NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Controlled Hydrogen Fleet and Infrastructure Analysis

Project ID# tv_01_wipke

2009 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

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Washington, DC

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Fuel Cell Vehicle Learning Demonstration Project Objectives, Relevance, and Targets

- Objectives
  - Validate H_2 FC Vehicles and Infrastructure in Parallel
  - Identify Current Status and Evolution of the Technology
- Relevance
  - Objectively Assess Progress Toward Technology Readiness
  - Provide Feedback to H_2 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

Photo: NREL

Project Overview

Timeline

- Project start: FY03
- Project end: FY10
- ~80% of Task III complete (see timeline slide)

Budget

- Context: Overall DOE project is ~$170M over 5 years
  - Equal investment by industry
- NREL funding prior to FY08 : $3042K
- NREL FY08 funding: $900K
- NREL FY09 funding: $700K

Partners

- See partner slide

Tech. Val. Barriers

A. **Vehicles** – lack of controlled & on-road H_2 vehicle and FC system data

B. **Storage** – technology does not yet provide necessary 300+ mile range

C. **Hydrogen Refueling Infrastructure** – cost and availability

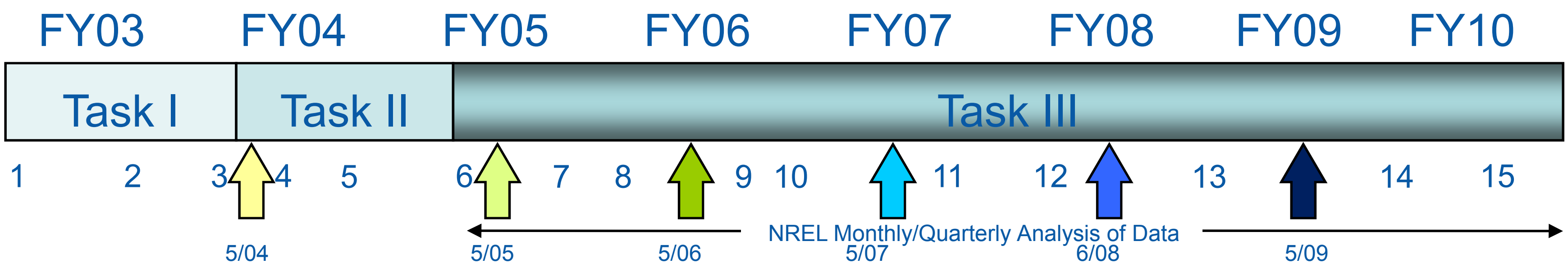
D. **Maintenance and Training Facilities** – lack of facilities and trained personnel

E. **Codes and Standards** – lack of adoption/validation

H. **Hydrogen Production from Renewables** – need for cost, durability, efficiency data for vehicular application

I. **H_2 and Electricity Co-Production** – cost and durability

Project Timeline and Major Milestones



Task I – Project Preparation [100% Complete]

1 Support development of RFP, statement of objectives (Appendix C)
2 Bidder's meeting in Detroit – launch of RFP
3 Create data analysis plan and presentation for discussion with industry

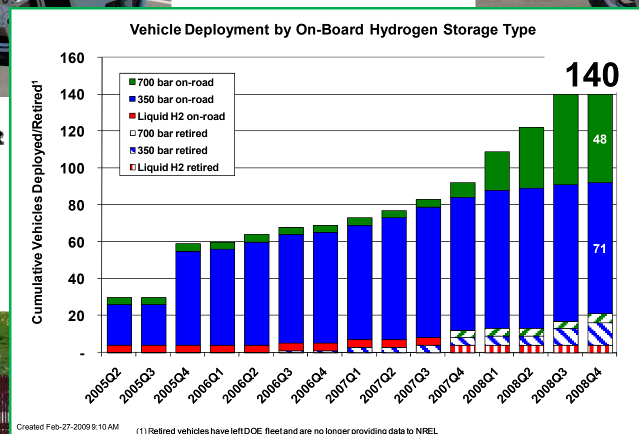
Task II – Project Launch [100% Complete]

4 Announcement of successful bidders (4/04)
5 Kick-off meetings and cooperative agreement awards

Task III – Data Analysis and Feedback to R&D activities (partial list) [80% Complete]

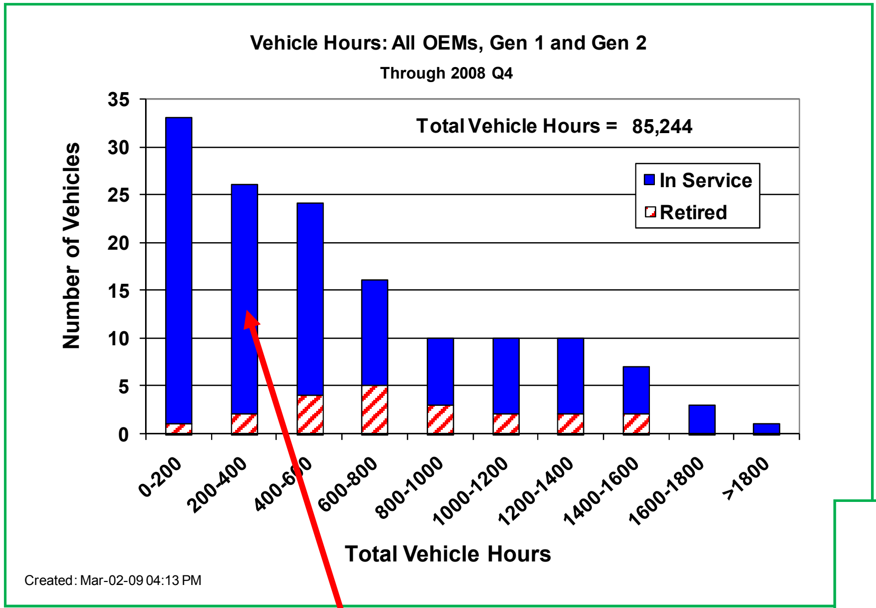
6 Preliminary data collection, analysis, and first quarterly assessment report
7 Demonstrate FCVs that achieve 50% higher fuel economy than gasoline vehicles
8 Publication of first "composite data products"
9 Evaluate FC stack time to 10% voltage degradation relative to 1000-hour target
10 Decision for purchase of additional vehicles based on performance, durability, cost
11 Preliminary evaluation of dominant real-world factors influencing FC degradation
12 Introduction of 2nd generation FC systems into vehicles begins
13 FCVs demonstrate 250-mile range without impacting passenger cargo compartment
14 Validate FCVs with 2,000 hour durability and $3.00/gge (based on volume production)
15 Decision to proceed with Phase 2 of the Learning Demonstration

Industry Partners: 4 Automaker/Energy-Supplier Teams; Gen 2 Fleet Is Now Fully Deployed, Some Vehicles Retired

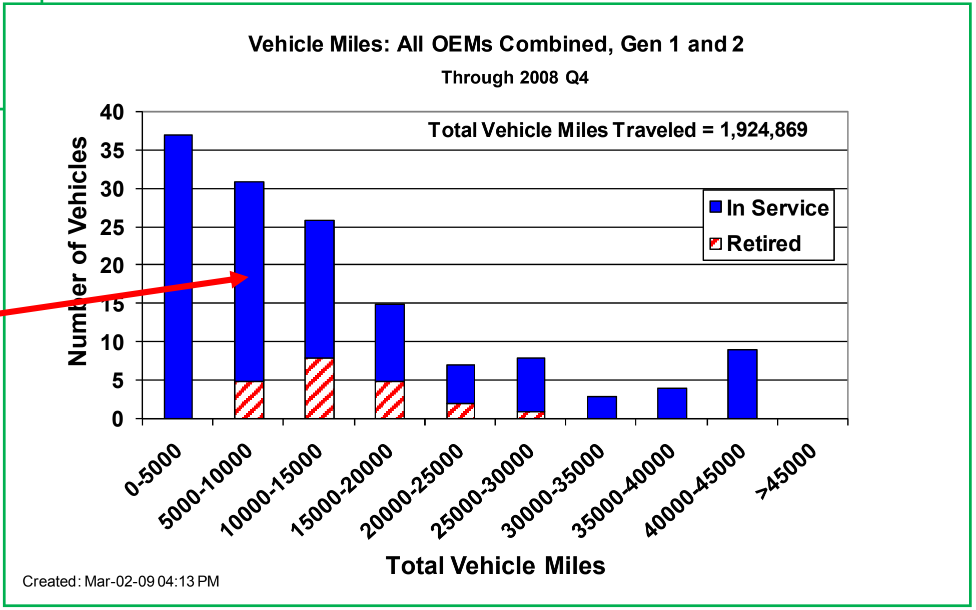


21 vehicles retired
119 still on road

DOE Learning Demo Fleet Has Surpassed 85,000 Vehicle Hours and 1.9 Million Miles

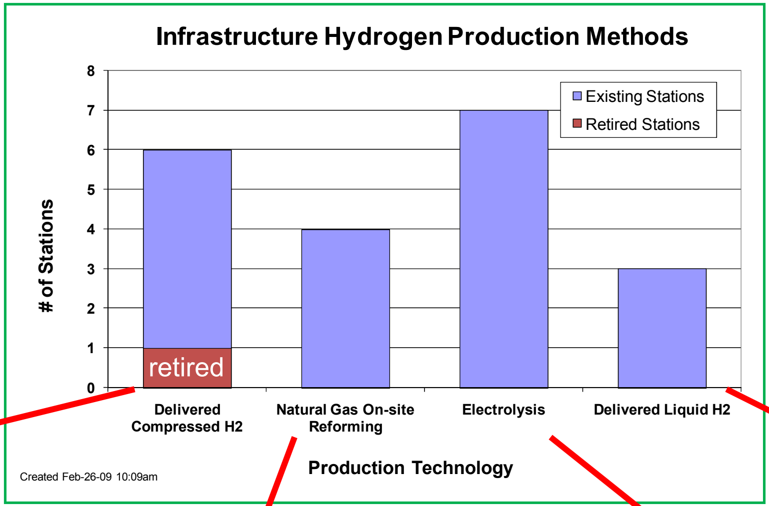


Some Gen 1 vehicles have now been retired (red bars)



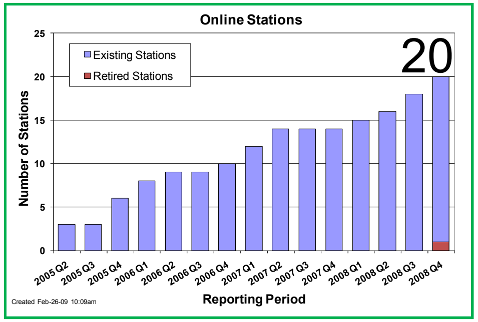
Gen 2 vehicles make up most of 2nd bulge at low hours/miles

Majority of Project's Fixed Infrastructure to Refuel Vehicles Has Been Installed – Examples of 4 Types



Mobile Refueler Sacramento, CA

Delivered Liquid, 700 bar Irvine, CA



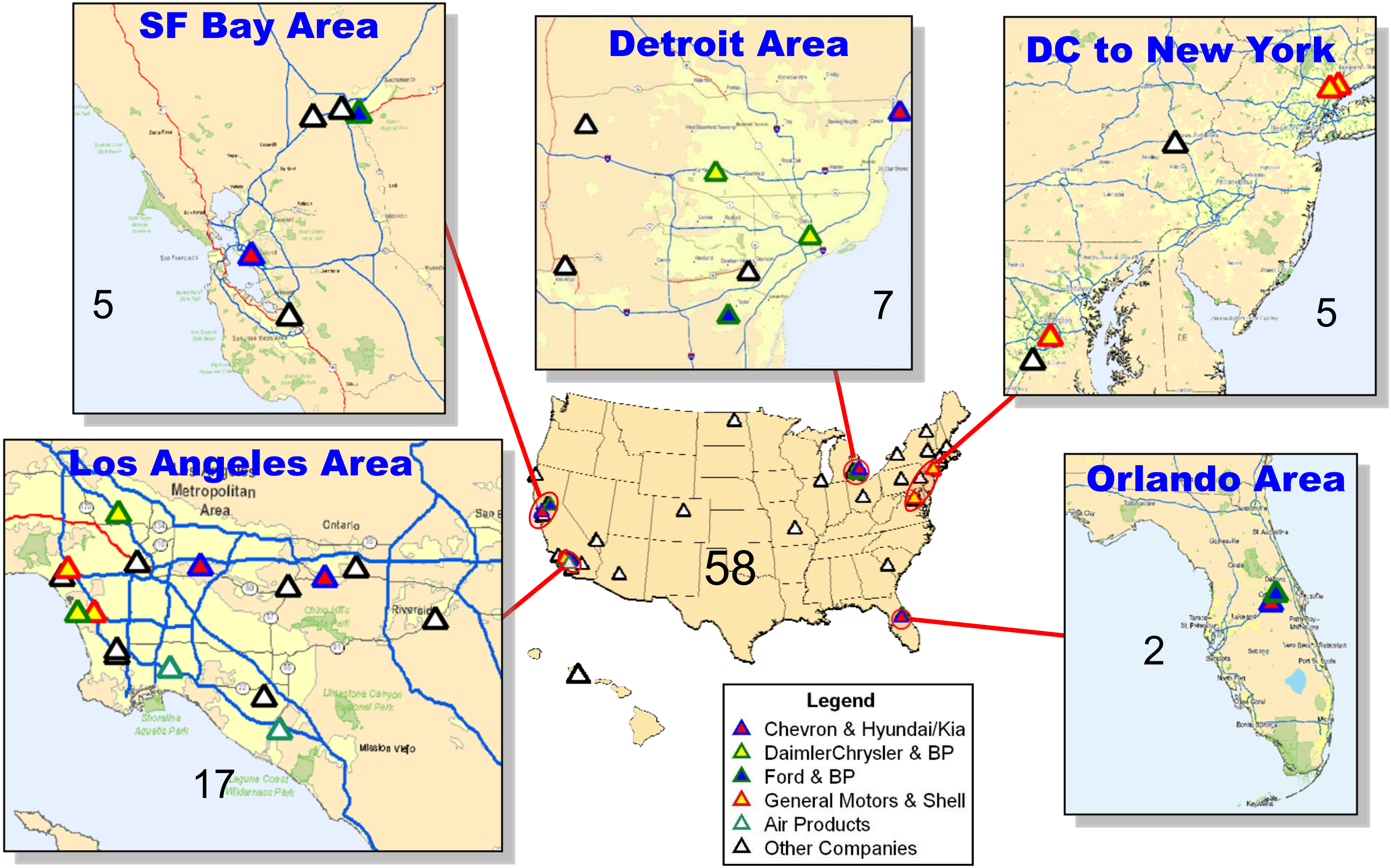
Steam Methane Reforming Oakland, CA

Water Electrolysis Santa Monica, CA

Total of 90,000 kg H_2 produced or dispensed

Stations added since June 2008:
Burbank, Long Beach, Ardsley, LAX-east
20 stations now deployed through Dec.

Refueling Stations Test Performance in Various Climates; Learning Demo Stations Comprise ~1/3 of all U.S. Stations



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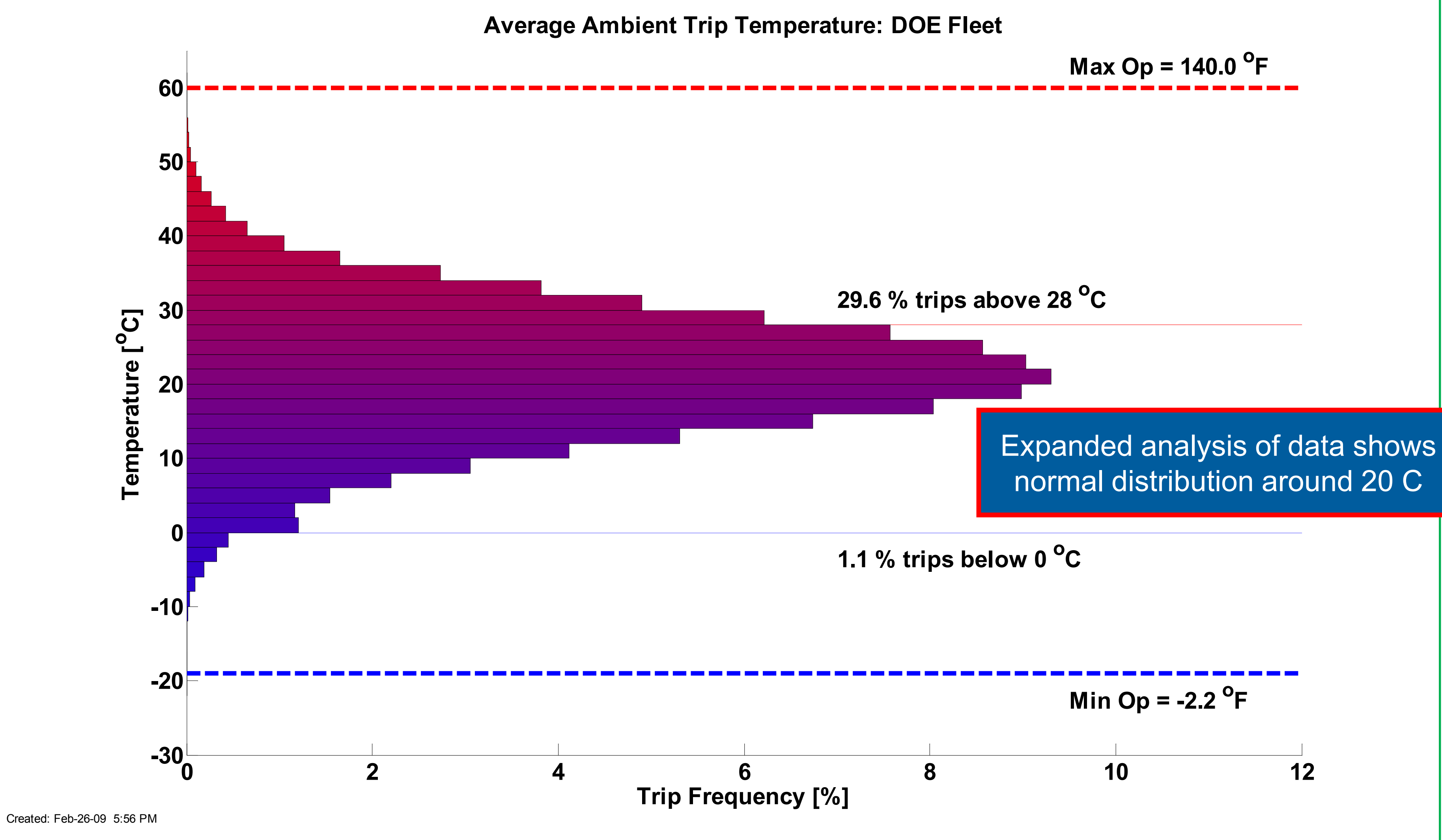
Distribution of Average Ambient Temperature During Vehicle Operation



Expanded analysis of data shows normal distribution around 20 C

Project Approach

- Provide facility and staff for securing and analyzing industry sensitive data
  - NREL Hydrogen Secure Data Center (HSDC)

- Perform analysis and simulation using detailed data in HSDC to:
  - Evaluate current status and progress toward targets
  - Feed back current technical challenges and opportunities into DOE H_2 R&D program
  - Provide analytical results to originating companies on their own data (detailed data products)
  - Collaborate with industry partners on new and more detailed analyses

- Publish/present progress of project to public and stakeholders (composite data products)

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

Raw Data, Reports

Hydrogen Secure Data Center (HSDC)

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

Composite Data Products

- Aggregate data results for public
- No confidential information

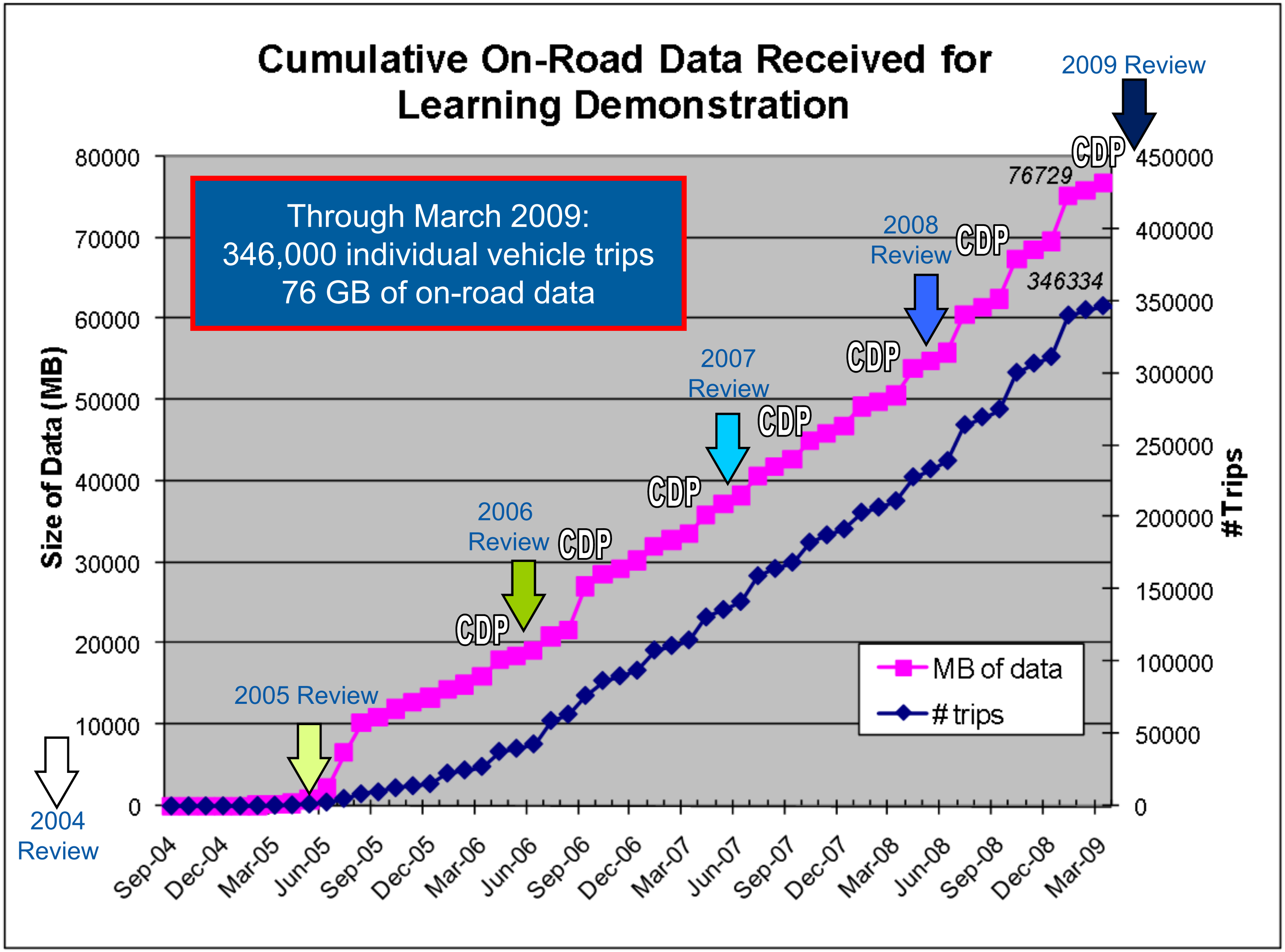
http://www.nrel.gov/hydrogen/cdp_topic.html

Detailed Data Products

- Only shared with company/team that originated the data

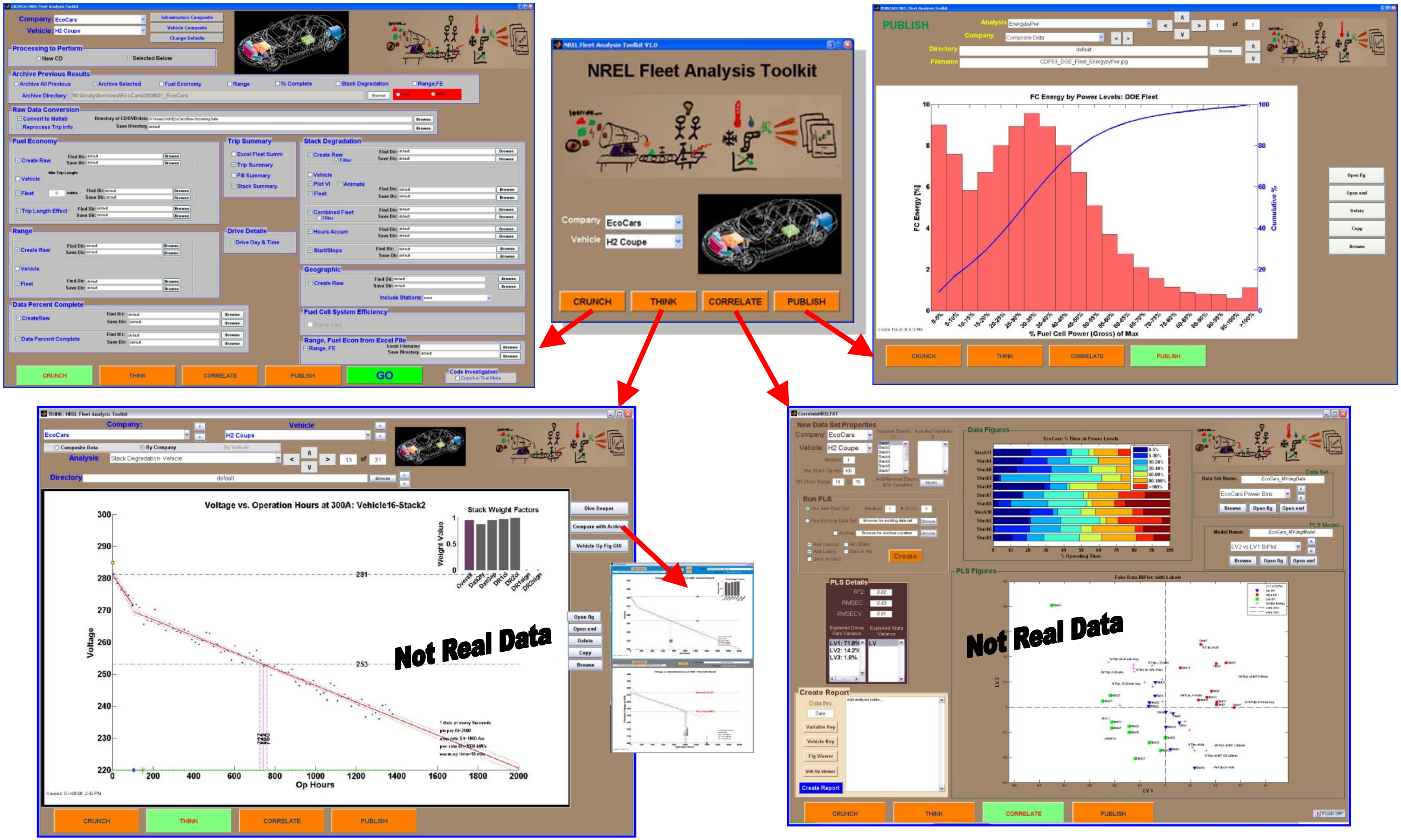
DDPs now provided at time of CDP review

Accomplishment: 15 Quarters of Data Analyzed to Date, Two New Sets of Composite Data Products Published



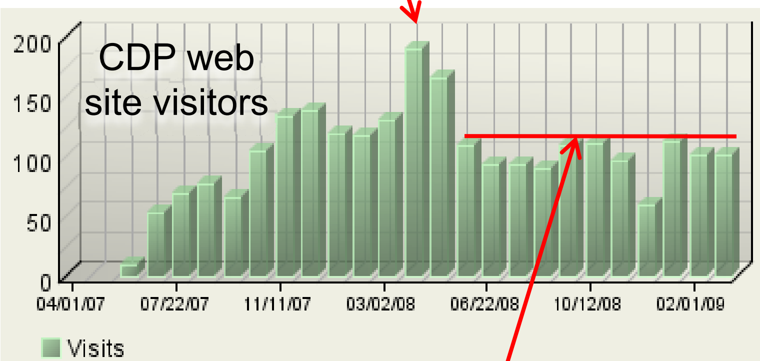
CDP = Composite Data Products Published

Accomplishment: Expanded NREL's Data Analysis Tool – Fleet Analysis Toolkit (FAT)



Accomplishment: Successfully Communicating Results, Papers, and Presentations Available to Public through Web Site

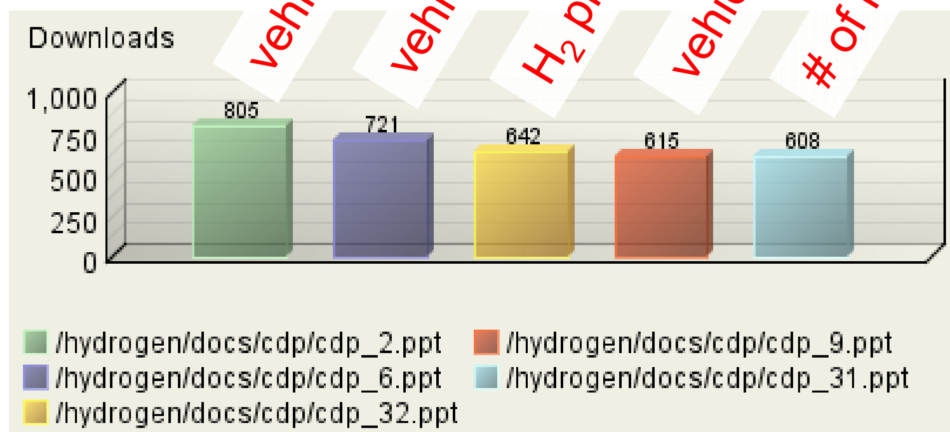
Spike in activity after NHA conference



Sustained activity Over the last year at ~100 visitors/month

Top 5 CDPs viewed

vehicle range
vehicle fuel economy
H_2 production method
vehicle safety
# of refueling stations

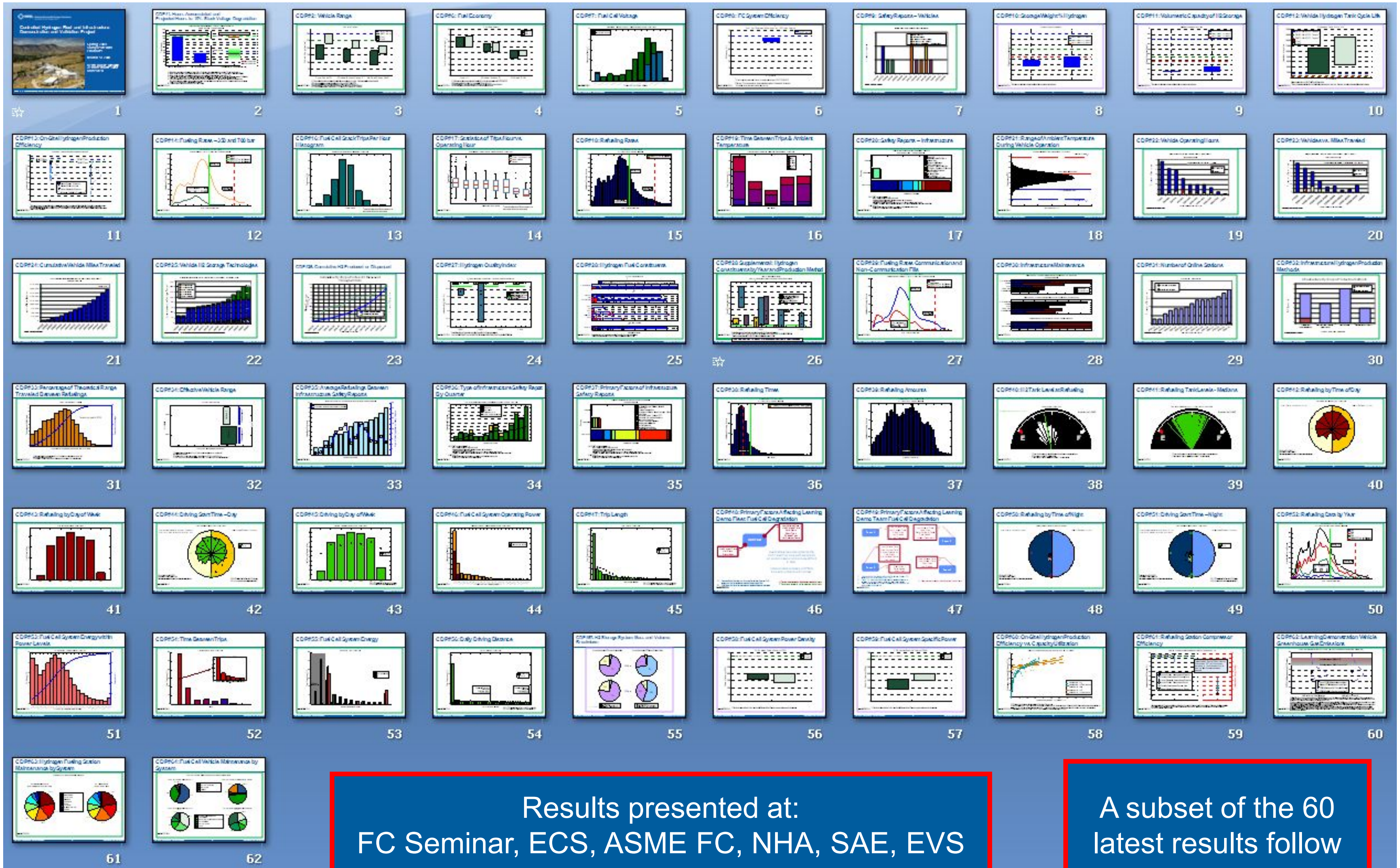


Visitor Summary	
Visitors	1,462
Visitors Who Visited Once	1,266
Visitors Who Visited More Than Once	196
Average Visits per Visitor	1.68

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

Summer 2007 Learning Demo Progress Report downloaded **2607** times (11th most popular on NREL's H_2 web site)

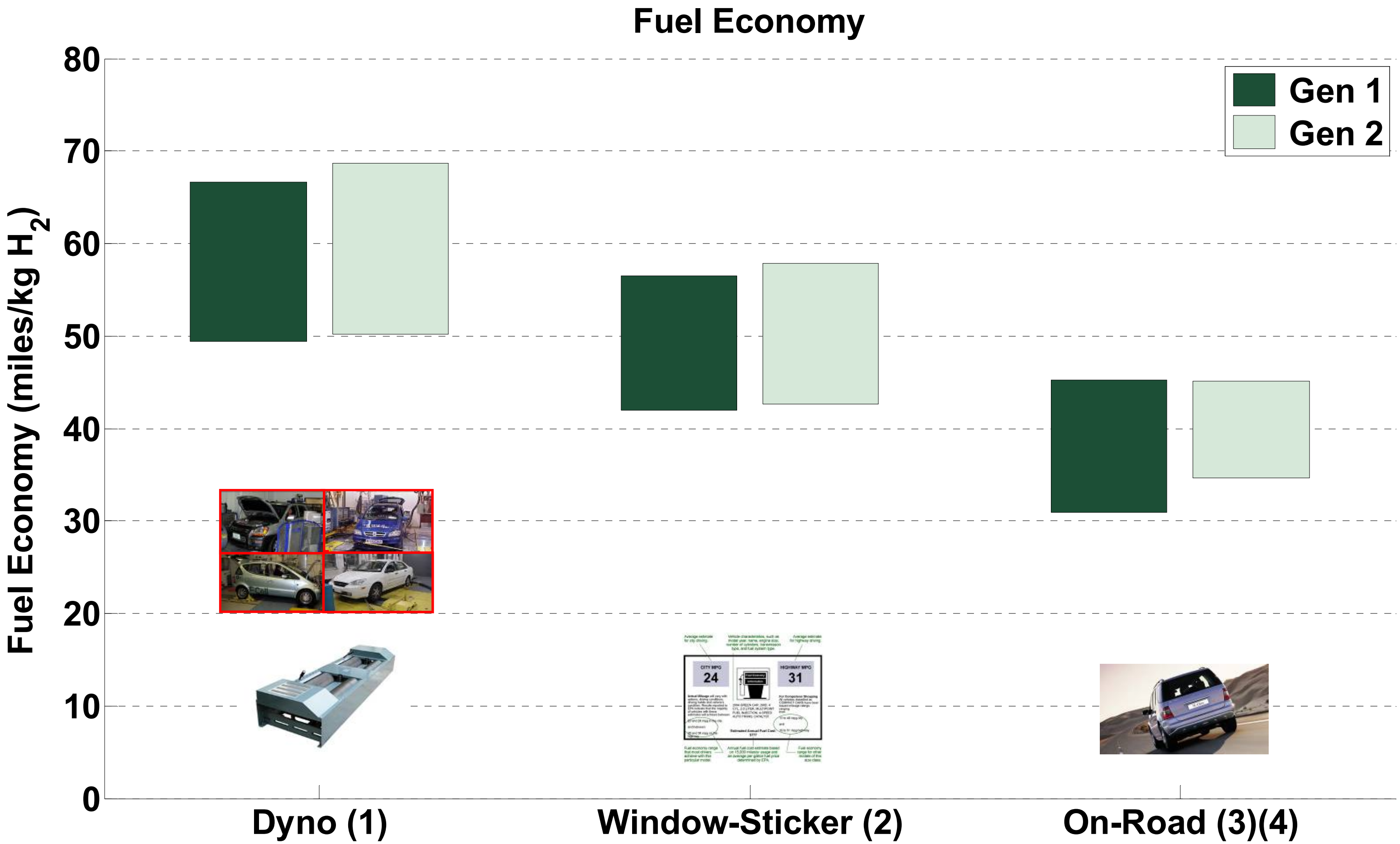
Accomplishment: 60 Public Composite Data Products Have Been Published; New Results and Updates Every 6 Months



Results presented at:
FC Seminar, ECS, ASME FC, NHA, SAE, EVS

A subset of the 60 latest results follow

Ranges of Fuel Economy from Dynamometer and On-Road Data Similar for Gen 1 & 2



(1) One data point for each make/model. Combined City/Hwy fuel economy per DRAFT SAE J2572.
(2) Adjusted combined City/Hwy fuel economy (0.78 x Hwy, 0.9 x 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.

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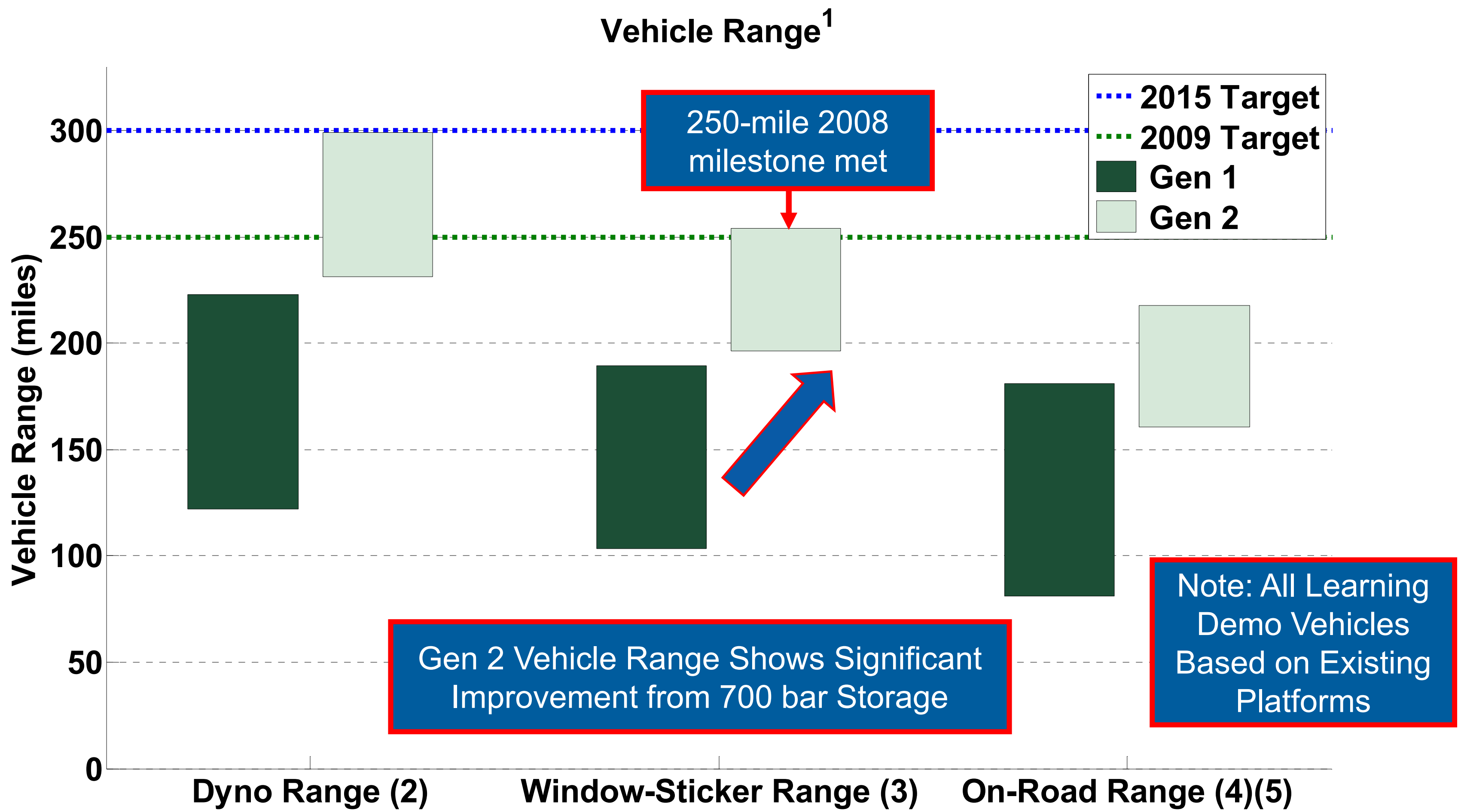
Driving Range for Gen 1 and Gen 2 Vehicles: Based on Fuel Economy and Usable H_2



(1) Range is based on fuel economy and usable hydrogen on-board the vehicle. One data point for each make/model.
(2) Fuel economy from unadjusted combined City/Hwy per DRAFT SAE J2572.
(3) Fuel economy from EPA Adjusted combined City/Hwy (0.78 x Hwy, 0.9 x City).
(4) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.
(5) Fuel economy calculated from on-road fuel cell stack current or mass flow readings.

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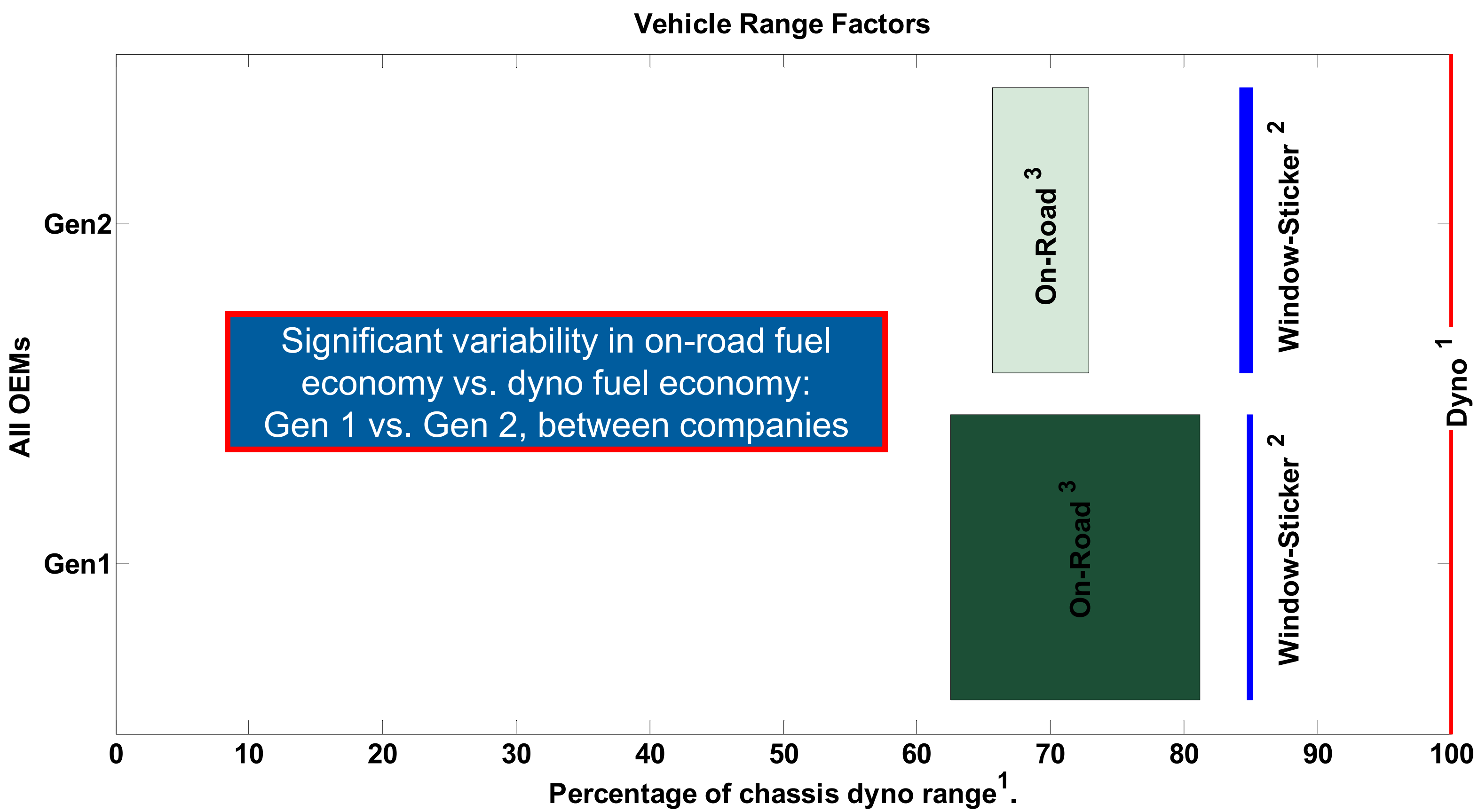
Spread of On-Road Range from Four Teams as a Percentage of Dyno Range



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).

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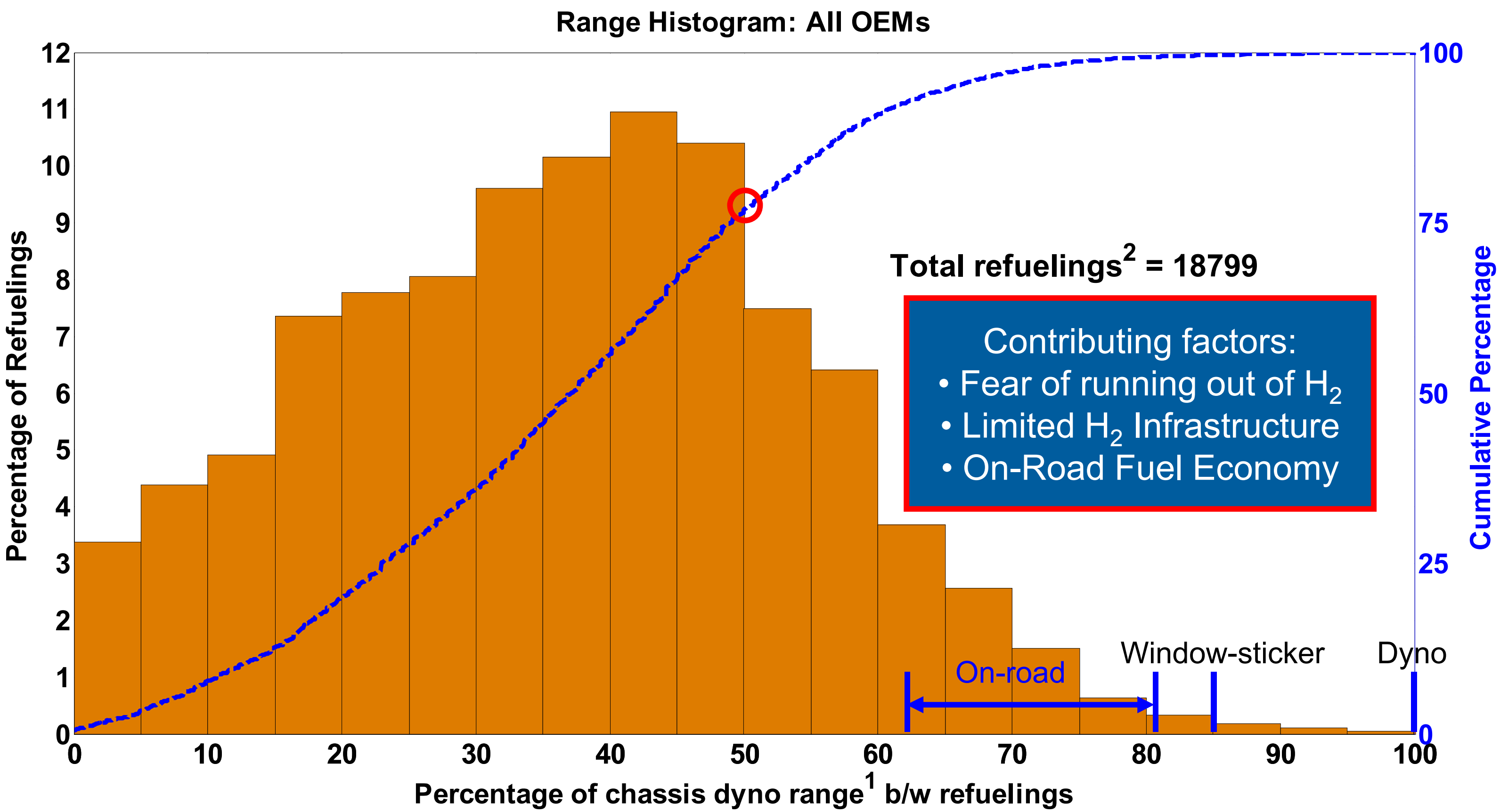
Majority (80%) of Vehicles Travel <1/2 of Dyno Range Between Refuelings



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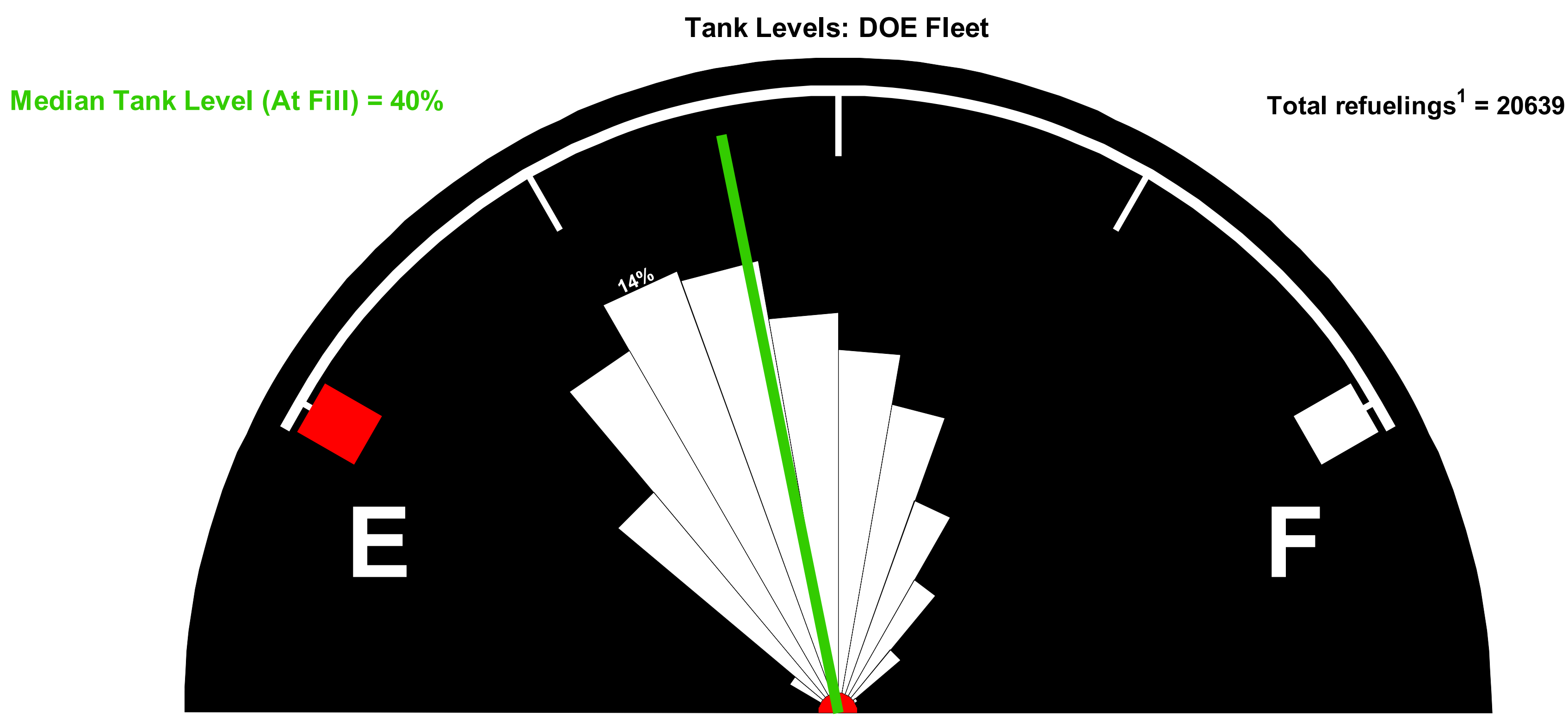
1. Range calculated using the combined City/Hwy fuel economy from dyno testing (not EPA adjusted) and usable fuel on board.
2. Some refueling events are not detected/reported due to data noise or incompleteness.

Large Spread in H_2 Tank Level at Refueling Peak at ~1/4 Full, Median at ~3/8 Full



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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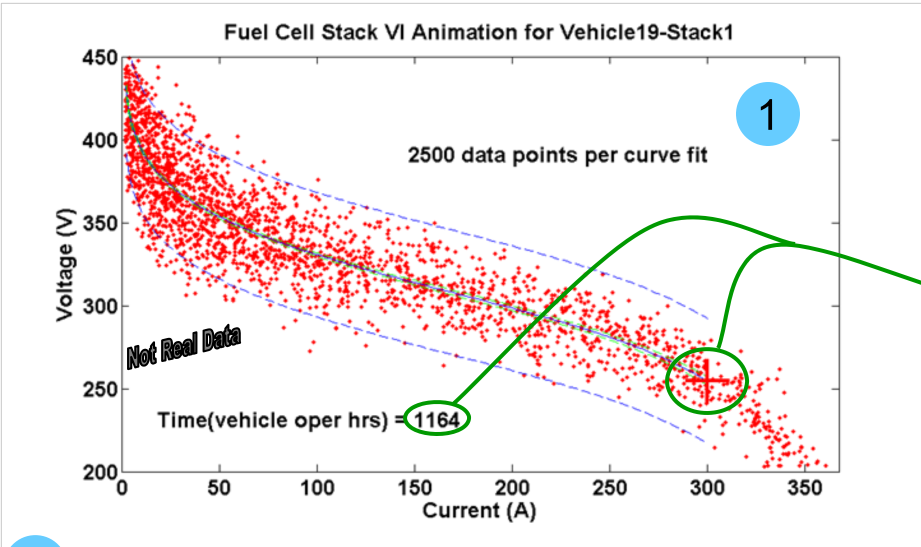
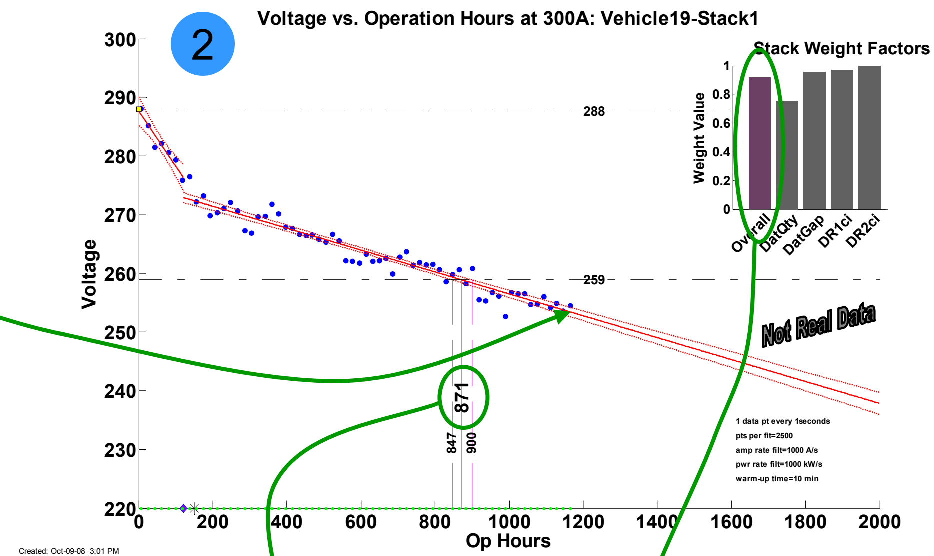
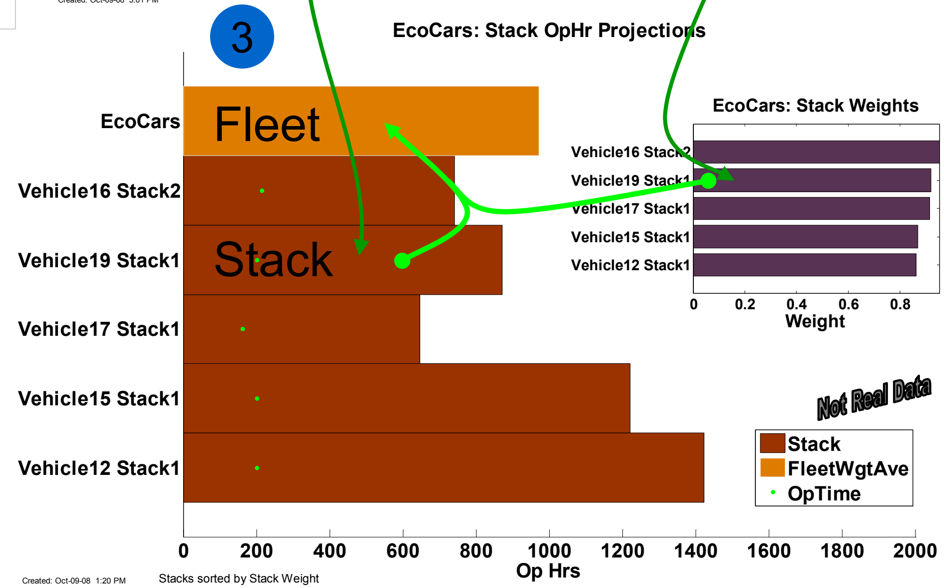
Improved Approach for Calculating Projected Time to 10% Voltage Drop for Stack and Fleet



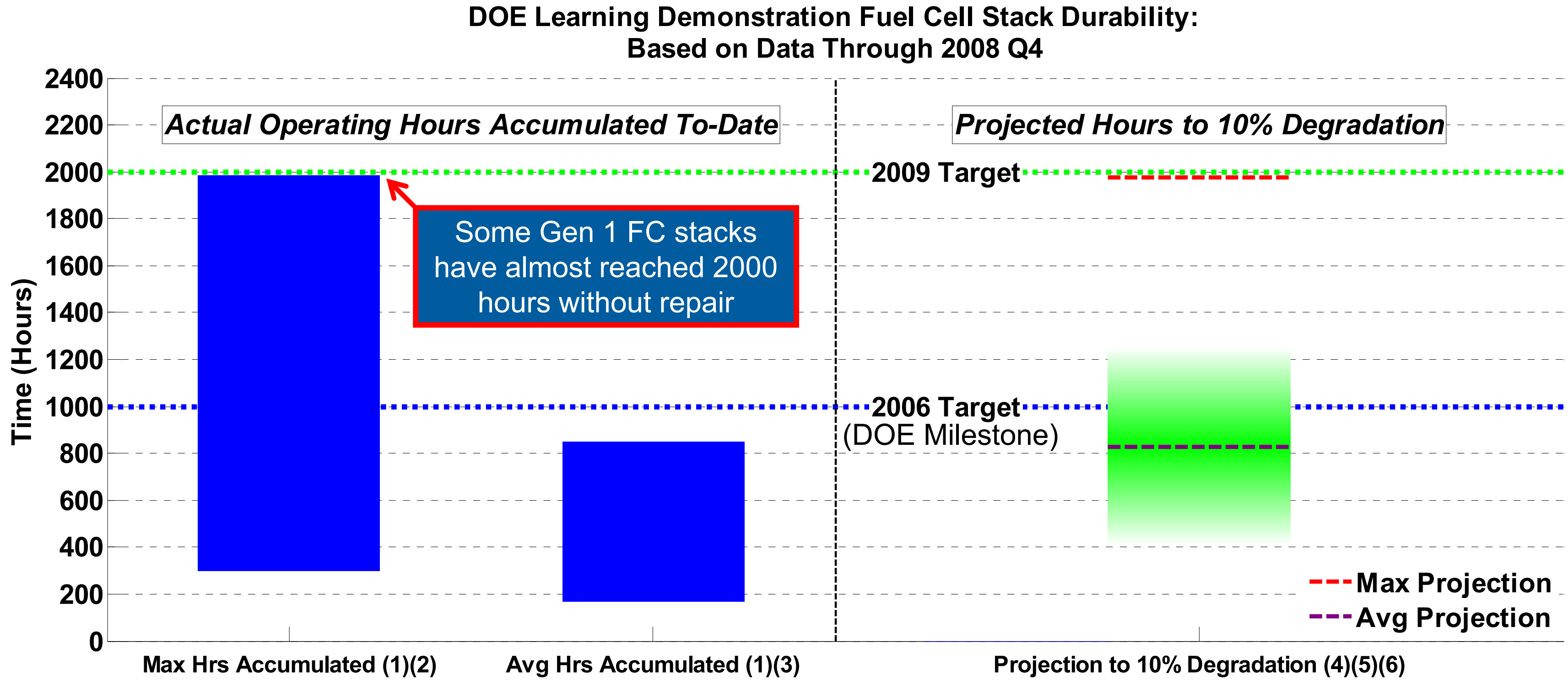




1. ***FC Stack*** voltage & current polarization fit
2. ***FC Stack*** voltage decay estimate using robust, improved **segmented linear fit** instead of linear fit (follows non-linear decay trends & early voltage decay)
3. ***Fleet*** weighted average using FC Stack operating hour projections and weights (based on data and confidence in fit)

Note, 10% voltage drop is a DOE target/metric, not an indicator of end-of-life

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



(1) Range bars created using one data point for each OEM. Some stacks have accumulated hours beyond 10% voltage degradation.
(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 on the "Avg Projection" due to data and methodology limitations. Projections will change as additional data are accumulated.
(6) Projection method was modified beginning with 2008 Q2 data.

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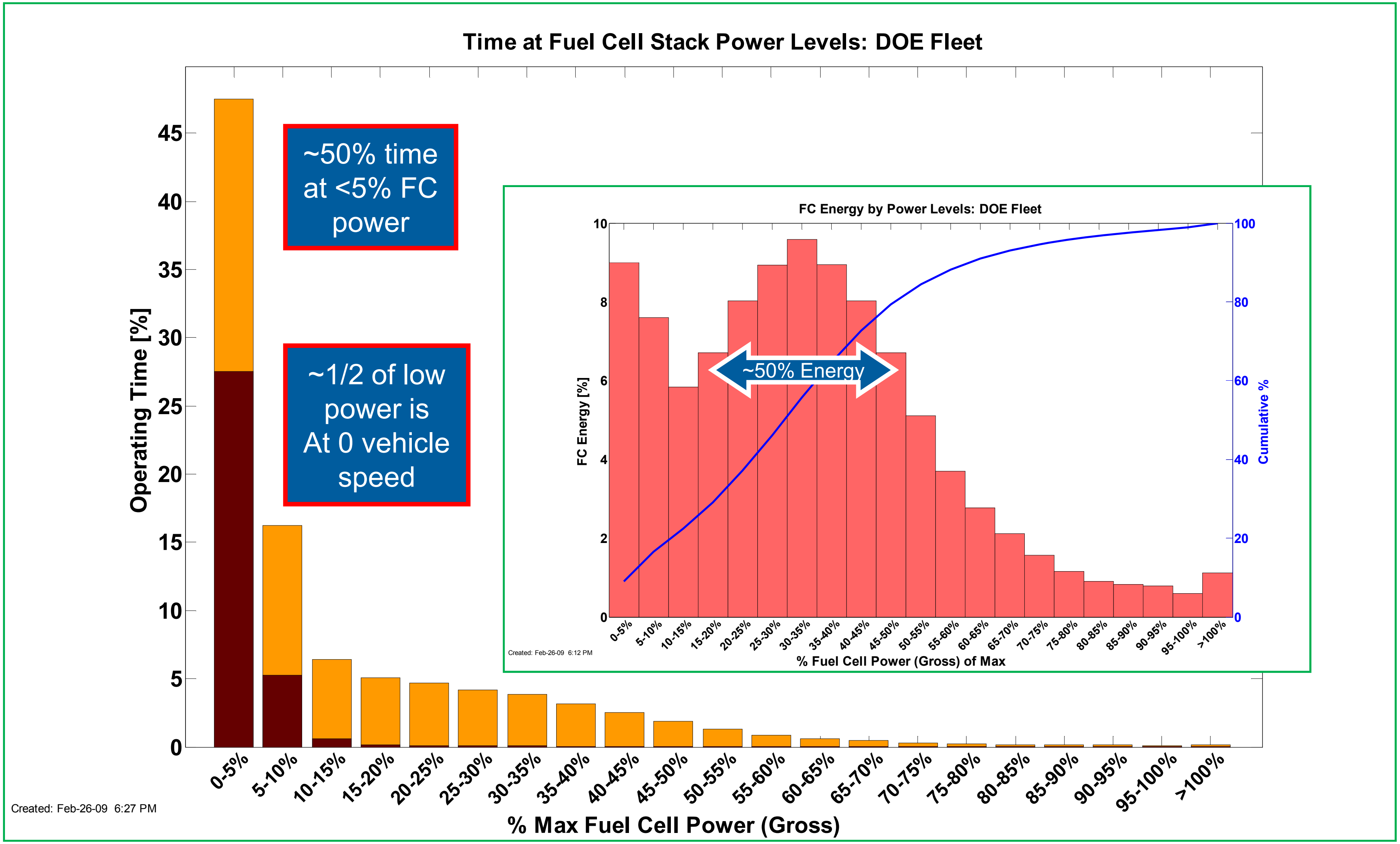
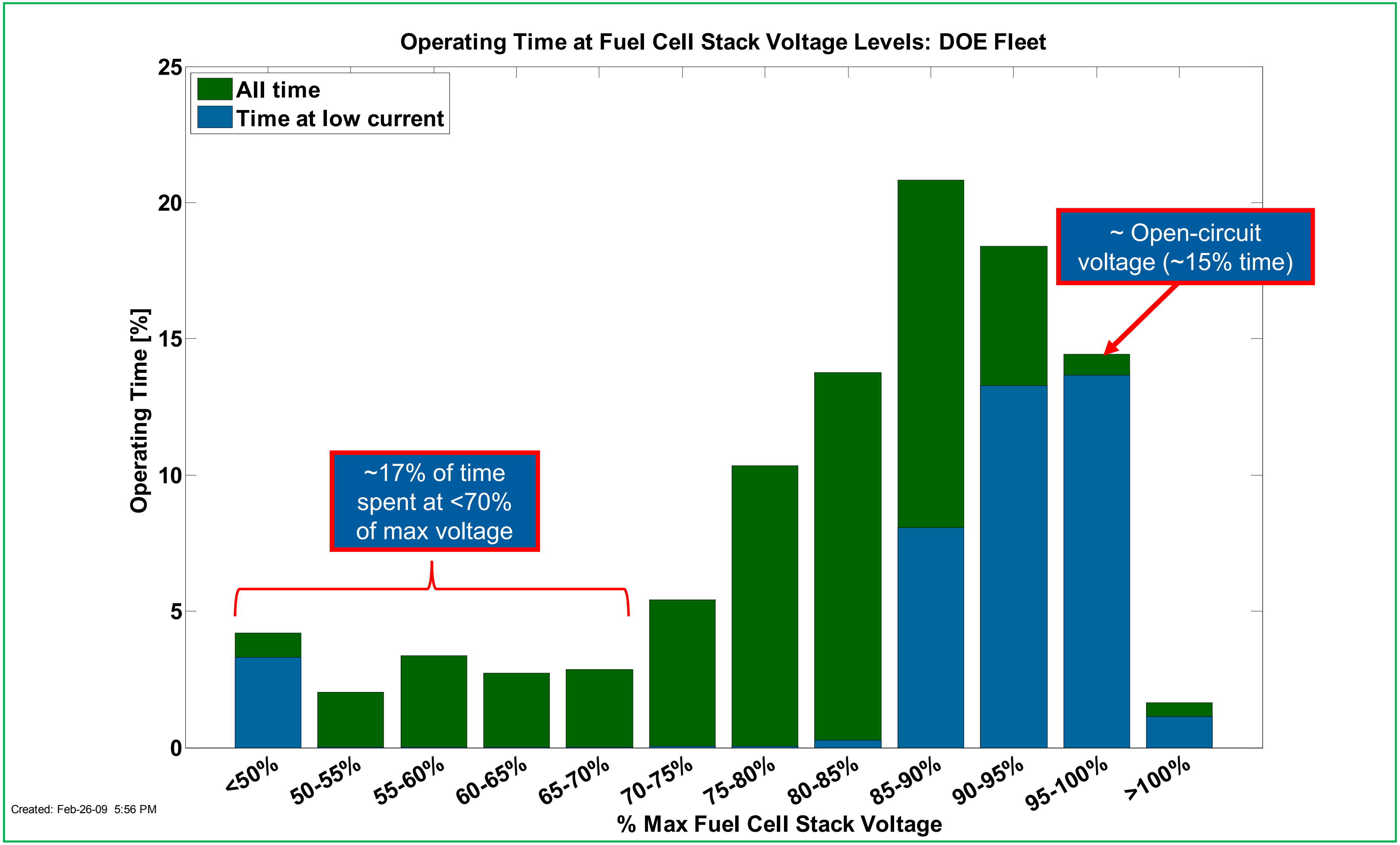
More data required to make Gen 2 projections (late 2009)

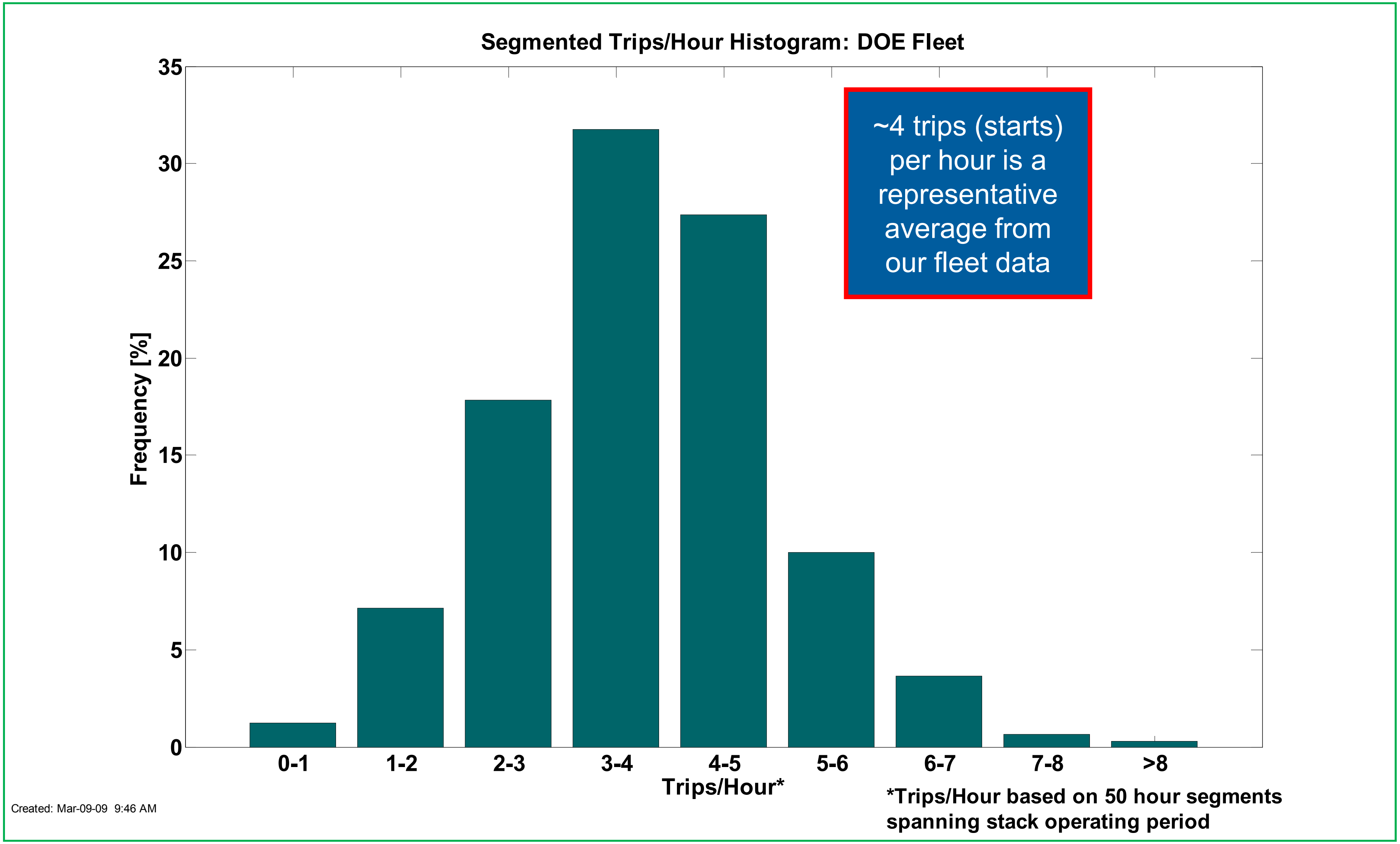
Most of FC *Time* is Spent at Idle, Bulk of *Energy* is at 20-50% Power



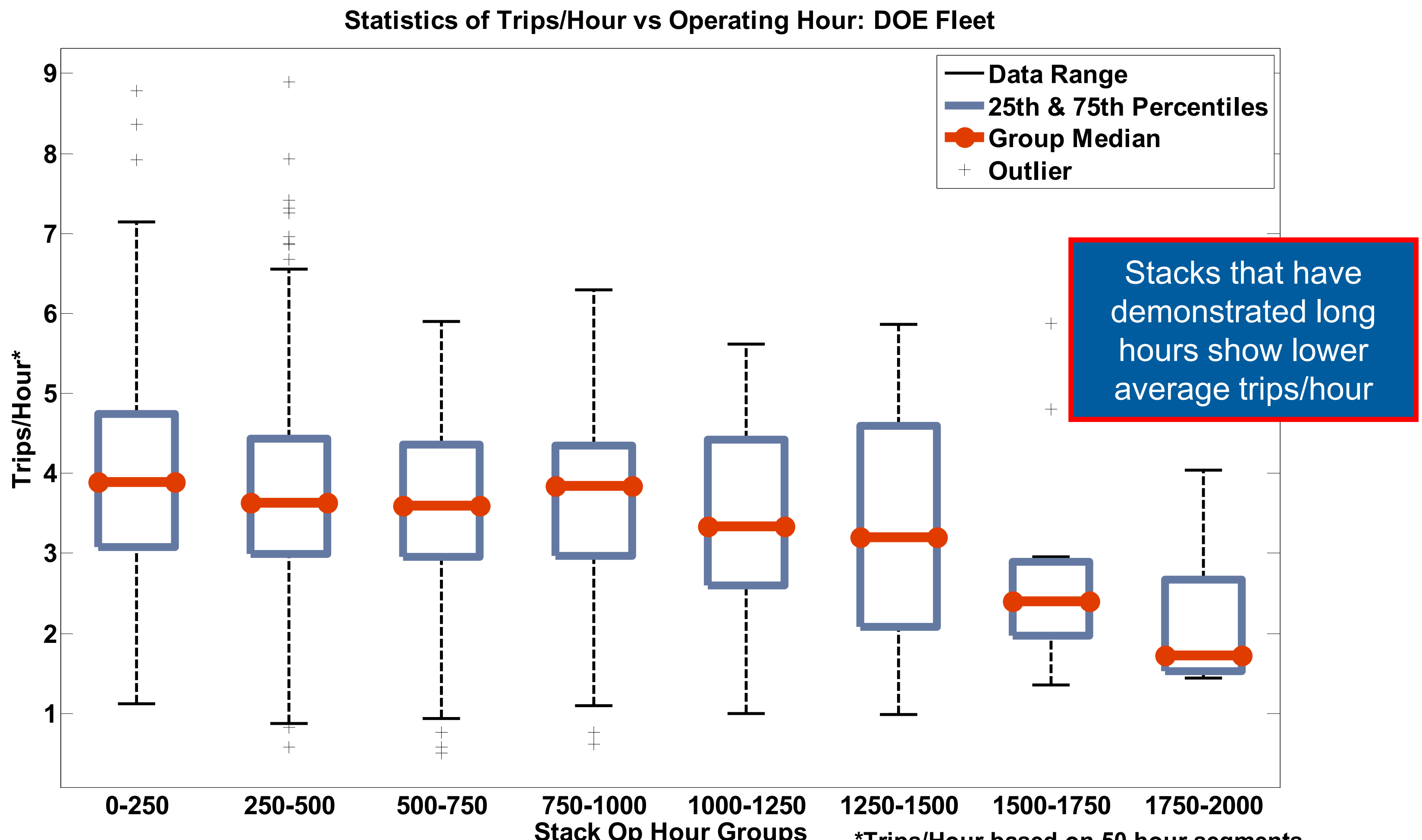
Stack Duty Cycle: Time Fuel Cell Spends at Various Voltage Levels Was Requested by FC Developers



Fuel Cell Stack Trips Per Hour Histogram Provided to FC Durability Protocol Task Force



Average Trips/Hour as a Function of Stack Operating Hour



*Trips/Hour based on 50 hour segments spanning stack operating period

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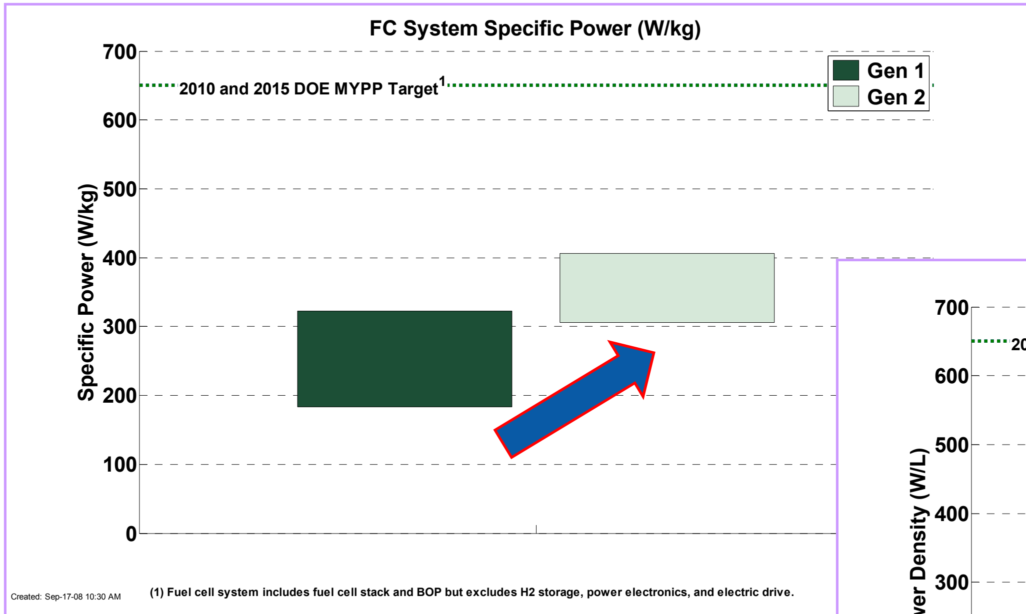
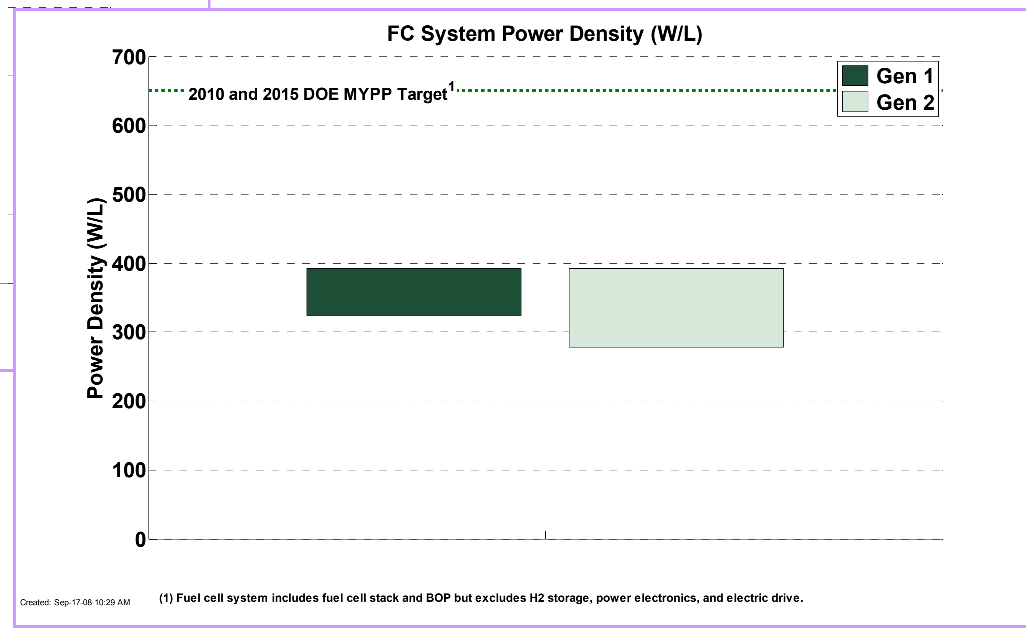
Comparison of FC System Specific Power and Power Density Between Gen 1 to Gen 2



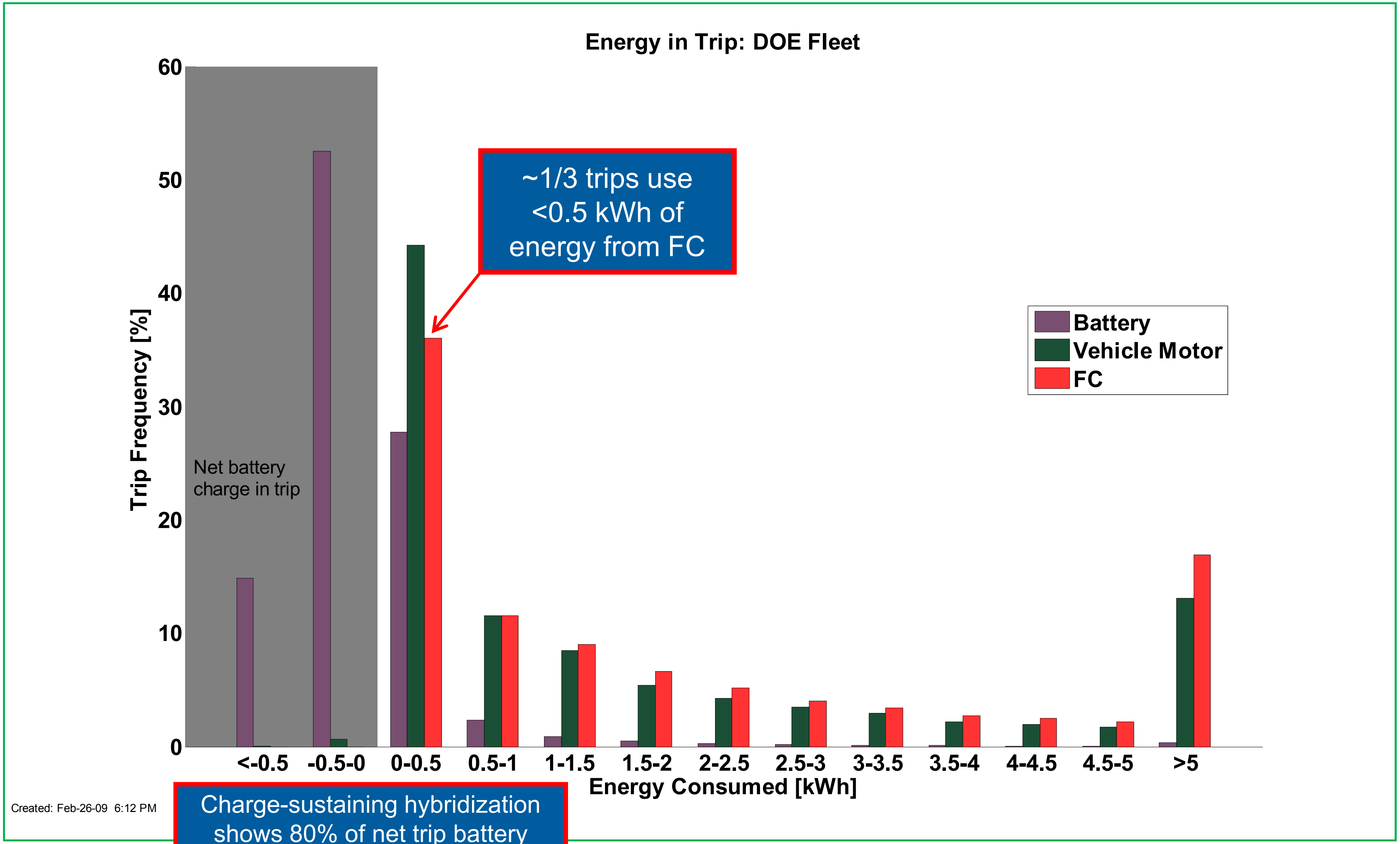
Freeze Capability of Gen 2 Systems May Have Increased Volume



Significant Improvements Seen in Specific Power (…systems getting lighter)

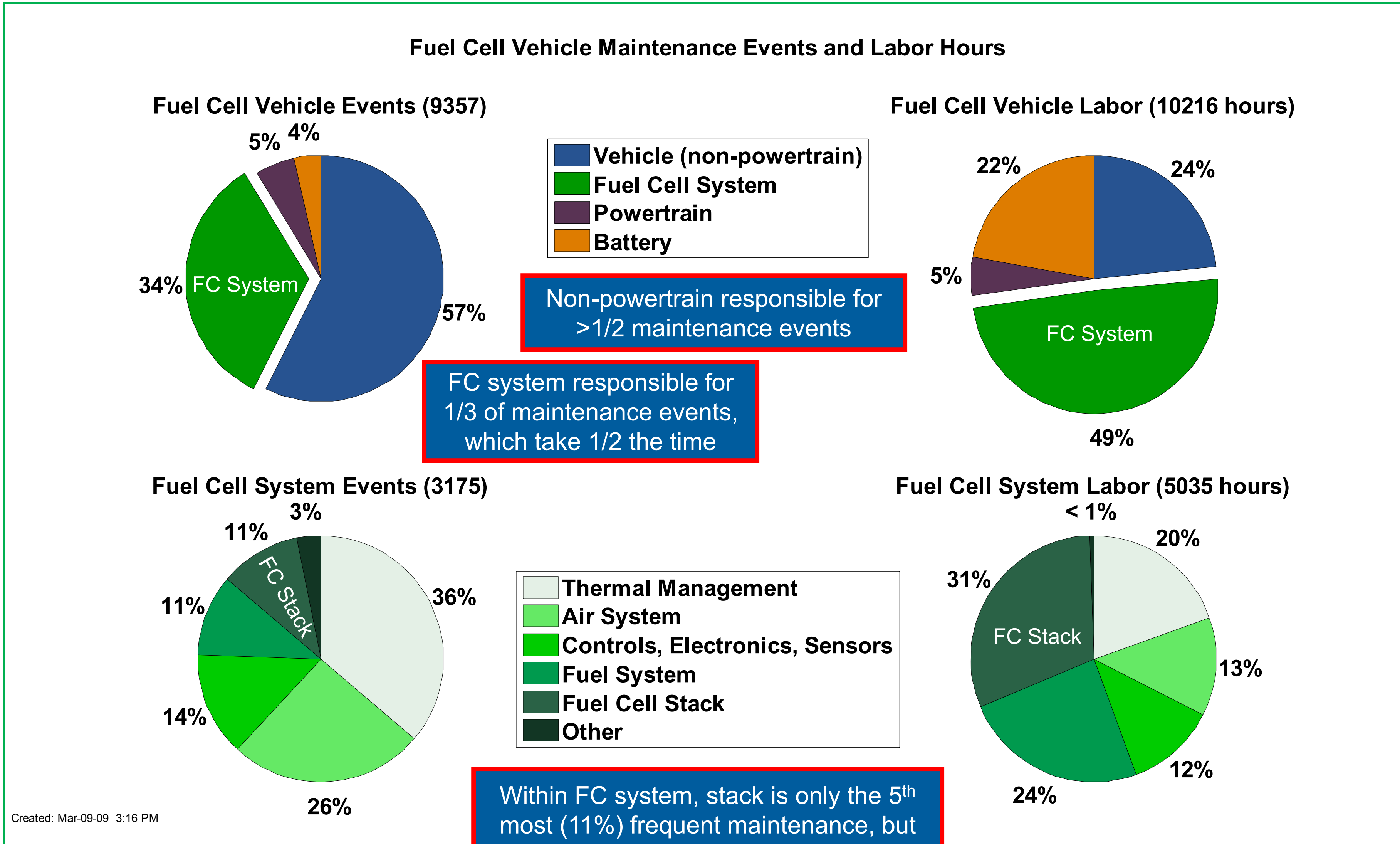
Power Density Did Not Improve Between Gen 1 and Gen 2 (…same size or larger)

Energy Flow Through Major FCV Powertrain Components by Percentage of Trips



Charge-sustaining hybridization shows 80% of net trip battery energy is within +/- 0.5 kWh

New Analysis of Vehicle Maintenance Data Highlights Areas for Improvement

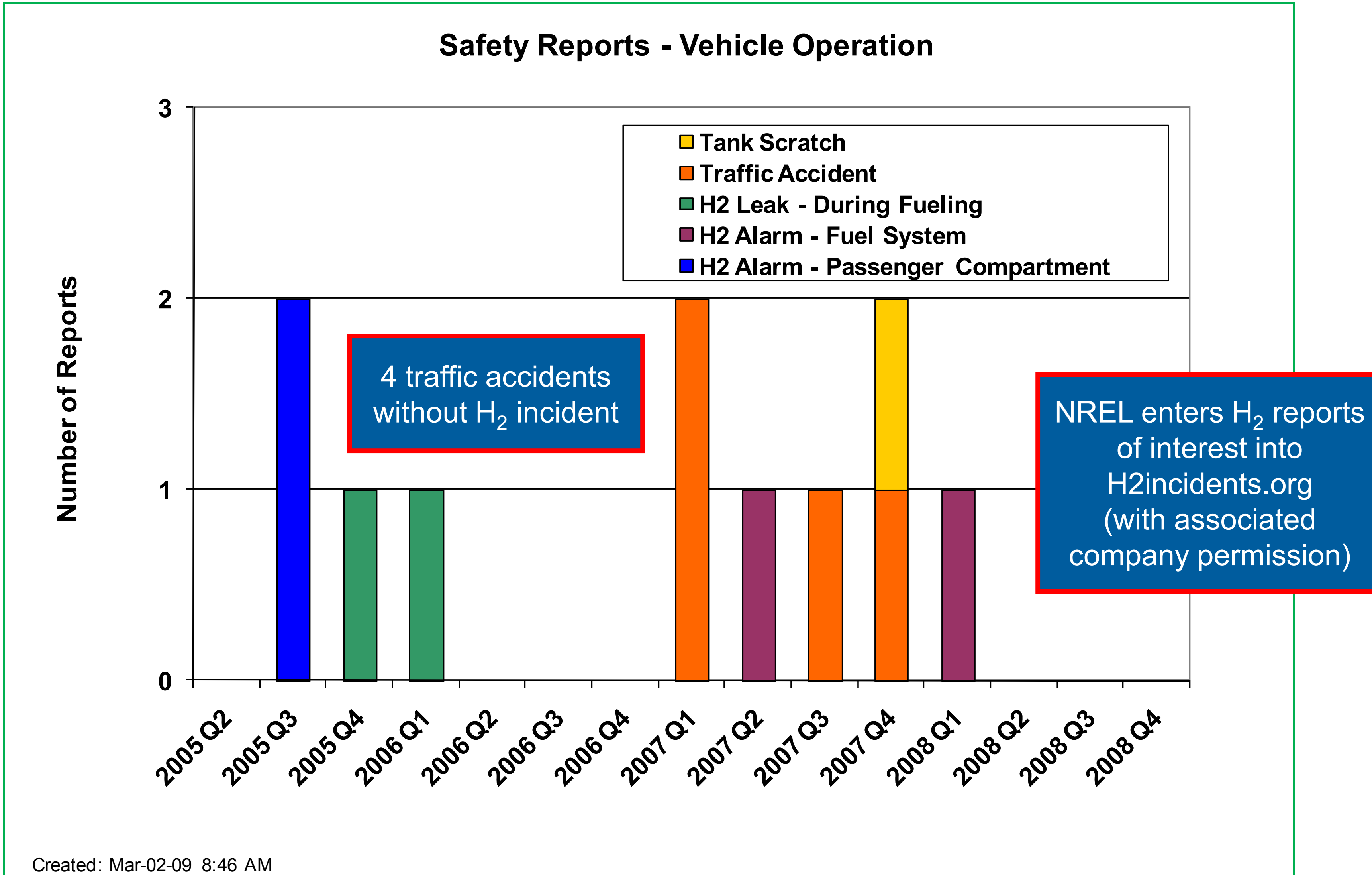


Non-powertrain responsible for >1/2 maintenance events

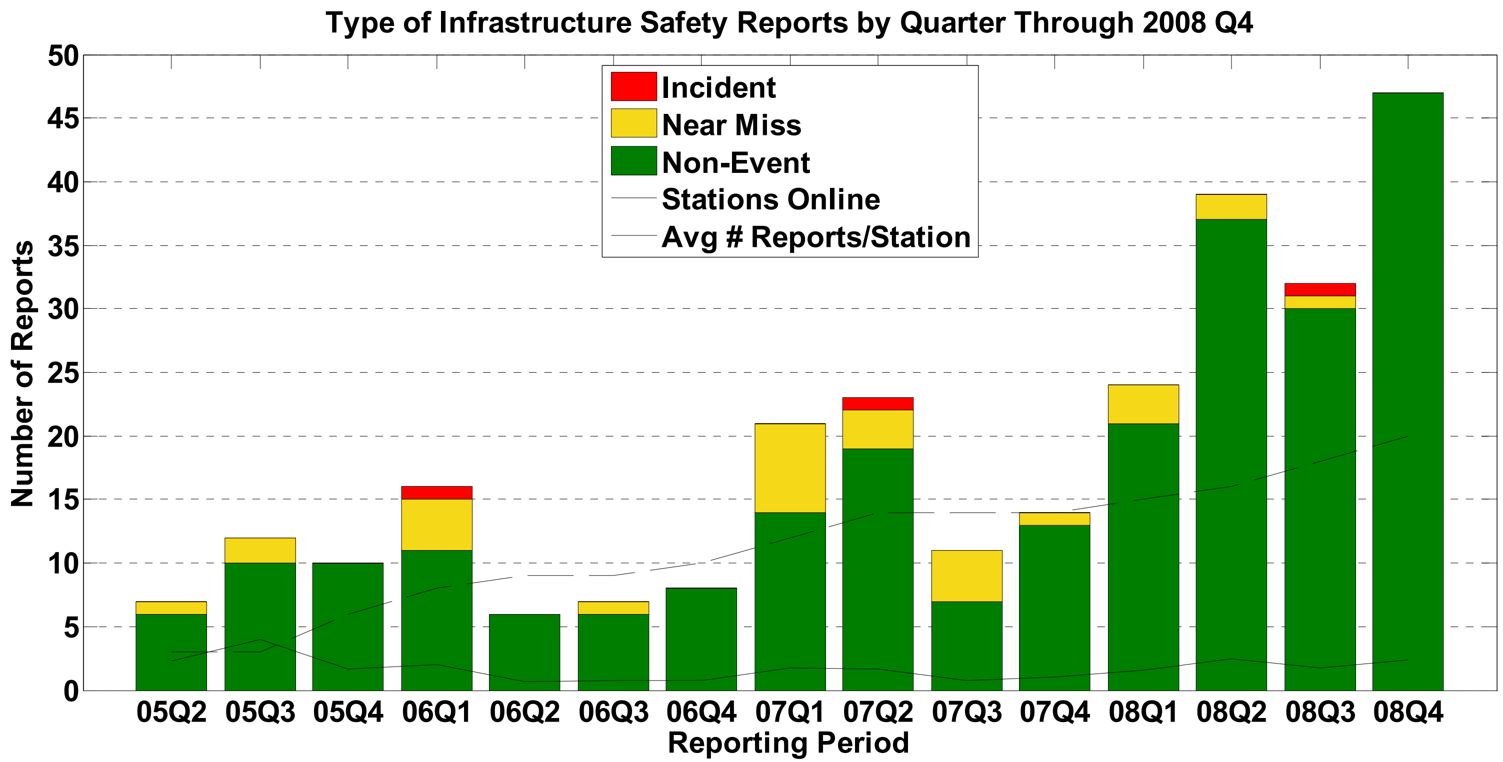
FC system responsible for 1/3 of maintenance events, which take 1/2 the time

Within FC system, stack is only the 5th most (11%) frequent maintenance, but responsible for 1/3 of repair time

Minimal Vehicle Safety Reports Continue to Demonstrate a Strong Vehicle Safety Record



Overall Infrastructure Reports Correlated with Increase in New Stations Coming Online



An INCIDENT is an event that results in:
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing compound (other than the hydrocarbons used as common fuels)

A NEAR-MISS is:
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

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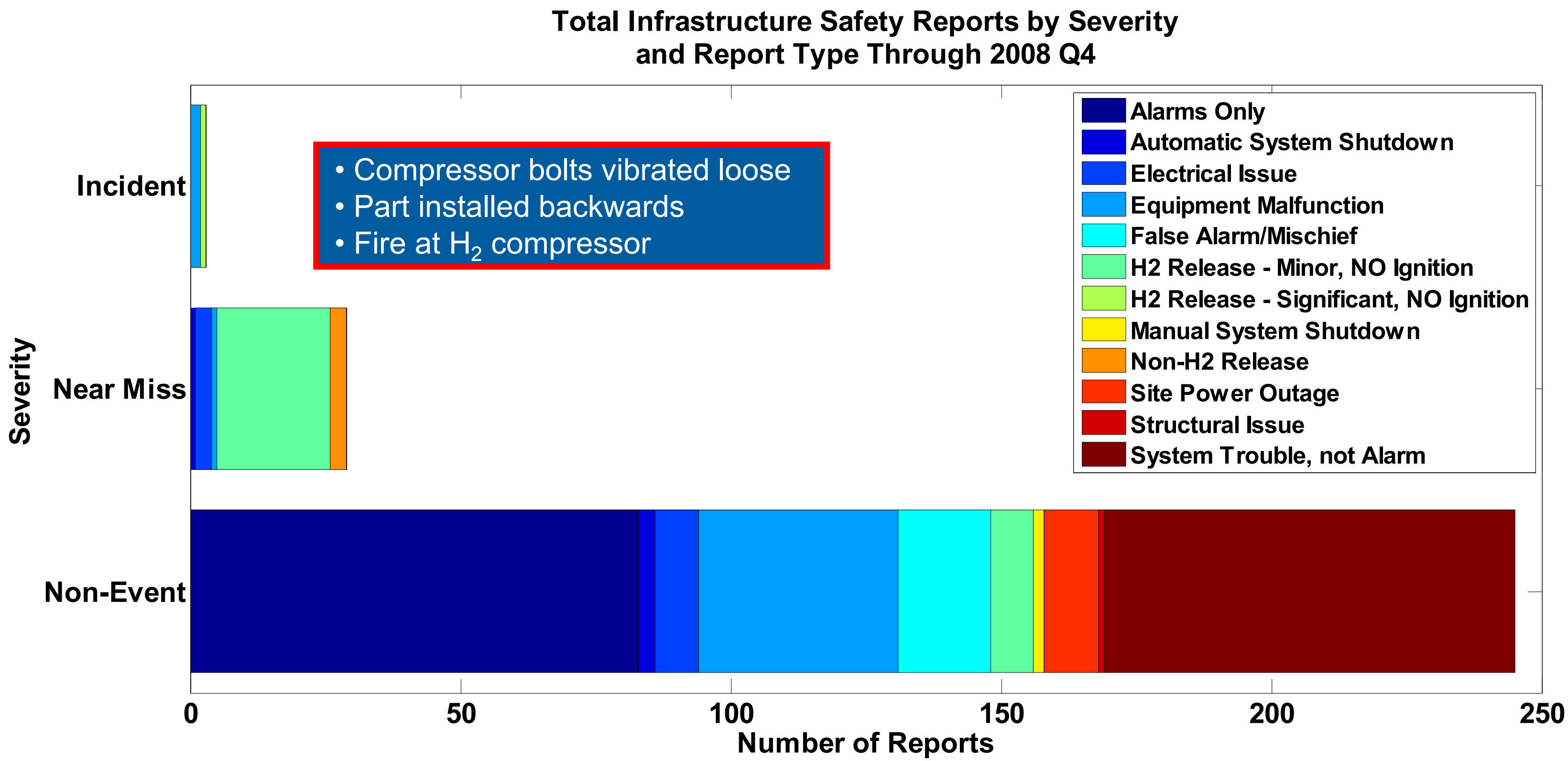
Most of Infrastructure Safety Reports Continue to Be Non-Events (and Most of Those, Alarms Only)



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A NEAR-MISS is:
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

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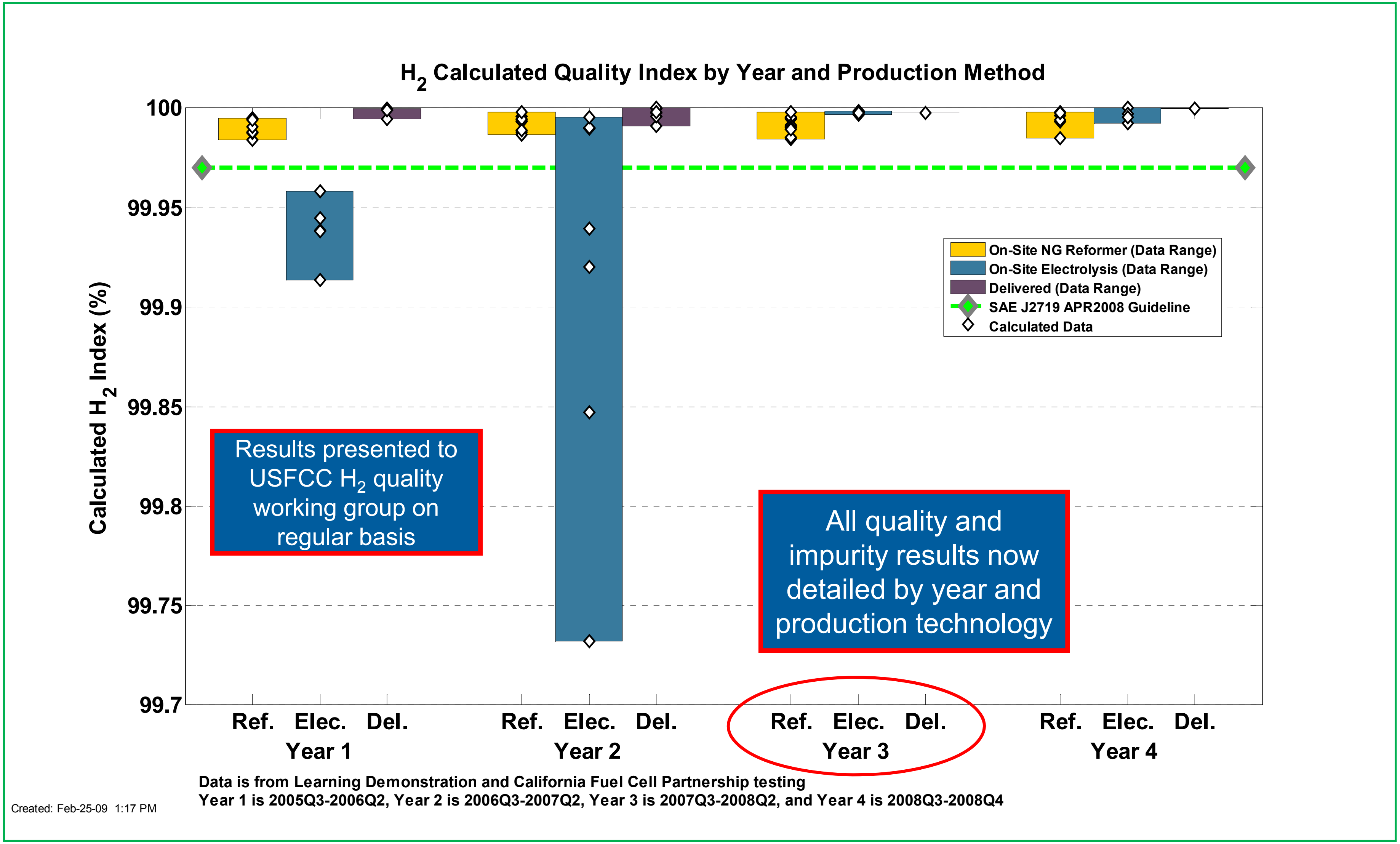
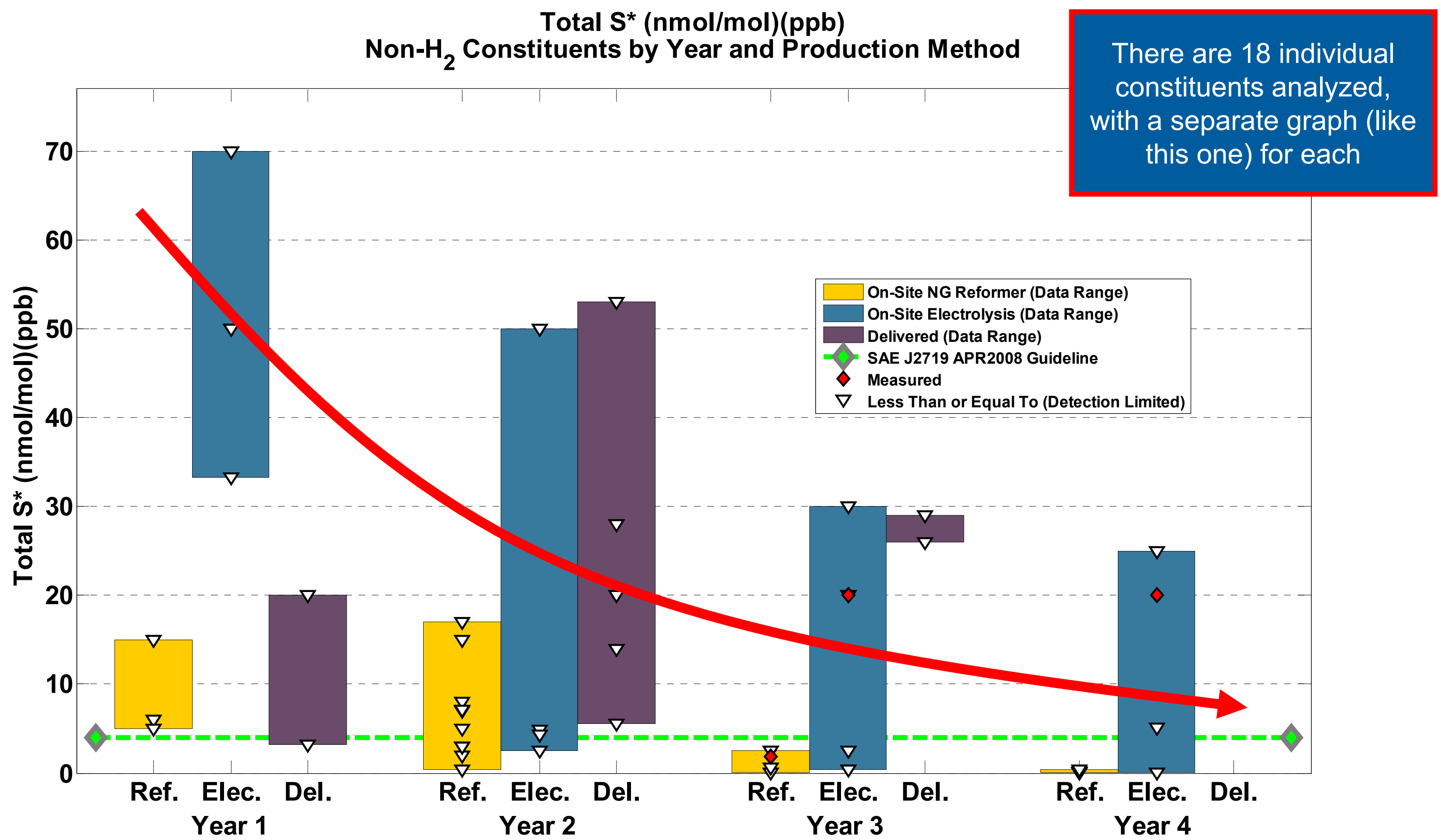
Note: All "incidents" are reported to H2incidents.org (with associated company permission)

New Hydrogen Quality Results Show that the Overall Quality Index Met the Target for Last 2 Years



Hydrogen Constituents by Year and Production Method – Example of Sulfur



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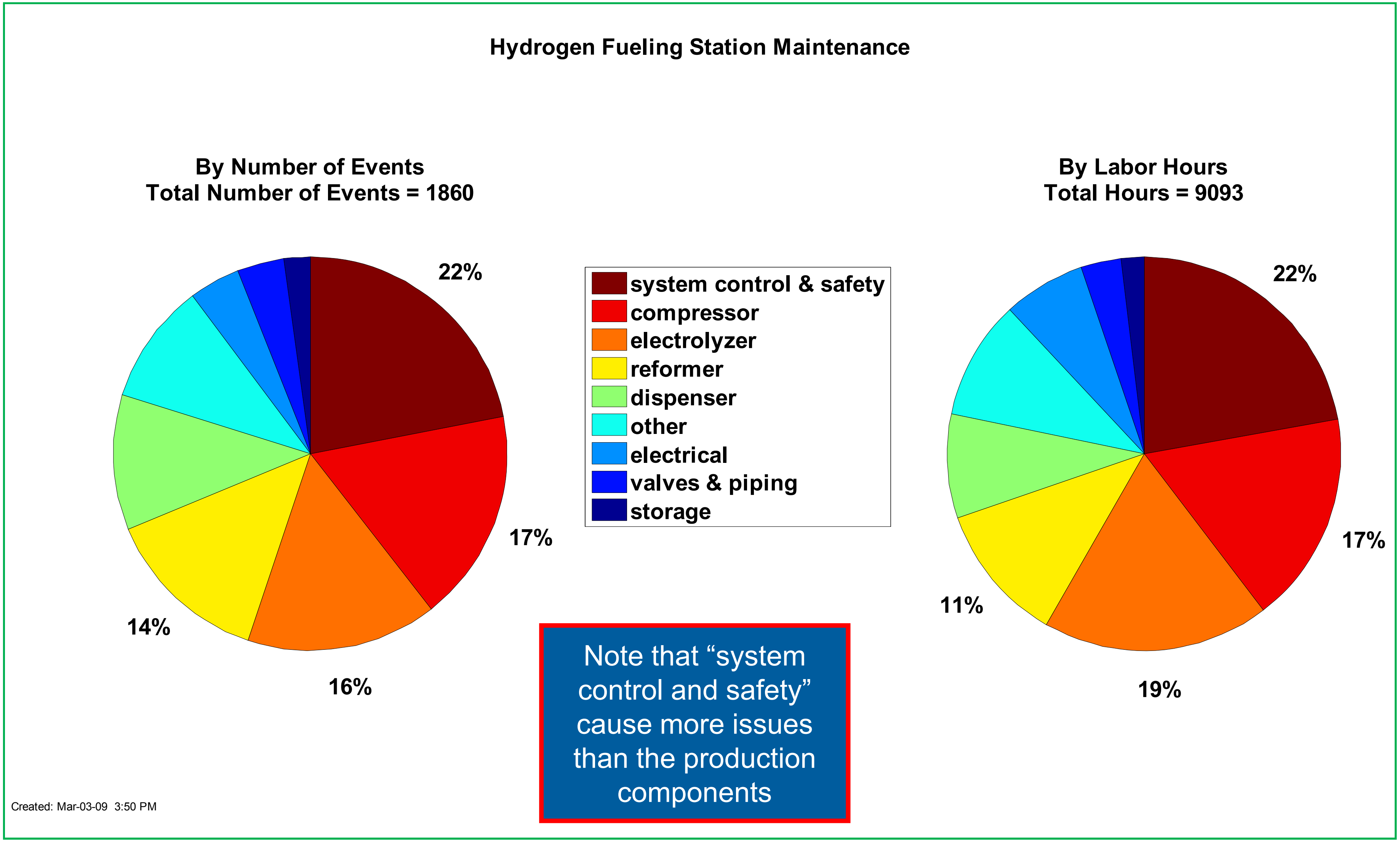
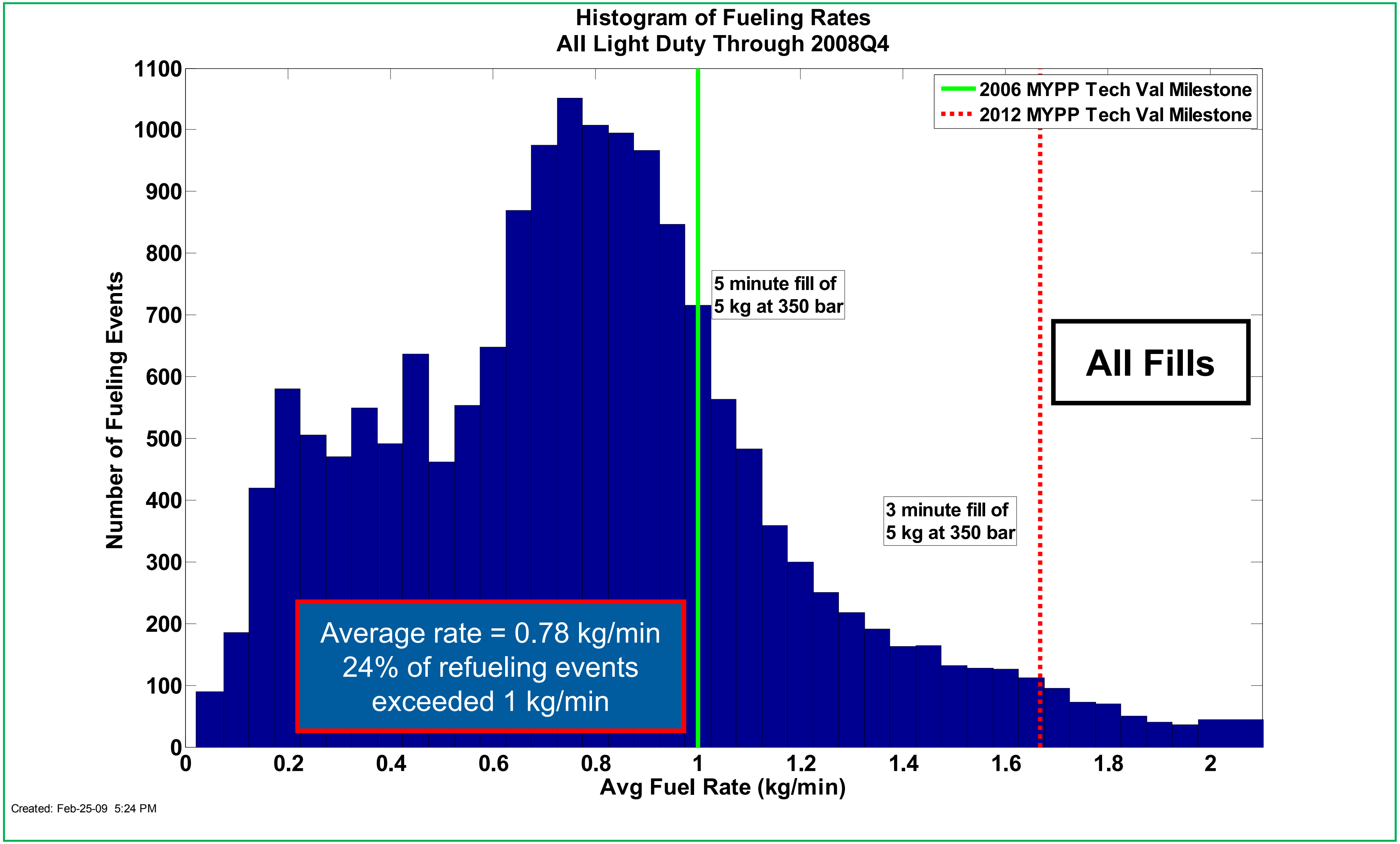
Data is from Learning Demonstration and California Fuel Cell Partnership testing
Year 1 is 2005Q3-2006Q2, Year 2 is 2006Q3-2007Q2, Year 3 is 2007Q3-2008Q2, and Year 4 is 2008Q3-2008Q4
*Total S calculated from SO2, COS, H2S, CS2, and Methyl Mercaptan (CH3SH).

Hydrogen Fueling Station Maintenance by System Shows ~Equal Responsibility of Major Components

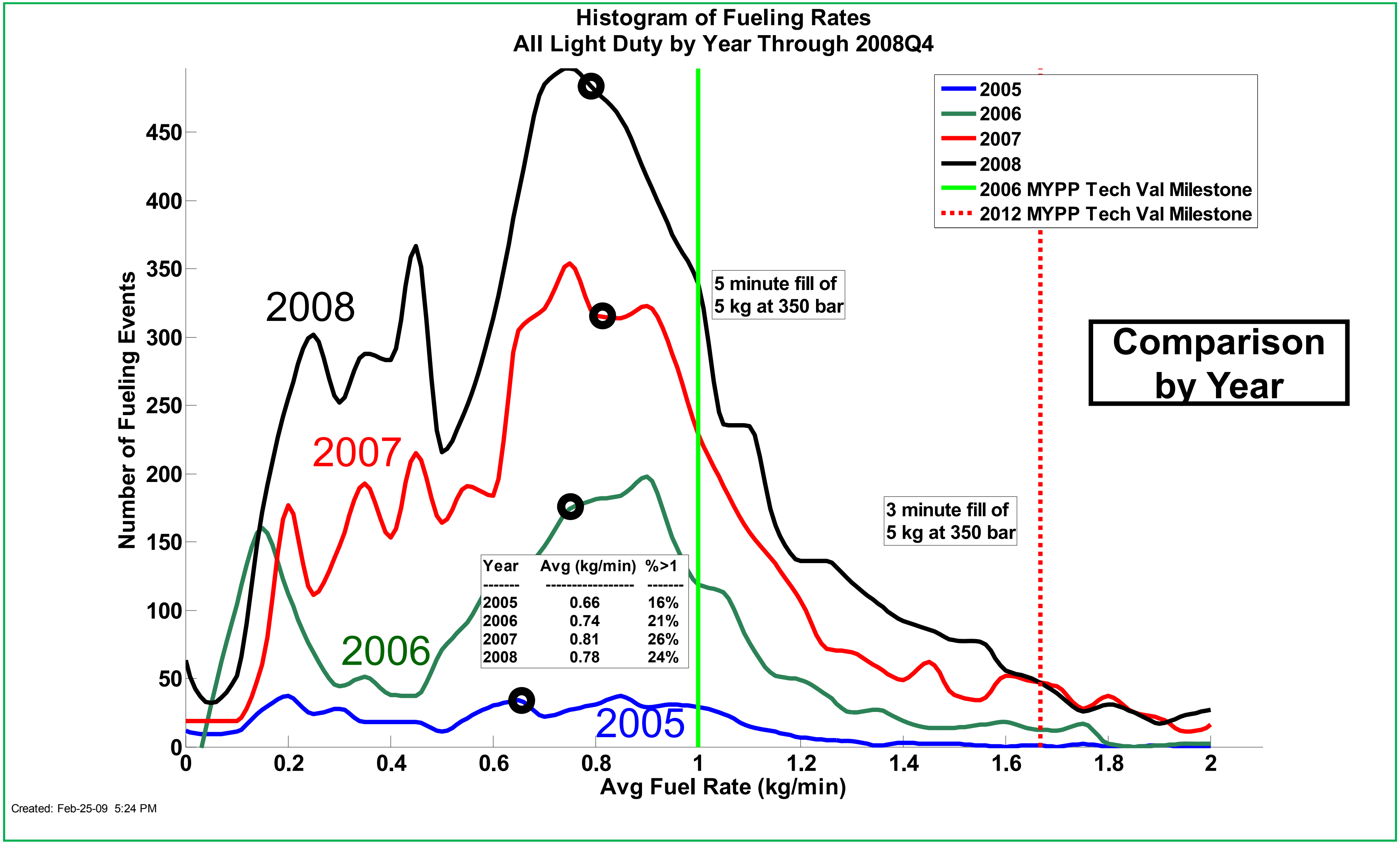


Note that "system control and safety" cause more issues than the production components

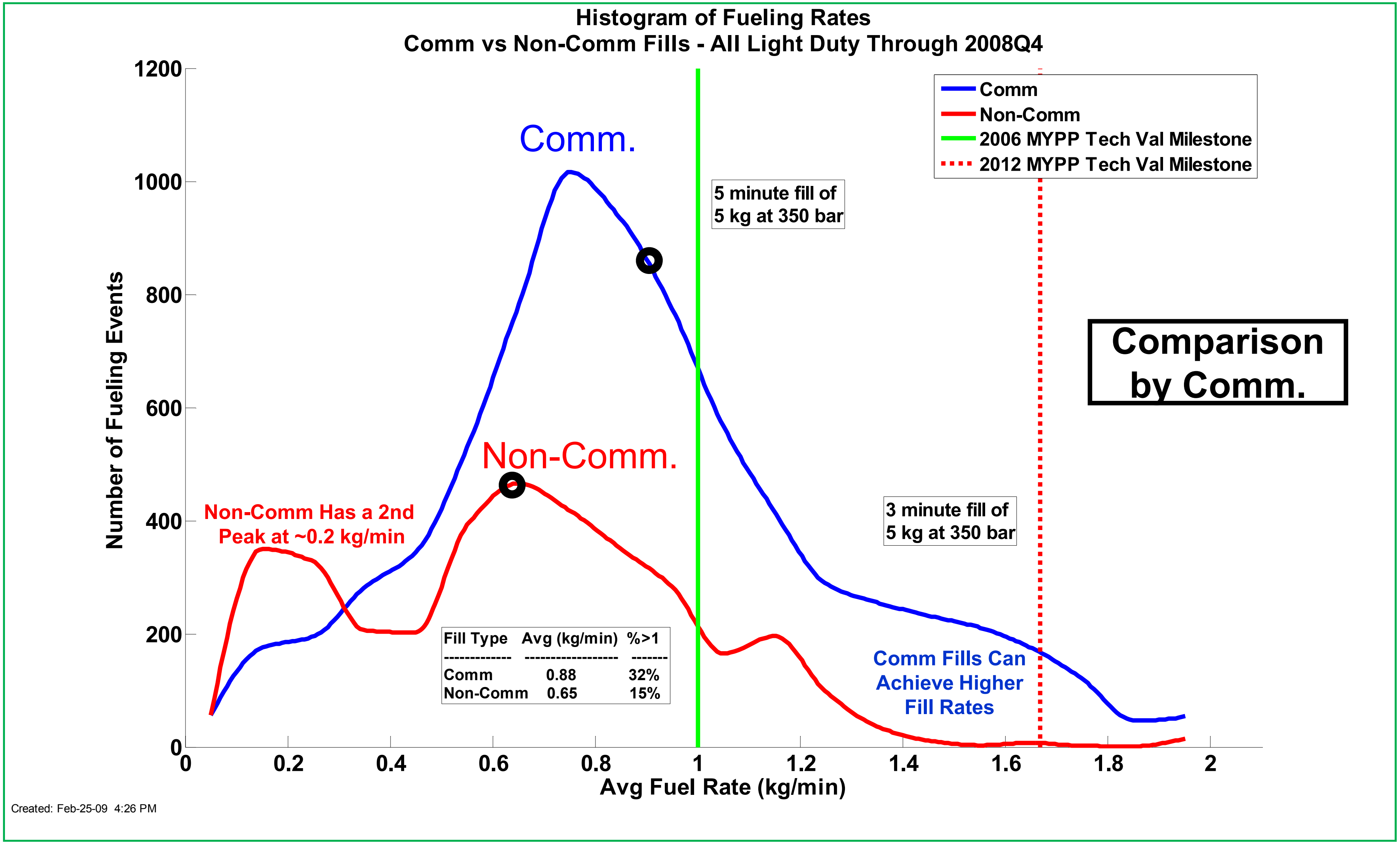
Actual Vehicle Refueling *Rates* from 16,000 Events: Measured by Stations or by Vehicles



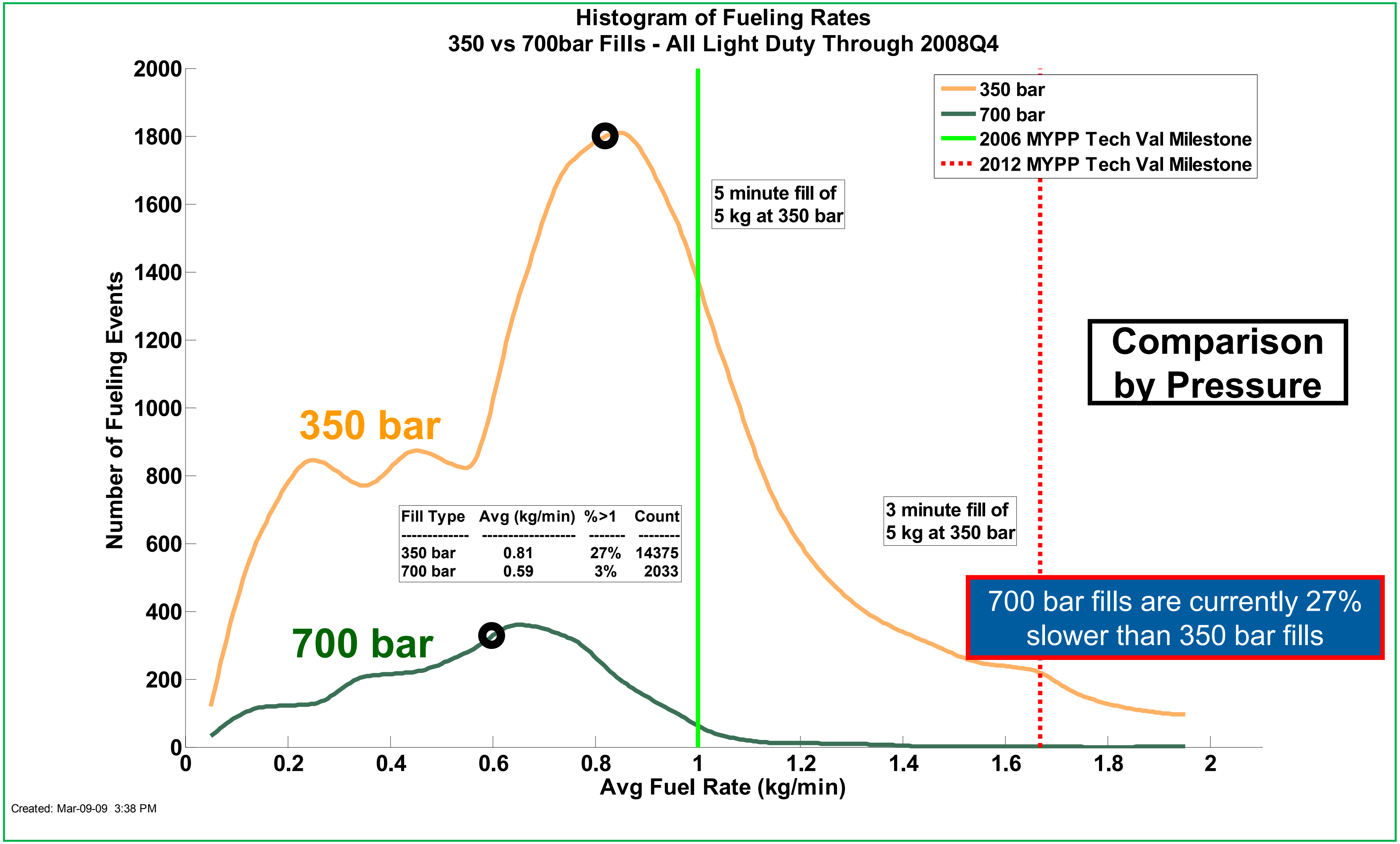
Refueling Rates by Year: Highest Number of Fills in 2008; ~1/4 Now Exceed 1 kg/min



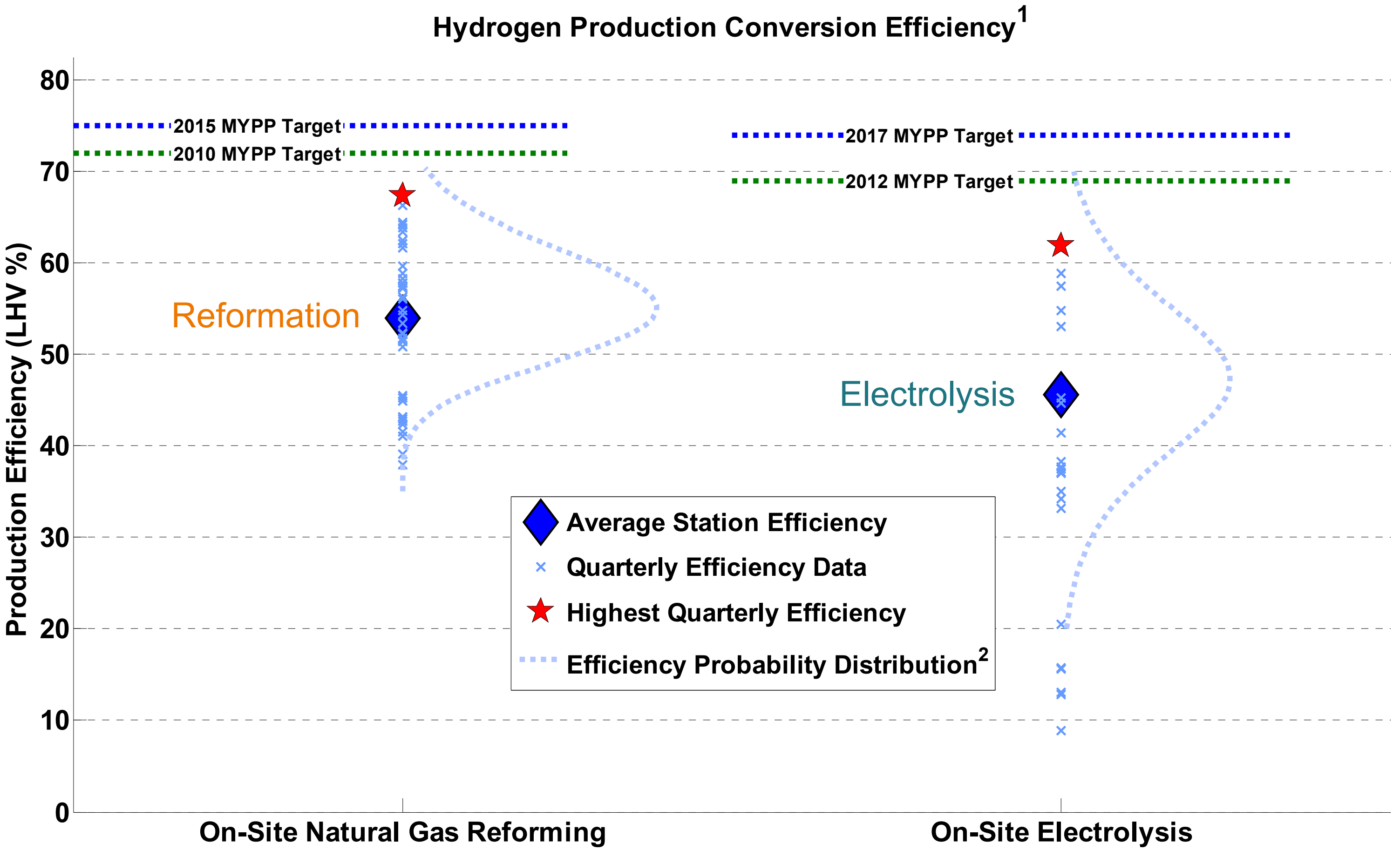
Communication H_2 Fills Achieving 35% Higher Average Fill Rate than Non-Communication



Comparison of Fueling Rates for 350 and 700 bar Pressure Fueling Events



On-Site Production Efficiency from Natural Gas Reformation and Electrolysis Compared to Targets



[1]Production conversion efficiency is defined as the energy of the hydrogen out of the process (on an LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.

[2]The efficiency probability distribution represents the range and likelihood of hydrogen production conversion efficiency based on monthly conversion efficiency data from the Learning Demonstration.

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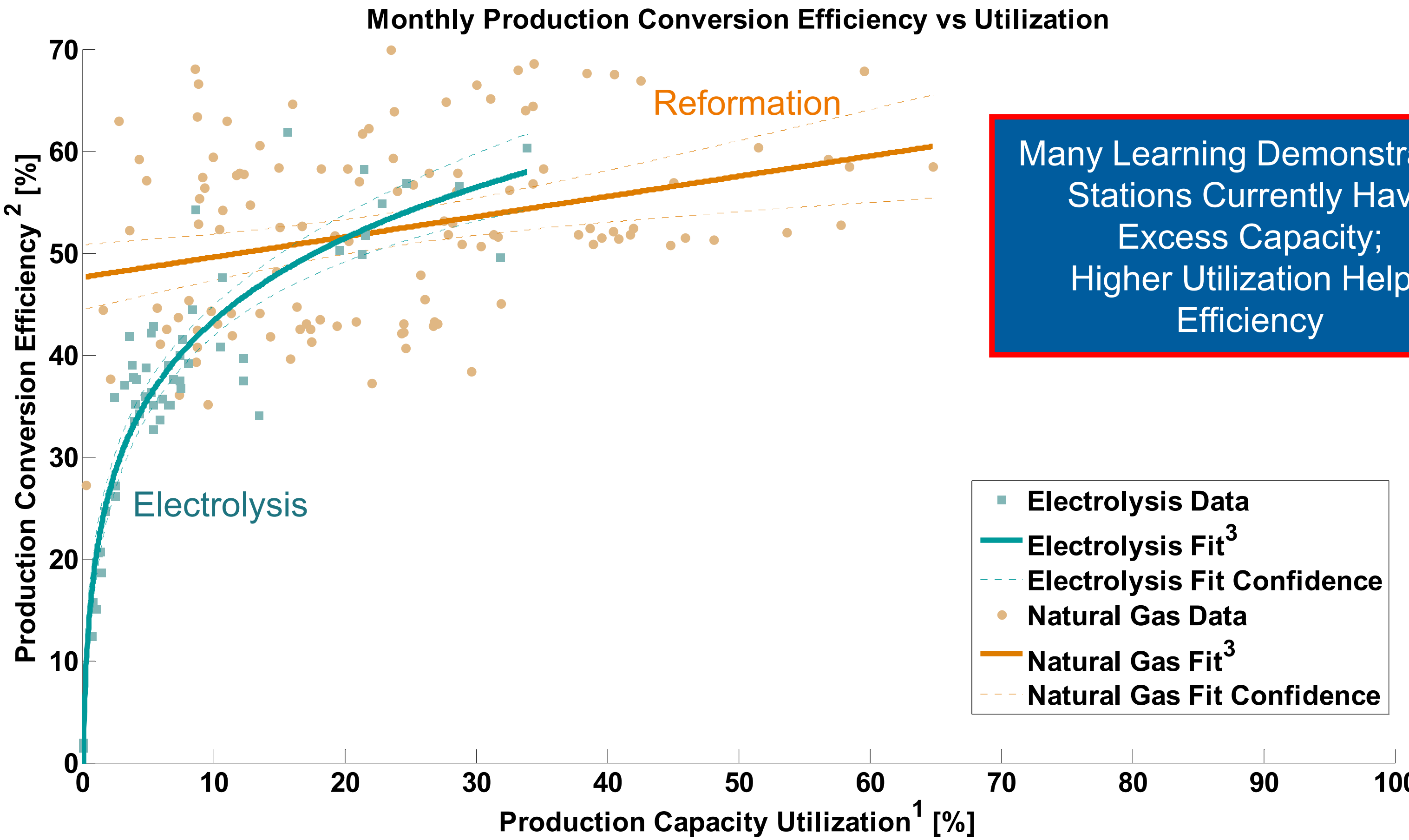
On-Site Hydrogen Production Efficiency vs. Capacity Utilization



Many Learning Demonstration Stations Currently Have Excess Capacity; Higher Utilization Helps Efficiency

1) 100% production utilization assumes operation 24 hrs a day, 7 days a week

2) Production conversion efficiency is defined as the energy of the hydrogen out of the process (on a LHV basis) divided by the sum of the energy into the production process from the feedstock and all other energy as needed. Conversion efficiency does not include energy used for compression, storage, and dispensing.

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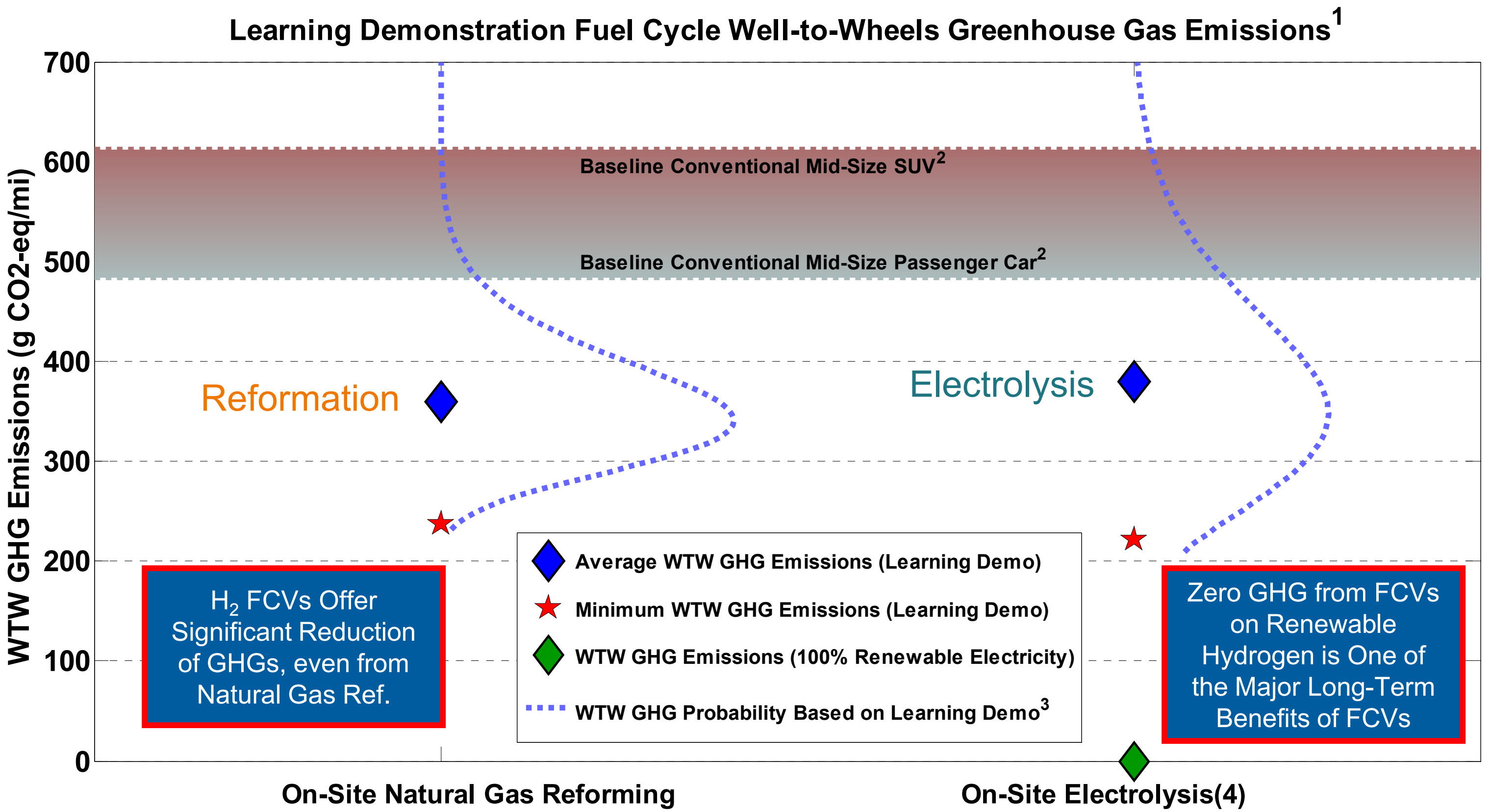
3) High correlation with electrolysis data (R^2 = 0.87) & low correlation with natural gas data (R^2 = 0.018)

Learning Demonstration Vehicle Greenhouse Gas Emissions Using Actual Production Efficiencies and Fuel Economies



1. Well-to-Wheels greenhouse gas emissions based on DOE's GREET model, version 1.8b. Analysis uses default GREET values except for FCV fuel economy, hydrogen production conversion efficiency, and electricity grid mix. Fuel economy values are the Gen 1 and Gen 2 window-sticker fuel economy data for all teams (as used in CDP #6); conversion efficiency values are the production efficiency data used in CDP #13.
2. Baseline conventional passenger car and light duty truck GHG emissions are determined by GREET 1.8b, based on the EPA window-sticker fuel economy of a conventional gasoline mid-size passenger car and mid-size SUV, respectively. The Learning Demonstration fleet includes both passenger cars and SUVs.
3. The Well-to-Wheels GHG probability distribution represents the range and likelihood of GHG emissions resulting from the hydrogen FCV fleet based on window-sticker fuel economy data and monthly conversion efficiency data from the Learning Demonstration.
4. On-site electrolysis GHG emissions are based on the average mix of electricity production used by the Learning Demonstration production sites, which includes both grid-based electricity and renewable on-site solar electricity. GHG emissions associated with on-site production of hydrogen from electrolysis are highly dependent on electricity source. GHG emissions from a 100% renewable electricity mix would be zero, as shown. If electricity were supplied from the U.S. average grid mix, average GHG emissions would be 1241 g/mile.

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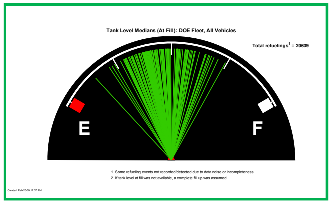
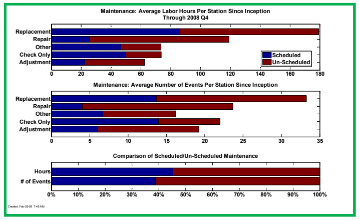
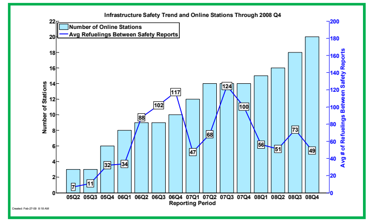
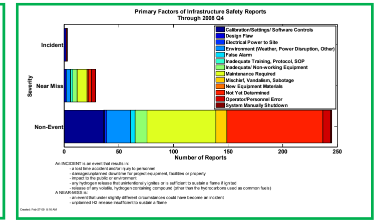
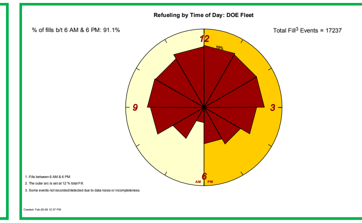
Other CDP Results Not Discussed Here Today

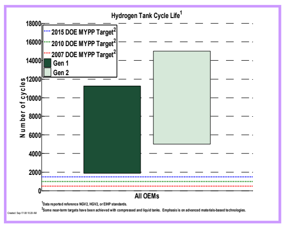


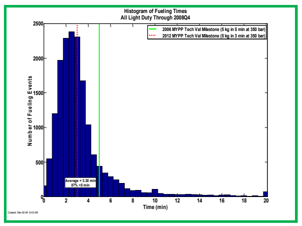


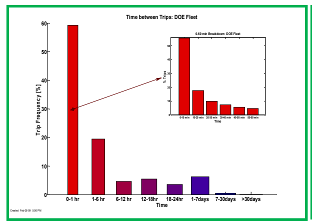


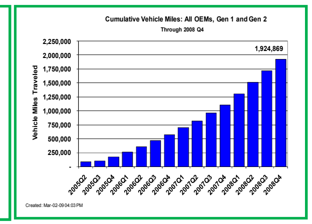


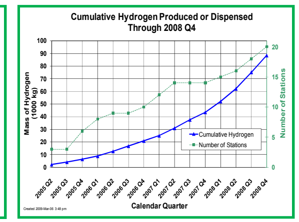


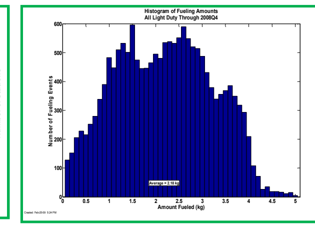


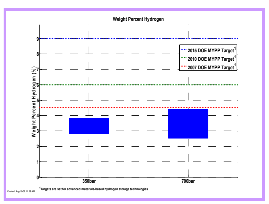


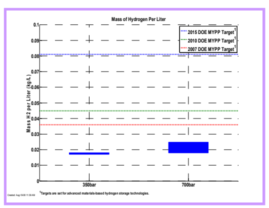


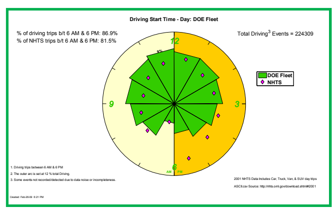


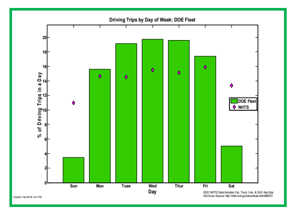


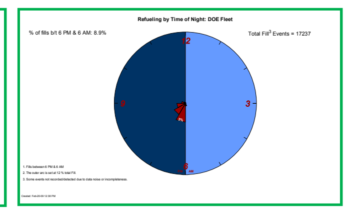


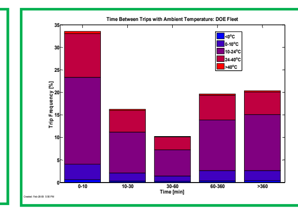


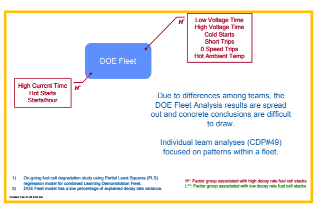


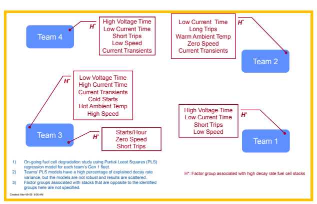


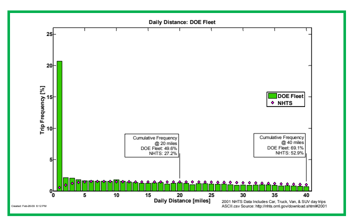


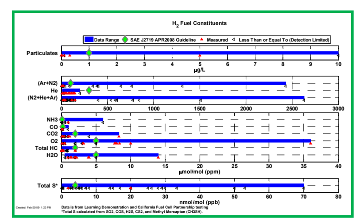


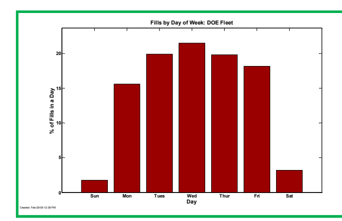


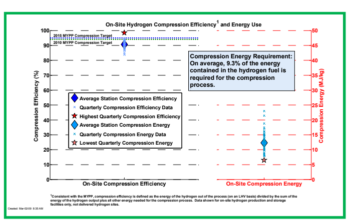


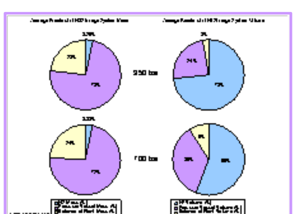


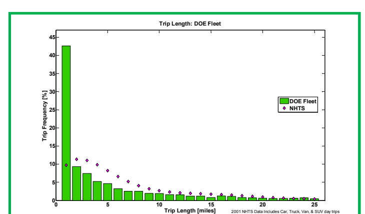


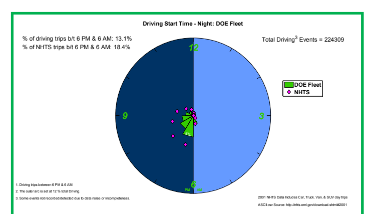


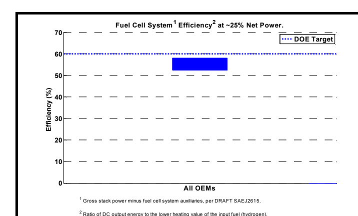












Highlights of Interactions and Collaborations in the Last Year

Auto/Energy Industry Partners

- Site visits with industry (at OEM site or NREL) to discuss detailed results and NREL methodology
- Focused on 2-way sharing of voltage degradation calculations and multivariate analyses
- Completed implementation for producing detailed data results and CDPs at same time for easier industry review

FreedomCAR and Fuel Technical Teams

- Fuel Cell (7/08, 4/09) and H_2 Storage (10/08, 4/09) Tech Teams

US Fuel Cell Council Technical Working Groups

- Transportation Working Group
- Joint H_2 Quality Task Force
- FC Durability Testing Protocol Working Group

California Organizations

- CaFCP: NREL now includes H_2 impurity test results in CDPs
- CARB: Agreement for data from new stations to be sent to NREL

Department of Defense (DLA)

- Leveraging experience to evaluate FC forklifts and backup power

Future Work

Remainder of FY09:

- Create new and updated composite data products (CDPs) based on data through June 2009 (Fall 2009 CDPs)
  - Prepare results for publication at 2009 Fuel Cell Seminar
- Key upcoming September 2009 DOE MYPP and Joule milestones on:
  - Hydrogen production cost from project compared to $3/gge target
  - Gen 2 stack voltage degradation time to 10% compared to target of 2000 hours
  - Gen 2 vehicle freeze capability and start-up energy requirements compared to targets
- Support OEMs, energy companies, and state organizations in California in coordinating early infrastructure plans

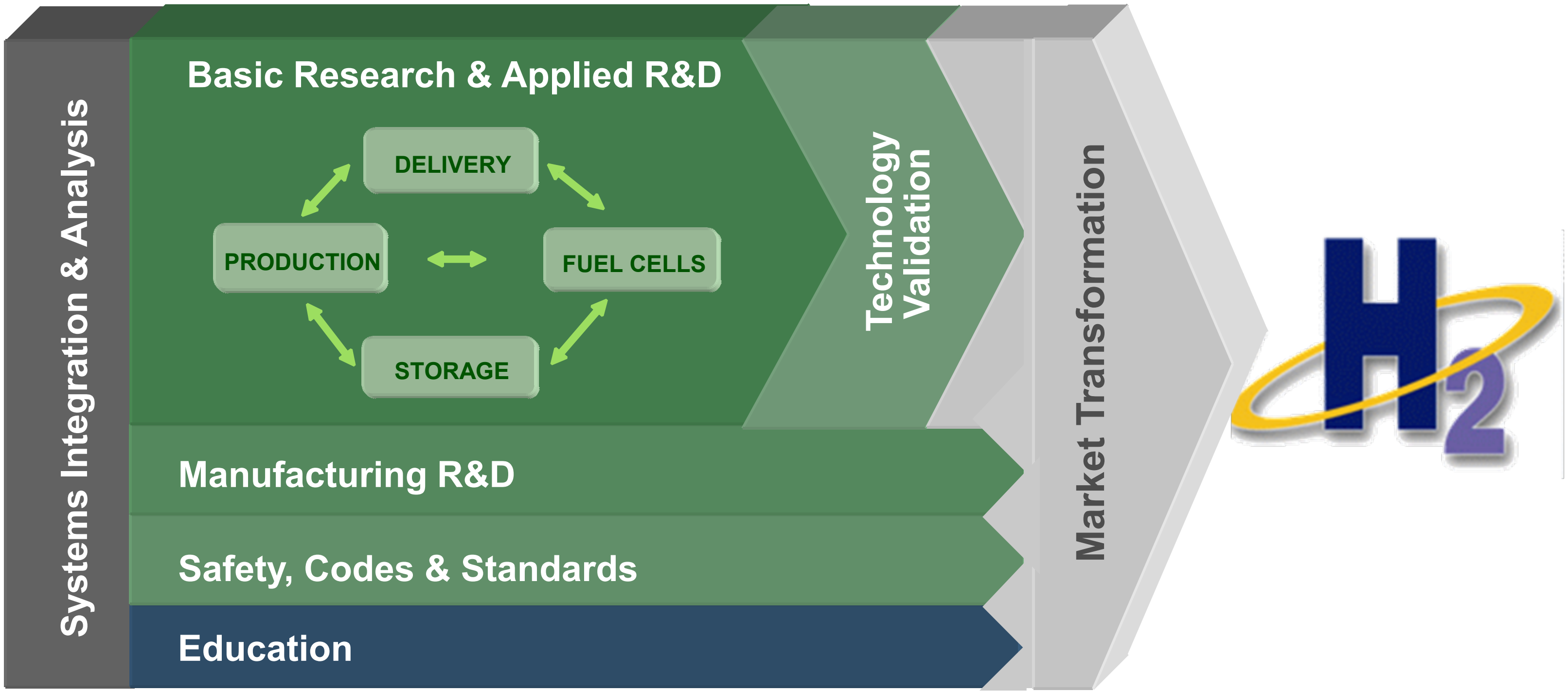
FY10:

- Continue to identify opportunities to feed findings from project back into VT/H_2 programs and industry R&D activities to maintain project as a "learning demonstration"
- Publish Spring 2010, Fall 2010 composite data products as the last anticipated results from the project
- Write final summary report for the project

Summary

- Learning Demo evaluation is ~80% complete
  - 140 vehicles and 20 stations deployed
  - 1.9 million miles traveled, 90,000 kg H_2 produced or dispensed
  - 346,000 individual vehicle trips analyzed
  - Project to continue through 2010
- Many new technical results since last AMR presentation
  - All but 2 updated since last AMR
  - 52 new/updated results since Fall 2008, 8 unchanged (total of 60)
    - H_2 production efficiency, compressor efficiency, vehicle GHG emissions
    - 350 vs. 700 bar refueling rates
    - Several new FC stack usage statistics
    - Time between trips & ambient temperature
    - H_2 fueling station maintenance by system
    - Fuel cell vehicle maintenance by system
  - All results available on web site
- Roll-out of 2nd generation vehicles is now complete
- Station deployment nearing completion

Questions and Discussion



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

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

Responses to Previous Year (FY08) Reviewers' Comments

Q: "Results should be used to provide future DOE direction and emphasis and identification of technical areas that require additional and/or expanded emphasis."

- New vehicle maintenance data pie charts reveal need for additional emphasis on stack thermal management, air system, and controls/electronics/sensors.
- New stack usage statistics (time at voltage, starts per hour) being considered by DOE/JARI as real-world inputs to harmonized FC durability testing protocol.

Q: "Future work should focus on identifying technical barriers limiting performance and efficiency of FC technology for automotive transportation."

- Since last AMR, there has been a focused effort to increase the level of detailed stack duty cycle info. to aid developers.
- Stack maintenance data also sheds light on important parts of FC system that need attention beyond just the stack.

Q: "Insufficient modeling/forecasting components in the project."

- The objectives of this project are to perform analysis of real-world data for validation and feedback to the R&D process, not for modeling/forecasting.
- Outputs from this project can and are now being used as real-world to bound other modeling/forecasting activities at national labs and universities.
- Voltage degradation analysis and projection improved since last year

Publications and Presentations

(Since FY08 Review, Key Text in Bold)

1. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "U.S. Fuel Cell Vehicle Learning Demonstration: Status Update and Early Second-Generation Vehicle Results ," **EVS-24 conference**, Stavanger, Norway, May 2009. (paper and presentation)
2. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Fuel Cell Vehicle Learning Demonstration Status and Results," **Society of Automotive Engineers,** Detroit, MI, April 2009. (presentation)
3. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Fuel Cell Vehicle Learning Demonstration: Spring 2009 Results Presentation," **National Hydrogen Association** Annual Hydrogen Conference, Columbia, SC, March 2009. (paper and presentation)
4. Wipke, K., Kurtz, J., presentation of FC stack usage statistics to the **FCCJ-DOE-USFCC Testing Protocol Harmonization meeting**, March 2009. (presentation)
5. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., "**Spring 2009 Composite Data Products** for the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project," Golden, CO: National Renewable Energy Laboratory, March 2009. (presentation)
6. Wipke, K, Sprik, S., Kurtz, J., **2008 Annual Progress Report** for NREL's "Controlled Hydrogen Fleet and Infrastructure Analysis Project," Section VII.12, November 2008. (paper).
7. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Fuel Cell Vehicle Learning Demonstration: Early Second-Generation Vehicle Results and Hydrogen Production Efficiency," 2008 **Fuel Cell Seminar** & Exposition, Phoenix, Arizona, October 2008. (presentation)
8. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Fuel Cell Vehicle and Infrastructure Learning Demonstration Status and Results," 214th **Electrochemical Society Meeting**, Honolulu, HI, October 2008. (presentation)
9. Wipke, K., presentation of Learning Demonstration results to **FreedomCAR and Fuels Hydrogen Storage Tech Team**, October 2008. (presentation)
10. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., Garbak, J., "Fuel Cell Infrastructure Learning Demonstration: Status and Results," **ECS Transactions**, September 2008. (paper)
11. Wipke, K., Sprik, S., Kurtz, J., Ramsden, T., "**Fall 2008 Composite Data Products** for the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project," Golden, CO: National Renewable Energy Laboratory, September 2008. (presentation)
12. Wipke, K., presentation of Learning Demonstration results to **FreedomCAR and Fuels Fuel Cell Tech Team**, July 2008. (presentation)
13. Kurtz, J., Wipke, K., Sprik, S., "FCV Learning Demonstration: Factors Affecting Fuel Cell Degradation," **ASME Fuel Cell 2008** conference, Denver, CO, June 2008. (paper and presentation)
14. Wipke, K., Sprik, S., Kurtz, J., Garbak, J.,"DOE's Hydrogen Fuel Cell Activities: Developing Technology and Validating It through Real-World Evaluation," **Alternative Fuels & Vehicles Conference**, Las Vegas, NV, May 2008. (presentation)

Critical Assumptions and Issues

- **Assumption:** Linear fit for stack degradation slope and calculated beginning of life voltage (under load) used for projecting time to 10% voltage drop
  - When just a few hundred hours of data existed, no shape other than linear was justifiable
  - As more data was received, some stacks showed an initial drop in the first few hundred hours with a more gradual slope after that
  - With more data, a linear fit with a calculated initial voltage overestimated the projected time to a 10% voltage drop.
  - **Issue solved since last AMR:**
    - NREL improved its voltage degradation technique to include a segmented linear fit (two lines) which matches the data much better, while retaining the robustness in noisy data of a linear fit.

- **Issue:** Influences from fuel quality and climate on stack degradation may not be strong enough to draw conclusions for 1st gen vehicles
  - Fuel quality good at all sites…have not had a site with bad fuel quality to track stack degradation of vehicles refueling there
  - First gen stacks not freeze-tolerant, so vehicles are not left to soak in cold. Therefore data not likely to show strong impact of different climates yet
  - **Proposed solution:**
    - 2nd gen vehicles will be operated and soaked in cold environments to not only verify freeze tolerance but also look at impact on stack durability.
    - Separate activities (codes and standards) are looking at impact of fuel impurities on durability, which is probably most direct/controlled way to examine impurity impacts.