

Fuel Cell Vehicle Learning Demonstration: Spring 2008 Results

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April 2, 2008

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This presentation does not contain any proprietary or confidential information

Outline

- Objectives and Partners
- Methodology and Data Analysis
- How to Access Full Results
- Results

Fuel Cell Vehicle Learning Demonstration

Project Objectives and Targets

- Objectives
 - Validate H₂ FC Vehicles and Infrastructure in Parallel
 - Identify Current Status and Evolution of the Technology
 - Assess Progress Toward Technology Readiness
 - Provide Feedback to H₂ 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

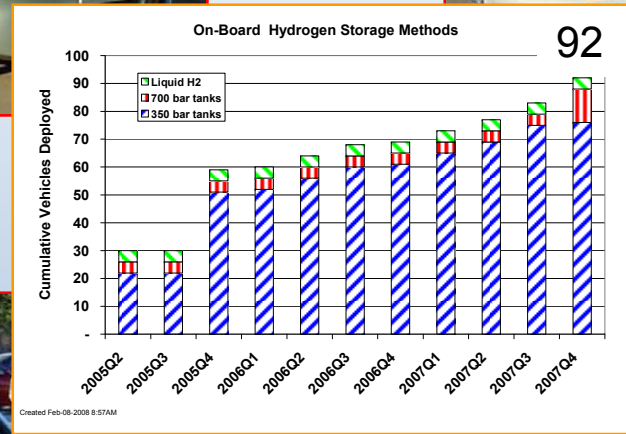
* To verify progress toward 2015 targets
** Subsequent projects to validate 2015 targets



Hydrogen refueling station, Rosemead, CA

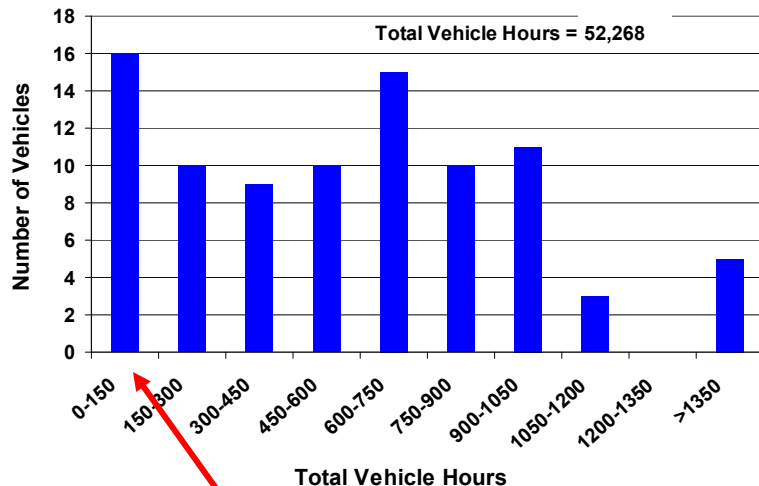
Photo: NREL

Vehicle Status: All of First Generation Vehicles Deployed, 2nd Generation Introduction in 2008 Has Begun



DOE Learning Demo Fleet Has Surpassed 50,000 Vehicle Hours and 1.1 Million Miles

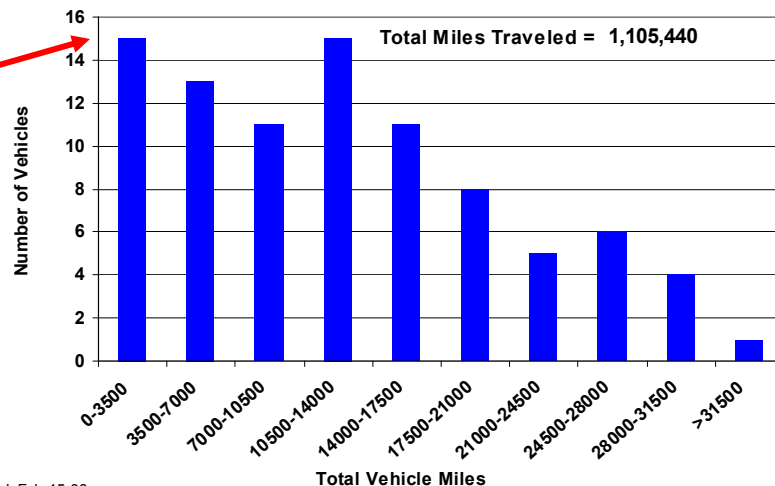
Vehicle Hours: All OEMs Combined
Through 2007 Q4



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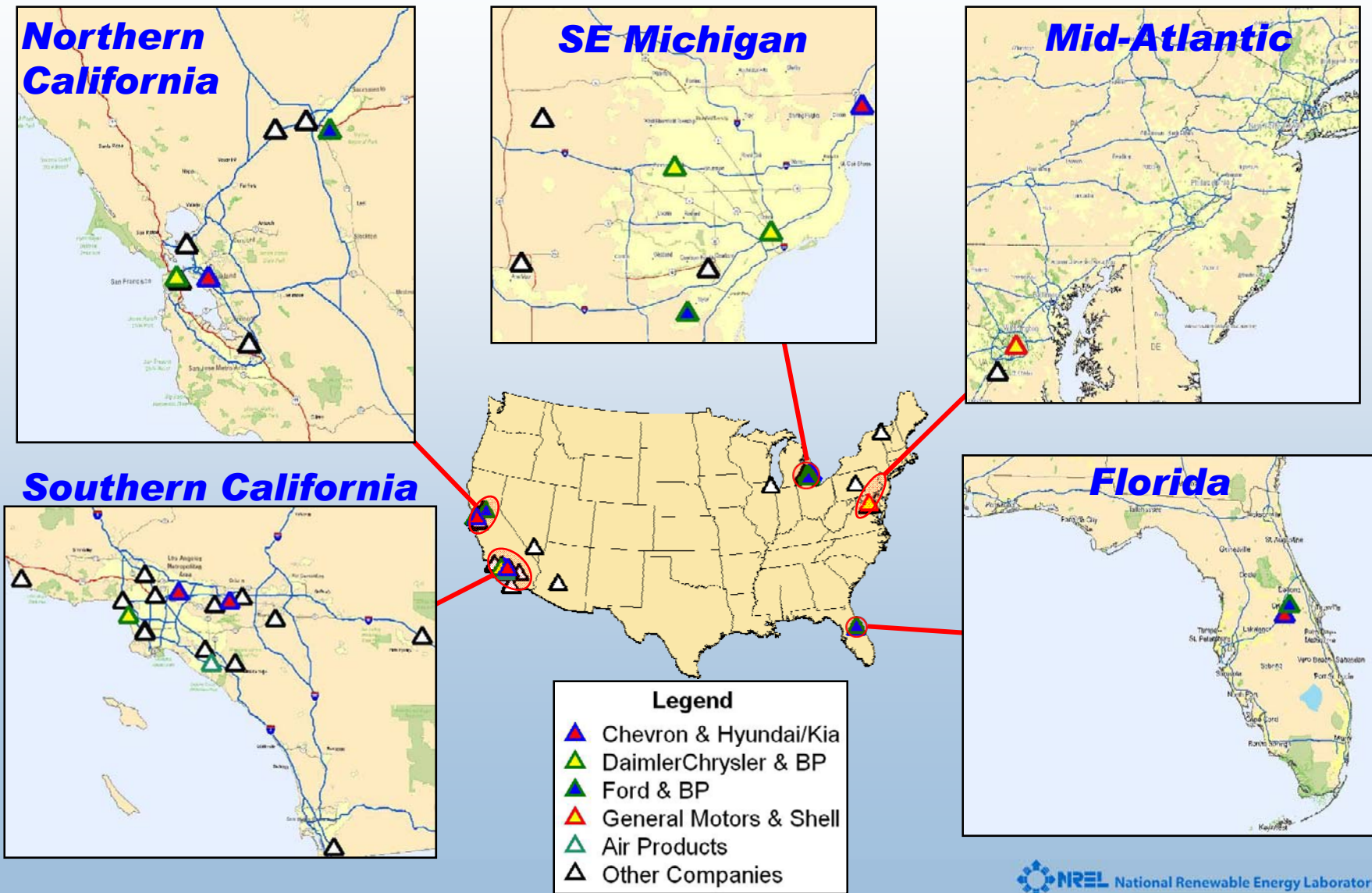
Gen 2 vehicle introduction now appears as the 2nd bulge at low hours/miles

Vehicle Miles: All OEMs Combined
Through 2007 Q4



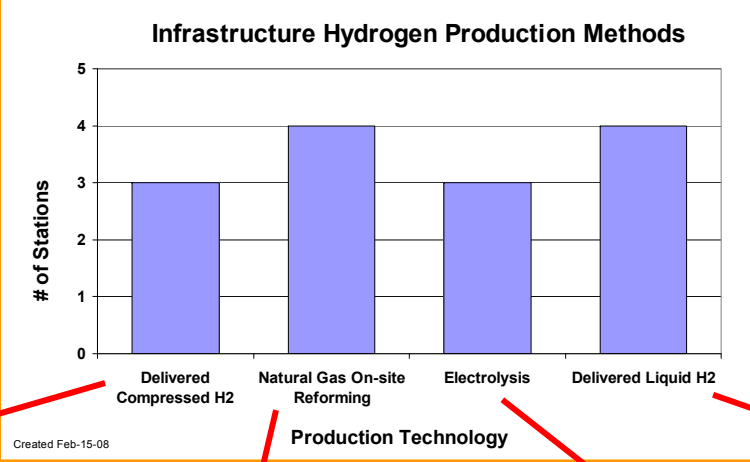
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Refueling Stations from All Four Teams Test Vehicle/Infrastructure Performance in Various Climates



~2/3 of the Project's Infrastructure to Refuel Vehicles Has Been Installed – 4 Types (examples)

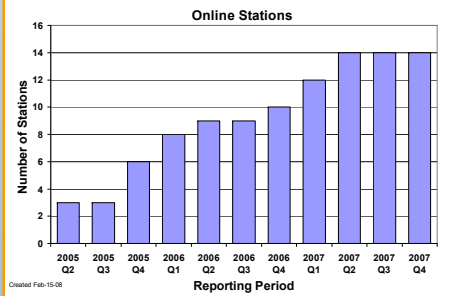
**Mobile Refueler
Sacramento, CA**



**Delivered Liquid, 700 bar
Irvine, CA**



Total: 14



**Steam Methane Reforming
Oakland, CA**



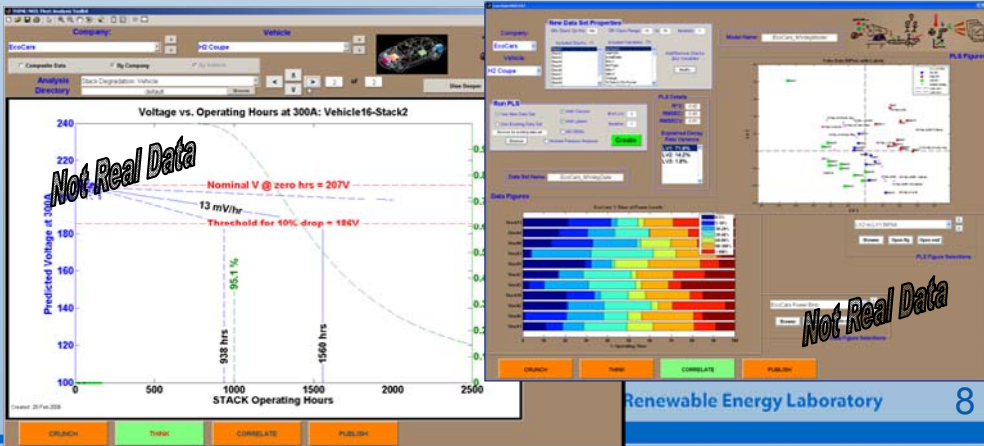
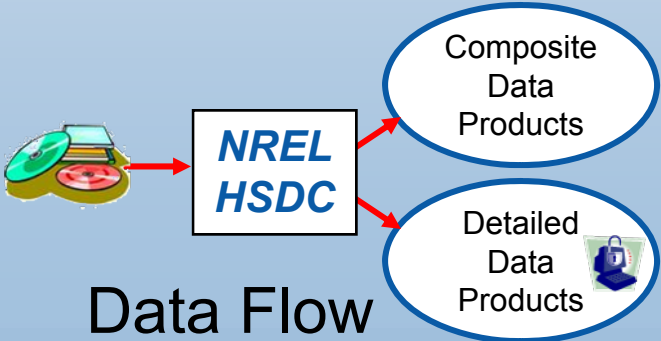
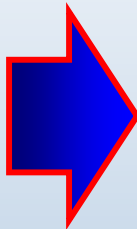
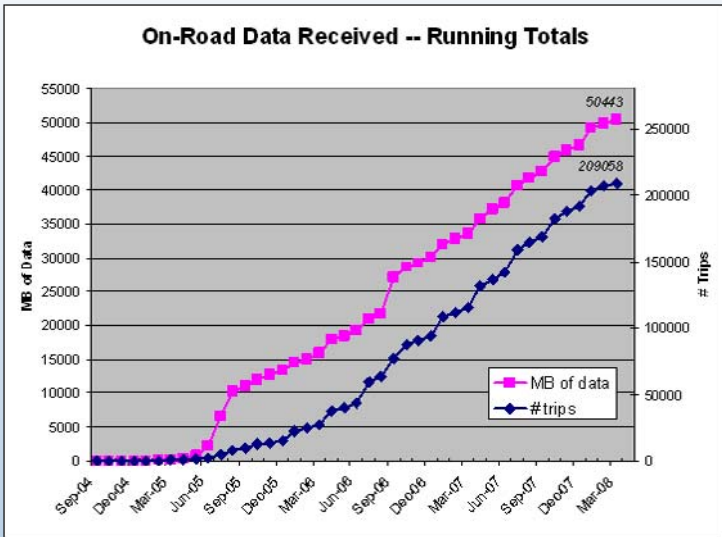
**Water Electrolysis
Rosemead, CA**



**SMUD and Burbank
Stations Opening Soon**

Extremely Large Data Sets (~3 Years, Every Trip) Have Resulted in Sophisticated NREL-Developed Data Processing Tools

Through February 2008:
209,000 individual vehicle trips
50 GB of on-road data



NREL Web Site Provides Direct Access to All Composite Data Products (47), Reports, and Presentations

http://www.nrel.gov/hydrogen/cdp_topic.html

Composite Data Products by Topic

The public technical analysis results from DOE's Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project are generated in the form of composite data products (CDPs). The following CDPs, which are organized by topic, are offered in both PowerPoint and JPEG formats.

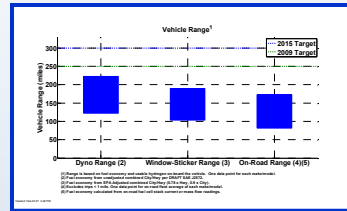
If these technical results are reproduced in your own documents or presentations, please provide appropriate reference to the U.S. Department of Energy's National Renewable Energy Laboratory.

Fuel Cell Stack Durability

- Fuel Cell Stack Hours Accumulated and Projected Hours to 10% Stack Voltage Degradation, CDP #1, 8/23/07 ([PowerPoint 39 KB](#)) ([JPEG 229 KB](#))
- Primary Factors Affecting Learning Demo Fleet Fuel Cell Degradation, CDP #48, 8/31/07 ([PowerPoint 26 KB](#)) ([JPEG 354 KB](#))
- Primary Factors Affecting Learning Demo Team Fuel Cell Degradation, CDP #49, 8/31/07 ([PowerPoint 39 KB](#)) ([JPEG 312 KB](#))

Fuel Cell Vehicle Range and Driving Behavior

- Fuel Cell Vehicle Range, CDP #2, 8/23/07 ([PowerPoint 35 KB](#)) ([JPEG 136 KB](#))
- Effective Fuel Cell Vehicle Range, CDP #34, 8/23/07 ([PowerPoint 35 KB](#)) ([JPEG 85 KB](#))
- Percentage of Theoretical Driving Range Between Refuelings, CDP #32, 8/23/07 ([PowerPoint 39 KB](#)) ([JPEG 114 KB](#))
- Driving Start Time — Day, CDP #44, 9/10/07 ([PowerPoint 37 KB](#)) ([JPEG 105 KB](#))
- Driving by Day of Week, CDP #45, 9/10/07 ([PowerPoint 35 KB](#)) ([JPEG 93 KB](#))



http://www.nrel.gov/hydrogen/proj_learning_demo.html

Presentations and Publications

Some of the following documents are available as Adobe Acrobat PDFs. [Download Adobe Reader.](#)

2007

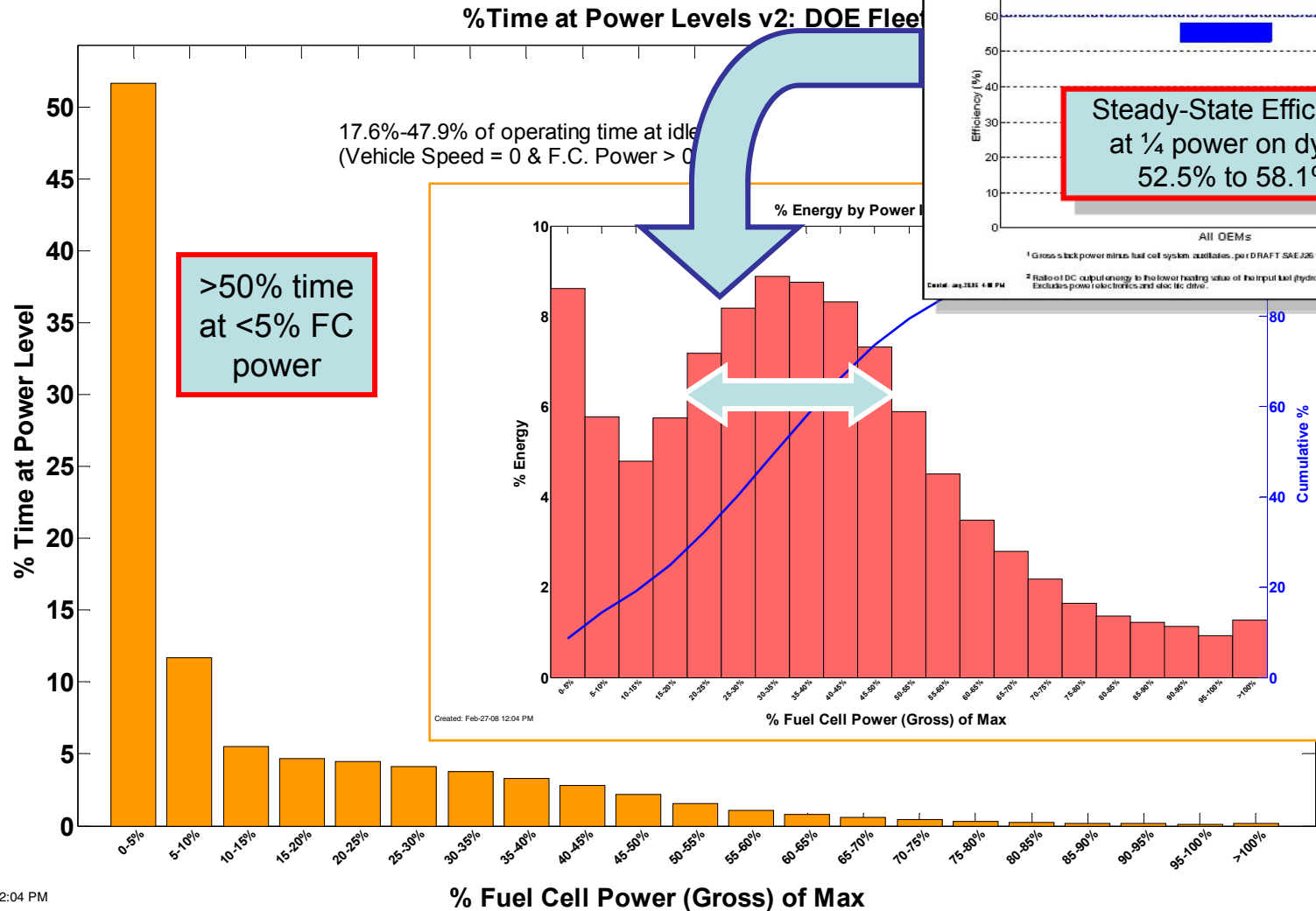
- FCV Learning Demonstration: First-Generation Vehicle Results and Factors Affecting Fuel Cell Degradation ([PDF 1.4 MB](#)), K. Wipke, S. Sprik, J. Kurtz, H. Thomas, J. Garbak. Presentation prepared for the Fuel Cell Seminar, San Antonio, TX. (October 2007)
- Learning Demonstration Interim Progress Report - Summer 2007 ([PDF 711 KB](#)), K. Wipke, S. Sprik, H. Thomas, C. Welch, J. Kurtz. NREL/TP-560-41848. (June 2007)
- Controlled Hydrogen Fleet and Infrastructure Analysis ([PDF 3.7 MB](#)), K. Wipke. Presentation prepared for the 2007 DOE Hydrogen Program Merit Review, Arlington, Virginia. (May 2007)
- Fuel Cell Vehicle Learning Demonstration: Spring 2007 Results ([PDF 1 MB](#)), K. Wipke. Presentation prepared for [National Hydrogen Association](#) Conference in San Antonio, Texas. (March 2007)

2006

- Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project—Initial Fuel Cell Efficiency and Durability Results ([PDF 314 KB](#)), K. Wipke, C. Welch, H. Thomas, S. Sprik, S. Gronich, J. Garbak. Paper prepared for the [World Electric Vehicle Association Journal](#), Vol. 1, 2007. (December 2006)
- 2006 Annual Progress Report for NREL's "Controlled Hydrogen Fleet and Infrastructure Analysis Project," System Analysis Section VI.G.1 ([PDF 1.24 MB](#)), K. Wipke, C. Welch, H. Thomas, S. Sprik. (November 2006)
- Hydrogen Learning Demonstration Project: Fuel Cell Efficiency and Initial Durability, K. Wipke. Presentation ([PDF 2.3 MB](#)) and abstract ([PDF 355 KB](#)) prepared for the 2006 Fuel Cell

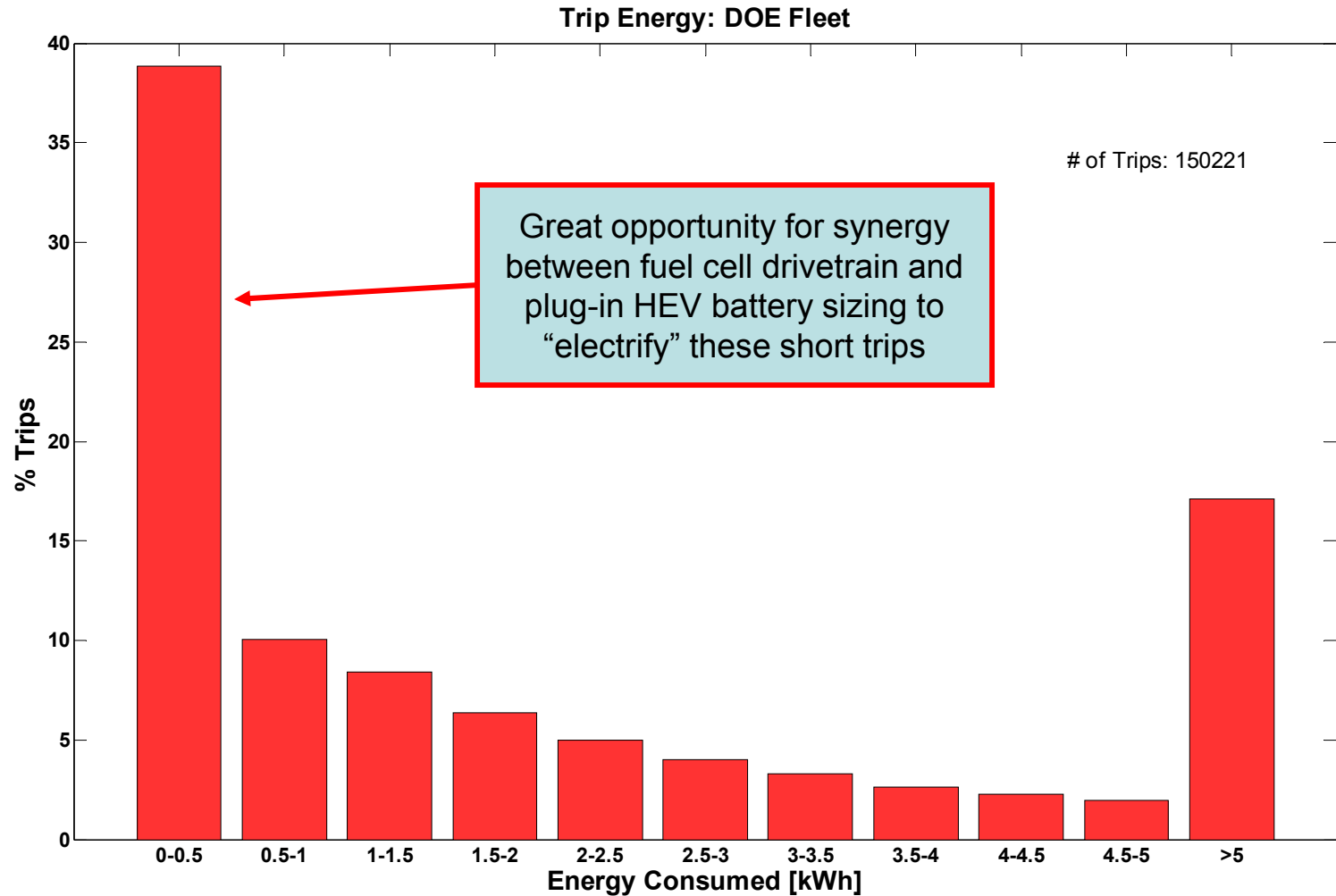
A subset of the 47 latest results will be presented now

While Most of FC Time is Spent at Idle, Bulk of Energy is at 20-50% Power



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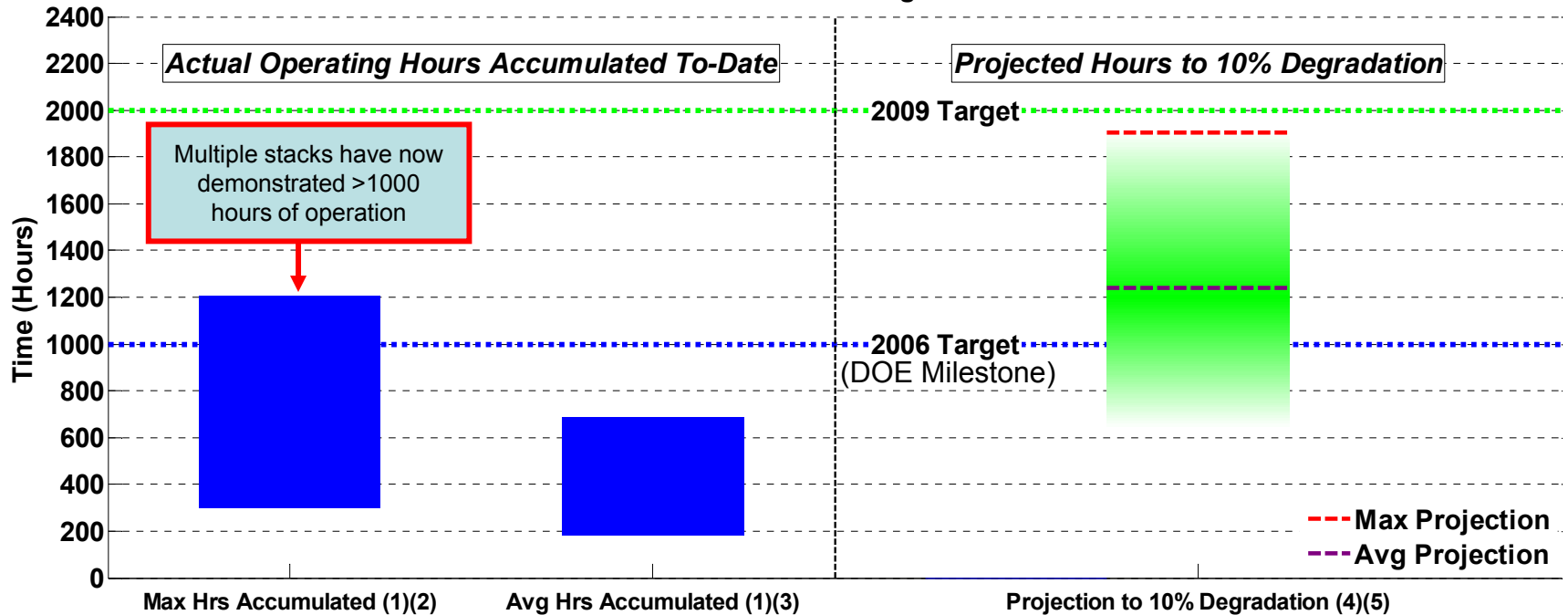
~40% of Learning Demo Trips Require <0.5 kWh of Fuel Cell Output Energy



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As More Gen 1 Data Is Accumulated, Some Teams Are Demonstrating Long FC Durability

DOE Learning Demonstration Fuel Cell Stack Durability:
Based on Data Through 2007 Q4

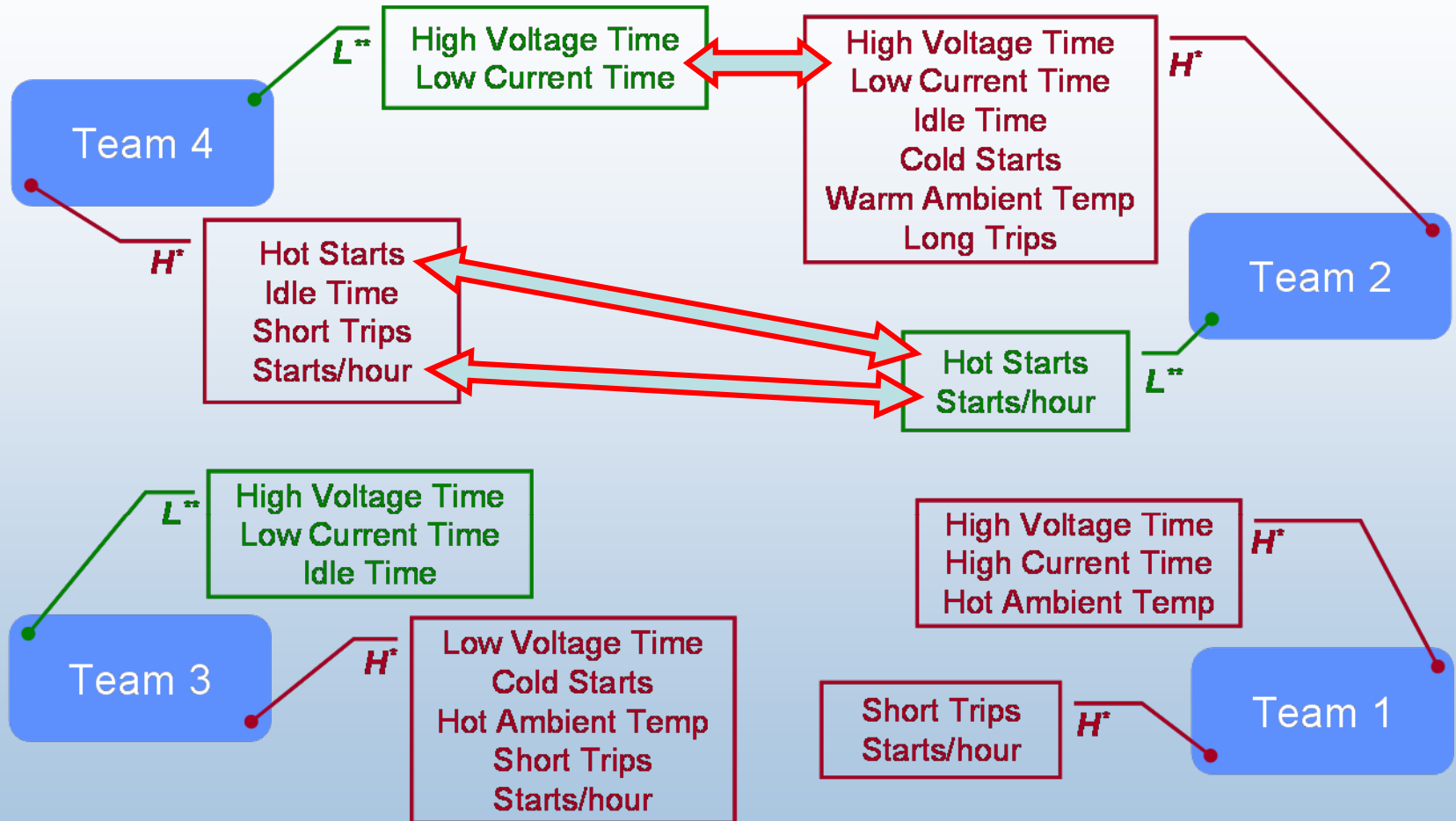


- (1) Range bars created using one data point for each OEM.
- (2) Range (highest and lowest) of the maximum operating hours accumulated to-date of any OEM's individual stack in "real-world" operation.
- (3) Range (highest and lowest) of the average operating hours accumulated to-date of all stacks in each OEM's fleet.
- (4) Projection using on-road data -- degradation calculated at high stack current. This criterion is used for assessing progress against DOE targets, may differ from OEM's end-of-life criterion, and does not address "catastrophic" failure modes, such as membrane failure.
- (5) Using one nominal projection per OEM: "Max Projection" = highest nominal projection, "Avg Projection" = average nominal projection.
The shaded green bar represents an engineering judgment of the uncertainty due to data and methodology limitations. Projections will change as additional data are accumulated.

Multivariate Analysis of FC Degradation Factors Continues; Now Available in Main GUI as “Correlate” Screen

The screenshot displays the 'CorrelateNREL/FAT' software interface. At the top left, the 'Company' is set to 'EcoCars' and the 'Vehicle' to 'H2 Coupe'. The 'New Data Set Properties' dialog is open, showing 'Included Stacks: 11' and 'Included Variables: 73'. The 'Run PLS' section has 'Use New Data Set' selected, with '# of LVs: 3' and 'Iteration: 1'. The 'Data Set Name' is 'EcoCars_MVdegData'. The 'PLS Details' section shows $R^2: 0.82$, $RMSEC: 0.43$, and $RMSECV: 0.51$. The 'Explained Decay Rate Variance' is listed as LV1: 71.8%, LV2: 14.2%, and LV3: 1.8%. The 'Fake Data BiPlot: with Labels' shows a scatter plot of LV2 vs LV1 with various data points labeled. The 'Data Figures' section contains a horizontal stacked bar chart titled 'EcoCars: % Time at Power Levels' for stacks Stack1 through Stack11, with a legend for power levels from 0-5% to >100%. The 'PLS Figure Selections' section includes a 'LV2 vs LV1 BiPlot' dropdown and 'Browse', 'Open fig', and 'Open emf' buttons. The 'Data Figure Selections' section includes an 'EcoCars Power Bins' dropdown and similar buttons. At the bottom, there are four buttons: 'CRUNCH', 'THINK', 'CORRELATE', and 'PUBLISH'. A large 'Not Real Data' watermark is visible in the bottom right corner.

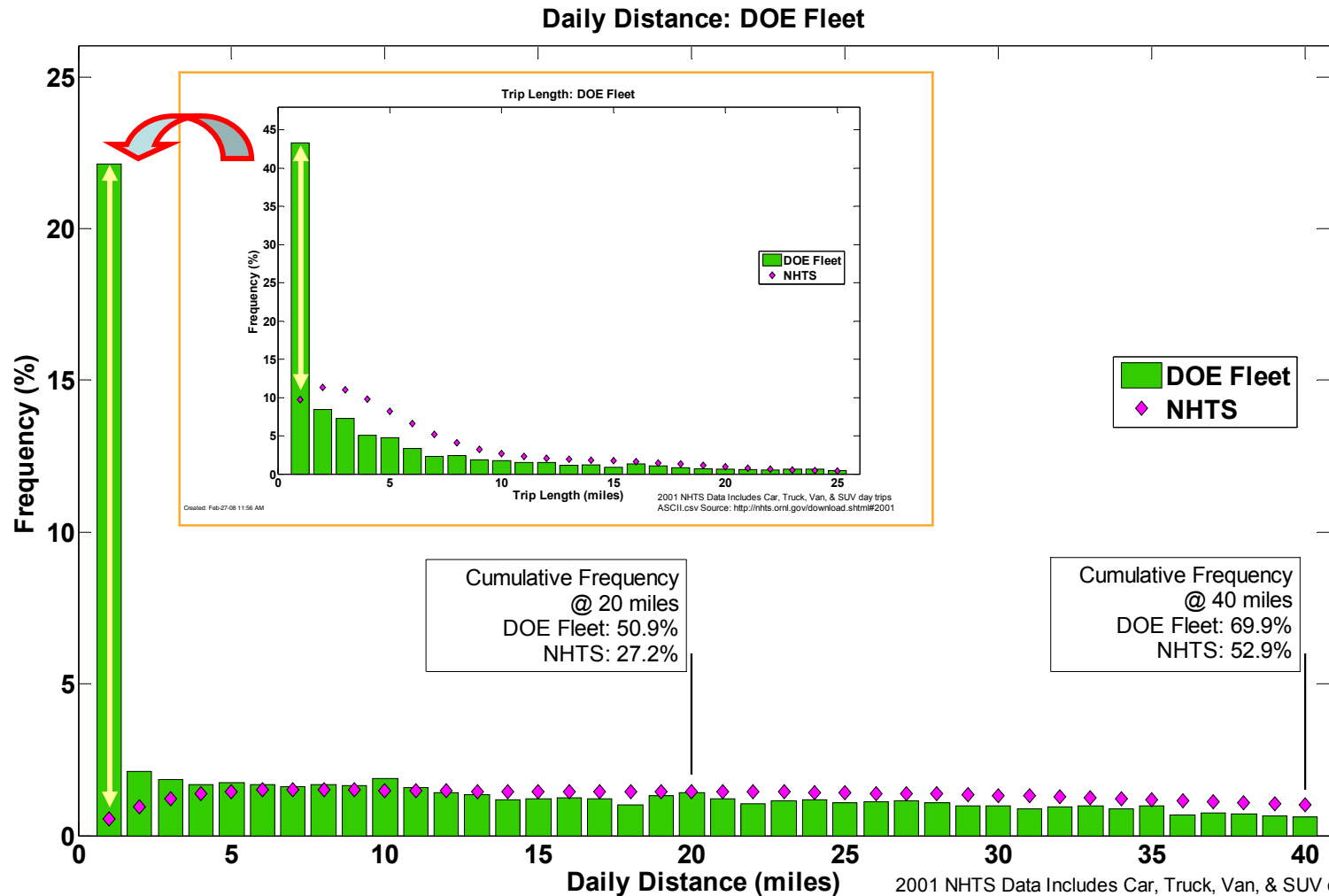
Primary Factors Affecting Fuel Cell Degradation are Hard to Extract, and Different (sometimes opposite) for Each Team



- 1) On-going fuel cell degradation study using Partial Least Squares (PLS) regression model for each team.
- 2) Teams' PLS models have a high percentage of explained decay rate variance, but the models are not robust and results are scattered.

H*: Factor group associated with high decay rate fuel cell stacks
 L**: Factor group associated with low decay rate fuel cell stacks

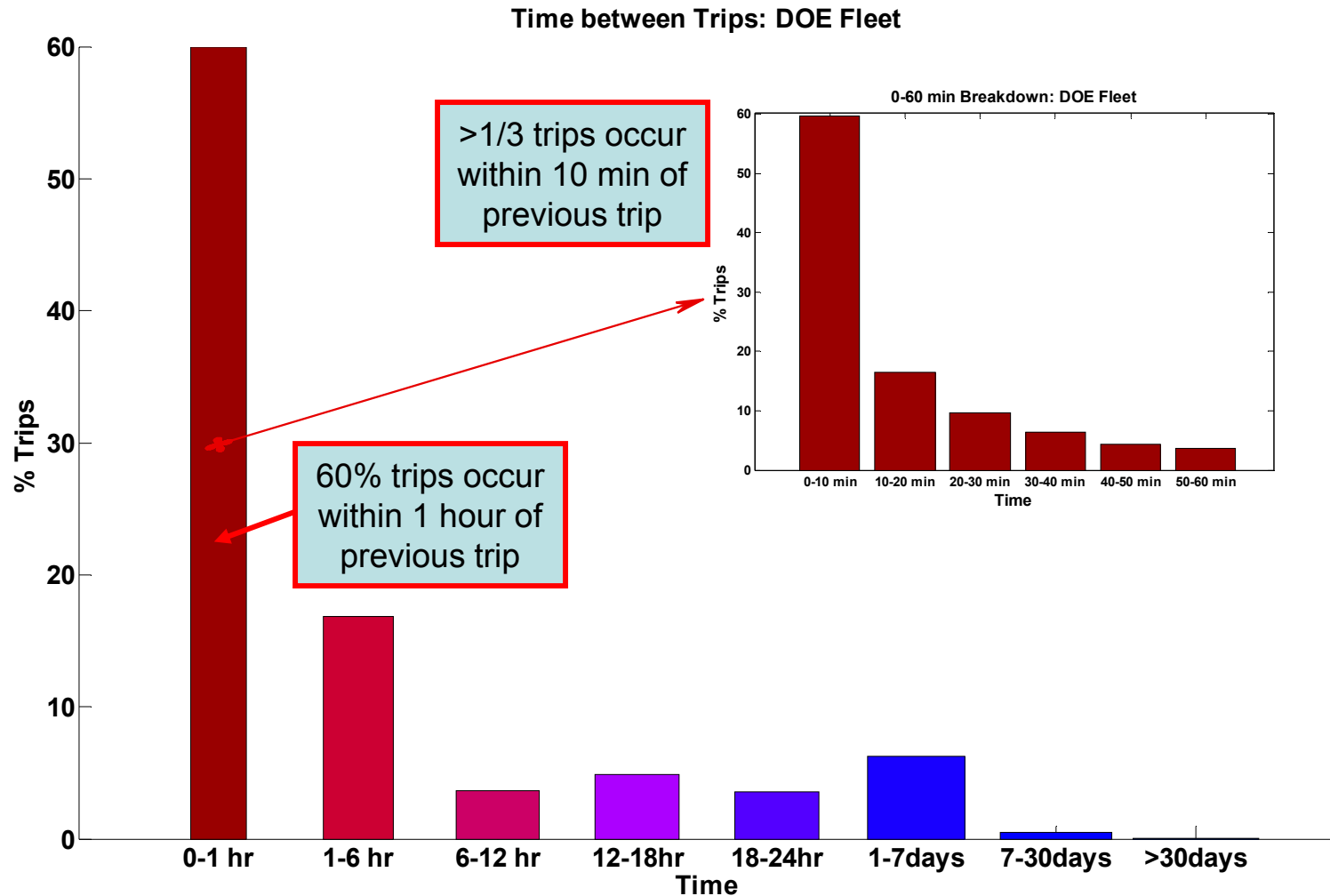
Large Number of Short Trips Contribute to a Lower Daily Distance than National Average



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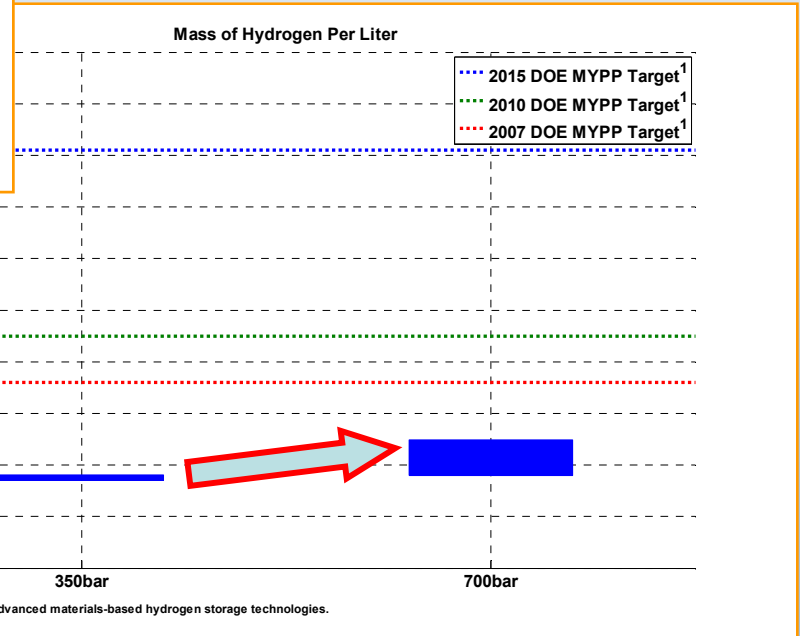
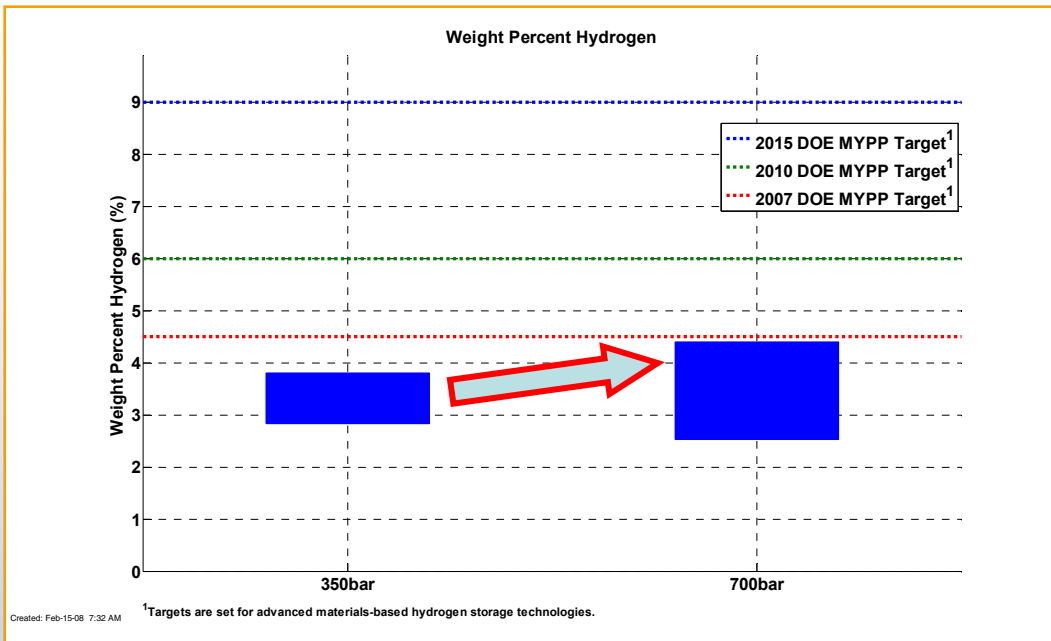
2001 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: <http://nhts.orl.gov/download.shtml#2001>

Examining Time Between Trips Shows Fuel Cells Experiencing Large # Hot Starts



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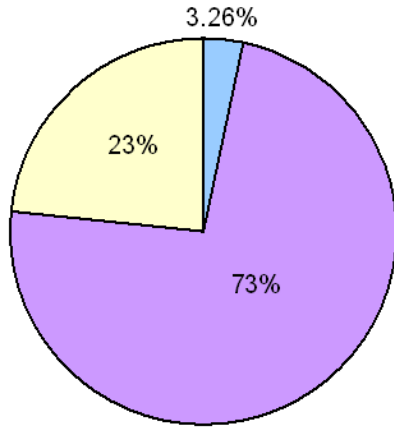
700 bar On-Board H2 Storage Systems Demonstrate Potential for Improved Performance Over 350 bar



2nd Gen Vehicle Storage Data Now Available; Allows a Comparison of 350 bar vs. 700 bar

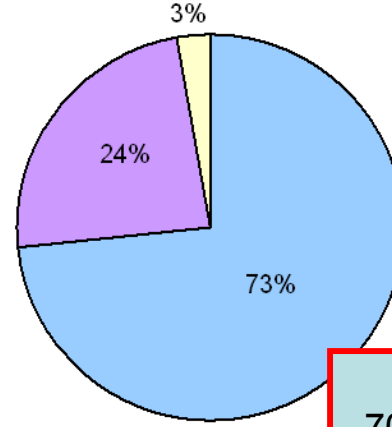
More Detailed Data Reporting Allows a Comparison of Mass and Volume of H2, Pressure Vessel, and BOP

Average Breakout of H2 Storage System Mass

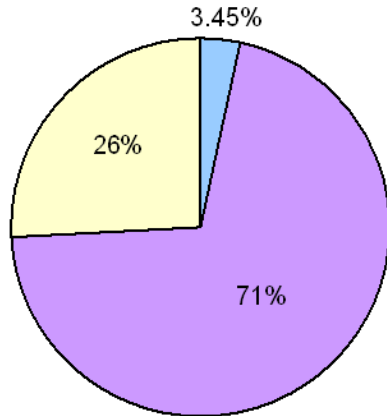


350 bar

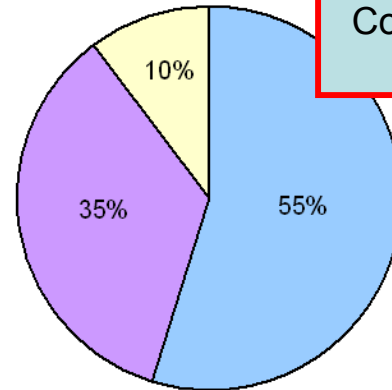
Average Breakout of H2 Storage System Volume



Pressure Vessel and BOP for 700 bar Systems Take Up Larger % of Volume, but Allow for a More Compact Package and Extended Range



700 bar

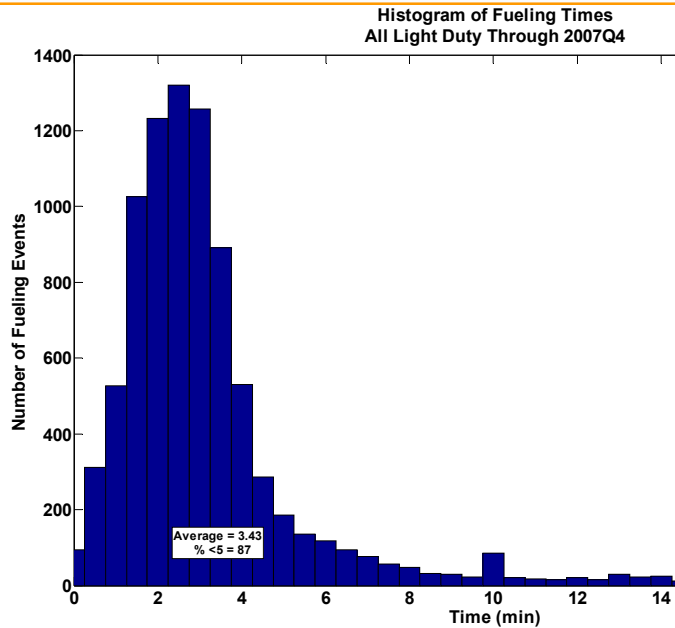


■ H2 Mass (%)
■ Pressure Vessel Mass (%)
■ Balance of Plant Mass (%)

■ H2 Volume (%)
■ Pressure Vessel Volume (%)
■ Balance of Plant Volume (%)

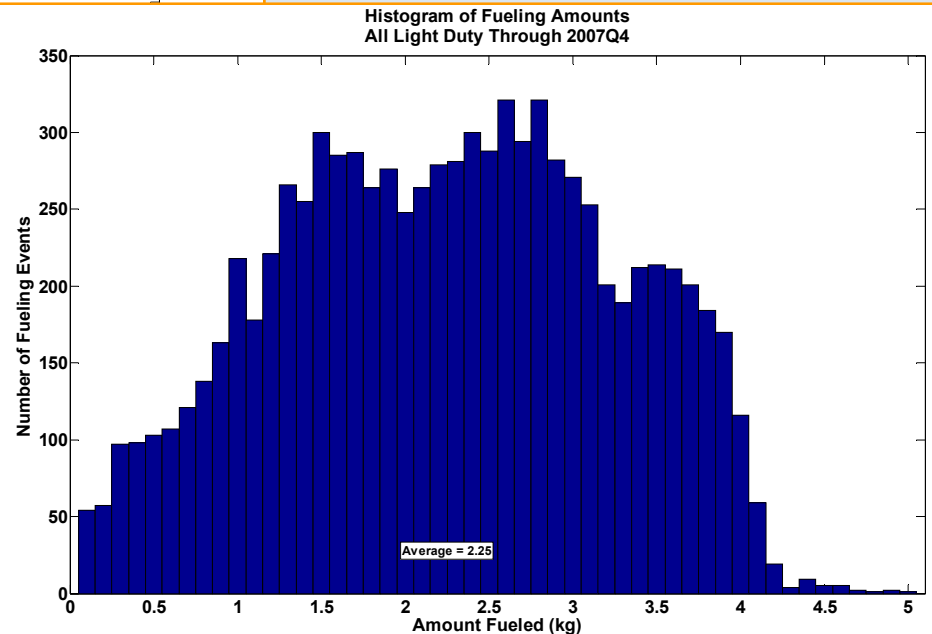
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Actual Vehicle Refueling Times and Amounts from 8,700 Events: Measured by Stations or by Vehicles



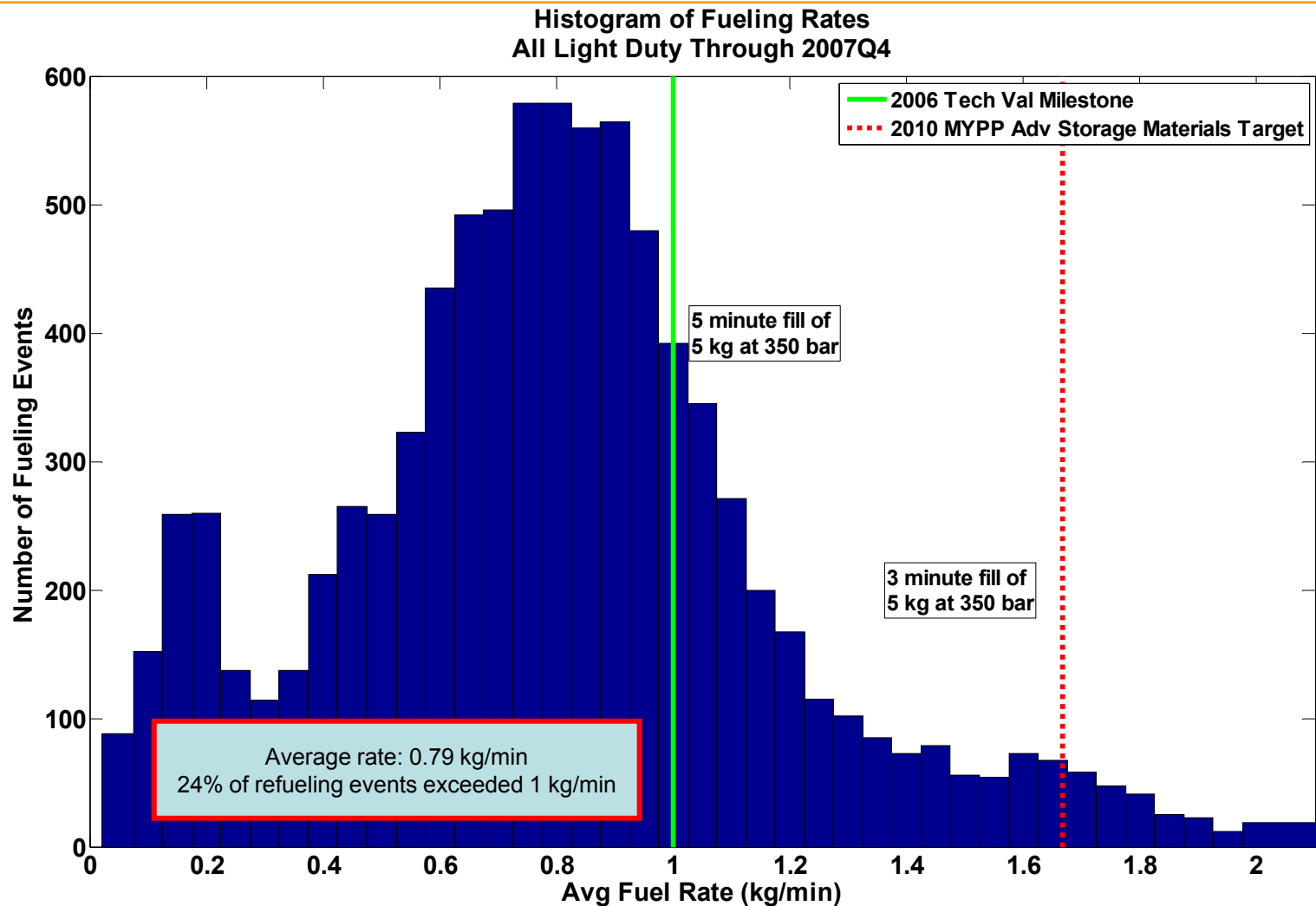
Average time: 3.43 min
87% of refueling events took <5 min

Average fill amount: 2.25 kg



Includes Communication and
Non-Communication Fills

Actual Vehicle Refueling Rates from >8,700 Events: Measured by Stations or by Vehicles

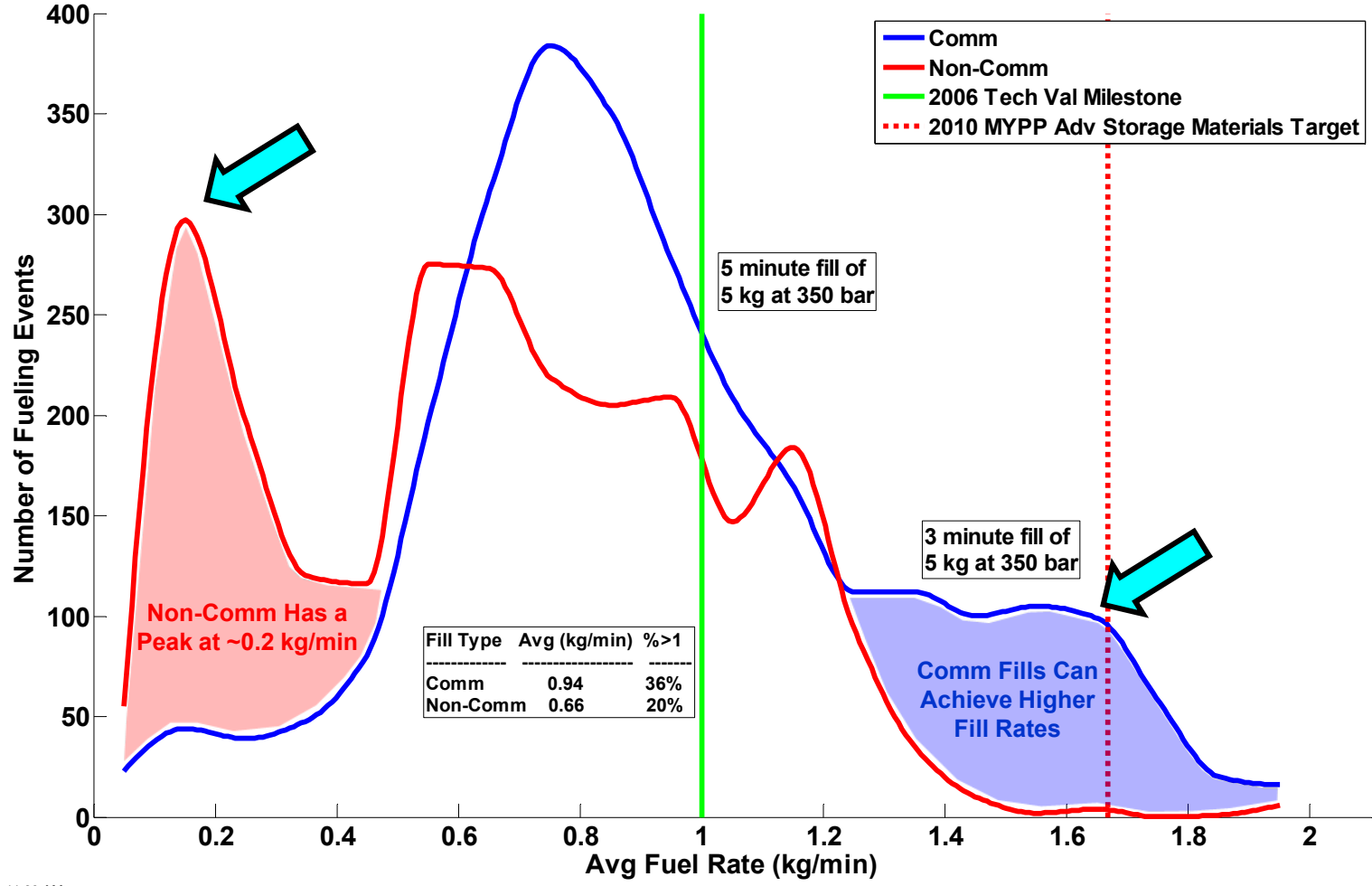


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Includes Communication and Non-Communication Fills

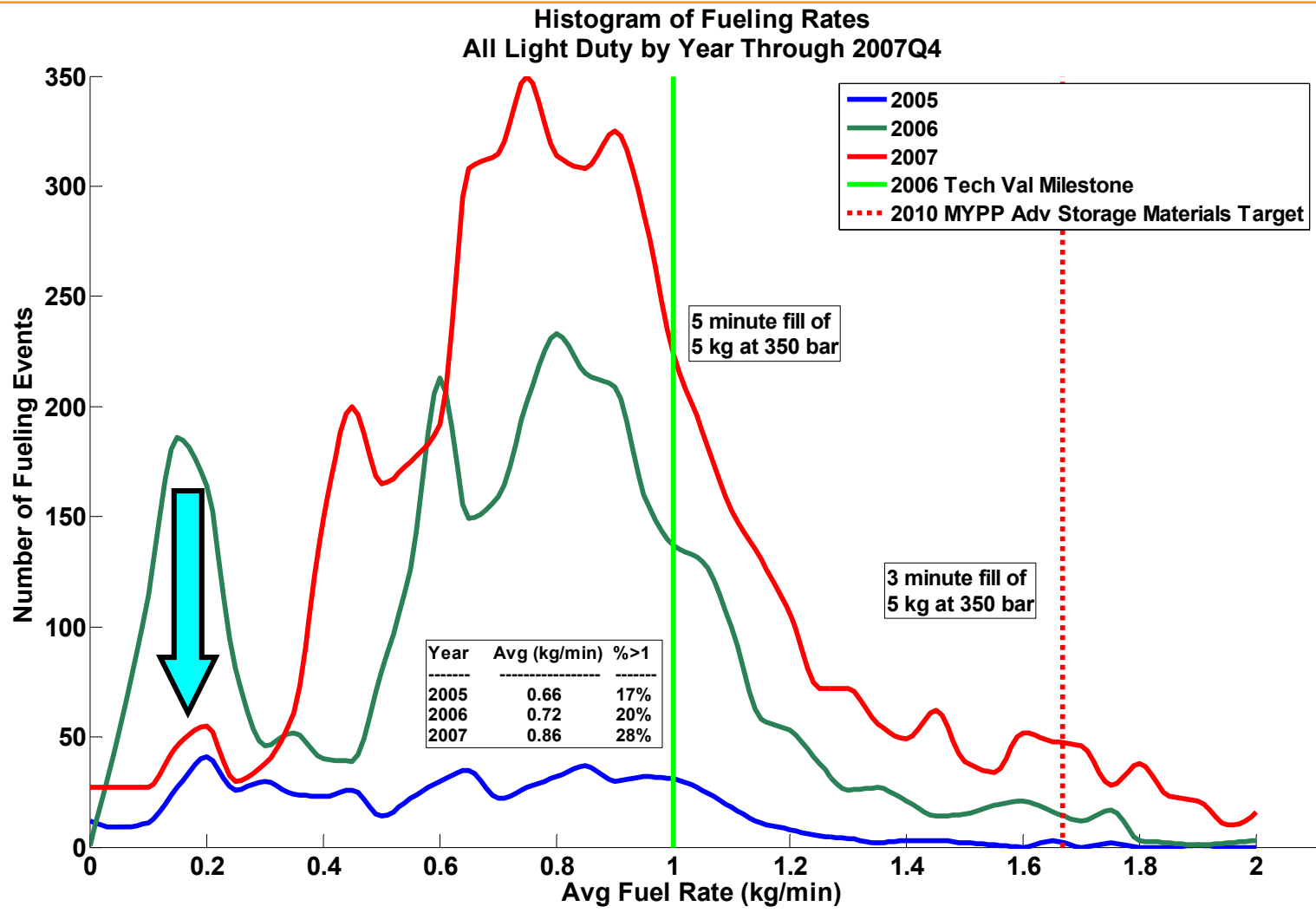
Communication H2 Fills Achieving Higher Fill Rate than Non-Communication

Histogram of Fueling Rates
Comm vs Non-Comm Fills - All Light Duty Through 2007Q4



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Examining Refueling Data by Year Shows 0.2 kg/min Rate Phased Out



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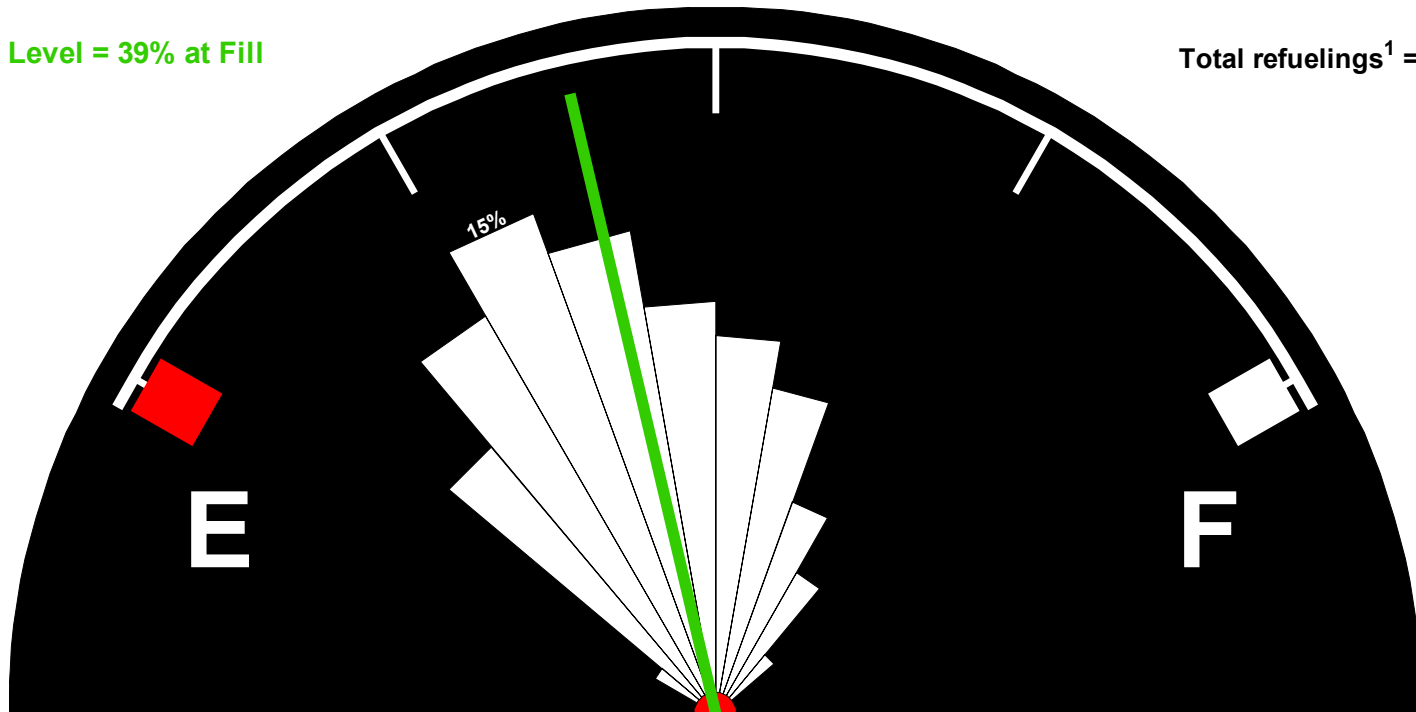
Includes Communication and Non-Communication Fills

Large Spread in H2 Tank Level at Refueling Peak at ~1/4 Full, Median at ~3/8 Full

Tank Levels: DOE Fleet

Median Tank Level = 39% at Fill

Total refuelings¹ = 13085

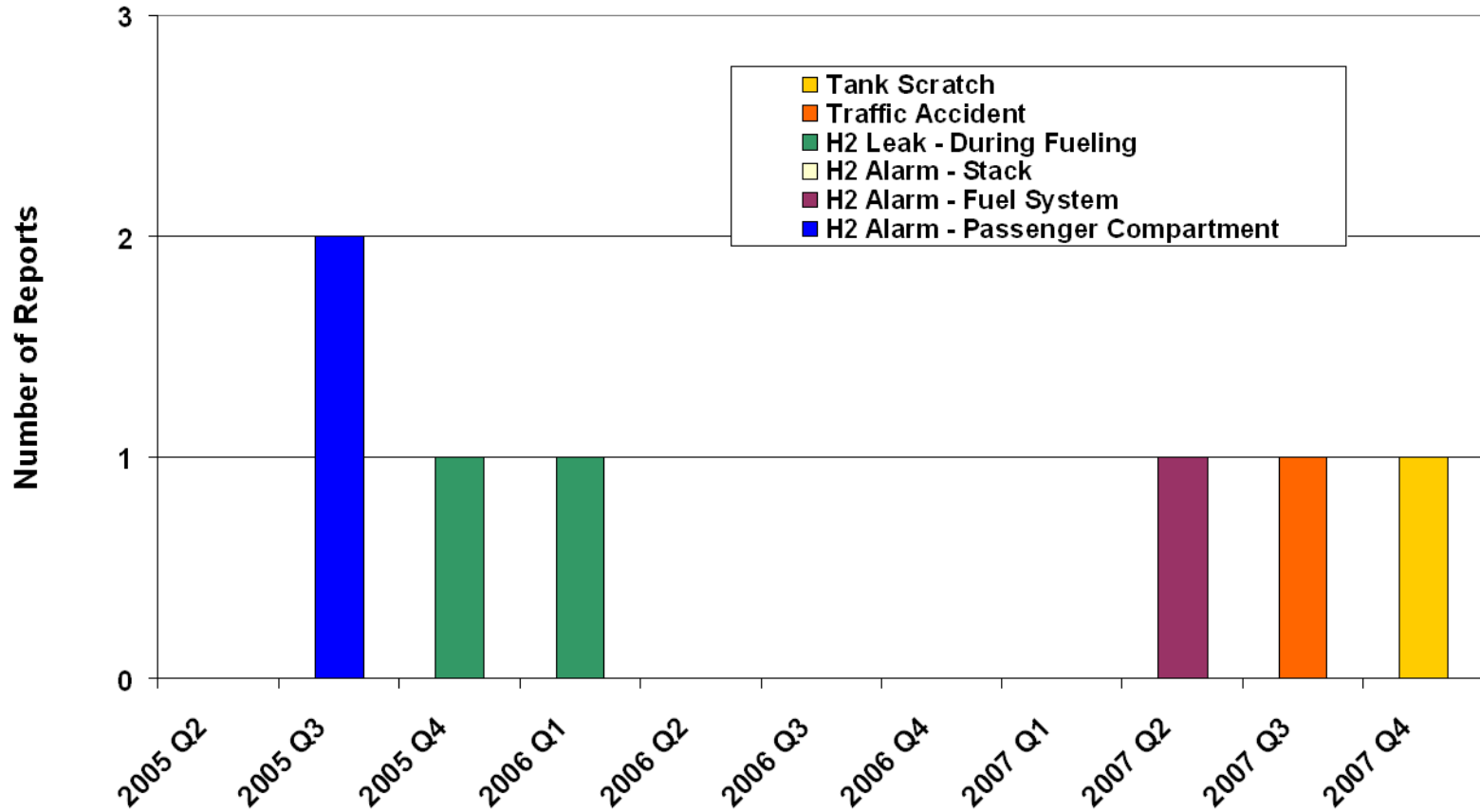


1. Some refueling events not recorded/detected due to data noise or incompleteness.
2. The outer arc is set at 20% total refuelings.
3. If tank level at fill was not available, a complete fill up was assumed.

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Minimal Vehicle Safety Reports Continue to Demonstrate a Strong Safety Record

Safety Reports - Vehicle Operation

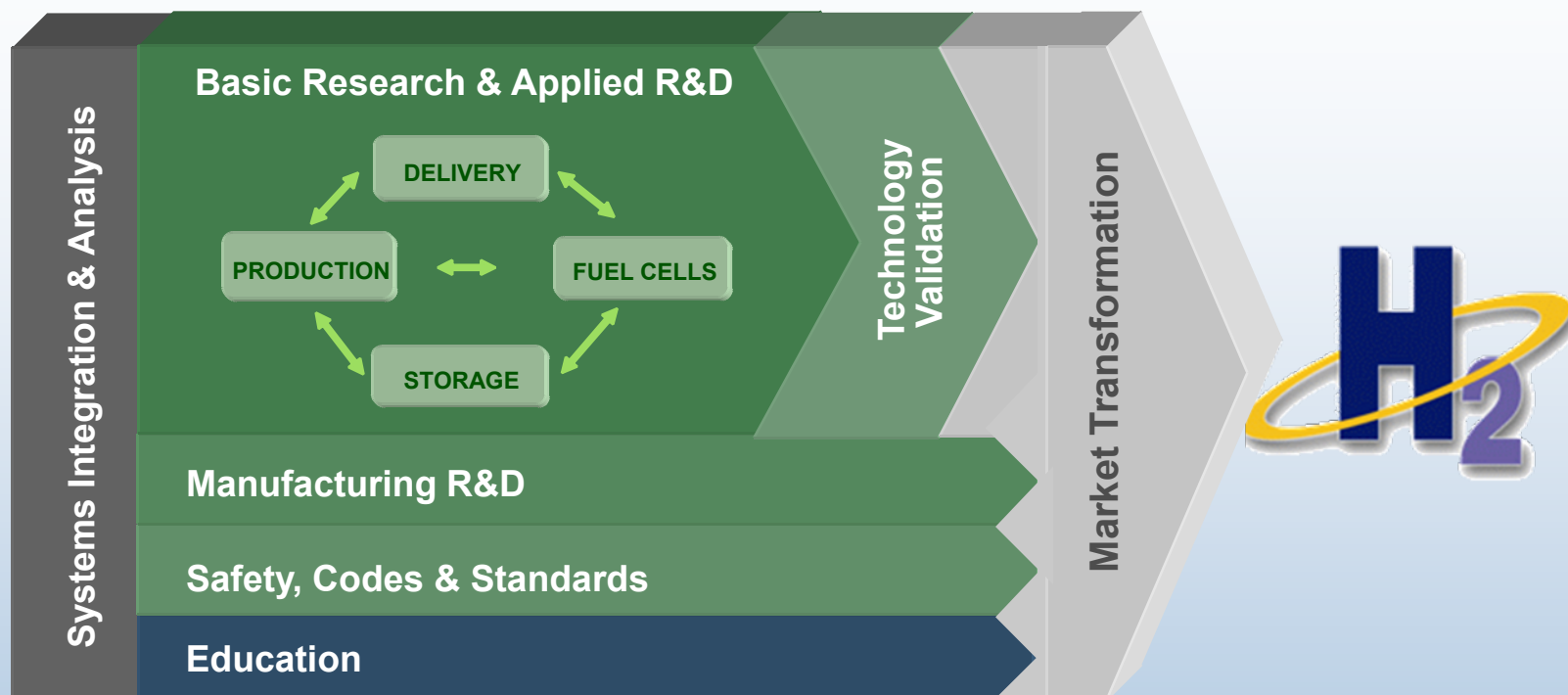


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Summary

- More than half of project completed
 - 92 vehicles and 14 stations deployed
 - 1.1 million miles traveled, 40,000 kg H₂ produced or dispensed
 - 209,000 individual vehicle trips analyzed
 - Project to continue through 2009
- Examination of Factors Affecting FC Degradation Continues
 - NREL collaborating with each team to understand results and refine inputs and analysis
 - Triggered more thorough analysis of vehicle/stack duty cycles, such as time between trips, trip length, FC power levels
- Total of 47 composite data products published to date
 - This presentation only covered some of the new/updated results
 - Web site allows direct web access to all CDPs
- Roll-out of 2nd generation vehicles has begun
 - Most of remaining vehicles to be deployed this year
 - Additional 700 bar stations coming online soon

Questions and Discussion



Project Contact: Keith Wipke, National Renewable Energy Lab
303.275.4451 keith_wipke@nrel.gov

All public Learning Demo CDPs, papers, and presentations are available online at http://www.nrel.gov/hydrogen/proj_tech_validation.html