't know, don't really care I'm just LOVING IT!"

4.7.2 <u>Constructive Feedback</u>

The top constructive driver comments were in the areas of hydrogen fueling process / availability, brake feel / effort, and vehicle reliability. The most consistent constructive comment was in the area of the hydrogen fueling process and fuel availability. When the project first launched, there were few 700 bar fueling stations available. Although the number of 700 bar fueling stations grew over the period of the project, they were still scarce and not as reliable as a gasoline station. Many drivers were limited to 350 bar fills and, consequently, a reduced range. Here is one driver's comment relative to fueling:

> "Refueling isn't perfect. I've had some "signal confirmation errors", etc. To me, this has been minor. The biggest thing I've taken for granted has been having a gas station almost everywhere. I've really had to be aware of my mileage so that I can very deliberately calculate my refueling. It's foremost on my mind when I drive. I have almost ran out of fuel...but managed to make it to the Riverside, CA station successfully. I have been warned, though, that although fueling stations are up and running, they are not always reliable at this time. There have been problems with nozzles, access, signal confirmation, etc. I think the infrastructure is probably my biggest concern."

The next area of driver constructive comments concerned the feel of the brakes of the vehicle. The Gen2 vehicle employs a regenerative brake system that uses the drive motor to capture the kinetic motion of the vehicle and turn it into electricity. The system is an electro hydraulic system that blends the braking effort between the electric and hydraulic systems depending upon many factors. The drivers were very sensitive to the blend points and the overall feel of the regenerative brakes as one driver commented:

> "One more comment on the braking, you can feel a couple of points during braking, when the system must be changing brake pressure because you can feel a distinct change. It's more noticeable during harder than normal braking."

Another area of constructive driver comments had to do with the vehicle reliability. A limited production vehicle using a highly advanced propulsion system is not likely to have the level of reliability the general public has come to expect. The following is an example comment from a driver relative to the reliability:

> "After I had driven about a half mile, I drove up a freeway on-ramp and had to "punch it" to get out of the way of a big semi. When I floored the accelerator, I got a lovely warning chime and a message of "Fuel Cell Propulsion Reduced" for a few seconds and the vehicle seemed a little sluggish (not scary slow, just slightly underpowered). Then the warning turned off and all seemed to be just fine."

In addition to the driver feedback collected by GM, a third party consultant was hired by Shell Hydrogen to conduct a market study called "Hydrogen Car Driver Interviews-GM Pack" in 2008. The summary report can be found in the Appendix under ***Attachment 1***. The report focused on driver experiences at the stations in White Plains, Shell Santa Monica and UC Irvine. Below is a summary of the results that conclude that fuel cell drivers:

- Want more hydrogen stations
- Want these stations to be highly visible and open
- Want to be seen using these stations

The strongest request for improvement was related to the placement and visibility of the stations themselves. Drivers are so enthusiastic about their hydrogen experience that their greatest wish is to share it as broadly as possible with others. They are happy to do self service – the act of dispensing one's own hydrogen is empowering, a concrete signal that they are actively taking control of their future. Drivers tout the fact that the process is cleaner and safer than that with regular gasoline. They therefore feel it is crucial to have mixed stations so that gasoline customers can see hydrogen fueling, underlining that the process is "normal."

Driver comment "They have to see me doing it with kids in the car so they realize it's safe, easy and better."

The fact that the stations are isolated/behind gates with no signage and nothing welcoming about them is disappointing. According to drivers, the stations should be in high traffic places with visible signage.

Driver comment "The station should be visible to the average consumer. Put it in a commercial gas station so that people can see it. We need to develop some comfort level with hydrogen, people need to see it."

As far as the fueling experience, drivers suggested some improvements to the process such as visualization of the filling process status. A suggestion was to use light emitting diodes (LEDs) of various colors to show the driver where they were in the filling process. The hydrogen dispenser should facilitate drivers' understanding of where they are in the process and thus constantly reassure them.

The stations sometimes had malfunctions. GM overcame the problem of malfunction in part by having the Driver Relationship Managers available 24/7. DRMs were trained to deal with any issues relating to the vehicle, including fueling questions and concerns. When fueling problems occurred, the DRMs would bring the vehicle to the GM facilities for fueling. This was a smart way to manage potential issues with drivers, but of course not one that is financially feasible once penetration grows, and it doesn't immediately resolve the problems encountered when originally at the station.

At stations where the infra-red communication link between the hydrogen dispenser and the vehicle was not available, drivers found the process of connecting the secondary communication cable to the vehicle—relatively dissatisfying. The extra step associated with using the cable to enable communication fueling encumbers the process and leaves drivers feeling frustrated. It is difficult to reach and see the socket where the cable needs to be connected in a specific position. Generally, the cable itself was too short, making the manipulation more difficult and requiring drivers to either step over or under it when going back to connect the nozzle for the hydrogen. This extra step makes the fueling process different from, and more laborious than gasoline. However, drivers realize that the dispenser 'communicated' with the vehicle through this data-port and understood that fueling station operators was plan to replace the cable with infrared technology. It should be noted the use of an IR nozzle at the station eliminates the need for such a communication cable and integrates the communication pathway with the fueling nozzle; these IR nozzles are future industry direction and have now been installed at a majority of fueling locations thus eliminating the issue.

Another issue associated with the refueling experience is the total time required to complete the process. In general, drivers are not willing to see their time extended significantly longer than the average time required to fill with gasoline. Wait time is particularly an issue with stations that do not utilize buffer storage for rapid cascade fills where the wait can be as long as 10-15 minutes to fill.

The study also suggests that GM should rethink the placement of the fuel receptacle on the vehicle. The position of the nozzle is considered to be high, thus making fueling quite cumbersome, particularly for shorter people.

The ideal hydrogen station needs to integrate the advantages of certain stations while eliminating the problems of others. In summary, it should deliver:

Accessibility • Easy to see/find • Plenty of room to park • Infrared vs. cable communication • Easy access to/positioning of sockets/ports	**Simplicity** • Limited data entry. Ideally IRDA • Single hand dispensing • Short waiting time to dispense and/or to "pre-check"
Comfort • Ergonomic pump • Comfortable receptacle placement on car (not too high) • Rain roof • Leave-on lever • Lever that drops/snaps smoothly and comfortably into each position	**Clear Communications** • Guidance for the lever positions • Visualization of the filling status (start, finish) • Signals for beginning and end of process

5. Conclusion and Recommendation

The project goal was to put a large fleet of cars in the hands of the everyday consumer and gather data.
GM demonstrated three key FCEV successes during the demonstration project:

1) Fuel Cell Electric Vehicles fully meet all functional needs for day-to-day use by individual customers.

2) Fuel Cell Electric Vehicles are fully functional in sub-freezing cold weather conditions.

3) Fuel Cell Stack durability rapidly increased over the life of the project due to the rapid response to data obtained during this project and is on track to meet commercial vehicle requirements in the near term.

5.1Conclusions Specifically Regarding Fuel Cell Electric Vehicles

A very important element of the demonstration project was the verification that the FCEV can meet all of the daily needs of private individuals and commercial customers under the range of climate and weather conditions found throughout the USA. GM is particularly pleased with the demonstration of the cold weather operational capability of the Gen2 FCEV. The majority of the cold ambient vehicle starts and operation in the entire Hydrogen Vehicle and Infrastructure Demonstration and Validation project were accomplished by GM's Equinox FCEV.

During the Gen1 vehicle deployment phase, GM demonstrated the technical feasibility of utilizing a fully-dynamic fuel cell system to provide for the current/power demands of an electric vehicle. During this phase, almost 5,000 individuals had the opportunity to ride/drive the FCEV, and for many of those guests, this represented their first exposure to an electric vehicle. Never the less, the Gen1 vehicles were clearly "engineering" vehicles requiring a significant level of "hands-on" engineering support in order to operate on a daily basis and were rarely turned over to non-GM personnel for unattended operation.

During the Gen2 vehicle deployment phase, GM demonstrated that the FCEV could meet two sets of key requirements for commercialization. First, the vehicle was designed, developed, and tested using GM's Global Vehicle Development Process and underwent all of the same testing, qualification, and government certification as any GM production program. The vehicles were assembled in the production vehicle facility (CAMI, Ingersoll, Ontario) using several low-volume processes for the installation of specific fuel cell and hydrogen storage components. Second, the Chevrolet Equinox Fuel Cell Electric Vehicle was the first FCEV to be deployed on a large scale for unattended operation by everyday customers. GM initiated a large-scale market test of FCEVs (including the 42 vehicles operating under the demonstration project). Vehicles were deployed to a variety of private individuals, commercial customers, government agencies, and media outlets. This market test was named "Project Driveway", and it allowed GM and DOE/NREL to obtain not only engineering and operational data from the FCEV fleet and HFS installations (see the Composite Data Product information reported by NREL throughout the demonstration project) but also customer feedback regarding HFS and FCEV technologies and an better understanding of how customers will interface with this new technology.

A key enabler for the commercial level of product performance evidenced in the Gen2 vehicles was the high level of effort focused on implementation of robust on-board diagnostic systems. This allowed the vehicle to adapt to unexpected system and component faults as well as significant variation in operating conditions without disrupting the operation of the vehicle from the customer perspective. The deployment of the large fleet of demonstration vehicles afforded the opportunity to assess operating condition variation across a statistically significant population of vehicles in a variety of climates and usages.

5.2 Conclusions Specifically Regarding Fuel Cell Stack Technology

As noted earlier in this report, GM was able to detect fuel cell stack failure modes during the vehicle demonstration which had not previously been observed in laboratory and Proving Ground testing. As a result, a “test-fail-analyze-redesign-test” cycle was implemented on an ongoing basis throughout the demonstration. This capability resulted in significant gains in expected fuel cell stack durability and reliability. The most recent learnings regarding the effects of certain operating conditions on stacks are now addressed.

Throughout the course of the demonstration, the GM engineering team developed an excellent working relationship with the data analysis team at NREL. The two teams worked closely together regarding data analysis techniques and interpretation of results. For example, at the outset of the demonstration, NREL and DOE reported fuel cell stack “end of life” as the point where stack voltage had fallen 10% from the as-new value at a constant current point (CDP #1 – “Projected Hours to 10% Stack Voltage Degradation”) as shown in ***Figure 59***.

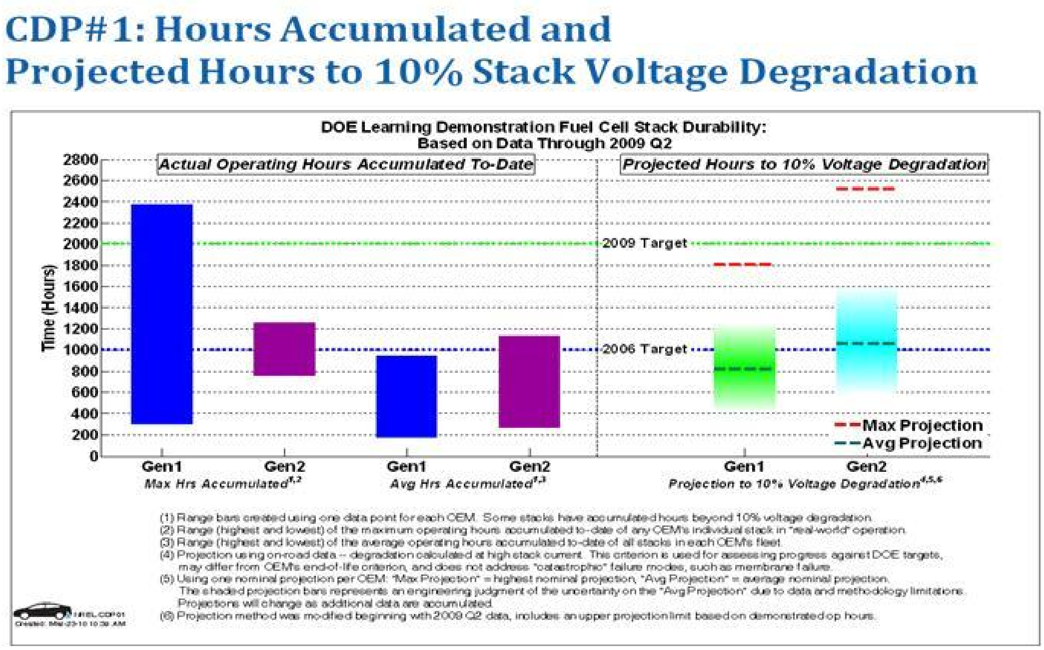


Figure 59 – CDP #1 Projected Hours to 10% Stack Voltage Degradation

Since the GM Fuel Cell System was designed to operate far beyond that point while still providing vehicle performance within specification, GM and NREL worked together to develop a

“Projected Hours to OEM Low Power Operation Limit” (CDP #71) metric which was added to the Fall, 2009 CDP publication as shown in ***Figure 60***.

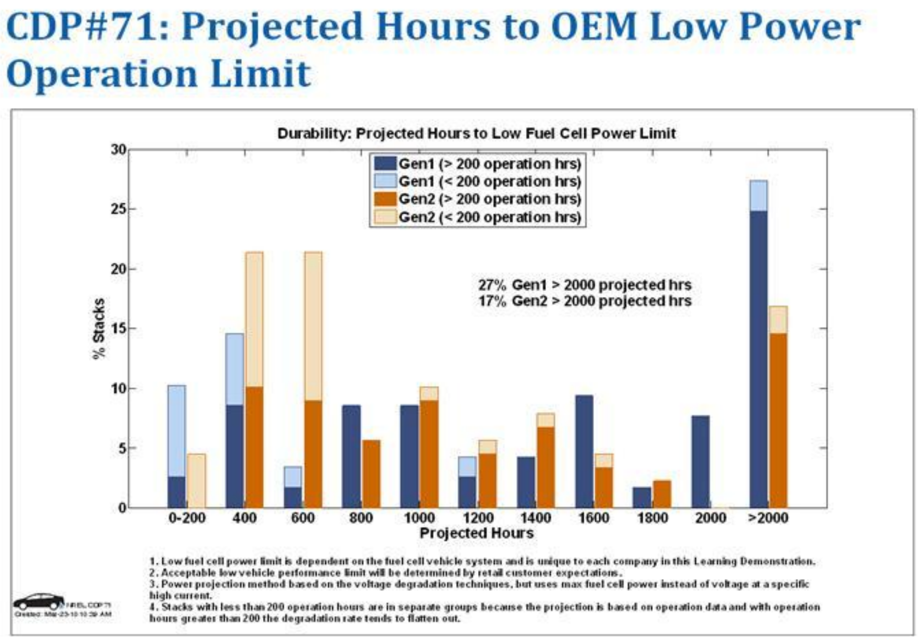


Figure 60 – CDP #71 Projected Hours to OEM Low Power Operation Limit

5.3 Conclusion Specifically Regarding Hydrogen Fueling Systems

Throughout the project, GM grappled with the operational impact of reliability issues impacting the availability of the individual fueling sites which GM customers relied upon. Keeping fuel available to customers so that they could go about their business without undue inconvenience was a key challenge. The hardware employed at the GM and Shell Hydrogen fueling sites, while demonstrating a range of production, storage, and compression technologies, was better suited for occasional demonstration use rather than for daily customer use over a period of years. As a result, a significant amount of effort was focused on maintenance and repair of fueling facilities as well as managing fleet and customer logistics to work around fueling locations that were out of service. A key next step in resolving these issues will be funding a robust product development and validation of a reliable compression and dispensing system which can be produced in volume and deployed to multiple sites. This level of hardware will be required in order to make installation, maintenance, and service of fueling sites fairly efficient and cost effective as regional hydrogen fueling infrastructure is implemented.

Another key to the hydrogen fueling infrastructure development will be the mitigation of “range anxiety” in users of hydrogen fueled vehicles. Range anxiety occurs when the driver is uncertain whether they will be able to find a fueling station when they need one. The fueling data shows that the FCEVs were often refueled when they still had 50% or more fuel already in the tank. This resulted in fewer miles between fueling events and more fueling stops than suggested by the operational range of the vehicles. This issue can be mitigated in two ways. First, a regional plan for construction of Hydrogen Fueling points in an area where FCEVs are deployed should allow for a convenient geographic distribution of fueling. Second, a telematics application such as the OnStar system employed in the GM Gen2 vehicles can be used to make it easy and convenient for drivers to find the nearest station and navigate to it. This functionality can also help “work around” a station that may be experiencing a problem by alerting a “real time” notification and diverting the driver to another point. In addition, 700 bar fueling capability is critical to achieving vehicle range that is acceptable to customers.

This demonstration project has shown that it is feasible to incorporate hydrogen into existing gasoline and CNG stations, and that it is feasible to expect general community interest and support. Most stations in the project have shown that it is practical to provide a retail-like experience where drivers of FCEVs can expect an acceptably fast and complete fueling. The public has had the opportunity to become further educated in the Hydrogen Economy through the public permit application processes, community outreach and engagement conducted during permitting, and as participants in the use of the HFS built in certain communities. Hydrogen stations built at existing gasoline stations have also enabled the general motoring public to witness hydrogen in a retail environment and to observe fuel cell vehicles fueling in the real world.

GM recently negotiated it’s first agreements to purchase hydrogen fuel “by the kilogram”. GM continues to launch new relationships with H2 station partners outside original project stations

- Rochester Institute of Technology
- Town of Hempstead, NY
- SunHydro, Wallingford, CT

Additional “learnings” are:

- Early community engagement/education is helpful in smoothing the permitting process.

- Equipment manufacturers and suppliers can only deliver existing solutions in the near term, new solutions need R&D timelines to deliver results.

- Compression is a cost and performance factor and future opportunity for new approaches. In most cases, the higher the pressure the higher the costs, but the Air Liquide fast-fill systems (pneumatic compression) proved cost-effective.

- Storage is also a cost driver. Composite station storage vessels may help to reduce this cost, but novel compression techniques as noted above might contribute significantly to reduced cost and physical footprint by reducing the amount of storage needed.

- The user-interface is a key driver for the customer experience—transition to IR nozzles, common fueling dispensers, and simple screen interactions provide an “easy as gasoline” experience.

- Hydrogen safety systems are effective and reliable but can be improved and simplified.

Overall, the hydrogen fueling system needs to be more reliable with a lower capital cost. GM urges that more work be funded in this area.

5.4 Recommendations to DOE

5.4.1 Fuel Cell Electric Vehicle recommendations

Based on the experiences gained from this project, the following recommendations regarding FCEVs are offered to DOE:

- Vehicle demonstrations:
  - Continued targeted vehicle demonstrations over the remaining 3-4 years until commercial roll-out serve 3 vital purposes:
    1. Continued rapid cycles of learning will continue to drive rapid improvements in fuel cell stack and fuel cell system durability and cost which will enable the broader application of automotive-based fuel cells to multiple markets including buses, trucks, and stationary generation. These applications will help drive the increases in overall production volumes critical to rapidly bringing down cost.
    2. Maintain public visibility and outreach/education efforts necessary to ensure consumer acceptance of fuel cell and hydrogen technology. Increased DoE support for fuel cell technology at this critical time close to commercialization will send the right message to key suppliers and infrastructure providers.
    3. Assure continued demand for hydrogen fuel from current and planned hydrogen stations to avoid the erosion of the current network and to avoid the appearance of loss of confidence/momentum in the area of hydrogen infrastructure
- Fuel Cell technology:
  - The vehicle demonstration has yielded valuable insight into methodology for assessing fuel cell durability. A continuing stream of vehicle data is critical to supporting industry convergence on assessment methodology. It also supports the development and confirmation of accelerated durability testing protocols to allow rapid testing of new technology outside of the vehicle.
  - Vehicle demonstrations yield real world confirmation of the results of other research into durable and cost-effective fuel cell materials which remains very important to fuel cells becoming cost-competitive with other transportation technology.
  - Very pure fuel supplies were generally used throughout the project as shown by the HFS sampling results, and no issues were identified related to the impact of fuel impurities or contamination on fuel cell performance or durability. Vehicle/HFS-level testing of such impurities and contaminants to confirm their effect (reversible and non-revesible) on catalysts and cell materials in real-world operation is recommended to help enable lower fuel costs as well as increasing fuel cell durability and to confirm the research-level findings from projects such as the "Effects of Fuel and Air Impurities on PEM Fuel Cell Performance" project recently completed at Los Alamos National Laboratory.

The vehicle demonstration has shown that fuel cell durability has continued to improve and customer performance has been maintained while Platinum usage has been reduced to less than 38% of the original level during the three generations of FCEV technology demonstrated.

5.4.2 Hydrogen fueling system recommendations

Based on the experiences gained from this project, the following recommendations regarding hydrogen fueling systems are offered to DOE:

- Project Management
  - Focus efforts to ensure that key regional markets can develop now (HI, LA/CA, NYC/NY).
  - Communicate directly with local communities targeted for fueling station and hydrogen facility development, specifically noting resources, references, and endorsing NFPA & International Codes Council (ICC) standards.
  - Develop and support networking opportunities for industry and targeted communities.
  - Support the development of common operational metrics for hydrogen stations.

- Outreach and Training
  - Provide and facilitate sponsorship of national conferences, forums, and workshops for AHJs .
  - Continue to facilitate communication of information for permitting officials with State governments and with National Association of State Fire Marshals (NASFM).

- Station Design
  - Support the design of next generation infrastructure to be commercially viable, i.e. beyond demonstration capability, with low capital cost, high reliability, and sized for early introduction volumes.

- Permitting and Installation
  - Continue to promote a common approach to hydrogen station design review, permitting, inspection and operation.
  - Support efforts at the State Fire Code level .
  - Develop regional hydrogen safety experts to help educate local permitting officials on existing code and to communicate local lessons learned .

- Encourage and support deployment of commercial stations in key regional market areas (HI, LA/CA, NYC/NY).

- Support development of low cost/high volume hydrogen station equipment:
  - Specific engineering of hydrogen compression, storage, and dispensing equipment for use in retail fuel stations is required to develop hardware suitable for rapid and cost-effective deployment. Design and tooling for high volume (hundreds or thousands of dispensers per year) production of hydrogen station equipment is needed to create and validate equipment that is robust, reliable, and inexpensive. These designs will be needed for stations constructed in the 2014-2015 timeframe.

The recommendations above represent the steps needed to move from the R&D/demo nature of the stations used in this project to the early commercial stations needed to support the initial commercial launch of Fuel Cell Electric Vehicles. High-volume retail stations for large populations of vehicles will then follow as demand and vehicle density grows.

6. Attachments

6.1 Attachment 1 – Customer Survey Results Provided by Shell Hydrogen

Future Fuels: Confronting consumer perceptions with market reality

A multi-pronged approach to evaluating the potential for hydrogen and other alternative fuels

by Leslie Pascaud, Isabelle Rémond and Duncan Macleod

The paper shows the results of an 18 month research programme conducted for the Shell Future Fuels division beginning in August 2007 .The goal of the study was to better understand American and German driver attitudes towards alternative fuels (with a particular focus on hydrogen fuel) and their impact on fuel preferences, fuel brand perceptions and behaviours. Although the study is not directly predictive, it does give insight into the targets most likely to move first to future fuels and the triggers that will incite them to do so.

The study was launched based on the hypothesis that a clearer understanding of consumer reactions to hydrogen fuel, the cars that run on it and the communication around it could help Shell to better evaluate the risks and rewards associated with a proactive approach to investment. There were four main objectives:

- To better understand American and German driver attitudes towards alternative fuels (with a particular focus on hydrogen fuel),
- To track the evolution in consumer awareness and attitudes so as to better influence the adoption curve,
- To monitor the impact that Shell's future fuel activities are having on brand image,
- To understand triggers and barriers to acceptance in order to design better cars, stations and communication campaigns.

The research had five key phases:

Phase (1) Stakeholder Interviews with Senior Shell executives, automobile manufacturer partners (General Motors, Honda and Daimler) and governmental and non-governmental bodies (German Ministry of Transport, European Commission Directorate General for Energy and Transport, Department of Energy, California Fuel Cell Partnership).

Phase (2) Create focus groups (6 per market) with mainstream and alternative fuel car drivers. CA was chosen as the representative of the future.

Phase (3) Quantitative on-line Barometer & Segmentation of attitudes and behaviours from 1000 German and 2000 American respondents.

Phase (4) Quantitative face-to- face Tracking (400 interviews) of respondents at a Shell hydrogen Station (US only) to understand what impact the Hydrogen offer had on consumer perceptions of the brand

Phase (5) Ethnographic interviews with 17 Hydrogen car drivers in US & Germany and 15 mainstream respondents in US driving fuel cell cars and pumping hydrogen fuel, to learn more about driver triggers and barriers through direct observation and exposure to the cars and the pumps.

We conducted interviews with eight of GM's project driveway drivers, in the car while driving and at the station while fuelling, in White Plains (NY), in Burbank (CA), and in Irvine (CA) on May 12th, 13th, 14th, and

15th. As part of the project all interviewees were selected by GM to drive the vehicle for a 3-month period. The interviews focused on the drivers experience with the hydrogen cars and hydrogen as a fuel, the **fuelling process and** the **communication** of the 'hydrogen story'.

Summary: The Hydrogen Car Driving Experience

- Two predominant factors drove interest in participating in Project Driveway: (1) the fear of scarcity of fuel and (2) environmental concerns, which has speared in them a sense of obligation/responsibility to preserve the planet. Thus pragmatism and altruism come together to seek out new automotive options. Virtually all of the respondents interviewed were grateful to be part of the project. They felt they were making history by helping shape the future of the country and the world.

- The experience of the hydrogen driver is overall a very positive. The pride/status of being at the leading edge of this exciting new/clean technology is very motivating for drivers. In the US the emphasis environmental and zero emissions is an easy and appealing way to sum up the car's uniqueness for most.

- The surprise of having a car that is more responsive than expected is an added plus. The unique sensations of the car (clean, quiet) juxtapose with reassurance of more familiar features. The right balance between the two will clearly depend on the target, with more mainstream consumers preferring more familiar codes and features.

- Safety is not an issue with drivers, however all drivers highlight the issues of autonomy and range as obvious hurdles to purchase.

Conclusion:

Interviews with hydrogen drivers have enabled us to see the enthusiasm that can be generated with this new technology. The combination of environmental friendliness, technological advancement, a cleaner overall experience (smell, feel sound) and surprisingly strong acceleration is a winner, all the more so when it comes in a car that is relatively familiar and therefore comfortable for drivers. The hydrogen cars have clear functional and emotional benefits for drivers.

Functional	Emotional
• Smooth Drivability	• Pride
• Comfortable in Use	• Status
• Emission Free	• Freedom from Dependence

Summary: The Hydrogen Refueling Experience

The ideal hydrogen station needs to integrate the advantages of certain stations while eliminating the problems of others. It should deliver accessibility, simplicity, comfort and clear communications:

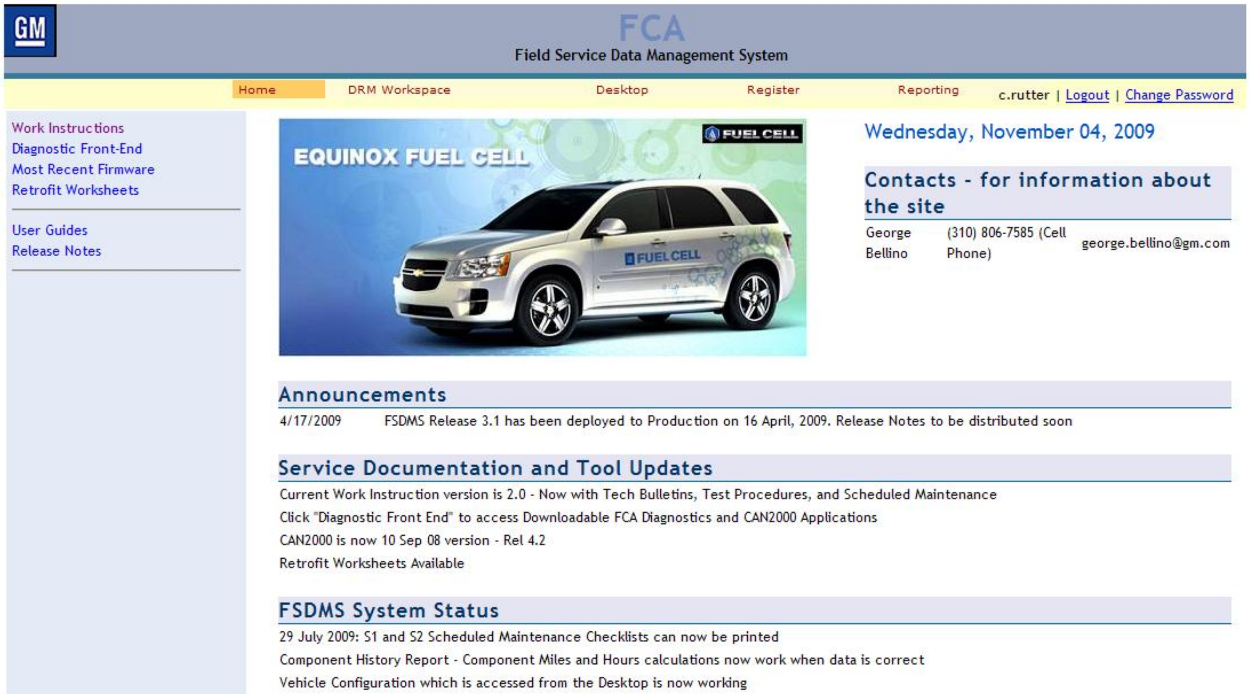
Accessibility
- Easy to see/find
- Plenty of room to park
- Sufficiently long cables
- Easy access to/positioning of sockets/ports

Simplicity
- Limited data entry. Ideally RFID
- Single hand pumping
- Short waiting time to pump and/or to "trouble-shoot"

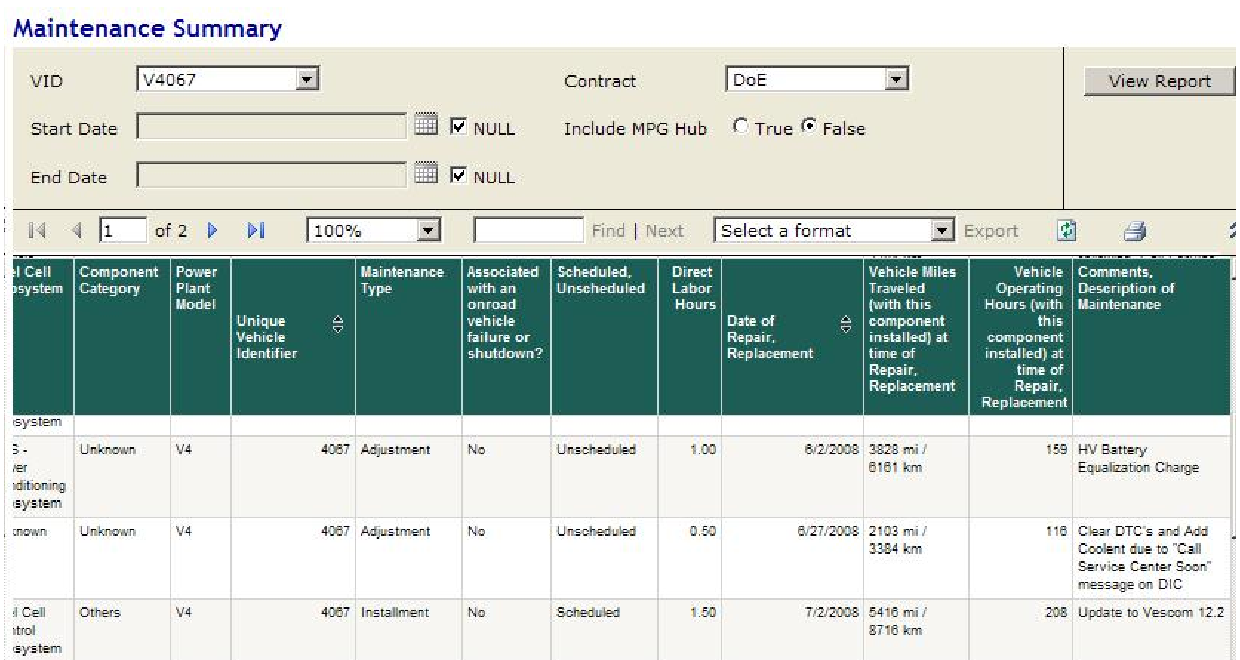
Comfort
- Ergonomic pump
- Comfortable nozzle placement on car (not too high)
- Rain roof
- Leave-on lever
- Lever that drops/snaps smoothly and comfortably into each position

Clear Communications
- Guidance for the lever positions
- Visualisation of the filling status (start, finish)
- Signals for beginning and end of process

6.2 Attachment 2 - Field Service Data Management System – stores data to service field vehicles



Service Records are stored in Field Service Data Management System



...l Cell ...bsystem	Component Category	Power Plant Model	Unique Vehicle Identifier	Maintenance Type	Associated with an onroad vehicle failure or shutdown?	Scheduled, Unscheduled	Direct Labor Hours	Date of Repair, Replacement	Vehicle Miles Traveled (with this component installed) at time of Repair, Replacement	Vehicle Operating Hours (with this component installed) at time of Repair, Replacement	Comments, Description of Maintenance
...system											
...S - ...er ...ditioning ...system	Unknown	V4	4067	Adjustment	No	Unscheduled	1.00	6/2/2008	3828 mi / 6161 km	159	HV Battery Equalization Charge
...nown	Unknown	V4	4067	Adjustment	No	Unscheduled	0.50	6/27/2008	2103 mi / 3384 km	116	Clear DTC's and Add Coolent due to "Call Service Center Soon" message on DIC
...l Cell ...trol ...system	Others	V4	4067	Installment	No	Scheduled	1.50	7/2/2008	5416 mi / 8716 km	208	Update to Vescom 12.2

Work instructions are stored in Field Service Data Management System

Fuel Cell Equinox Work Instruction Matrix

No.	Procedure Name
001	Coolant Loop Fill and Degas
002	101X FCV- Deploy CHECKLIST DRM
003	101X- FCV Deploy CHECKLIST HUB
004	CAN2000 Automated SCB Bleed Routine
005	Coolant Handling Guideline
006	CTA Purge
007	CVM Check In Vehicle
008	DTC Check
009	Extended Parking Preparation

Technical Bulletins are stored in Field Service Data Management System

Technical Bulletins Fuel Cell Equinox

No.	Year	Subject	Status	Implemenation Date:
012	2008	Equalization charging of RESS (HV Battery) affected	Released	05-Mar-08
013	2008	Time and date adjustment of PC 104 Clock	Released	06-Mar-08
014	2008	Checking the inner and outer seal pack of the receptacle	Released	
015	2008	Rear License Plate Bracket Spring Lubrication	Released	14-Mar-08
016	2008	Proper handling of FCI - X14 Connector	Released	17-Mar-08

Engineering Change Requests are stored in Field Service Data Management System

www.atcfsdms.com - /FSDMS/files/retrofit/

```
[To Parent Directory]
     Wednesday, July 30, 2008 10:20 AM      8491008 BSD 1002703-R#121-Steering Column Pivot Bolt.xls
     Wednesday, July 30, 2008 10:25 AM        74240 BSD 1003962-R#120-Software Reflash VeSCoM 12.3.xls
     Wednesday, July 30, 2008 10:21 AM      1682347 BSD 1007085-R#122-HT Coolant Pump Cable Routing Check.xls
      Friday, August 22, 2008 11:00 AM        84480 BSD 1011324-R#123 GMT101x V13.0 Rework-Retrofit Worksheet.xls
     Monday, January 05, 2009  9:09 AM      3993524 BSD 1012003-R#129 P127 dry bleed-Ver2.xlsx
```

Front End Diagnostic tool

EQUINOX FUEL CELL Service and Diagnostic Frontend

Lists/Tables | Techn. Data | Help | Back

DTC Descriptor

Coolant Tank Level Low

Index

Typical Scan Tool Data

Use CAN 2000 and read {VeLTCH_b_CoolTankLvlFull} (Instruction Set FCPS Cooling System).

Index

Circuit/System Description

The coolant tank has a sensor to measures the level of the coolant.
In case of an low level the DTC will be set. The sensor is located in the
coolant tank.

6.3 Attachment 3 – Summary of Outreach Activities

General Motors

On the Road with ***Project Driveway***

October Update • Issue 4

- *Hydrogen Station Opening*
- *Mainstream Deployments*
- *Public Policy*
- *Grassroots Events*
- *Penny Marshall*

Mainstream Deployments

Kevin Hovis takes delivery of his EFCEV at Shell Benning Road

Matt Grubler of Brooklyn, NY takes delivery of his EFCEV on 10/27 at Shell JFK

Public Policy

Monica Murphy and Rep. John Sarbanes (D – MD) at the Regional Manufacturing Institute of Maryland conference

Town of Hempstead Opens First Hydrogen Station on Long Island!

The Chevy Equinox FCEV was on-hand as Town of Hempstead Supervisor Kate Murray dedicates the first hydrogen station on Long Island at Point Lookout, NY on 10/21 The station will provide hydrogen, natural gas, as well as hythane – a CNG/H2 blend.

Grassroots Events

EFCEV displayed at National Grid Customer Service Day on 10/7 in Melville, NY

EFCEV displayed at AltWheels on 10/5 in Framingham, MA

EFCEV displayed at the Pyramid Shriners Car Show on 10/4 in Orange, CT

Penny Marshall

PD alumni actress Penny Marshall arrives at charity event in Times Square in the EFCEV.

Page 1

On the Road with Project Driveway

October Update • Issue 4

- *2010 Vancouver Olympics*
- *Internet Community Event*
- *Road & Track*
- *Culver City Station Opening*
- *Celebrity Connection*
- *Community Outreach*

2010 Olympics

Matt Crossley, GM Canada's Director of Engineering, Ann Duffy, Vancouver Olympic Committee's (VANOC) Corporate Sustainability Officer and John Furlong, VANOC's CEO at the Vancouver Olympic Centre.

Torch Relay Events with Olympians (& the TORCH!)

Internet Community

Just a few of our Project Driveway alumni that came to the Burbank event October 23-24.

Media

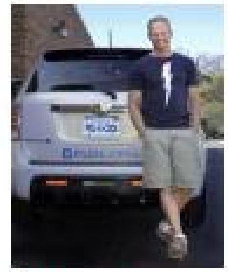
Dennis Simanaitis writes about his 1-week FCEV loan in the October issue of Road & Track.

Station Opening

The sun rises on our newly opened station – Shell Culver City

Celebrity Connection

Helen Mirren said that she can't wait to show off the Equinox FCEV to everyone!



Ian Ziering was very excited to receive his FCEV loan this month.

Producer / President Rhino Films ***Stephen Nemeth*** praised our vehicle to ***Senator Arlen Specter***, shown with Stephen, & former PD participant ***Peter Fonda***.

Community Outreach

Project Driveway supporters ***Pierce & Keely Brosnan*** invited GM to attend ***Dr. Jane Goodall's "Roots & Shoots"*** annual ***Day of Peace*** on Santa Monica's Pier.

Page 2

General Motors

On the Road with Project Driveway

October Update • Issue 4

- *Frankfurt Auto Show*
- *Alternative Propulsion Exhibit*
- *HG4 in Warsaw*
- *CE Symposium*
- *Deployment, Ride & Drives / Exhibits*

2009 Frankfurt Auto Show

Alternative Propulsion Exhibit

HydroGen4 Show Car and Chassis at an Alternative Propulsion exhibit in a German shopping center.

Our FCEV was the vehicle which got the most interest and we received many information requests.

HydroGen4 in Poland

HG4 was in Warsaw, and was presented to seven key automotive media including a very popular TV station specializing in autos, TVN Turbo.

Car was exhibited at the 1st Eco Cars conference in Warsaw, as the only Fuel Cell vehicle. We had Deputy Prime Minister Pawlak and Minister of Environment Nowicki examining our car, Mr. Pawlak invited GM to his office for a private presentation of our alternative sources of energy presentation.

CE Symposium

1st Deployment, Ride & Drives / Exhibits

First Mainstream Driver receives vehicle!

Ride and Drives were conducted at the F-Cell Conference in Stuttgart

Exhibition and ride sessions at an Opel dealership re-opening - - all were flabbergasted by performance, as usual!

Page 3

General Motors

On the Road with Project Driveway

October Update • Issue 4

- *Shanghai FCV*
- *EXPO 2010*
- *GM Interactive Website*

Shanghai FCV

Equinox and Shanghai FCV at Garage

First Shanghai Fuel Cell Vehicle Made in China

16th.Oct.2009, Shanghai- The first Shanghai FCV made in China almost is almost ready to hit the ground, the build of which was started on 9th Sep. 2009.

EXPO

EXPO 2010 SHANGHAI CHINA

World Expo 2010 Shanghai will run from May 1 to October 31, 2010. GM and SAIC are sponsoring the Expo and fielding a fleet of fuel cell electric vehicles for VIP shuttling. Equinox and Shanghai FCV are part of that fleet.

"During Expo 2010, GM and our partner SAIC will introduce our vision for the future of urban transportation," said Kevin Wale, President and Managing Director of the GM China Group. "We envision a future in which vehicle emissions, traffic congestion and accidents are all in the past, and a future in which driving is more fun and exciting than ever before."

For additional information about GM's participation, please visit www.gmexpo2010.com

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GM Launches Interactive Website

24th.Sep.2009, Shanghai – General Motors Company, a joint global automobile partner of World Expo 2010 Shanghai, today kicked off its "Drive to 2030" Expo 2010 campaign through the official launch of its interactive website (www.gmexpo2010.com).

It also introduced a century of GM innovations that have transformed the industry, including its vehicle-to-vehicle (V2V) communication technology, which GM demonstrated for the first time in China. This next-generation technology will be one of the features at Expo 2010.

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6.4 Attachment 4 – HFS Process for Siting, Development, and Operation

6.4.1 Siting

After determining local geographic preferences based on expected FCEV driver patterns, specific properties were assessed for compatibility with anticipated or existing hydrogen fueling codes and standards, local surroundings and impacts, restrictions, and opportunity related to the property owner. After thorough screening of several candidate locations, a single target location was identified and the project initiated. In only one occasion was the selected site not able to be successfully developed due to local opposition.

There are often trade-offs when considering different properties such as proximity to desired target vs. term of availability. It is helpful to have a local expert on the property types under consideration provide a summary of local issues, property owner profiles, and area trends if possible.

6.4.2 Development

Three primary functions are associated with Development: Design, Permitting (including community engagement), and Construction.

Each HFS was designed for the specific site considered to ensure full compliance with all applicable requirements. Several different suppliers were engaged for each project, providing opportunity to develop a working base and to also test/experience different technologies. This demonstration project required at least one renewable technology be demonstrated, and Shell was able to do this at two locations by using electrolysis on-site with renewable power from the grid. The retail stations were designed from components-up to fit the existing station situation while the private stations mostly utilized pre-packaged or containerized systems for a less consumer-look and feel and more of a temporary appearance. Costs are somewhat lower for the containerized/private sites, but mostly due to not including ancillary aspects such as Learning Centers and other retail image demands or convenience store work.

Permitting varied from one site to the next, as did the extent of community engagement necessary. In all cases however, technical design satisfied local permitting officials. In most cases, time for permit issuance ranged from 90 days to 12 months. GM's LAX site proved to a positive outlier, requiring only four weeks (30 days) to permit. In all cases Shell and/or GM met with the local permitting jurisdiction to discuss the concept and provide any preliminary design information for discussion. The input received during these preliminary meetings was very helpful in preparing a final permit package for submittal later in the process. Some projects involve not only building and safety permits but also planning approval by the city. Planning approval processes vary but typically operate on a fixed cycle, and dockets are generated which can significantly extend the length of time before final permits can be applied for and eventually received. In some cases, issues unrelated to the hydrogen installation comprised the critical path for permitting; for example, landscaping and non-fueling equipment generated questions and redesign efforts. Site selection can play a key role in identifying sites that do not require planning approval.

Construction typically required 4 – 6 months, but in one case as long as 10 months. Equipment lead time was sometimes an issue due to the unique nature of some of the systems involved and required Shell to order and pay partially upfront before permits were approved. This risk was accepted due to the relative short duration of the Project and the need to fit design, permitting, equipment delivery, and construction into tight timeframes.

General contractors were not initially familiar with hydrogen station construction. However, over the course of five years and the deployment of multiple DOE Project stations there did evolve somewhat of a base to work from. The network of contractors with hydrogen installation experience gradually developed, particularly in Southern California and New York.

6.4.3 Operation

Once fully commissioned, all safety systems validated, and training completed, the stations were placed into regular operation. Each station had an Operations Manual, Emergency Response Manual, and Training Manual developed specifically for its systems. Periodic safety inspections and audits were conducted over the course of the Project. Operations Coordinators (one responsible for each coast) managed daily operations, maintenance, and reporting. Additionally, Shell trained local maintenance contractors to provide routine site inspections several times per week. Three Maintenance Inspection Service Technicians (MIST) were developed, one in WDC, one in NYC, and one in LA. The MIST provides Shell with real-time fast response to site issues and helps coordinate hydrogen system maintenance work with the key equipment supplier. GM utilized its own staff and technicians to complete routine inspections and maintenance at its own sites, but also worked closely with Clean Energy Fuels to integrate the hydrogen system maintenance and repair into the existing CNG site's normal operations.

The stations sited at retail gasoline stations are basically staffed 24 hours, but there are no dedicated hydrogen staff on-site as the hydrogen systems are effectively un-staffed and self-serve. The privately sited stations are similarly un-staffed and self-serve. However, in some cases there are gates that can prevent non-business hour utilization.

Operationally the stations functioned as expected. However, start-up issues did sometimes extend over several months before all bugs were worked out and final adjustments were completed. Integrated monitoring systems that issue alarm notifications to Shell and others inform when any monitored system is out of specification, non-functional, or if there are leaks detected. Additionally, heat and fire sensors are utilized and in some cases these call-out directly to local fire departments if activated.

Shell has had several false alarms with fire sensors and one actual fire. In all cases the response by Shell and the local fire departments are the same "just in case." However, Shell has dramatically reduced false alarms from fire sensors by deploying Infrared-type detectors rather than ultra-violet type detectors, and by adjusting the sensitivity or "view" to be as specific or targeted as possible. Fire detectors on several occasions have gone into alarm due to lightning in the area, welding in the area, and power outages. Shell's preference will likely move away from the use of fire detectors, if permitted, and instead utilize linear heat sensors which are much less prone to false alarms and provide a much quicker response if an actual fire is present.

Shell's Project stations also focused on not only fueling GM FCEVs but also any other Project and non-Project vehicles. This policy was decided upon upfront and was intended to provide Shell experience and learning in fueling many automaker FCEVs. It was also intended to maximize station utilization. GM vehicles comprised the majority of the fuelings at Shell stations; however, non-GM vehicles provided a significant share of fueling and exposed Shell to various issues that were either common amongst all OEMs or were specific to only a few or only one. This experience base widened Shell's understanding and provided a broader industry perspective on various issues and needs.

In the specific cases of component performance, GM and Shell have worked with both system and part manufacturers to drive field learning into redesign, reconfiguration, new control strategies, and future models. In many respects, the industry is still transitioning to purpose-built hydrogen components.

The experience with current suppliers has exhibited a range of responses:

- Partnership Response: A strong willingness to drive learning into existing designs and begin discussions on next generation equipment.
- Defensive Response: A posture with the supplier noting (1) equipment being installed was not recommended for hydrogen system use in the first place or (2) strong likelihood something else in the system is impacting such a component.
- A Wait-and-See Response: A supplier who is not convinced there is a problem.

Another overall concern with downtime and component manufactures is the location of the supplier. With only a handful of organizations working with such technologies, there continues to be a concern with having access to local service providers to improve turnaround-time with repairs. This forced GM to maintain nearly a complete set of replacement parts for the systems to minimize downtime and ensure customer access to fuel. Local suppliers or servicers would greatly improve operations. Currently, it is not uncommon for a part to be unavailable for 8-10 weeks due to customs issues or access to supplier resources.