

# Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project

## *Project Overview and Fall 2006 Results*

Keith Wipke, Cory Welch, Holly Thomas, Sam Sprik<sup>1</sup>  
Sigmund Gronich, John Garbak, Doug Hooker<sup>2</sup>

California Air Resources Board – ZEV Technology Symposium  
September 25, 2006

<sup>1</sup>NREL, <sup>2</sup>US Dept. of Energy

This presentation does not contain any proprietary or confidential information

---

## Disclaimer and Government License

This work has been authored by Midwest Research Institute (MRI) under Contract No. DE-AC36-99GO10337 with the U.S. Department of Energy (the “DOE”). The United States Government (the “Government”) retains and the publisher, by accepting the work for publication, acknowledges that the Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for Government purposes.

Neither MRI, the DOE, the Government, nor any other agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe any privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply its endorsement, recommendation, or favoring by the Government or any agency thereof. The views and opinions of the authors and/or presenters expressed herein do not necessarily state or reflect those of MRI, the DOE, the Government, or any agency thereof.

# Outline

- Project Objectives and Overview
- Industry Partners; H2 vehicles and stations
- Process and Methodology for Making Results Public
- Key Fall 2006 Results
  - Vehicles
    - Net fuel cell system efficiency
    - Fuel economy and range
    - Safety
  - H2 Refueling Infrastructure
    - Refueling Rates
    - Safety
    - H2 station purity and impurities
    - Maintenance
  - High-level project status metrics
- Summary and Future Results

# Project Objectives and Targets

- Objectives

- Validate H<sub>2</sub> FC Vehicles and Infrastructure in Parallel
- Identify Current Status of Technology and its Evolution
- Assess Progress Toward Technology Readiness
- Re-Focus H<sub>2</sub> Research and Development



## Key Targets

Performance Measure	2009*	2015**
Fuel Cell Stack Durability	2000 hours	5000 hours
Vehicle Range	250+ miles	300+ miles
Hydrogen Cost at Station	\$3/gge	\$2-3/gge

\* To verify progress toward 2015 targets

\*\* Subsequent projects to validate 2015 targets

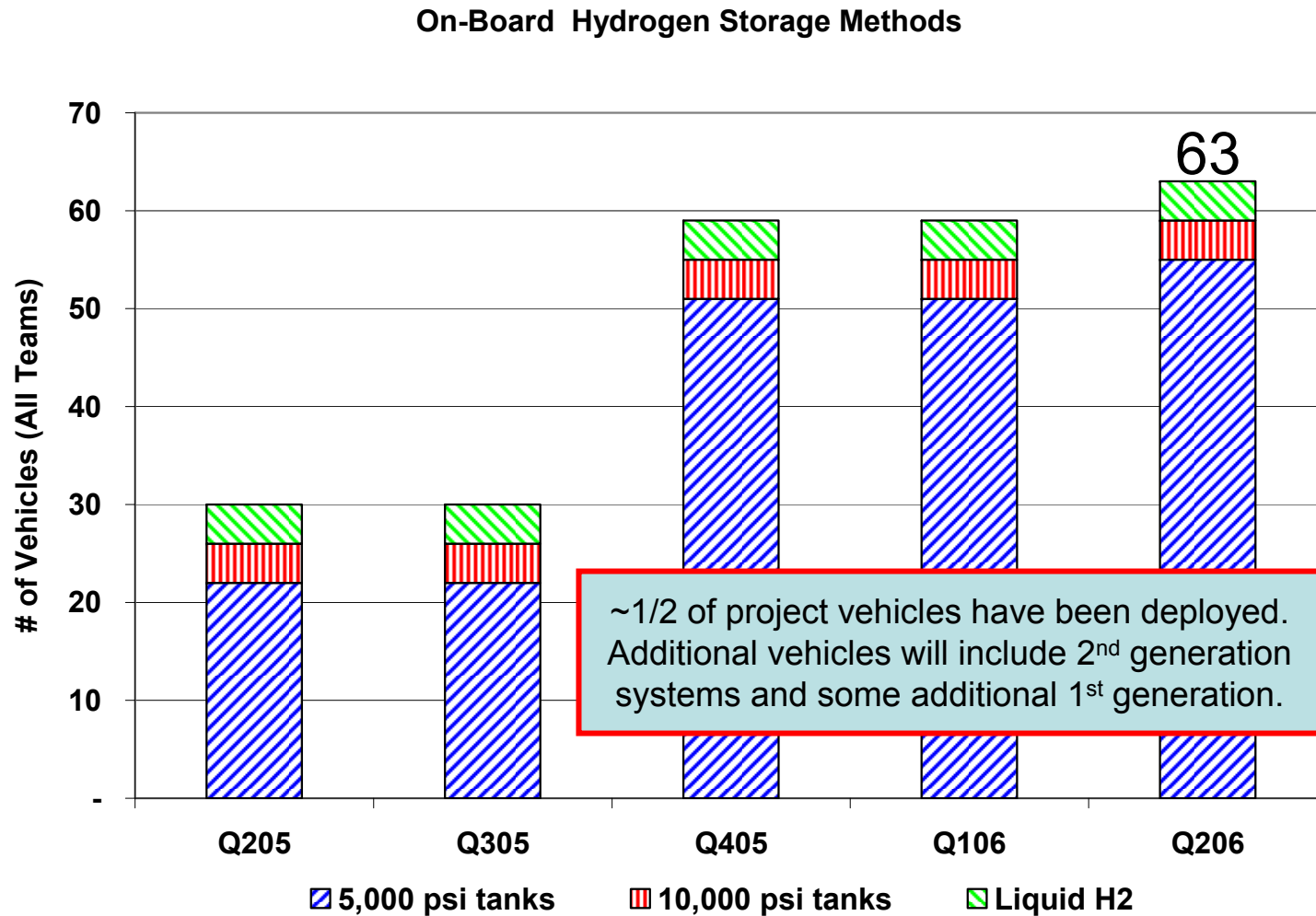


# Teams are Fielding Four Main Types of Vehicles



# Number of Learning Demo Vehicles in Operation

## H2 Storage Technologies Used



Created 25-Aug-2006



# Representative Hydrogen Refueling Infrastructure Supporting Vehicles



DTE/BP Power Park, Southfield, MI



LAX refueling station



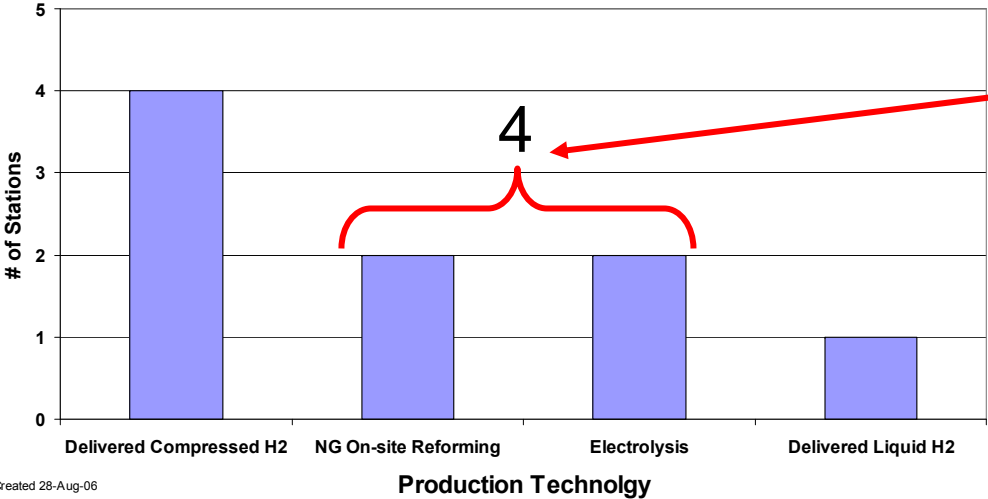
Hydrogen and gasoline station, WA DC



Chino, CA

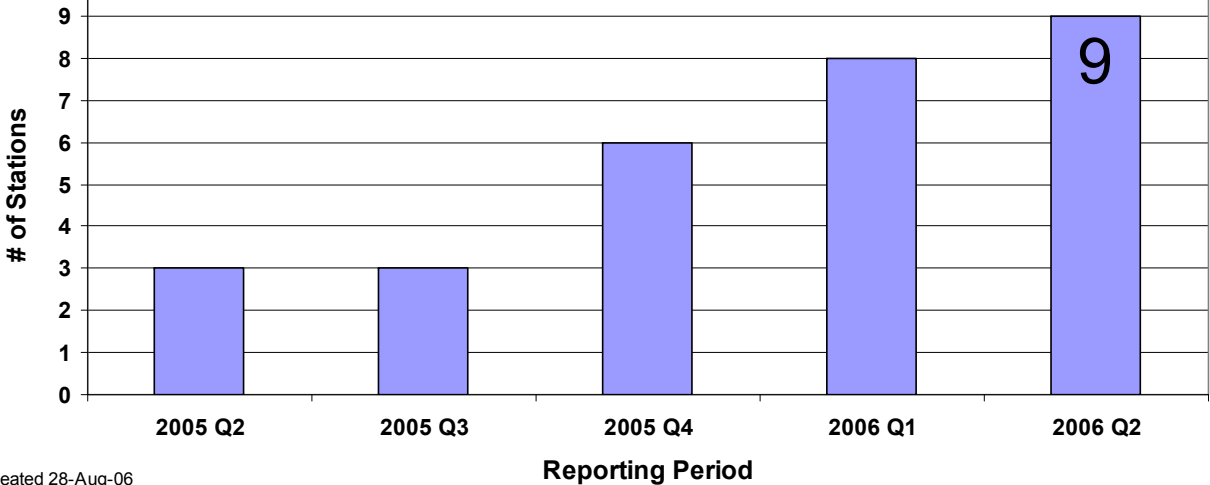
# Number and Type of Learning Demo Hydrogen Refueling Stations Online

### H2 Production Methods Through Q2 2006



~1/2 of stations are producing H2 on-site  
~1/2 of 20 planned refueling stations are online

### Number of Stations

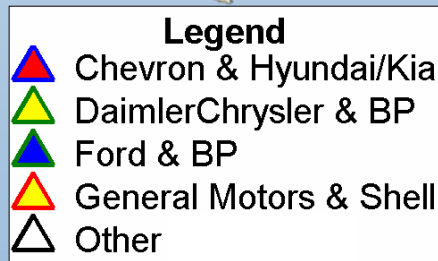
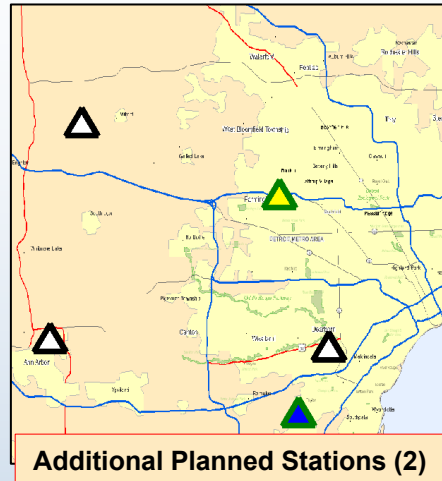
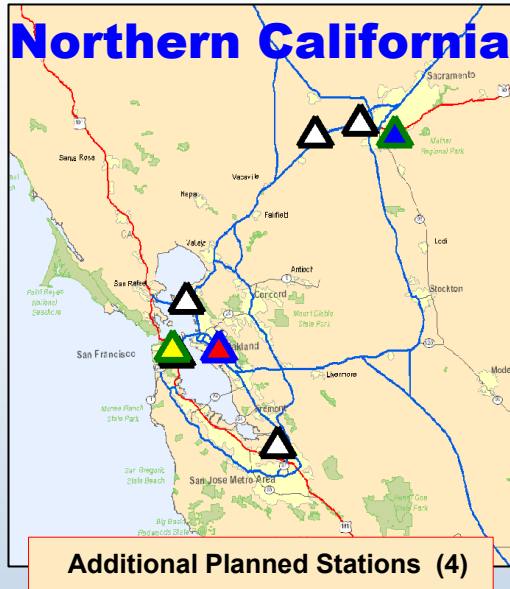


Created 28-Aug-06

Created 28-Aug-06



# Refueling Stations from All Four Teams Test Vehicle/Infrastructure Performance in Various Climates



# Providing Data Analysis and Results for Both the Public and for the Industry Project Teams

## Hydrogen Secure Data Center (HSDC)

- Located at NREL: Strictly Controlled Access
- Detailed Analyses, Data Products, Internal Reports

### Raw Data, Reports



Data is delivered to NREL's Hydrogen Secure Data Center (HSDC) on CD/DVDs



Data protected in HSDC for 5 years after data is developed under EPCIA 2005, Sec. 810

### Composite Data Products

- Pre-agreed upon aggregate data results for public
- No confidential information

### Detailed Data Products

- Only shared with company which originated the data

# Key Vehicle and Infrastructure Data Collected

## Key Vehicle Data

Stack Durability

Fuel Economy (Dyno & On-Road) and Vehicle Range

Fuel Cell System Efficiency

Maintenance, Safety Events

Top Speed, Accel., Grade

Max Pwr & Time at 40C

Freeze Start Ability (Time, Energy)

Continuous Voltage and Current (or Power) from Fuel Cell Stack, Motor/Generator, Battery & Key Auxiliaries: (Dyno & On-Road)

## Key Infrastructure Data

Conversion Method

Production Emissions

Maintenance, Safety Events

Hydrogen Purity/Impurities

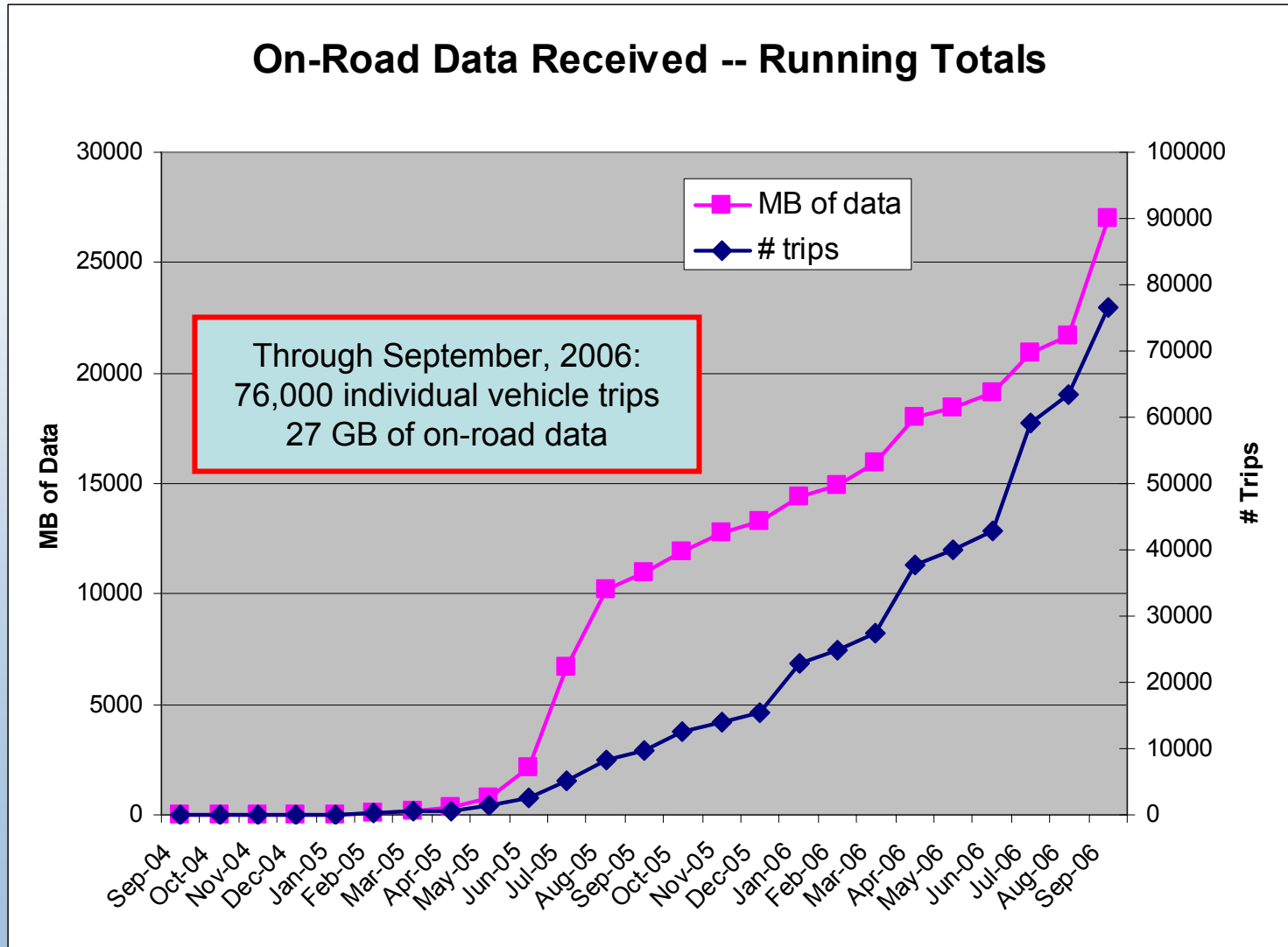
Refueling Events, Rates

H<sub>2</sub> Production Cost

Conversion, Compression, Storage, and Dispensing Efficiency

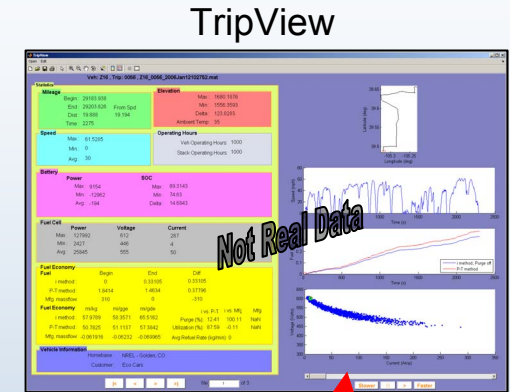
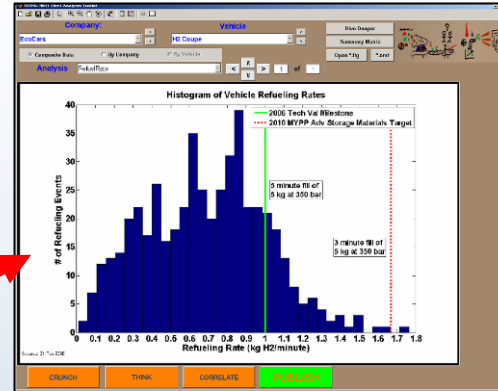
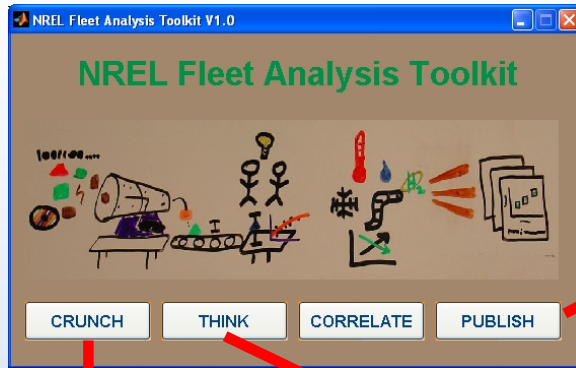
# Five Quarters of Data Analyzed

Current Status of Data Reporting to the Hydrogen Secure Data Center at NREL





# Analysis Calculations and Results are from NREL-Developed GUI – Fleet Analysis Toolkit (FAT)



CRUNCH NREL Fleet Analysis Toolkit

Company: EcoCars Vehicle: H2 Coupe

Processing to Perform: New CD Selected Below

Archive Previous Results: Archive All Previous Archive Selected Fuel Economy Range % Complete Stack Degradation Range, FE

Raw Data Conversion: Convert to Matlab Directory of CD/DVD data Save Directory

Fuel Economy: Create Raw Min Trip Length Vehicle Fleet Trip Length Effect

Range: Create Raw Vehicle

Data Percent Complete: Create Raw Data Percent Complete

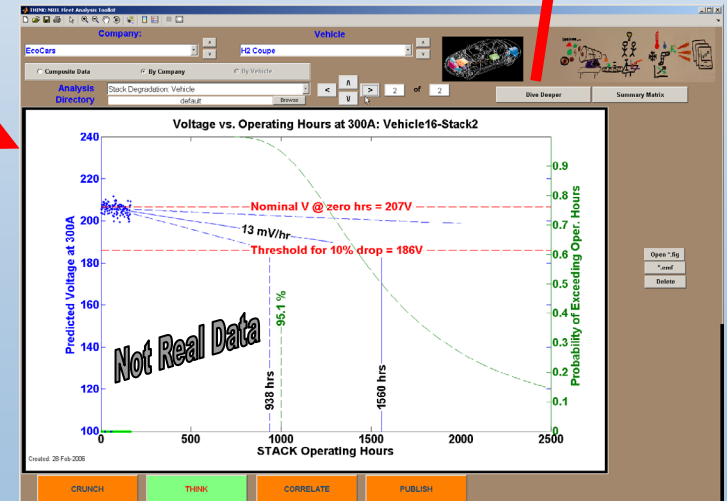
Stack Degradation: Create Raw Vehicle Combined Fleet Filter Hours Accum Start/Stops

Geographic: Create Raw Include Stations

Fuel Cell System Efficiency: Curve Calc

Range, Fuel Econ from Excel File: Range, FE

CRUNCH THINK CORRELATE PUBLISH GO



# After Industry and DOE Review, Composite Data Products are Published in Hydrogen/Vehicle Conferences

## Spring 2006

**CONTROLLED HYDROGEN FLEET AND INFRASTRUCTURE DEMONSTRATION AND VALIDATION PROJECT: PROGRESS UPDATE**

K. Wipke<sup>1</sup>, C. Welch<sup>1</sup>, H. Thomas<sup>1</sup>, S. Sprick<sup>1</sup>, S. Gorkavil<sup>1</sup>, J. Garbak<sup>1</sup>, D. Hooker<sup>1</sup>

**Abstract**

The U.S. Department of Energy (DOE) initiated the "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project" through a competitive solicitation process in 2003. The purpose of this project is to conduct an integrated field validation that will ultimately evaluate the performance of fuel cell vehicles and the supporting hydrogen infrastructure. Insights from the vehicle and infrastructure validation will be fed back into DOE's research and development programs to guide the development of future hydrogen and fuel cell technologies. Five teams were selected and five cooperative agreements were awarded. These five cooperative agreements will ultimately report some 100 fuel cell vehicles, which will be delivered in 2006 to more than 25 hydrogen refueling stations. Fifteen hydrogen refueling stations have already entered into service with customers, and several more hydrogen refueling stations have opened, with more vehicles and stations planned. Lessons learned from this project on the interrelationship between the vehicle and the infrastructure will address ongoing development of codes and standards. The role industry will play in the energy transition is strongly emphasized in this project, and the government's involvement in this project is assessed by each industry team.

The DOE industry collaborative project will continue for a total of 3 years, during which multiple generations of technology will be tested. The initial performance of all vehicles and infrastructure will be reported during DOE report of the demonstration stages and at project completion. Milestones of 2003 DOE validation targets include: 25 refueling stations, 100 fuel cell vehicles, 1000 miles of vehicle test miles, and a hydrogen production cost of 1 \$/gpc normal, when produced in quantity. This paper provides a status report covering the progress of the demonstration and validation project over the last year. This includes the first composite data products to be released from this project, along with a summary of the data inputs and analysis methodology. The composite data products aggregate demonstration data from:

<sup>1</sup>The work has been conducted in an application of the National Research Institute under Contract DE-AC02-03-OR21400 with the U.S. Department of Energy. The United States Government is authorized to reproduce and retransmit this work for government purposes, not withstanding any copyright notation that may appear hereon. Reproduction of this work in whole or in part for non-governmental purposes is prohibited without the express written permission of the U.S. Department of Energy.

<sup>2</sup>U.S. Department of Energy - Golden Field Office, Golden, CO.

- 1 of 21 -

A National Laboratory of the U.S. Department of Energy  
Office of Energy Efficiency & Renewable Energy

**NREL National Renewable Energy Laboratory**  
Innovation For Our Energy Future

## Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project – Progress Update

Keith Wipke, Cory Welch, Holly Thomas, Sam Sprick<sup>1</sup>  
Sigmund Gronich, John Garbak, Doug Hooker<sup>2</sup>

March 13, 2006  
National Hydrogen Association Meeting

NREL, U.S. Dept. of Energy

NREL is operated by Midwest Research Institute, Boulder, CO

## National Hydrogen Association Conference March 13, 2006

**CONTROLLED HYDROGEN FLEET AND INFRASTRUCTURE DEMONSTRATION AND VALIDATION PROJECT: FALL 2006 PROGRESS UPDATE**

KEITH WIPKE

Soren Fajerskov<sup>1</sup>, National Renewable Energy Laboratory  
CORY WELCH, HOLLY THOMAS, SAM SPRICK, Sigmund Gronich, National Renewable Energy Laboratory  
SIGMUND GRONICH, JOHN GARBAK, U.S. Department of Energy

**Abstract**

The U.S. Department of Energy (DOE) initiated the "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project" through a competitive solicitation process in 2003. The purpose of this project is to conduct an integrated field validation that will ultimately evaluate the performance of fuel cell vehicles and the supporting hydrogen infrastructure. Insights from the vehicle and infrastructure validation will be fed back into DOE's research and development programs to guide the development of future hydrogen and fuel cell technologies. Five teams were selected and five cooperative agreements were awarded. These five cooperative agreements will ultimately report some 100 fuel cell vehicles, which will be delivered in 2006 to more than 25 hydrogen refueling stations. Fifteen hydrogen refueling stations have already entered into service with customers, and several more hydrogen refueling stations have opened, with more vehicles and stations planned. Lessons learned from this project on the interrelationship between the vehicle and the infrastructure will address ongoing development of codes and standards. The role industry will play in the energy transition is strongly emphasized in this project, and the government's involvement in this project is assessed by each industry team.

The DOE industry collaborative project will continue for a total of 3 years, during which multiple generations of technology will be tested. The initial performance of all vehicles and infrastructure will be reported during DOE report of the demonstration stages and at project completion. Milestones of 2003 DOE validation targets include: 25 refueling stations, 100 fuel cell vehicles, 1000 miles of vehicle test miles, and a hydrogen production cost of 1 \$/gpc normal, when produced in quantity. This paper provides a status report covering the progress of the demonstration and validation project over the last year. This includes the first composite data products to be released from this project, along with a summary of the data inputs and analysis methodology. The composite data products aggregate demonstration data from:

<sup>1</sup>The work has been conducted in an application of the National Research Institute under Contract DE-AC02-03-OR21400 with the U.S. Department of Energy. The United States Government is authorized to reproduce and retransmit this work for government purposes, not withstanding any copyright notation that may appear hereon. Reproduction of this work in whole or in part for non-governmental purposes is prohibited without the express written permission of the U.S. Department of Energy.

<sup>2</sup>U.S. Department of Energy - Golden Field Office, Golden, CO.

**Hydrogen Refueling Demonstration Project: Fuel Cell Efficiency and Initial Viability**

K. Wipke<sup>1</sup>, S. Welch<sup>1</sup>, S. Sprick<sup>1</sup>, S. Gorkavil<sup>1</sup>, J. Garbak<sup>1</sup>, D. Hooker<sup>1</sup>

Soren Fajerskov<sup>1</sup>, National Renewable Energy Laboratory  
CORY WELCH, HOLLY THOMAS, SAM SPRICK, Sigmund Gronich, National Renewable Energy Laboratory  
SIGMUND GRONICH, JOHN GARBAK, U.S. Department of Energy

**Abstract**

The U.S. Department of Energy (DOE) initiated the "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project" through a competitive solicitation process in 2003. The purpose of this project is to conduct an integrated field validation that will ultimately evaluate the performance of fuel cell vehicles and the supporting hydrogen infrastructure. Insights from the vehicle and infrastructure validation will be fed back into DOE's research and development programs to guide the development of future hydrogen and fuel cell technologies. Five teams were selected and five cooperative agreements were awarded. These five cooperative agreements will ultimately report some 100 fuel cell vehicles, which will be delivered in 2006 to more than 25 hydrogen refueling stations. Fifteen hydrogen refueling stations have already entered into service with customers, and several more hydrogen refueling stations have opened, with more vehicles and stations planned. Lessons learned from this project on the interrelationship between the vehicle and the infrastructure will address ongoing development of codes and standards. The role industry will play in the energy transition is strongly emphasized in this project, and the government's involvement in this project is assessed by each industry team.

The DOE industry collaborative project will continue for a total of 3 years, during which multiple generations of technology will be tested. The initial performance of all vehicles and infrastructure will be reported during DOE report of the demonstration stages and at project completion. Milestones of 2003 DOE validation targets include: 25 refueling stations, 100 fuel cell vehicles, 1000 miles of vehicle test miles, and a hydrogen production cost of 1 \$/gpc normal, when produced in quantity. This paper provides a status report covering the progress of the demonstration and validation project over the last year. This includes the first composite data products to be released from this project, along with a summary of the data inputs and analysis methodology. The composite data products aggregate demonstration data from:

<sup>1</sup>The work has been conducted in an application of the National Research Institute under Contract DE-AC02-03-OR21400 with the U.S. Department of Energy. The United States Government is authorized to reproduce and retransmit this work for government purposes, not withstanding any copyright notation that may appear hereon. Reproduction of this work in whole or in part for non-governmental purposes is prohibited without the express written permission of the U.S. Department of Energy.

<sup>2</sup>U.S. Department of Energy - Golden Field Office, Golden, CO.

## Fall 2006

EVS-22 Conference  
October 26, 2006

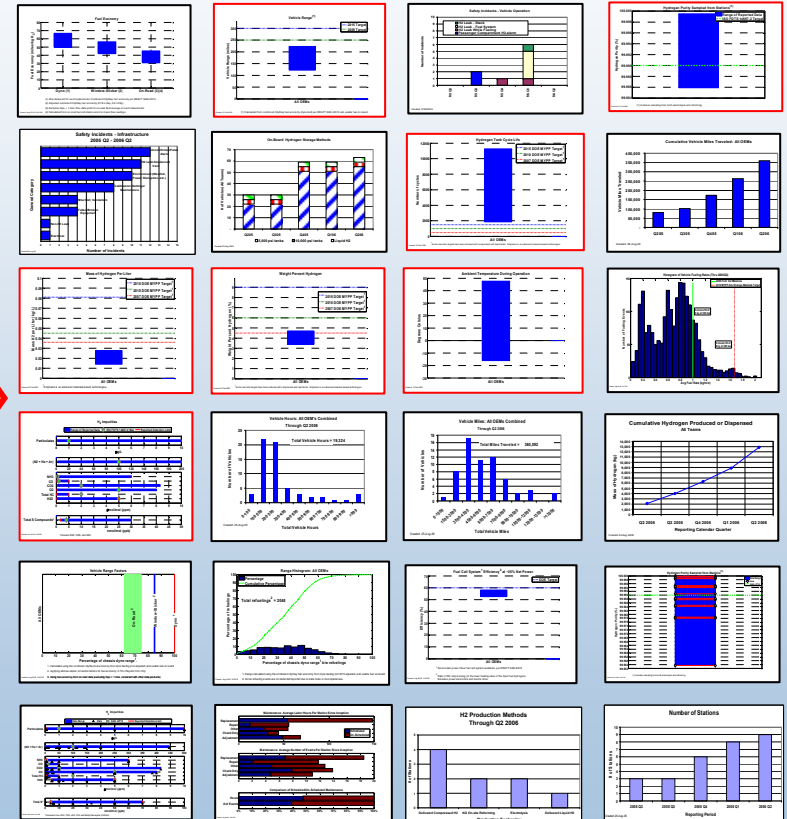
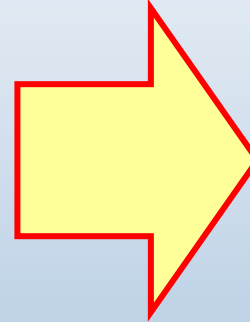
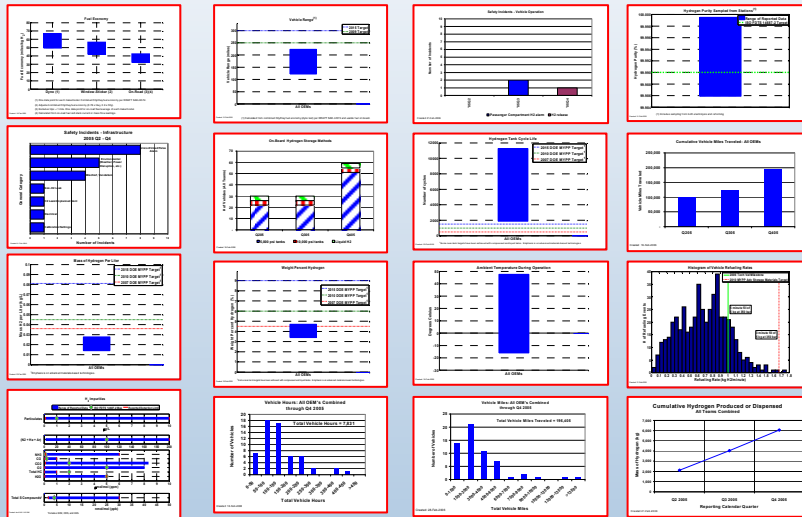
Fuel Cell Seminar  
November 15, 2006

All public Learning Demo papers and presentations are available online at [http://www.nrel.gov/hydrogen/proj\\_tech\\_validation.html](http://www.nrel.gov/hydrogen/proj_tech_validation.html)

# Quantity of Project Results Continues to Increase; Updates Every Six Months

## Fall 2006

## Spring 2006



24 Composite Data Products Have Now Been Published, Including Updating Many of the 16 Published in Spring 2006

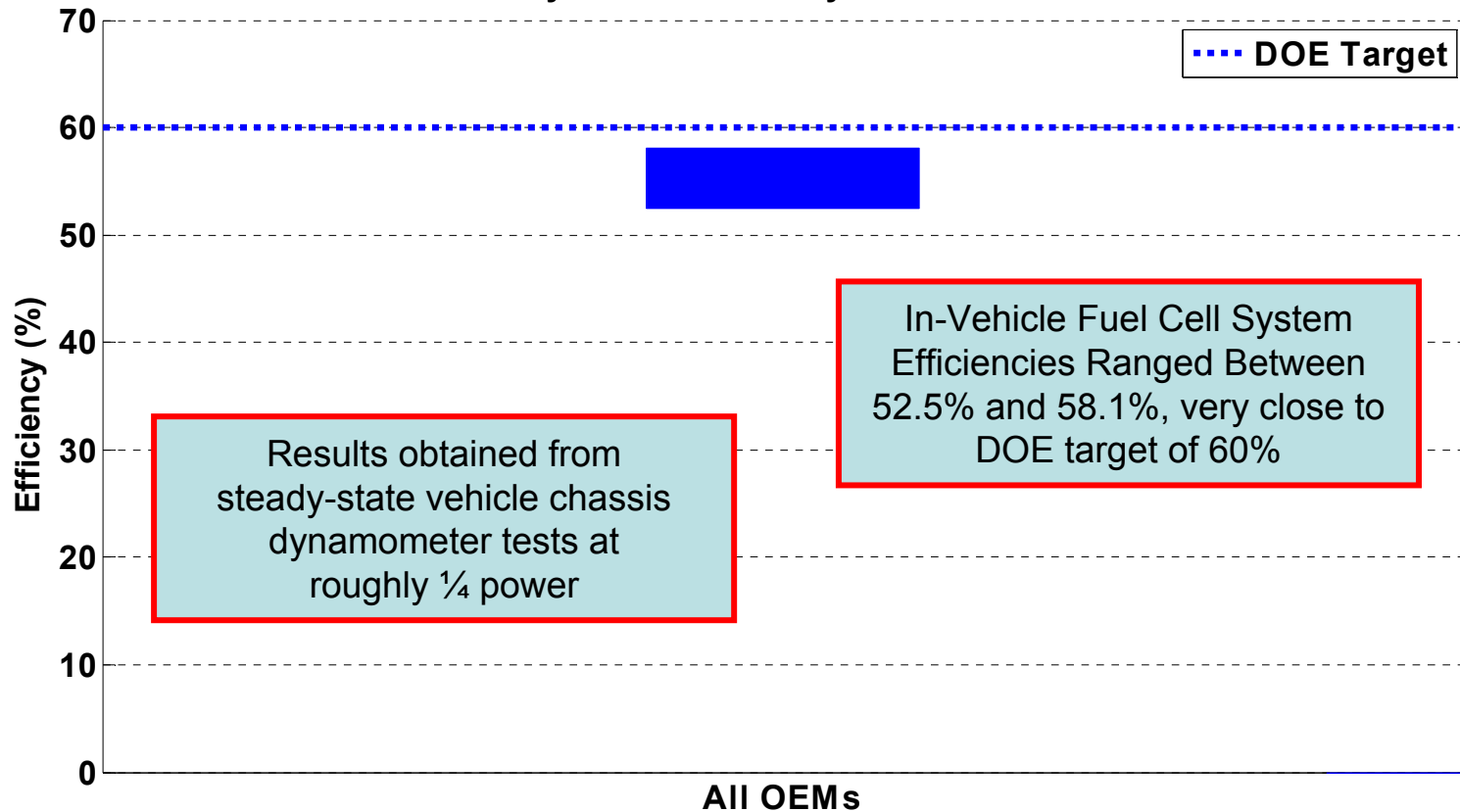
---

# RESULTS



# Controlled System Tests Verify High Fuel Cell System Conversion Efficiency

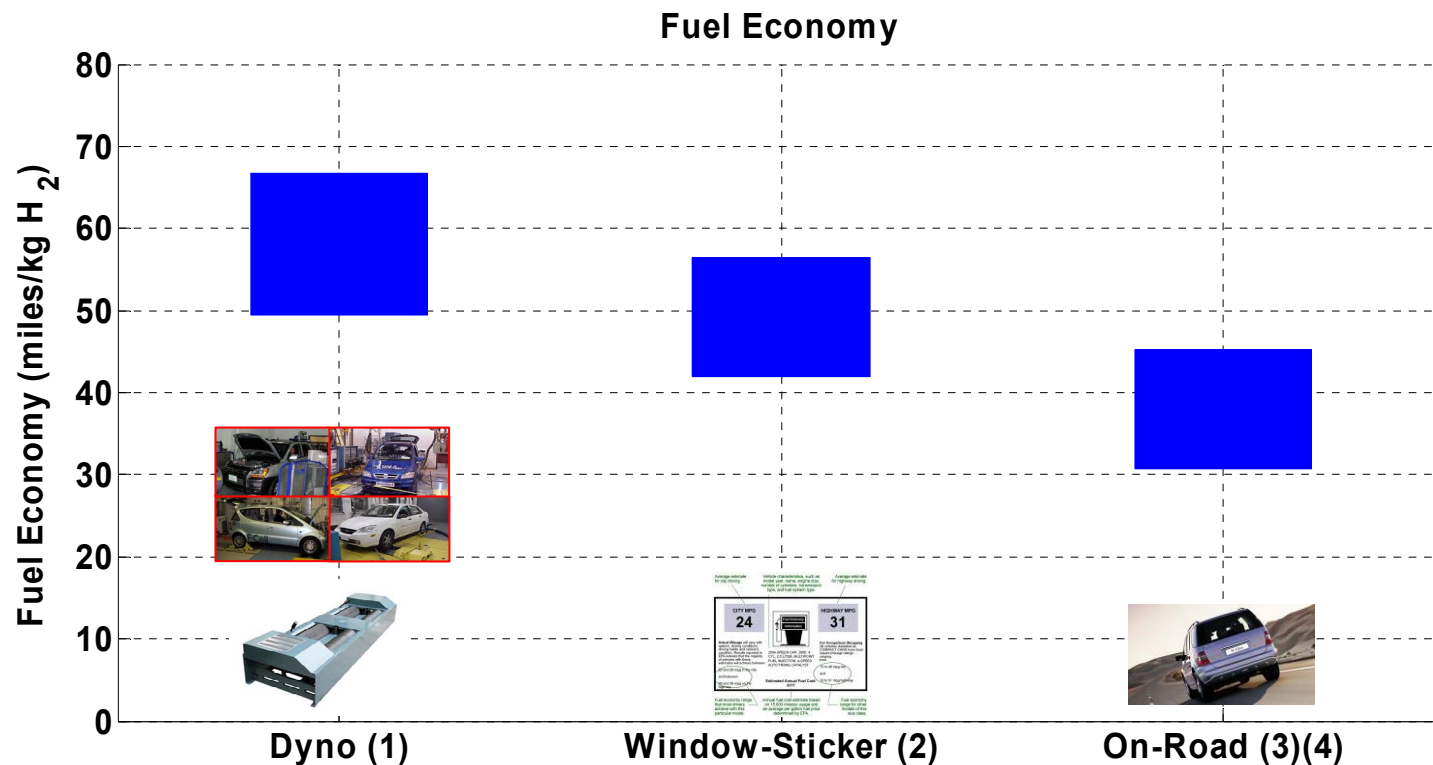
Fuel Cell System<sup>1</sup> Efficiency<sup>2</sup> at ~25% Net Power.



<sup>1</sup> Gross stack power minus fuel cell system auxiliaries, per DRAFT SAEJ2615.

<sup>2</sup> Ratio of DC output energy to the lower heating value of the input fuel (hydrogen). Excludes power electronics and electric drive.

# Dynamometer and On-Road Fuel Economy from Learning Demonstration Vehicles



(1) One data point for each make/model. Combined City/Hwy fuel economy per DRAFT SAEJ2572.

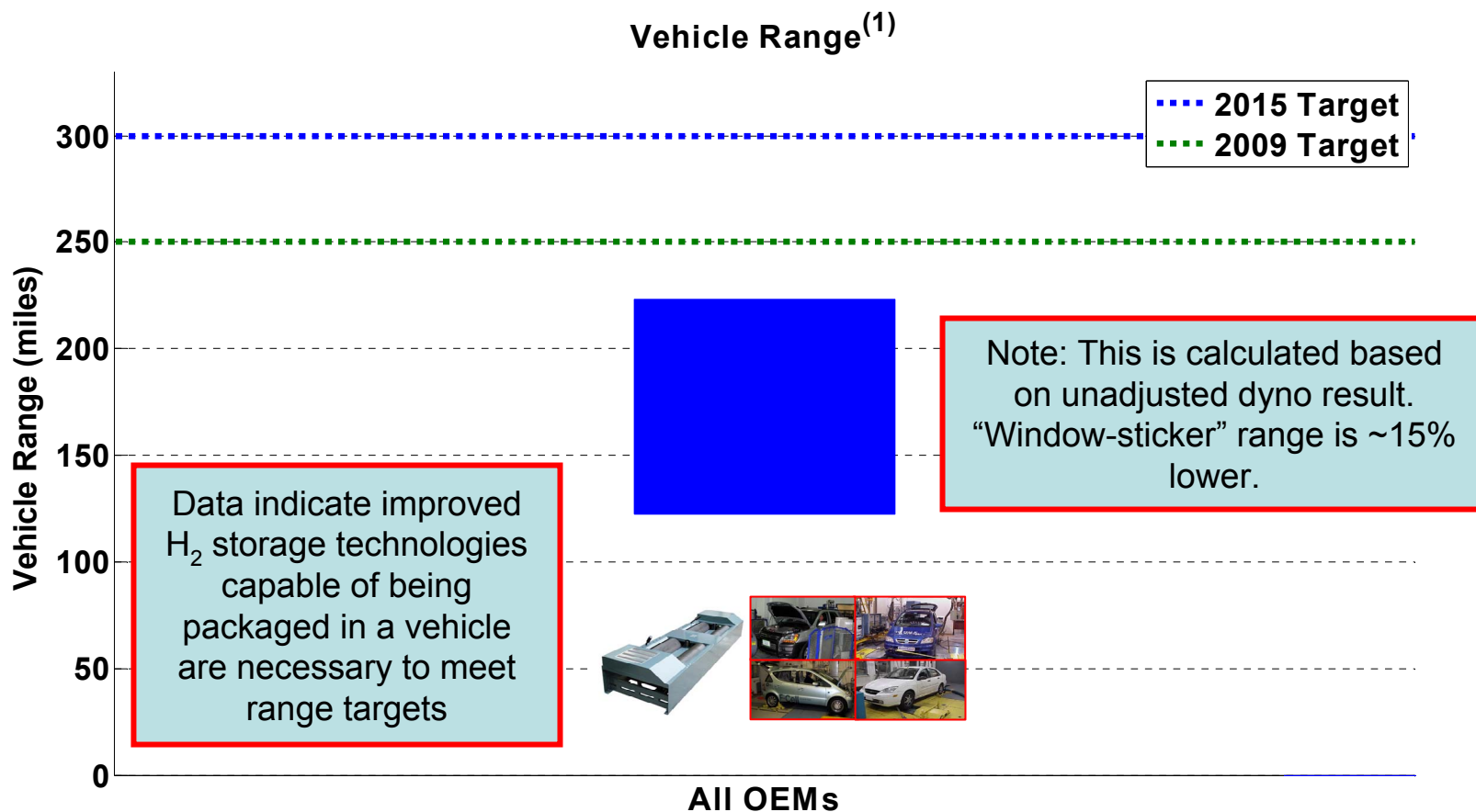
(2) Adjusted combined City/Hwy fuel economy ( $0.78 \times \text{Hwy}$ ,  $0.9 \times \text{City}$ ).

(3) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.

(4) Calculated from on-road fuel cell stack current or mass flow readings.

Created: Aug-25-06 10:45 AM

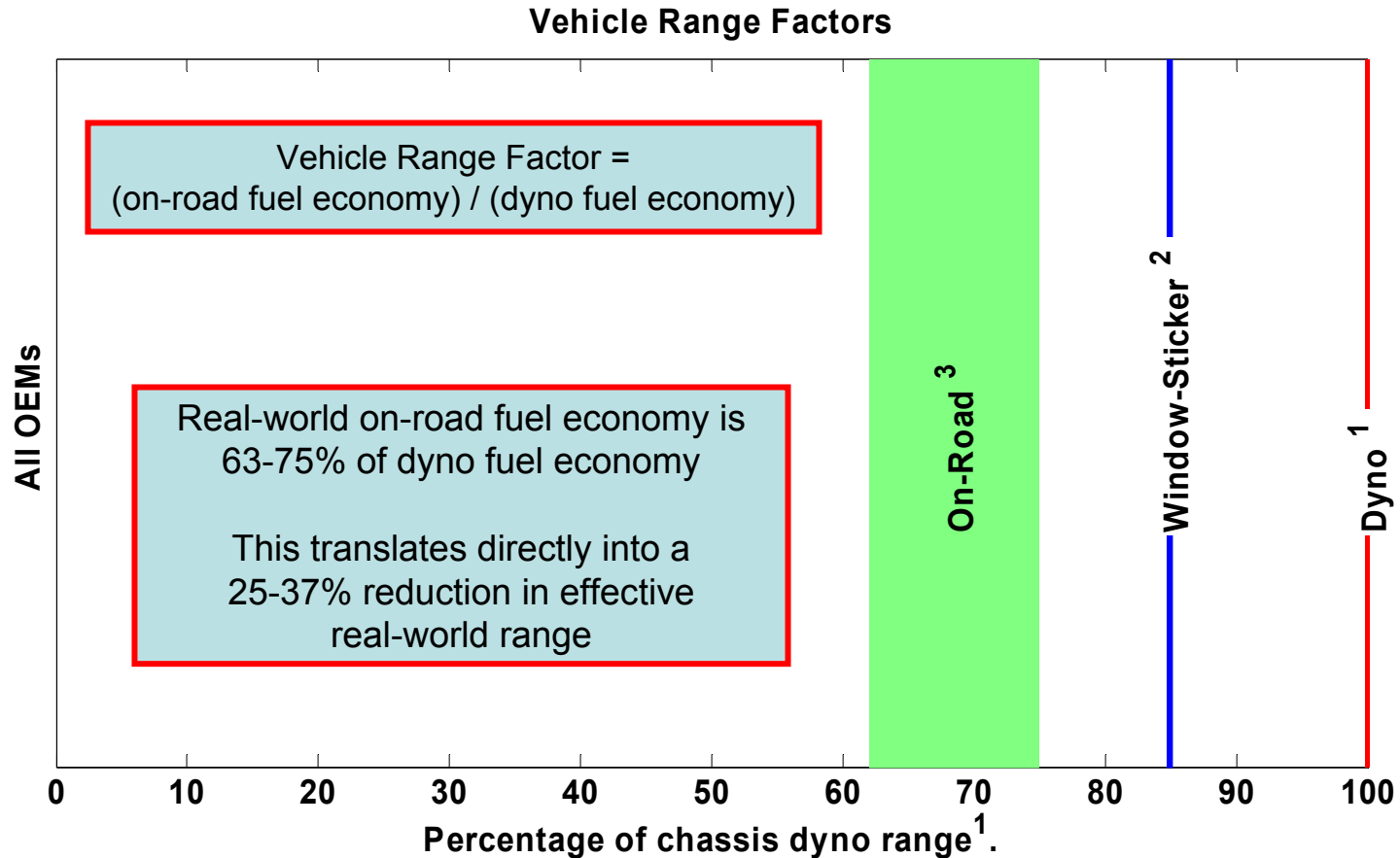
# Vehicle Range Based on Dyno Results and Usable H<sub>2</sub> Fuel Stored On-Board



Created: 21-Feb-2006

(1) Calculated from combined City/Hwy fuel economy (dyno test) per DRAFT SAE J2572 and usable fuel on board.

# Effective Vehicle Range Reduced from Dyno Range by On-Road Fuel Economy

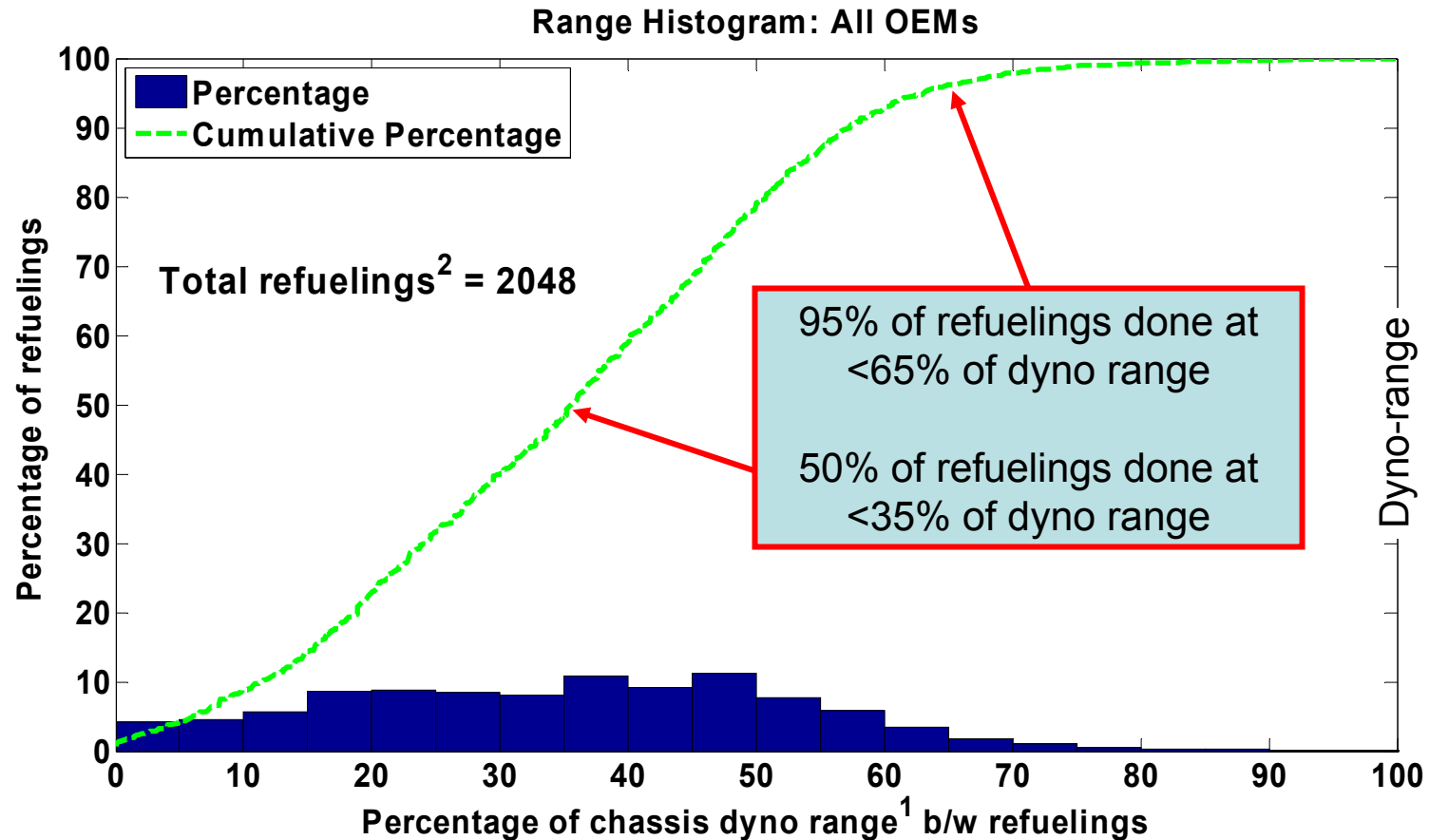


1. Calculated using the combined city/hwy fuel economy from dyno testing (non-adjusted) and usable fuel on board
2. Applying window-sticker correction factors for fuel economy: 0.78 x Hwy and 0.9 x City
3. Using fuel-economy from on-road data (excluding trips > 1 mile, consistent with other data products)

Created: Aug-30-06 3:09 PM



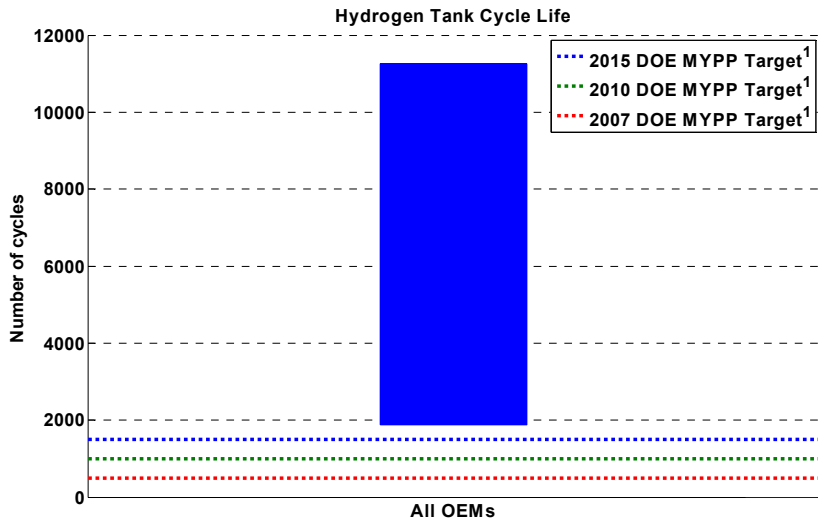
# Learning Demo Data Show Actual Refueling Behavior as % of Theoretical



1. Range calculated using the combined city/hwy fuel economy from dyno testing (not EPA adjusted) and usable fuel on board.
2. Some refueling events are not detected/reported due to data noise or incompleteness.

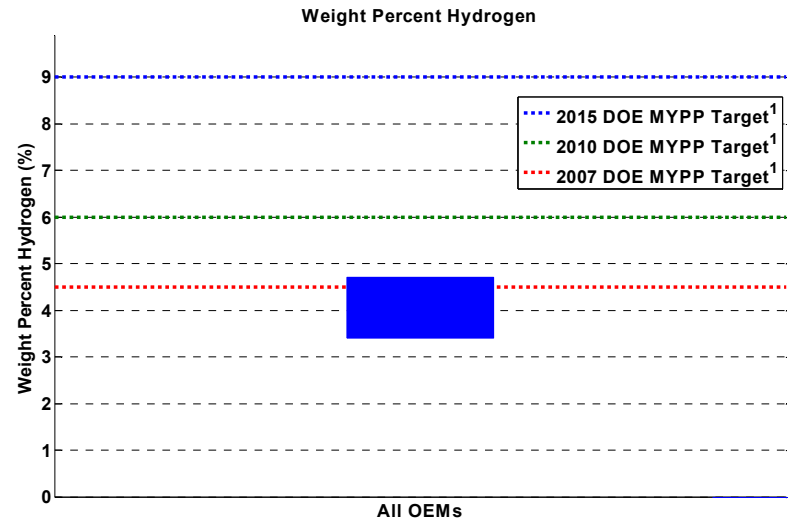
Created: Aug-30-06 3:09 PM

# Technical Status of On-Board H<sub>2</sub> Storage Technologies Being Validated



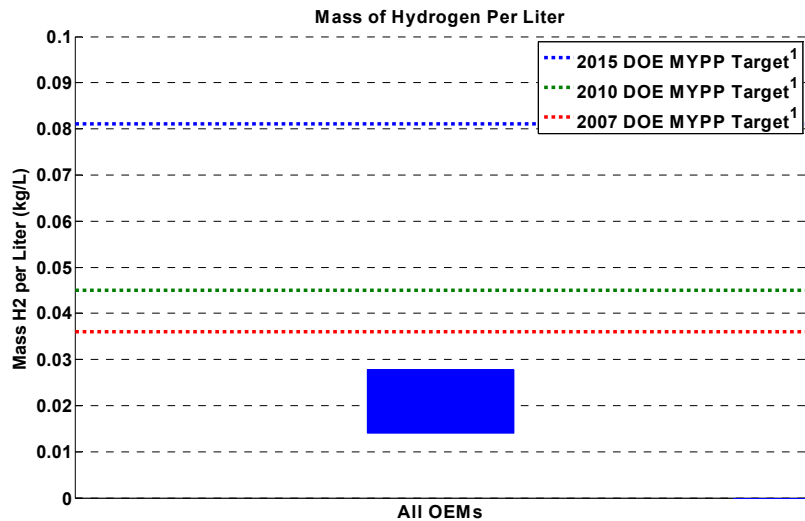
Created: 23-Feb-2006

<sup>1</sup>Some near-term targets have been achieved with compressed and liquid tanks. Emphasis is on advanced materials-based technologies.



Created: 23-Feb-2006

<sup>1</sup>Some near-term targets have been achieved with compressed and liquid tanks. Emphasis is on advanced materials-based technologies.

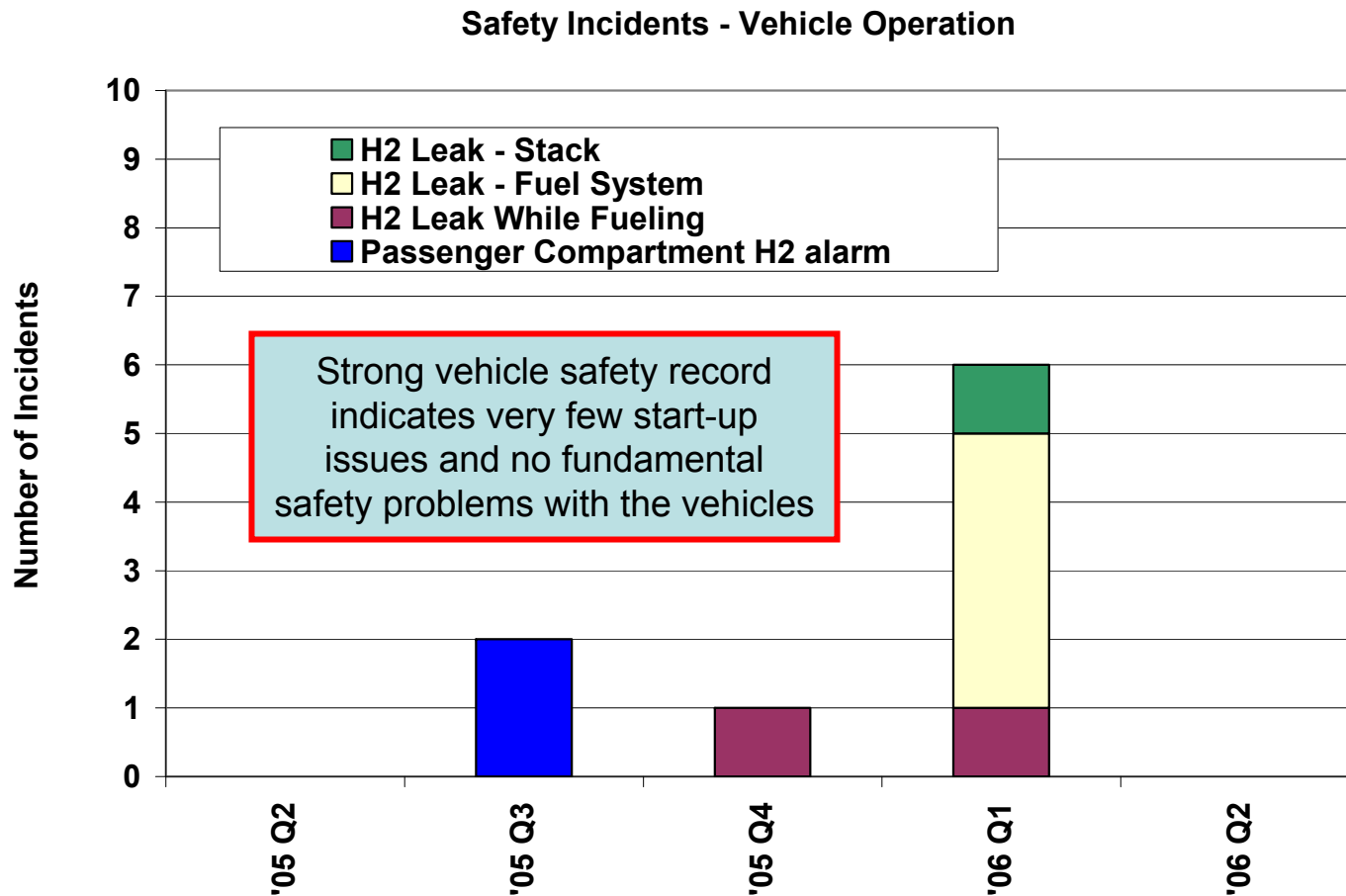


Created: 23-Feb-2006

<sup>1</sup>Emphasis is on advanced materials-based technologies.

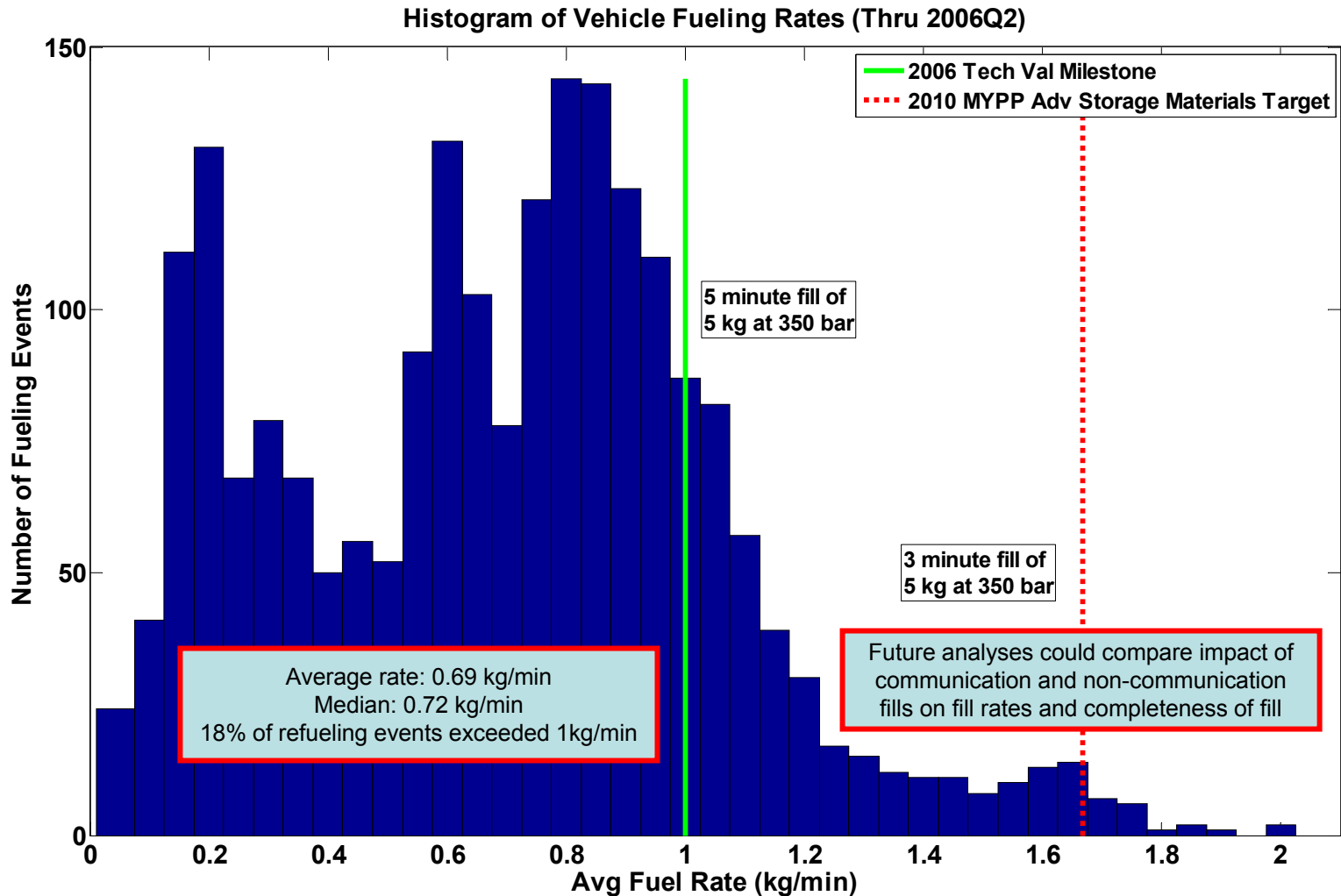
Compressed and liquid H<sub>2</sub> tanks meet durability and short term weight %, but don't meet long-term weight % or volumetric capacity targets for vehicles

# Safety Incidents – Vehicles



Created: 8/28/2006

# Actual Vehicle Refueling Rates from >2000 Events: Measured by Stations or by Vehicles

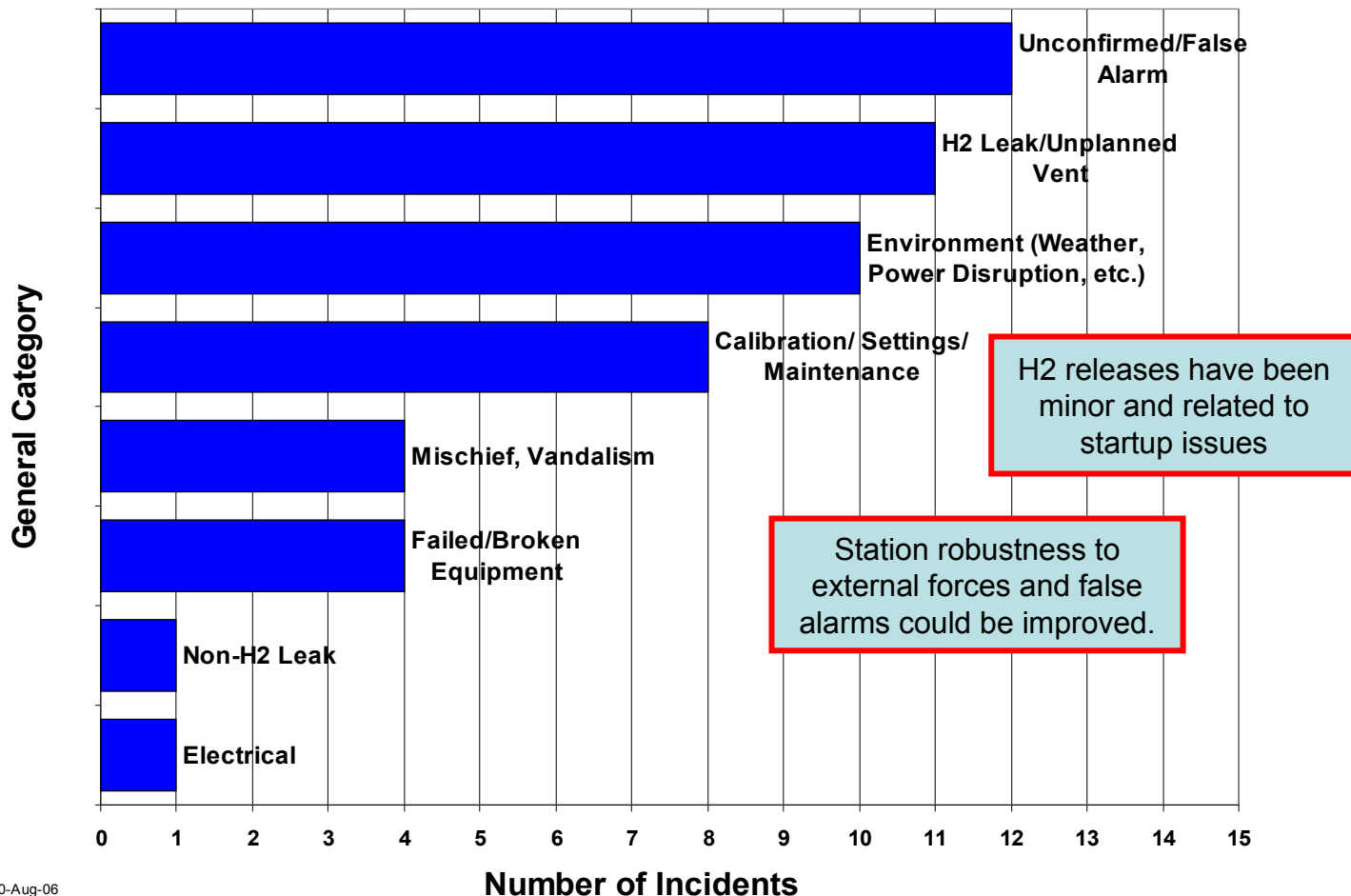


Created: Aug-29-06 4:47 PM



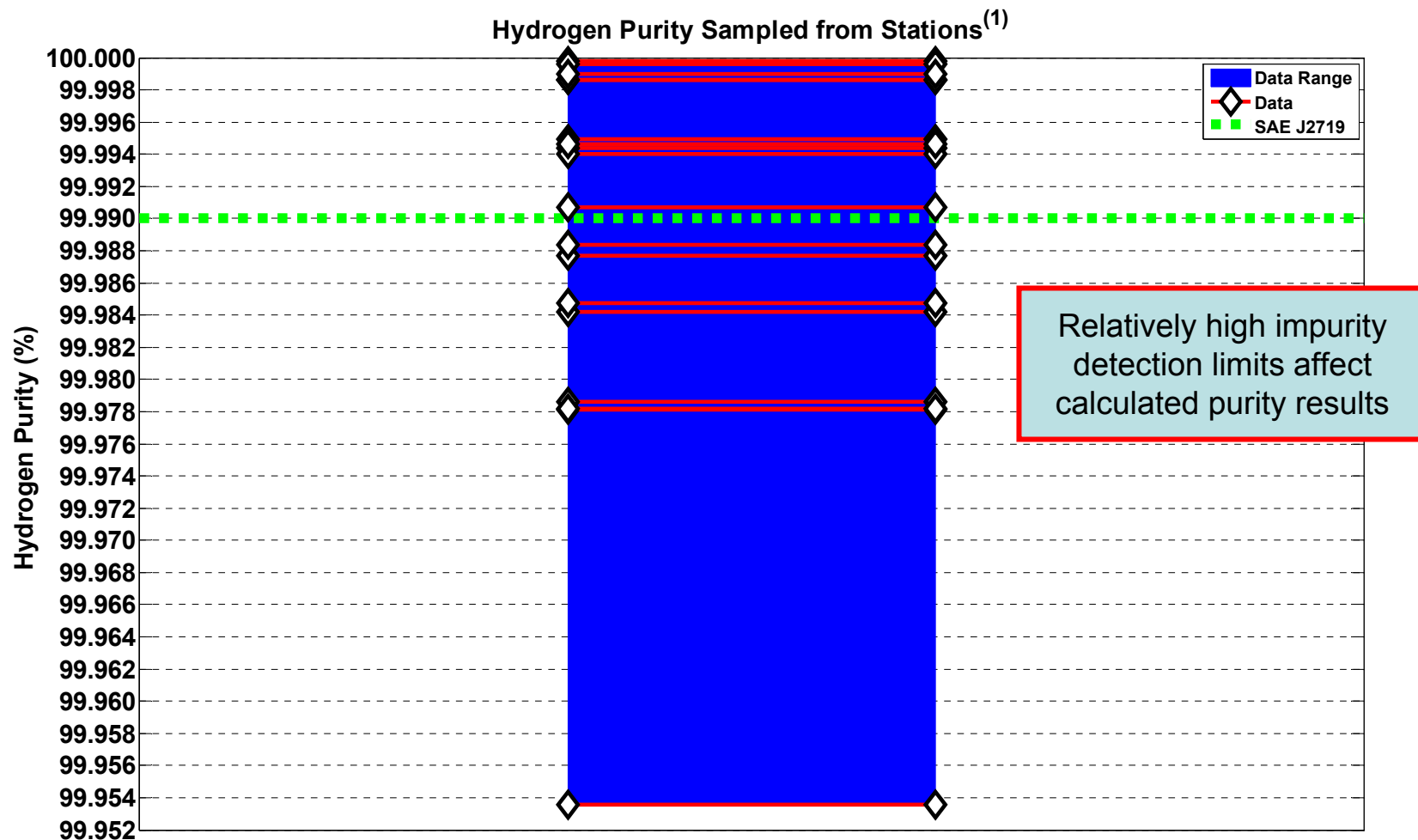
# Safety Incidents – Infrastructure

Safety Incidents - Infrastructure  
2005 Q2 - 2006 Q2



Created 30-Aug-06

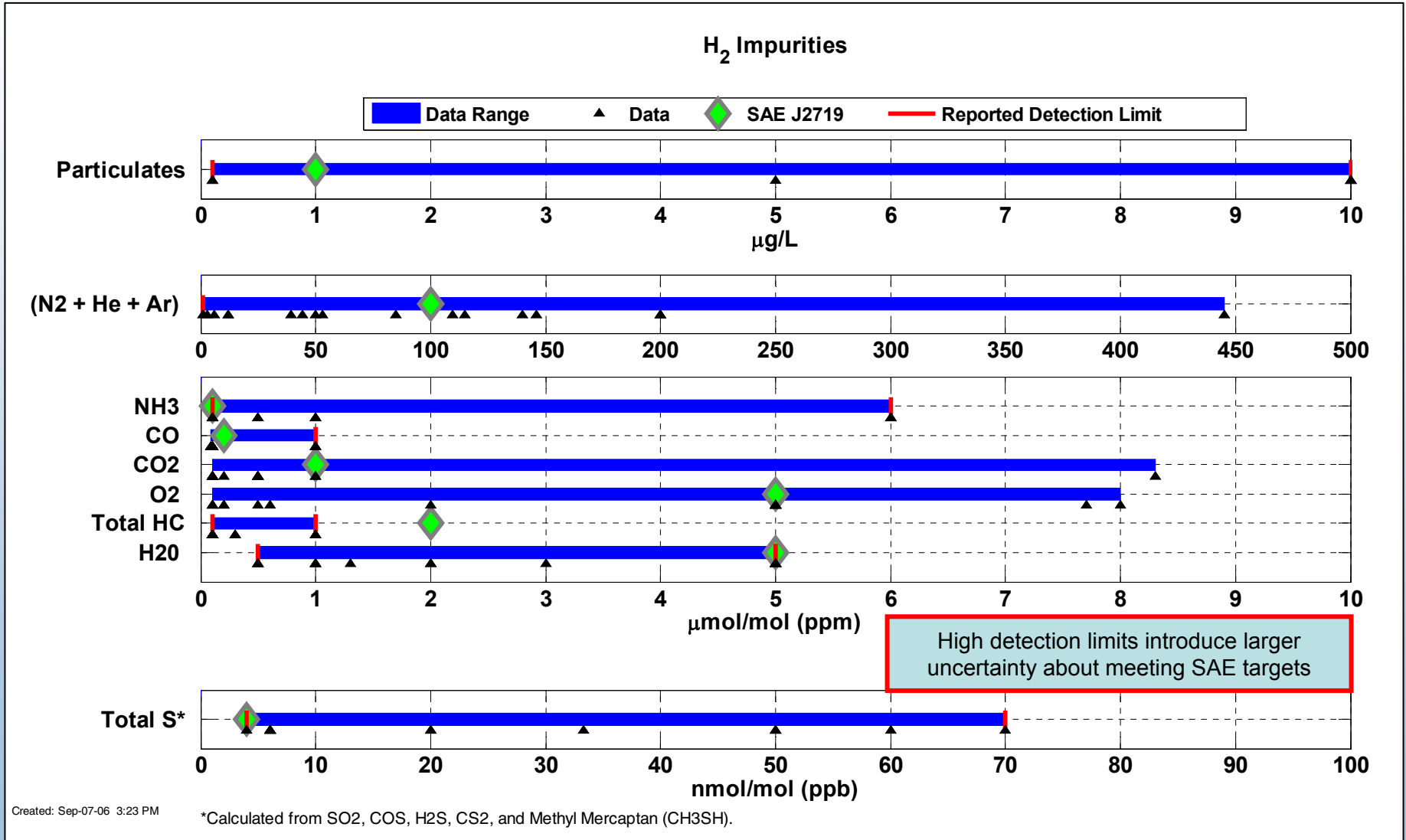
# Hydrogen Purity Sampled from Stations Close to Target Majority of the Time



(1) Includes sampling from both electrolysis and reforming

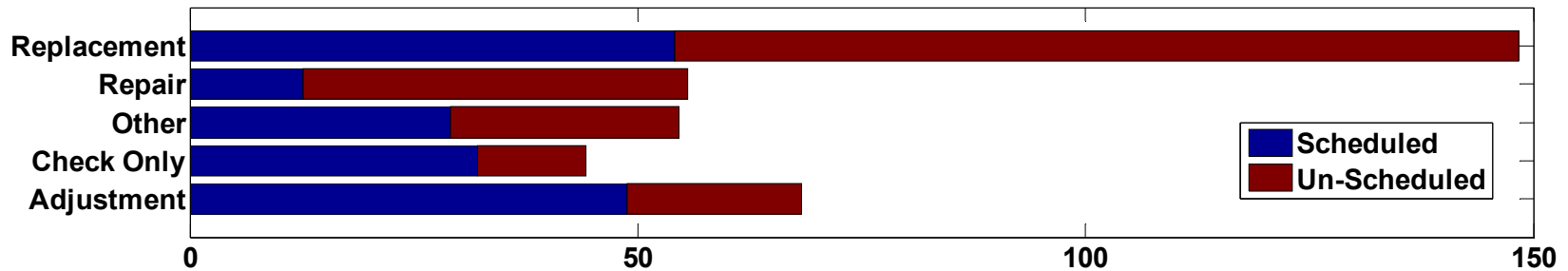
Created: Sep-07-06 3:32 PM

# Hydrogen Impurities Sampled from All Stations – Includes On-Site Reformation, Electrolysis, and Delivered H<sub>2</sub>

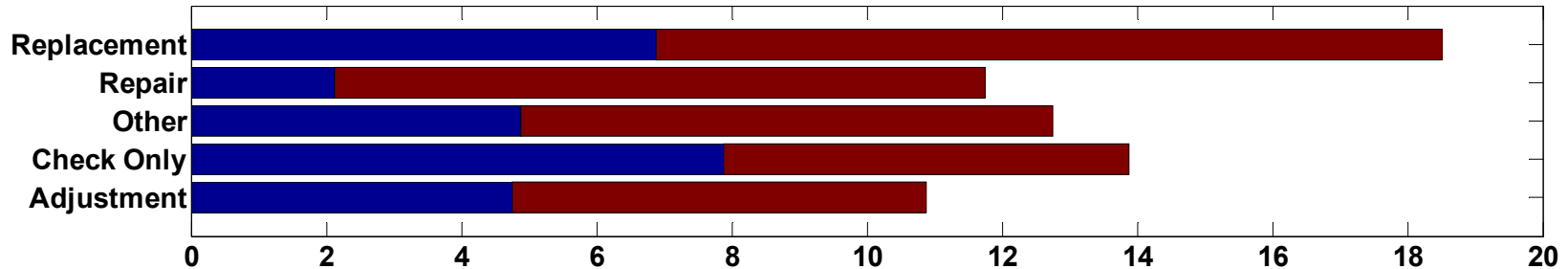


# Unscheduled H2 Refueling Infrastructure Maintenance ~50-60% of Total

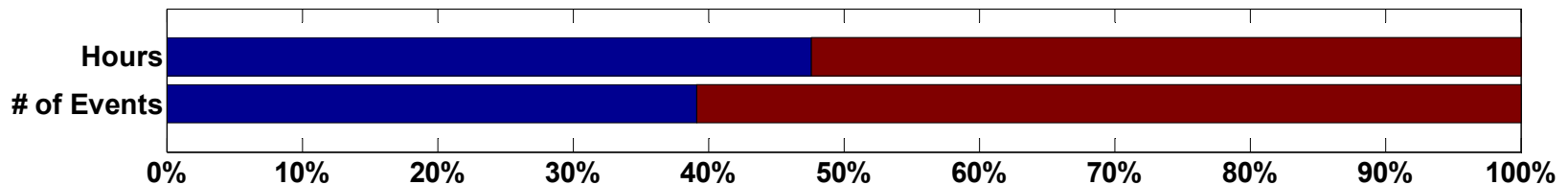
Maintenance: Average Labor Hours Per Station Since Inception



Maintenance: Average Number of Events Per Station Since Inception

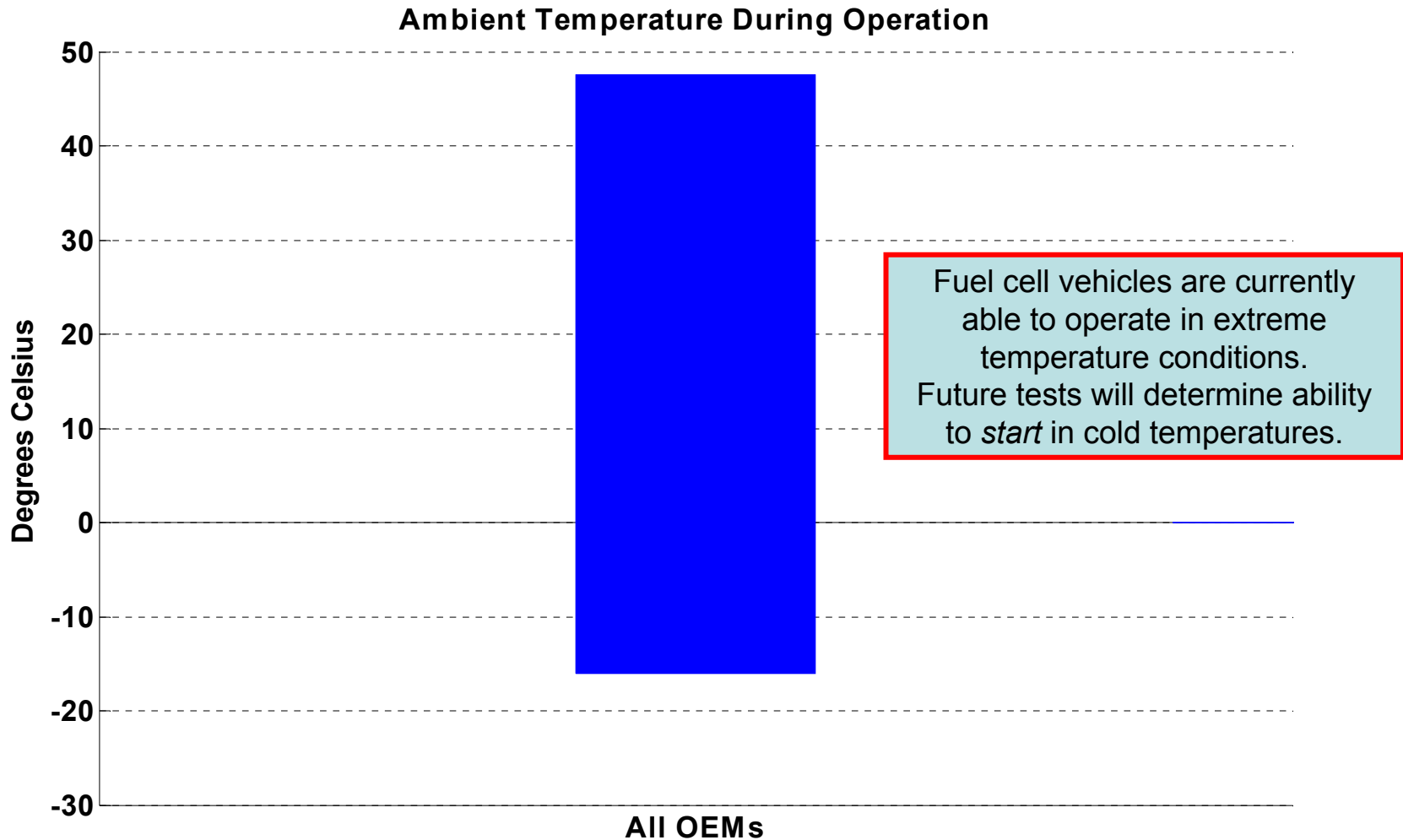


Comparison of Scheduled/Un-Scheduled Maintenance



Created: Aug-30-06 3:04 PM

# Range of Ambient Temperature During Vehicle Operation

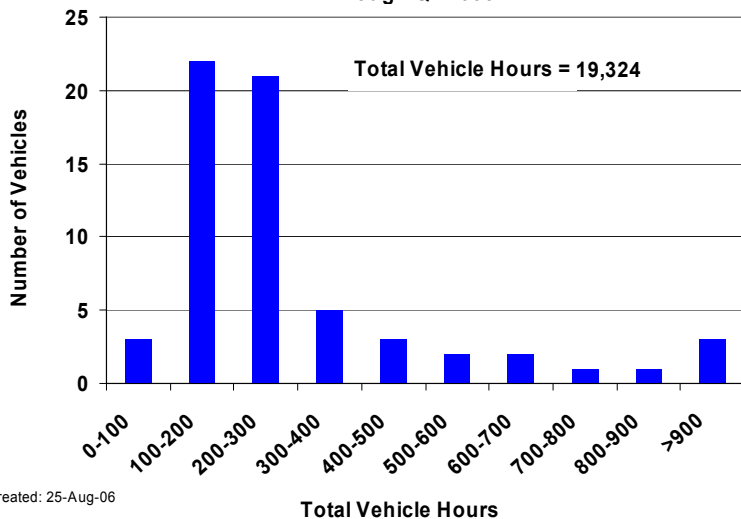


Created: 16-Feb-2006



# Vehicle Operating Hours and Miles Traveled Distribution

Vehicle Hours: All OEM's Combined  
Through Q2 2006

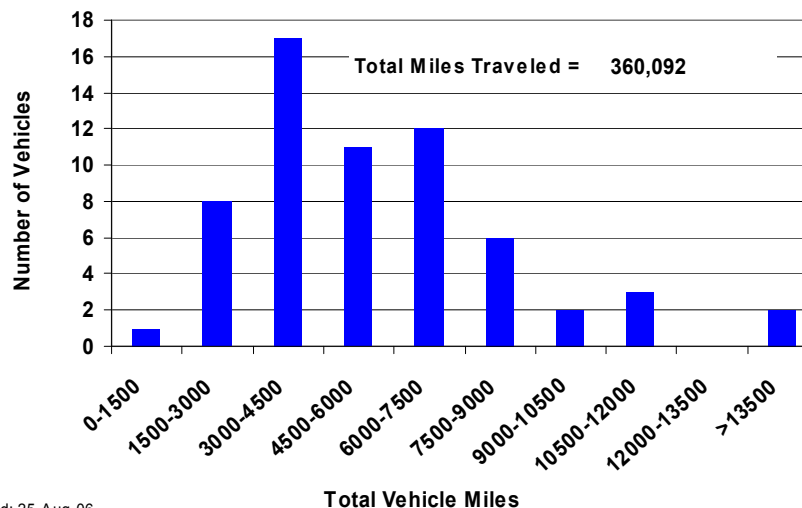


Created: 25-Aug-06

The bulge of operating hours and miles traveled is now shifting to the right.

New Gen 1 vehicles continue to be introduced, but 2<sup>nd</sup> bulge will appear at left with Gen 2 vehicle introduction.

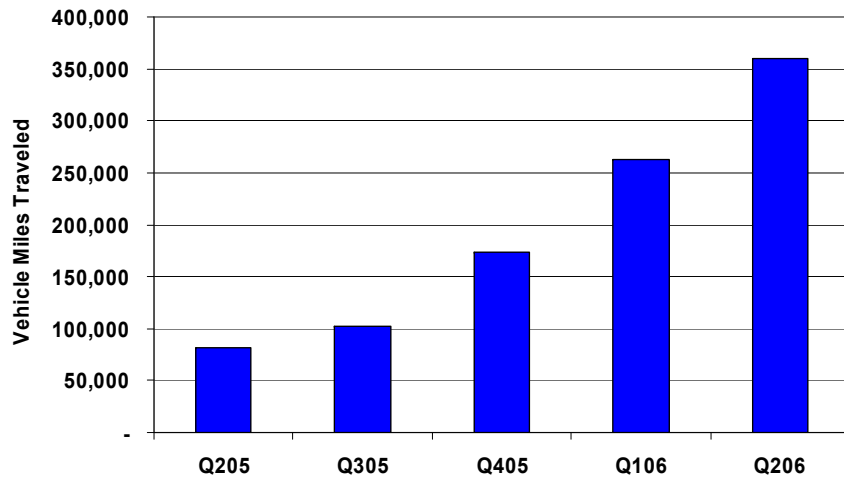
Vehicle Miles: All OEMs Combined  
Through Q2 2006



Created: 25-Aug-06

# Cumulative Vehicle Miles Traveled and Mass of H<sub>2</sub> Produced or Dispensed

Cumulative Vehicle Miles Traveled: All OEMs

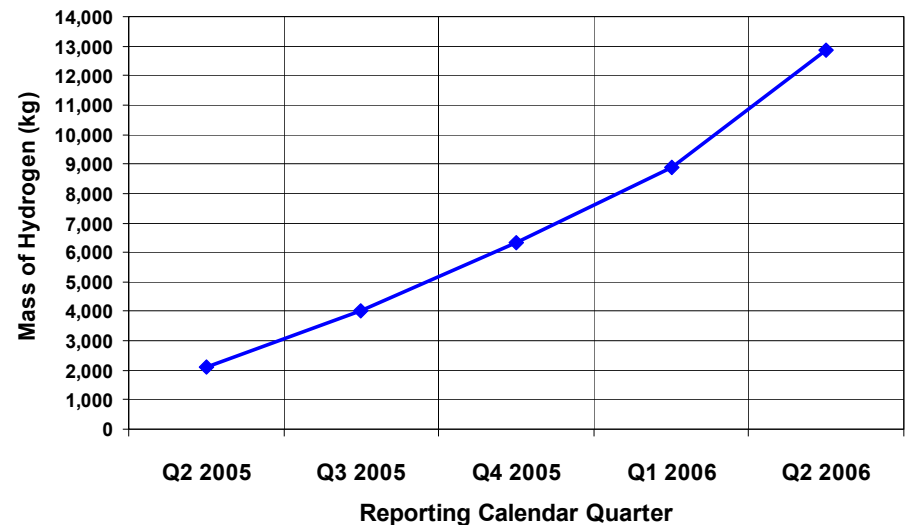


Created: 28-Aug-06

Rate of mileage accumulation increasing as initial fleets approach full Gen 1 vehicle deployment

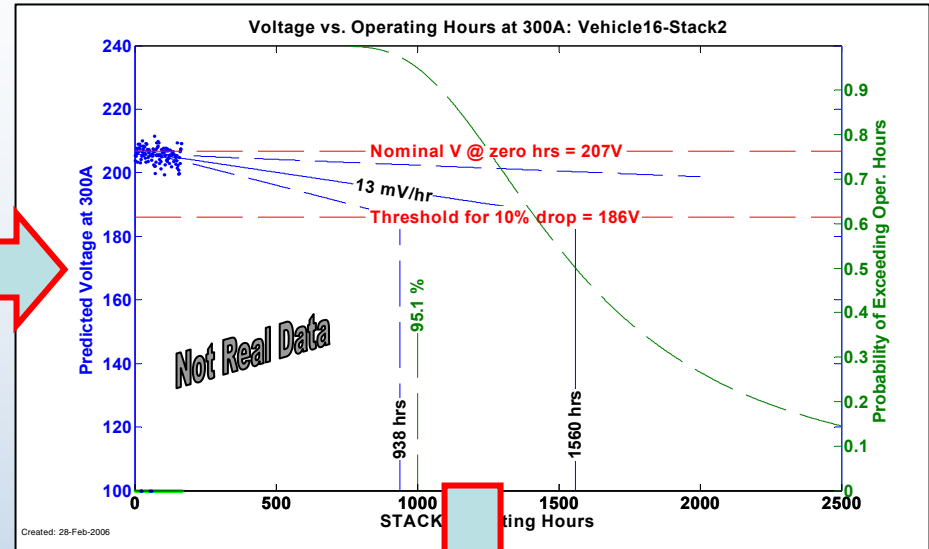
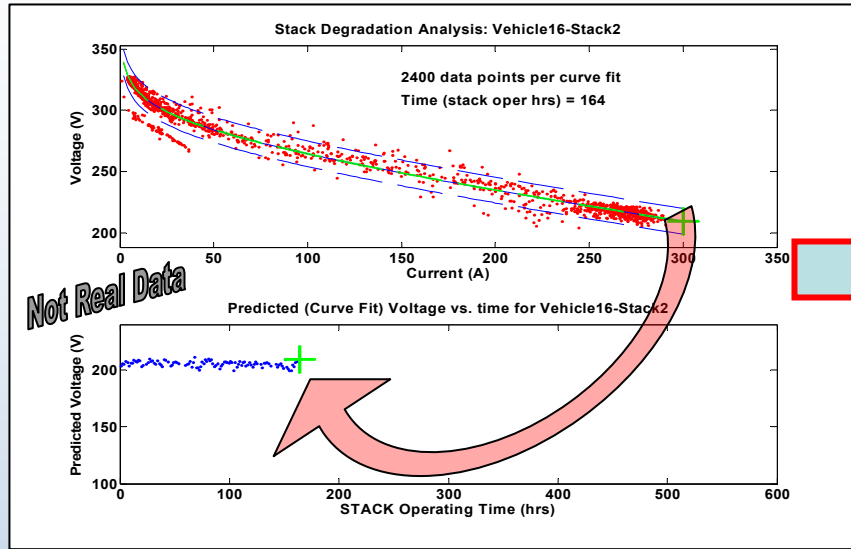
Current deployment of new H<sub>2</sub> refueling stations for this project is about 50% complete. Many mobile refuelers will be replaced with on-site generation

Cumulative Hydrogen Produced or Dispensed  
All Teams



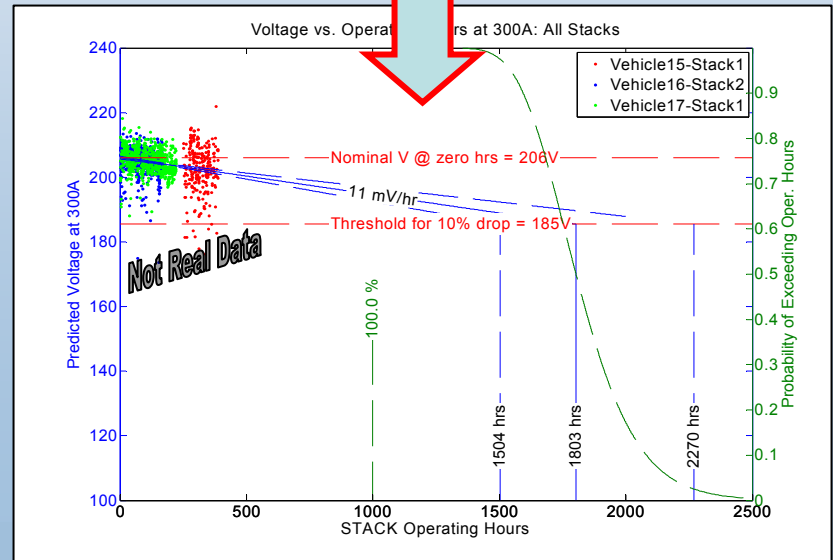
Created 24-Aug-2006

# Methodology for Projecting Stack Durability— Results to be Published this Fall



Technique Makes Performance Projection Based on All Available FC Data; Includes Reporting Confidence in Results

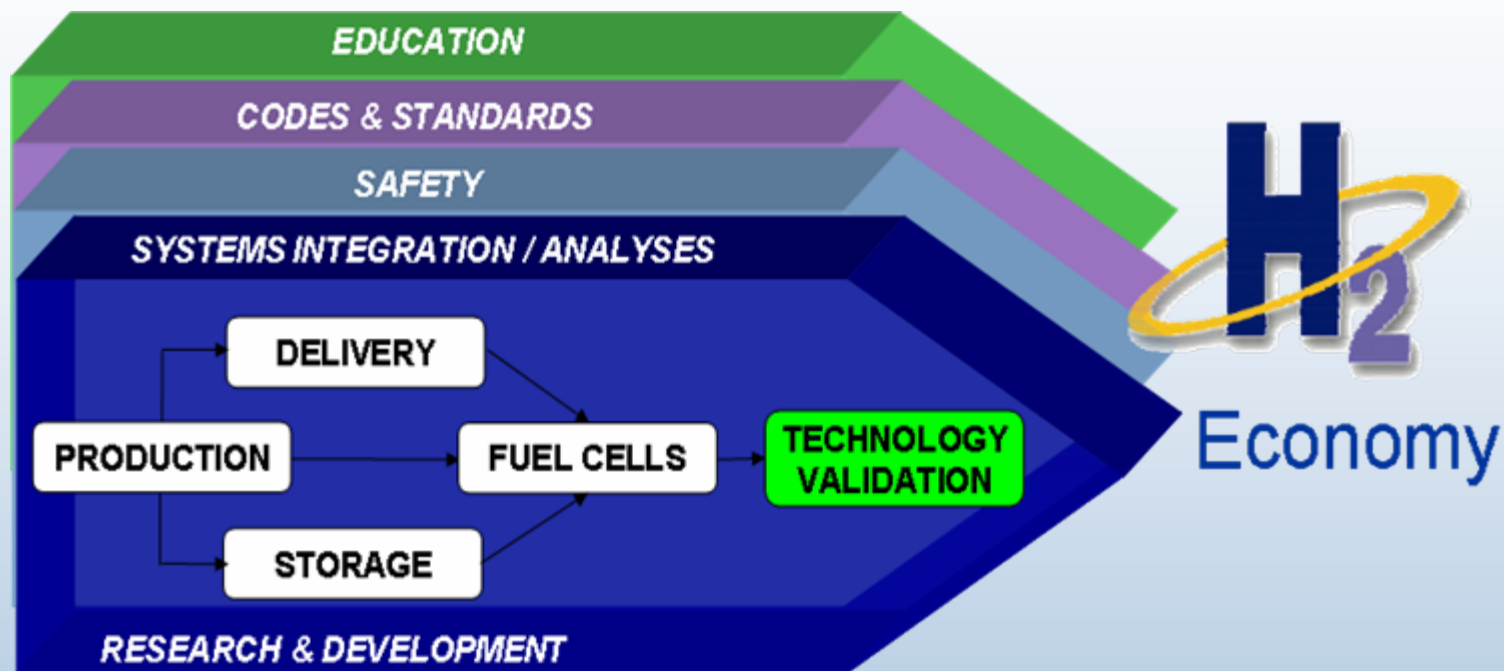
Voltage Degradation Analysis Technique Key to Evaluating Data Relative to DOE FC Durability Target in Fall 2006



# Summary

- First 5-quarters of project completed
  - 63 vehicles now in fleet operation
  - Several new refueling stations opened
  - No major safety problems encountered
  - Total of 24 composite data products published
- Project has identified current technical status relative to program targets
  - Will track improvements from 2<sup>nd</sup> generation stacks/vehicles introduced mid-way through project
- Future public results will include:
  - 6-month updates to existing composite data products
  - Fuel cell durability\* and cold start-up times
  - H<sub>2</sub> production cost and efficiency
  - Other composite data products created based on insights learned

# Questions and Discussion



Contact: Keith Wipke, National Renewable Energy Lab  
303.275.4451 keith\_wipke@nrel.gov

All papers and presentations are available online at  
[http://www.nrel.gov/hydrogen/proj\\_tech\\_validation.html](http://www.nrel.gov/hydrogen/proj_tech_validation.html)