2010 U.S. DOE HYDROGEN PROGRAM and VEHICLE TECHNOLOGIES PROGAM ANNUAL MERIT REVIEW AND PEER EVALUATION MEETING

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Hydrogen Vehicle and Infrastructure Demonstration and Validation

EQUINOX FUEL CELL

Project ID #: TV005

Overview

Timeline

- Project Start = 10/1/04
- Project End = 9/30/11
- Project is in Phase 2 vehicle demonstration with Technology Insertion element "in process" with 10 baseline and 10 Technology Insertion FCEVs

Budget

- $88.0 M Original Project
  - $44.0 M DOE share
  - $44.0 M GM share
- $31.4 M Funded to date

Barriers

- Targets

- Vehicles
  - Vehicle range and fuel cell (FC) durability
- Hydrogen Fueling Infrastructure
  - $H2/gge
- Maintenance and Training Facilities

Gen 2 Partners

Vehicle operators

- Project Driveway customers and drivers
- U.S. Environmental Protection Agency
- U.S. Postal Service
- City of White Plains, NY
- University of California at Irvine
- Department of Sanitation – New York City
- Port Authority of NY and NJ
- Monroe County, NY
- Disney (CA and NY)
- Virgin Atlantic Airways (CA)

Objectives

Program Objective

- General Motors and energy partner Shell Hydrogen deployed a system of hydrogen fuel cell electric vehicles integrated with a hydrogen fueling infrastructure to operate under real world conditions
  - Demonstrate progressive generations of fuel cell system technology
  - Demonstrate multiple approaches to hydrogen generation and delivery for vehicle fueling
  - Collect and report operating data

Past Year Objectives – Execute next generation of fuel cell technology

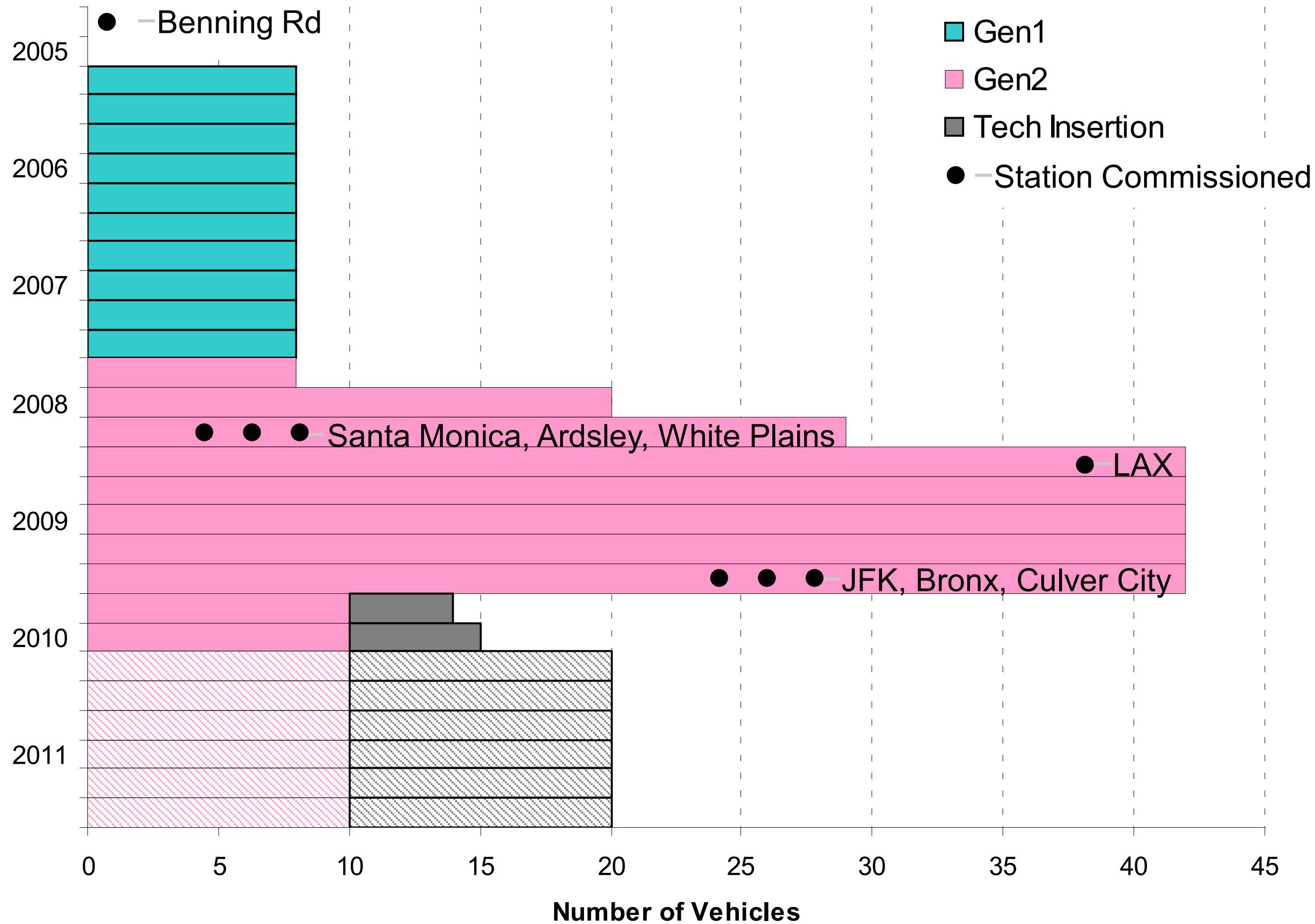
- ✓ Work with vehicle operators to obtain hours and data
- ✓ Collect, analyze, report data from program vehicles and fueling locations
- ✓ Complete, operate and maintain fueling stations and provide data
- ✓ Produce and submit Interim Technical Report

Current Year Objectives

- Complete Technology Insertion into vehicle fleet
- Collect, analyze, report data from Technology Insertion and Baseline vehicles

Program Milestones

Vehicle and Fueling Station Implementation



Approach

Demonstrate fuel cell electric vehicles

- Deploy fuel cell electric vehicles (FCEVs) in various terrains, driving conditions, and climates including cold weather
- Demonstrate two generations of fuel cell technology
  - Insert Technology with recent advances to test Gen2 learnings

Establish retail-like hydrogen stations for public fueling

- Install and operate total of eight fueling stations on East and West coasts
- Explore hydrogen generation/delivery options such as electrolysis

Set up maintenance and service operations in support of FCEVs

- Train personnel in maintenance, fueling, technical support, safety

Generate and report data required under the Program

- Capture vehicle on-road and dynamometer test data
- Capture hydrogen infrastructure production/fueling data

Evaluate Vehicle Performance against Targets

- Vehicle range, stack durability, cold weather performance

Project Driveway

Objective: Demonstrate FC vehicles under real-world conditions

First meaningful and largest market test of fuel cell electric vehicles

- Over 100 Chevrolet Equinox Fuel Cell Electric vehicles
- Launched in late 2007 continuing through 2010
- Markets with diverse climates and conditions:
  - California (LA, Sacramento)
  - Washington, D.C.
  - Greater New York City metropolitan area

Comprehensive feedback on all elements of customer experience and vehicle performance to guide future FCEV and infrastructure development

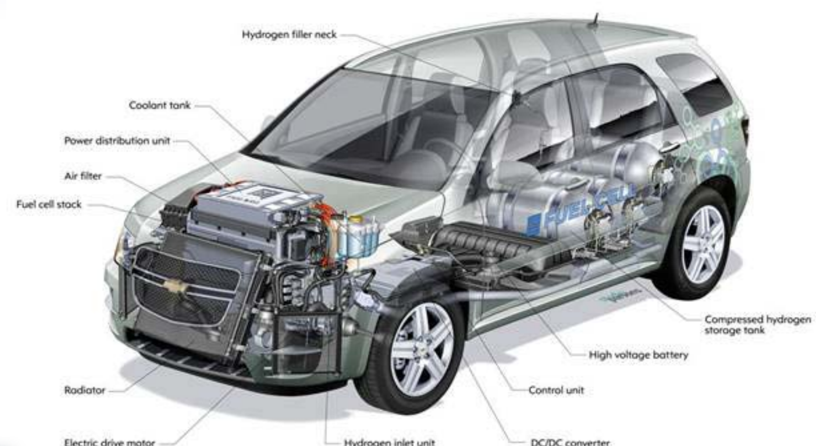
Drivers

- Businesses, government
- General public
- Celebrity influencers, policymakers and media

Program Accomplishments

Objective: Demonstrate progressive generations of fuel cell system technology

Gen1 Opel Zafira Fuel Cell Electric Vehicle



Gen2 Chevrolet Equinox Fuel Cell Electric Vehicle

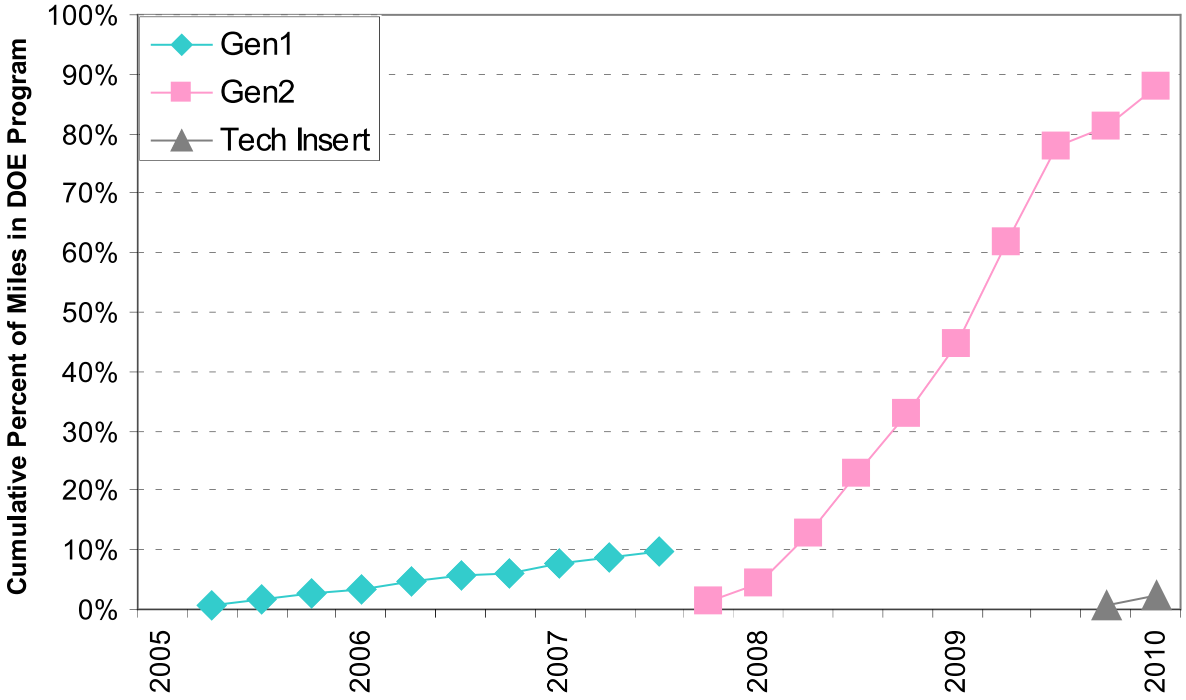
Gen2 Chevrolet Fuel Cell Electric Vehicle with Technology Insertion

- Gen1 -> Gen2 : Moved from experimental vehicle with engineers driving to pre-production vehicle with real customers
- Gen2 Technology Insertion : Advanced hardware, diagnostics and software controls developed from Gen2 learnings are implemented in the Gen2 Technology Insertion vehicles.

Program Accomplishments

Objective: Collect and Report operating data

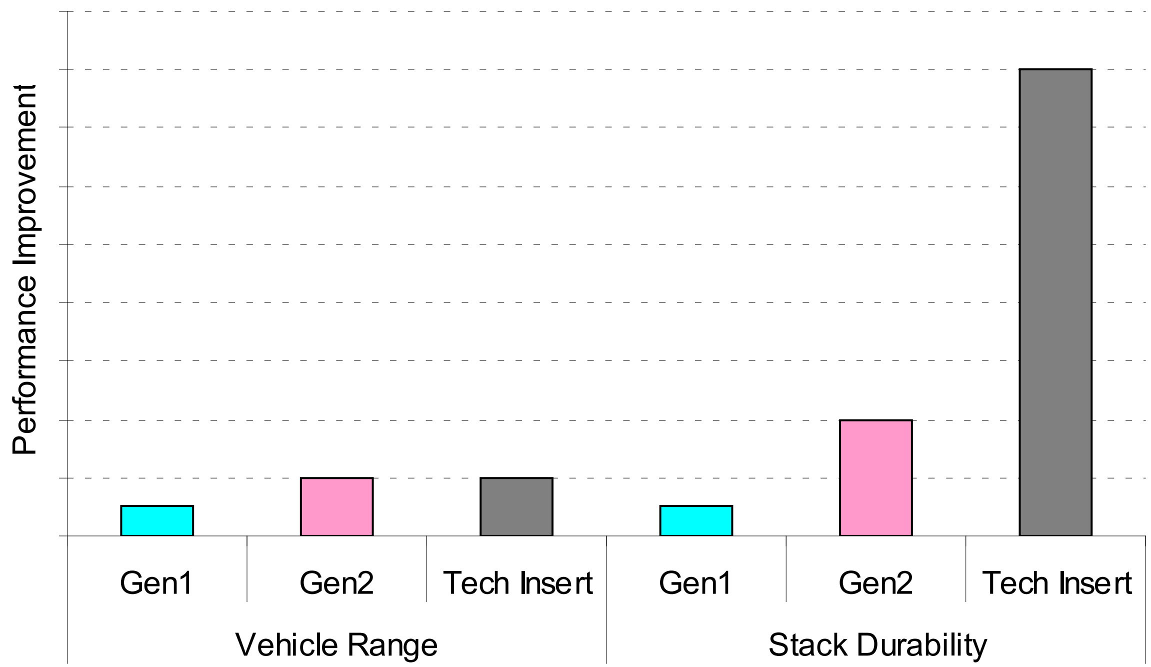
- From April 2005 to March 2010, 88% of the miles GM submitted to NREL came from Gen2 vehicles



Technical Accomplishments

Objective: Vehicle Range and Fuel Cell Stack Durability

- A major program emphasis is learning about Fuel Cell Stack durability
  - Component reliability
  - Material degradation
  - Impact of control strategy
  - test-fail-analyze-redesign-test cycle



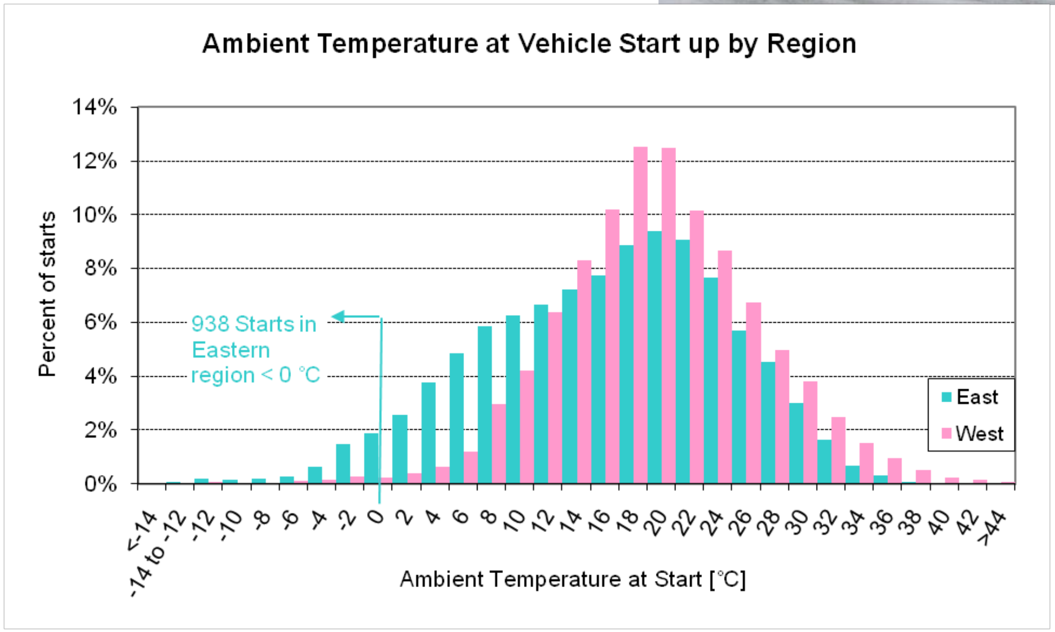
Technical Accomplishments

Objective: Cold Weather Performance

- Vehicles in the eastern region performed 938 starts at ambient temperature less than 0˚C without any issues.
- GM Vehicles exhibited very fast cold start/driveaway times under sub-freezing temperatures.

Proving ground testing for cold start up (Kapuskasing, ON in Canada)

Engineering testing was performed as low as -25˚C



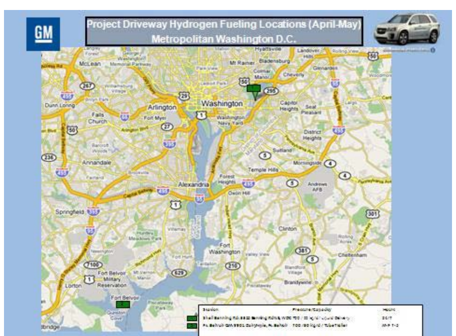
Technical Accomplishments

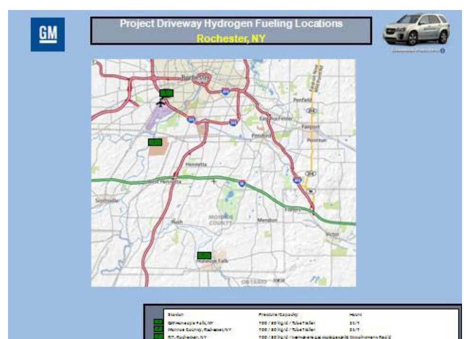
Objective: Hydrogen refueling operates under real world conditions

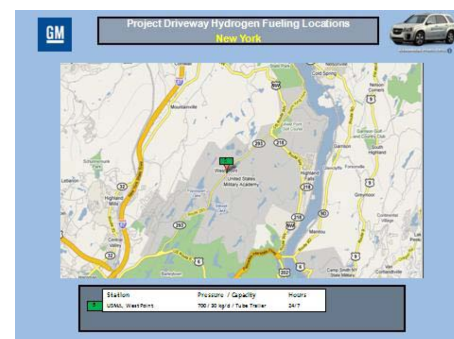
- Most refueling being done is "self serve" by vehicle customers
- Worked with local authorities and partners to satisfy safety requirements without the use of PPE by customers

Maps of Fueling Stations

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







Technical Accomplishments

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

Below-grade LH2 storage, Benning Rd, WDC

- On site production
- Delivered compressed gas
- Delivered Liquid

Hydrogen Compression Skid, Culver City, CA

On-site Electrolyzer, White Plains, NY

Technical Accomplishments

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

- Commercially acceptable ($3.00/gge) hydrogen costs not demonstrated within this project.
    - High cost of experimental equipment coupled with small volume dispensed
- Critical insights to reaching the $3.00/gge milestone were developed in this demonstration project.
    - 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.
    - 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.
    - 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.
- Increased effort on hydrogen station technologies is a 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.

Technical Accomplishments

Codes and Standards (C & S) – NextEnergy

Database

- Successfully transferred hydrogen permitting database tools to new website. Coordinated with the DOE and its partners to transfer the databases' layout and functionality to DOE ownership, for public benefit and use

Annual Conference September 30, 2009

- Attracted many diverse individuals from the national codes and standards organizations, as well as local officials and permitting authorities.
- Promoted education by exposing the community to the internet tools available today, as well as the most up-to-date progress on H2 regulations.

Code Development

- 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 30th, both Task Groups completed their review of the latest NFPA revision

Collaboration with Others

- Individual "retail" customers
- Fuel providers/suppliers/ infrastructure equipment
  - Air Liquide (dispensing equipment)
  - Shell Hydrogen
  - Praxair ("Green Hydrogen")
- State/university collaborations
  - UCI
  - CaFCP
- NREL (methodology development)
- Business-to-Business fleet Applications
  - Port Authority of New York and New Jersey (siting of fuel dispensing)
  - Disney
  - Virgin Atlantic
- Agencies
  - U.S. Department of Defense (Army, Marines)
  - U.S. Postal Service (>1 million pieces of mail in Gen2)
  - U.S. Environmental Protection Agency
  - Department of Energy
  - D.C. Department of Transportation
- Influential
  - Various WDC dignitaries, policy makers and celebrities
  - Vancouver Winter Olympics

Future Work

- Operate 10 Gen2 “Baseline” vehicles thru 2011 to demonstrate real world stack durability
- Upgrade 10 Gen2 vehicles with advanced hardware, diagnostics, and software (run through 2011)
- Provide lab data from accelerated durability testing to enhance understanding of Fuel Cell durability
- Continue work with NREL to refine data analysis methodologies

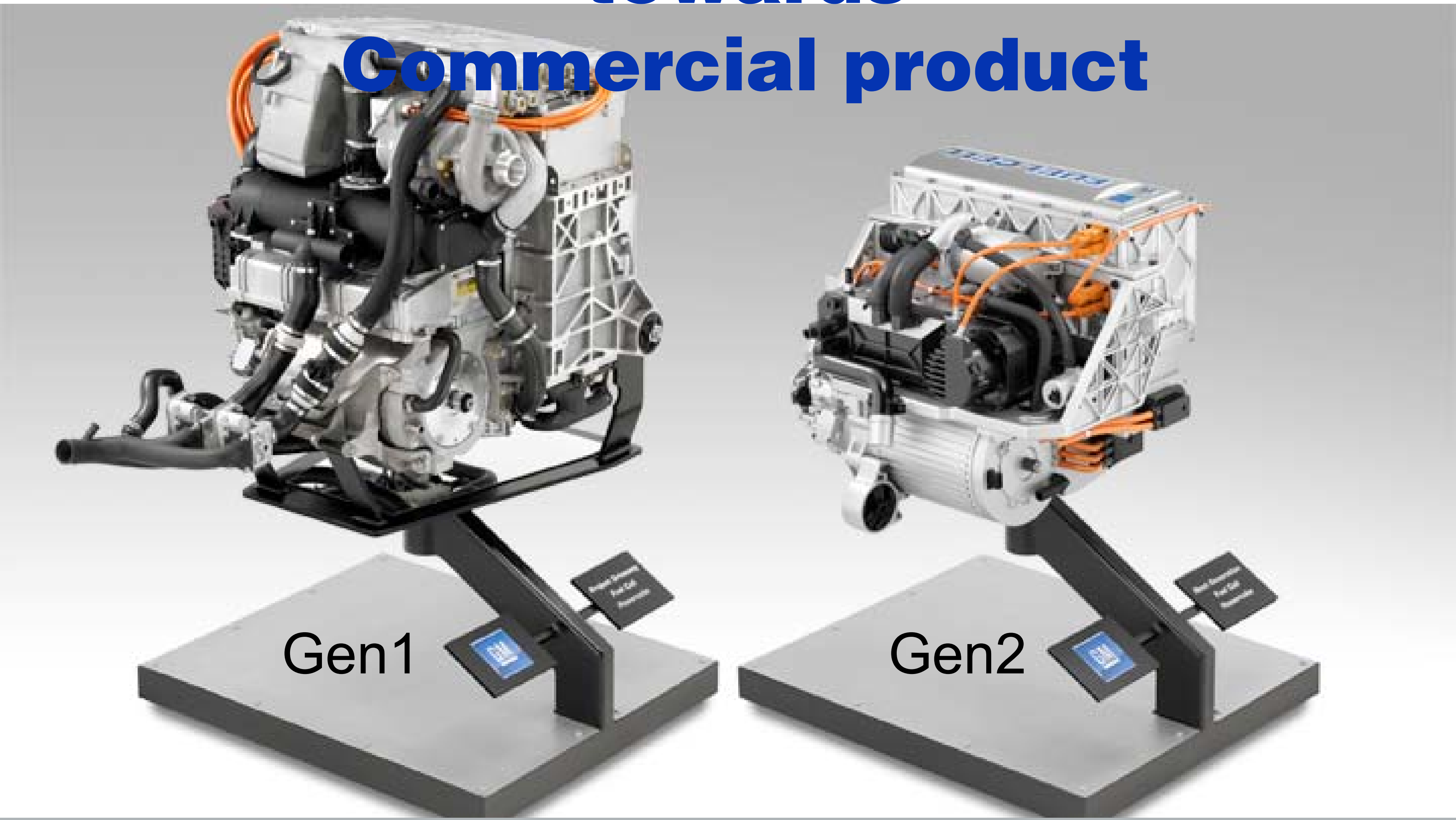
Project Summary

Accomplishments	Barrier / Target
• Real world application in Project Driveway • Multiple Generations of Vehicles • Collect and report operating data	Learnings 

• Stack Durability
    • Identification/correction of specific failure modes
    • Rapid implementation in Tech Insertion
• Cold Weather performance
	Vehicle Performance
	

• Ease of Use – retail like operation • Multiple H2 supply approaches • Evaluate Infrastructure Costs • Future focus on equipment costs/reliability	Infrastructure 

Program learnings moving us towards Commercial product



Supplemental Slides

Technical Accomplishments

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

Station	Location	350 bar	700 bar	Generation/Delivery	Comments
GM Maintenance & Training Center 	Ardsley, NY	N/A	3/08	Delivered compressed gas	•450+ First Responders trained •Infrared capable •Can fill 3 FCEVs back-to-back •5 min each, 7-10 per day •1st U.S. station tested for H2 quality at 700 bar
Shell Hydrogen City of White Plains 	White Plains, NY	9/07	3/08	Onsite electrolysis	•Fire Incident investigation completed 12/08 with DOE participation
Shell Hydrogen Benning Rd. 	Washington, D.C.	11/04	6/08	Delivered liquid	•400+ First Responders trained •Gaseous fueling accommodating all vehicle manufacturers
Shell Bronx, NY 	Bronx, NY	N/A	9/09	Delivered compressed gas	•First hydrogen station within the city of New York •700 bar
Shell JFK, NY 	JFK, NY	N/A	7/09	Delivered compressed gas	•Created a Hydrogen Fueling “Network” for New York City

Technical Accomplishments

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

Station	Location	350 bar	700 bar	Generation/Delivery	Comments
Clean Energy/GM 	LAX, CA	N/A	1/09	Delivered compressed gas	•Completed <5 months •Permitting <6 weeks •Infrared capable •Can fill 3 FCEVs back-to-back •5 min each, 7-10 per day
GM Maintenance & Training Center 	Burbank, CA	11/07	11/07	Delivered compressed gas	•200+ First Responders trained •Faster-fill (15-minute) installation under construction
Shell Hydrogen, Santa Monica Blvd. 	West LA, CA	6/08	N/A	Onsite Electrolysis on Canopy	•100+ First Responders trained •World's first Canopy-mount electrolyzer based gaseous station at 350 bar •Gaseous refueling accommodating all vehicle manufacturers
Shell Hydrogen, Culver City 	Culver City is an extension of West LA, CA		9/09	Delivered compressed gas	•700 bar •Utilized Fast-Fill Technology to support Los Angeles Deployments

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

Technical Accomplishments

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.

- 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.

- 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.

- 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.

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.

Technical Accomplishments

Codes and Standards (C & S) – NextEnergy

Database

- Successfully transferred hydrogen permitting database tools to new website. Coordinated with the DOE and its partners to transfer the databases' layout and functionality to DOE ownership, for public benefit and use

- Here are the links to the hydrogen permitting database:

Permitting Officials

http://www.nextenergy.org/nextenergyh2/h2permittingofficials/home.asp?cityID=0

Function: To help identify the key decision makers throughout Michigan who will make the "yes" or "no" decision for the permitting a hydrogen station in their respective municipalities. Note: the input data is from prior to the project end date in September 2009, and as such may be slightly out of date.

Permitting Experiences:

http://www.nextenergy.org/nextenergyh2/h2permittingexperiences/Home.asp

Function: 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.

Future Work

GM is poised to take a significant step by introducing elements of our next generation Fuel Cell Stack and System into a small group of Equinox FCEVs for continued Gen2 operation/demonstration during 2010 and 2011. GM believes that the learnings from the demo program so far have helped enable materials and operating controls within the Fuel Cell System that will clearly demonstrate the ability of the Gen2 vehicles to meet and exceed the demo program stack durability goal of 2000 hours.

Furthermore, GM looks forward to a continued relationship and collaboration with NREL in the areas of Fuel Cell Stack and FCEV data analysis methods. GM believes that this work is helping establish a strong foundation for future work throughout the Fuel Cell industry to develop universally accepted metrics for assessing the performance of Fuel Cells and FCEV.

Conclusions

- GM detected 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. The FCEVs are now poised to demonstrate significant durability gains during the completion of the demonstration during 2010 and 2011.

- GM engineering team developed an excellent working relationship with the Data Analysis Team at NREL and the two teams worked closely together regarding data analysis techniques and interpretation of results. GM and NREL are currently working together to further refine the Fuel Cell Stack life prediction metrics.

- Significant 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.