National Renewable Energy Laboratory
Innovation for Our Energy Future

National Fuel Cell Vehicle Learning Demonstration Nears Full Deployment

2009 National Hydrogen Association Conference

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Fuel Cell Vehicle Learning Demonstration Project Objectives and Targets

- Objectives
  - Validate H_2 FC Vehicles and Infrastructure in Parallel
  - Identify Current Status and Evolution of the Technology
  - 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

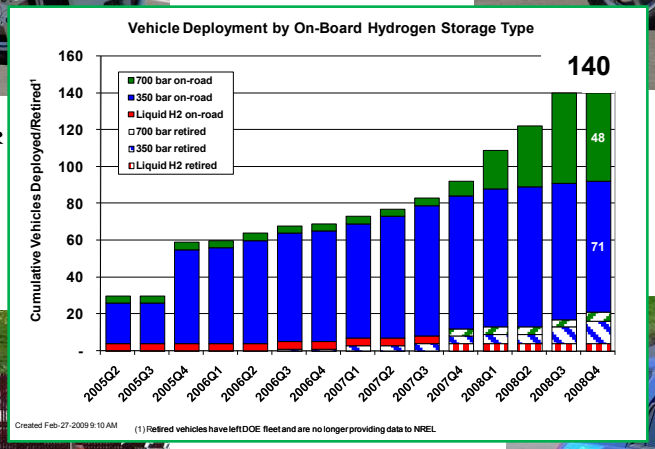
Industry Partners: 4 Automaker/Energy-Supplier Teams; Gen 2 Fleet Is Now Fully Deployed, Some Vehicles Retired

CHRYSLER

bp

Ford

bp



GM

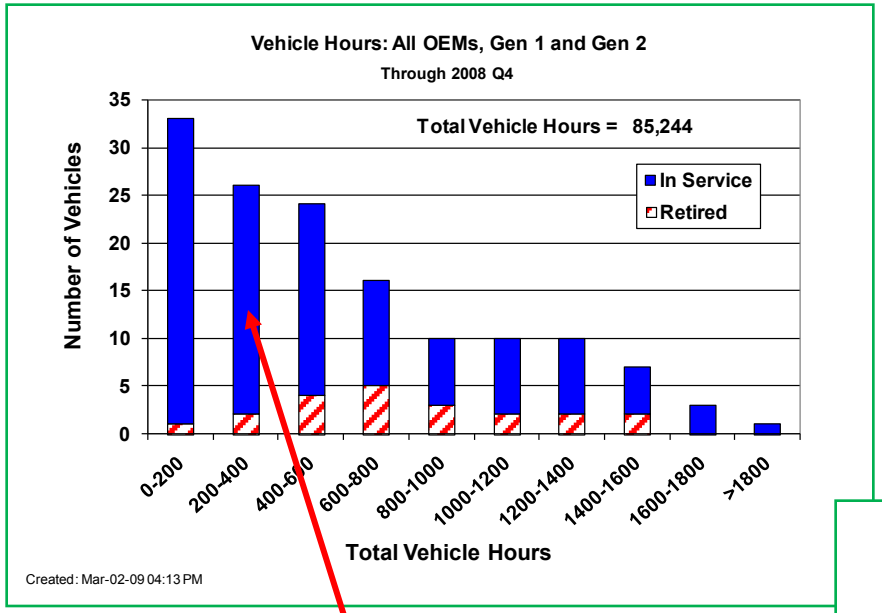
Chevron

HYUNDAI

KIA

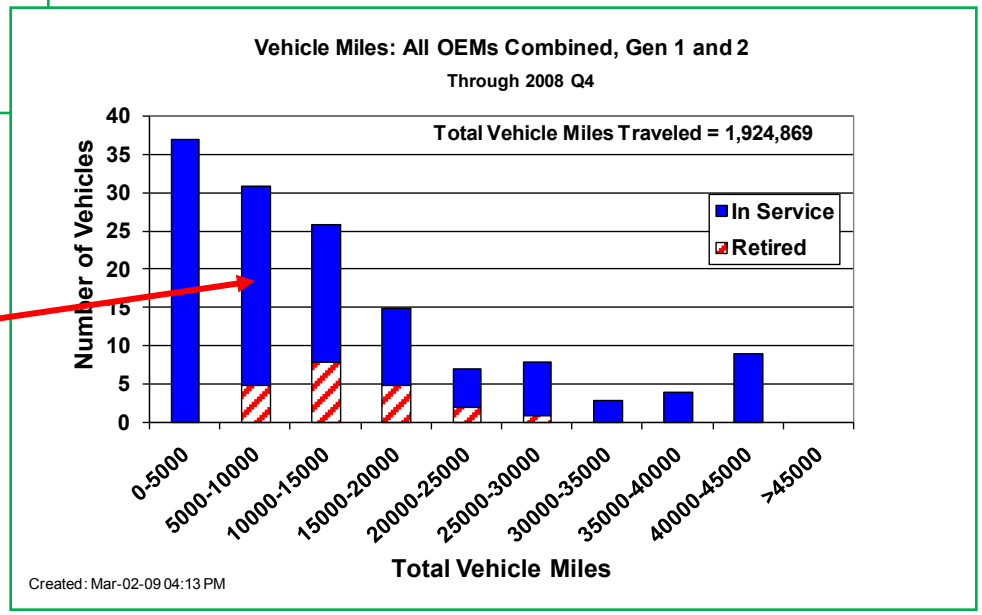
UTC Power
A United Technologies Company

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

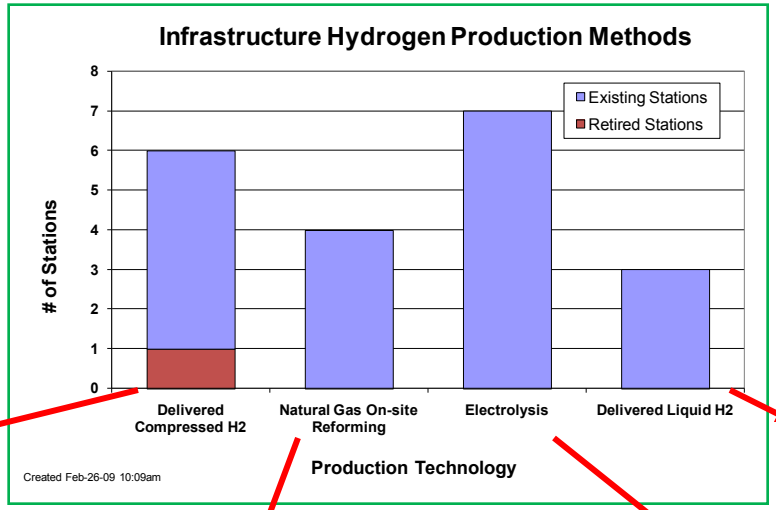


Some Gen 1 vehicles have now been retired (red bars)

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

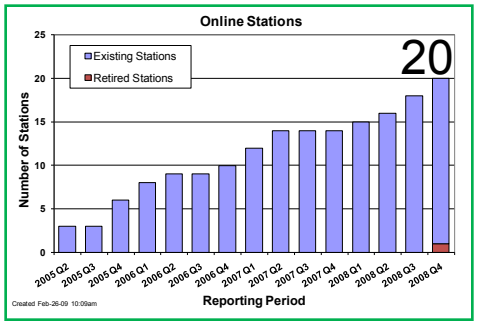


Majority of Project's Fixed Infrastructure to Refuel Vehicles Has Been Installed – Examples of 4 Types



Mobile Refueler Sacramento, CA

Delivered Liquid, 700 bar Irvine, CA



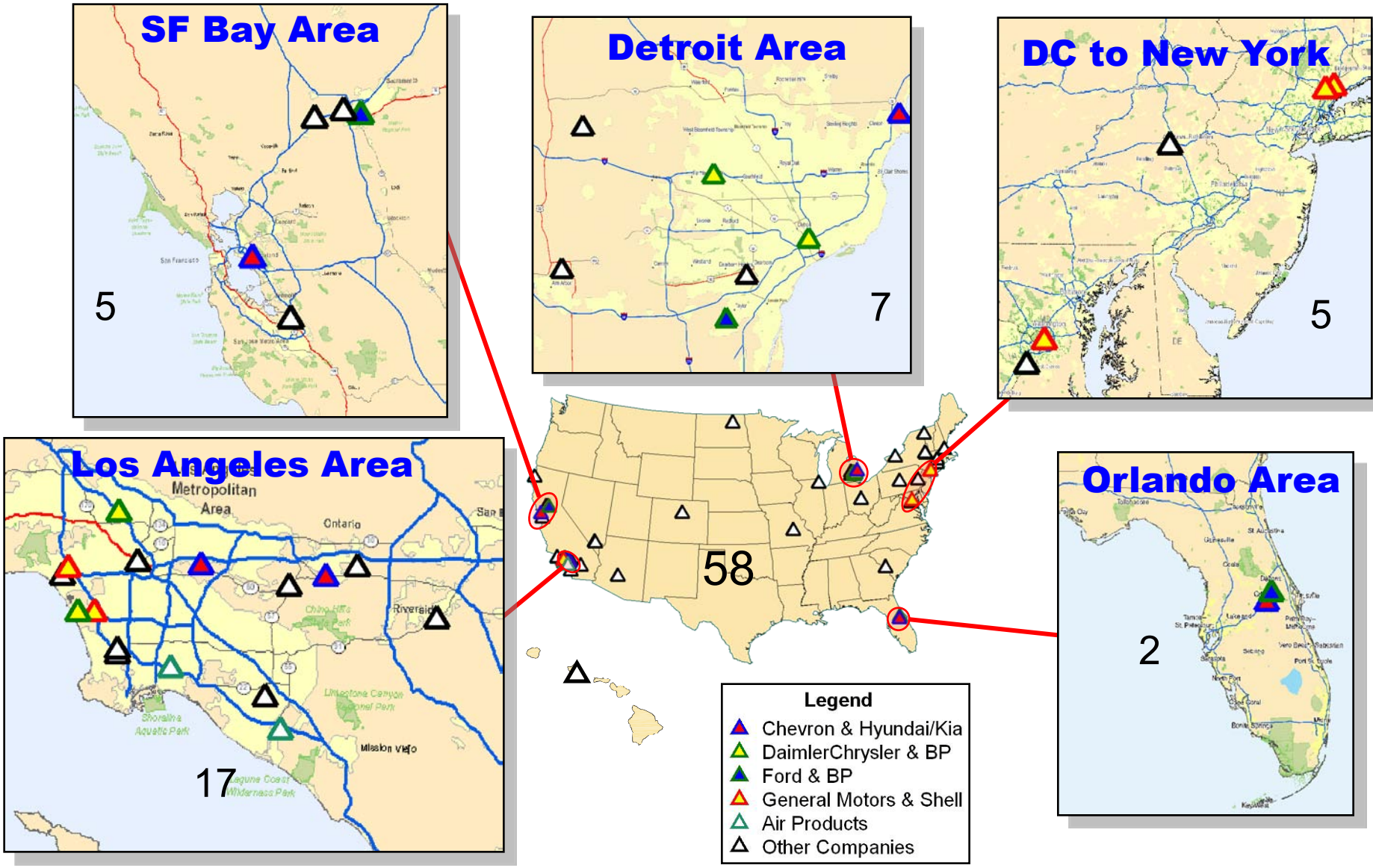
Steam Methane Reforming Oakland, CA

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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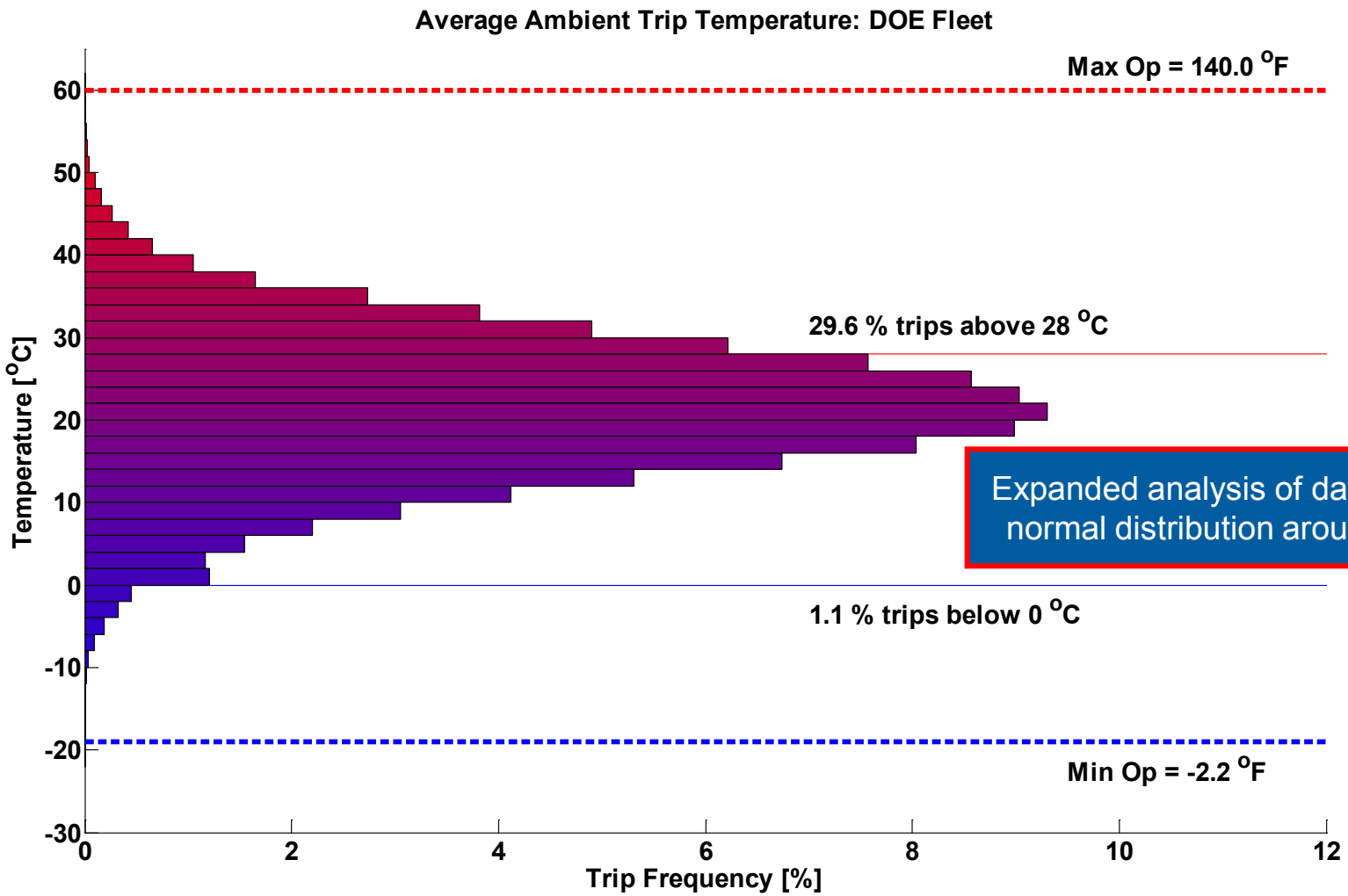
Distribution of Average Ambient Temperature During Vehicle Operation



Expanded analysis of data shows normal distribution around 20 C

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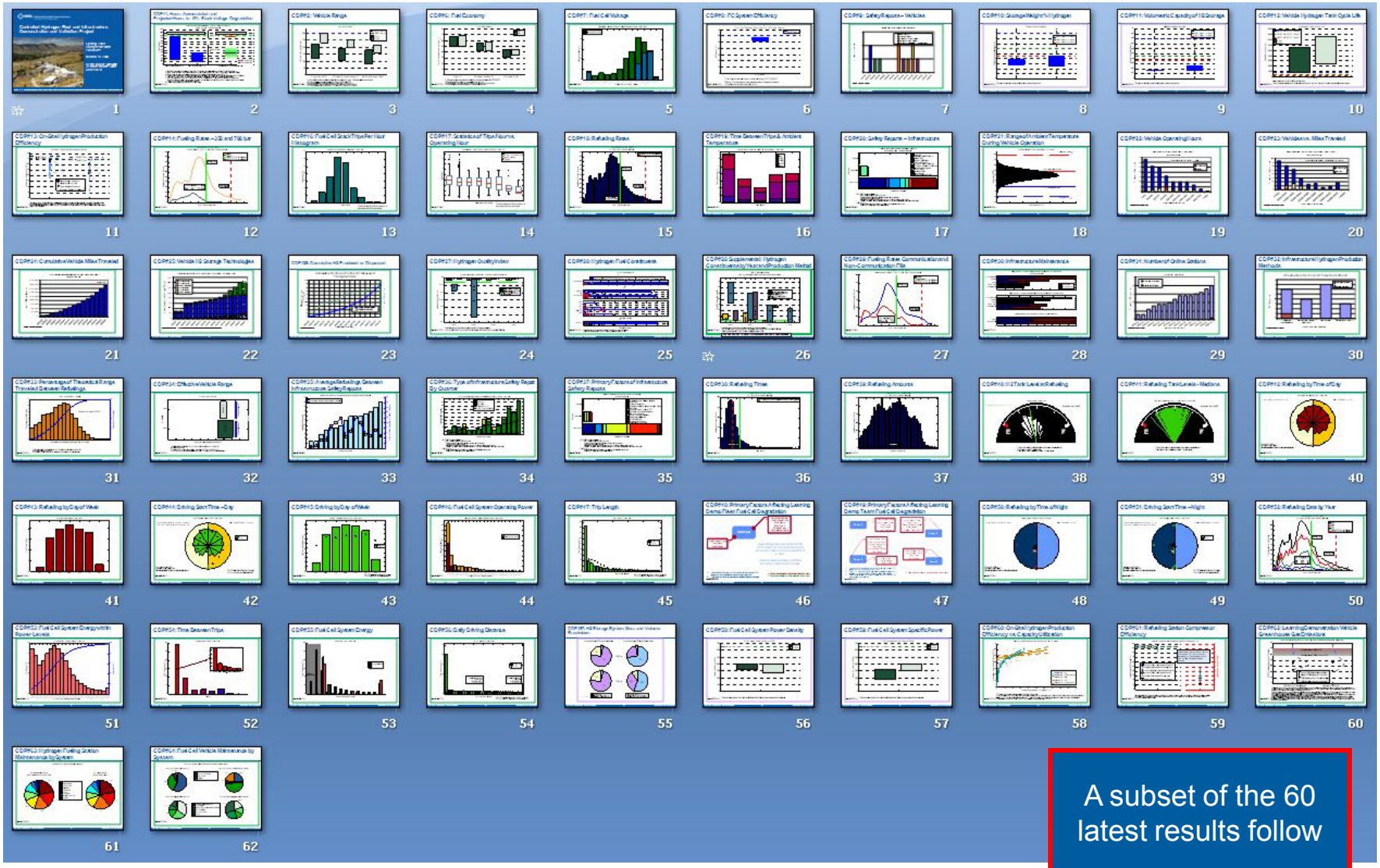
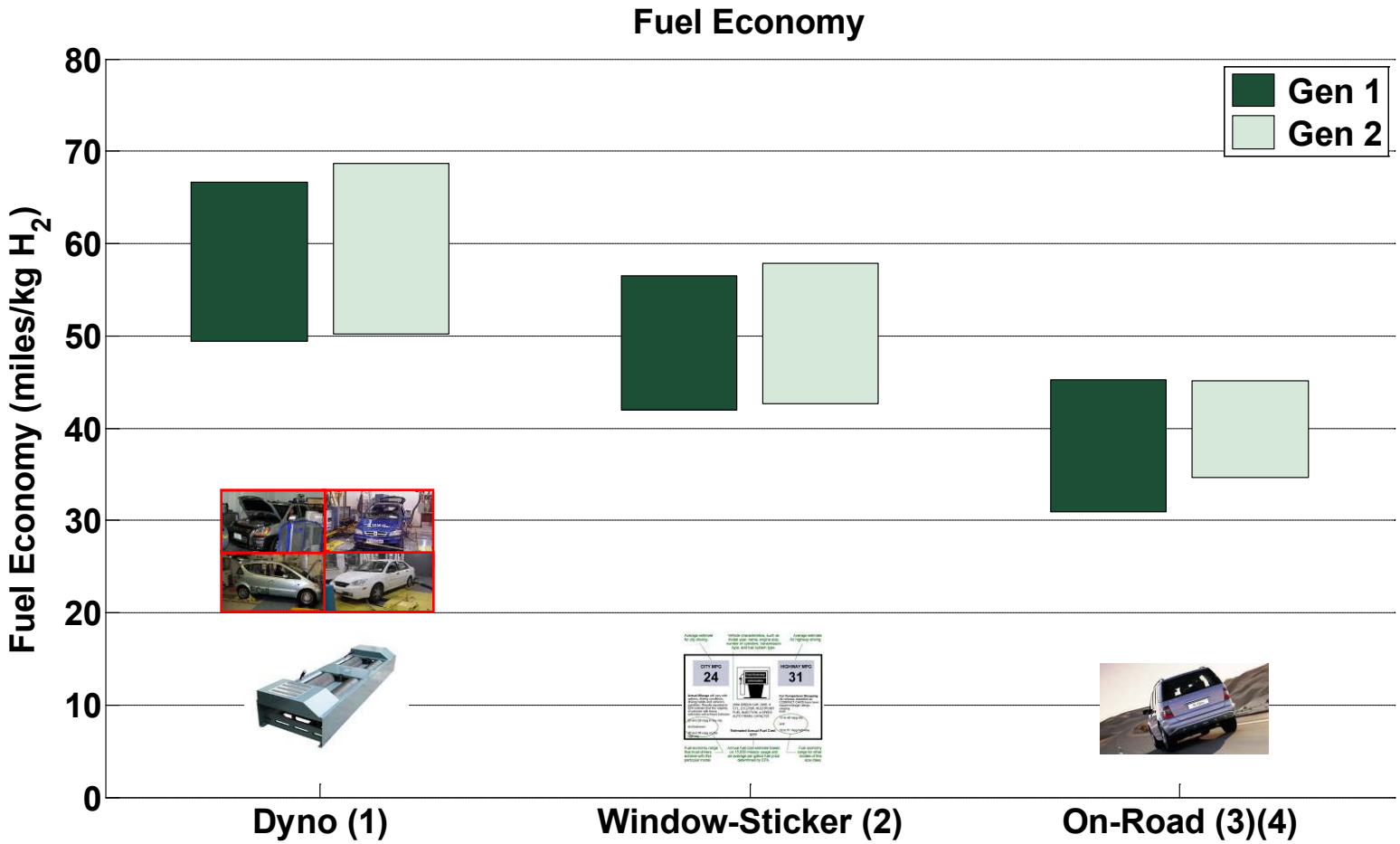
60 Public Composite Data Products Have Been Published; New Results and Updates Every 6 Months



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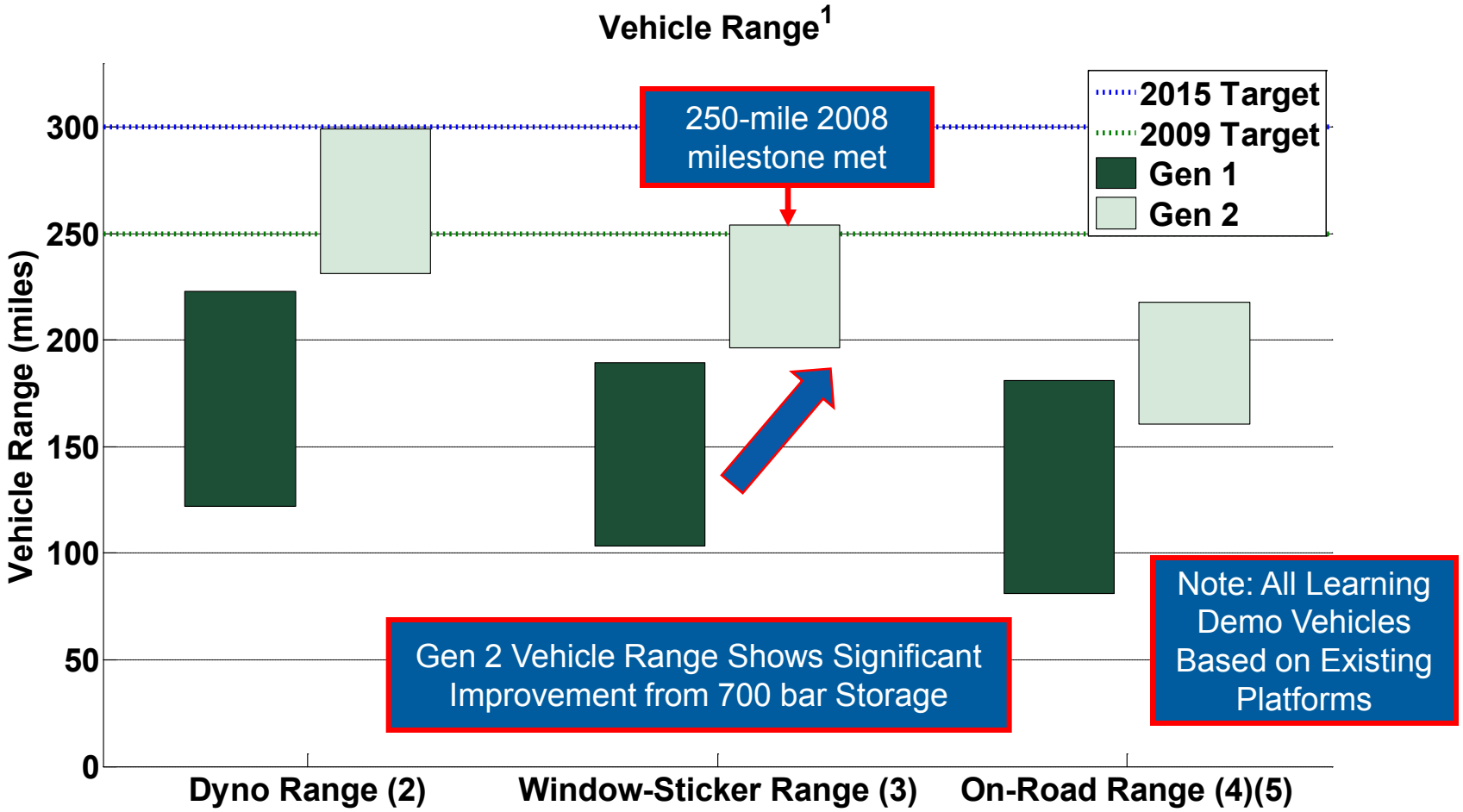
Driving Range for Gen 1 and Gen 2 Vehicles: Based on Fuel Economy and Usable H_2



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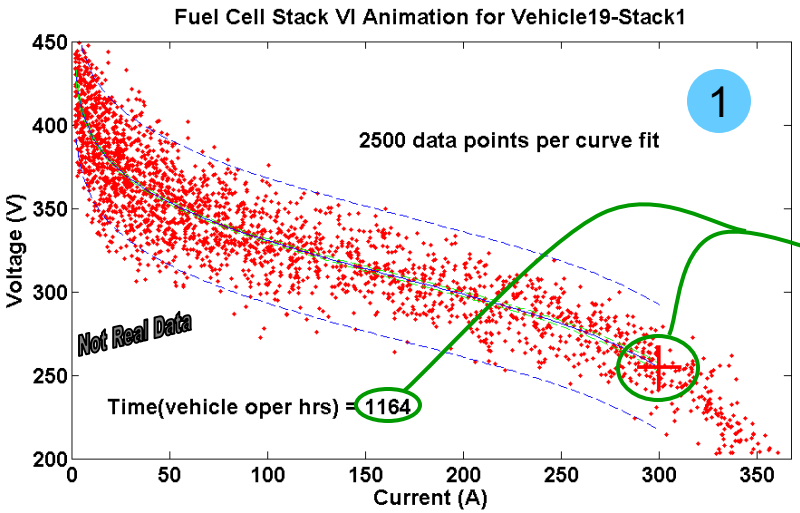
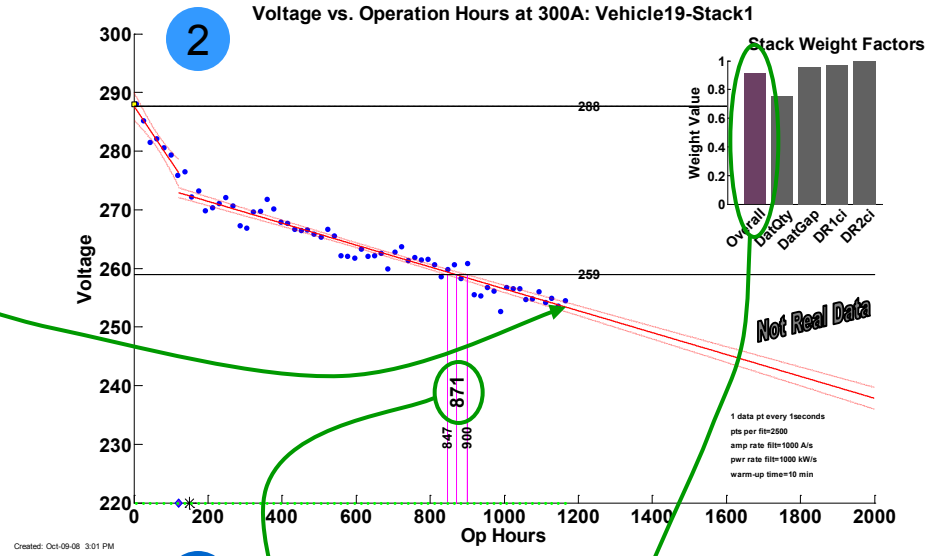
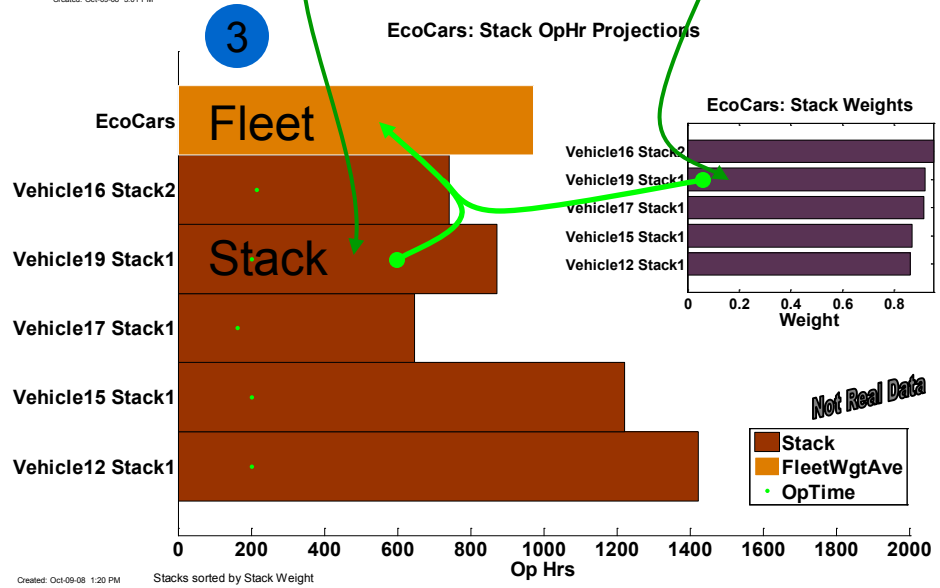
Improved Approach for Calculating Projected Time to 10% Voltage Drop for Stack and Fleet



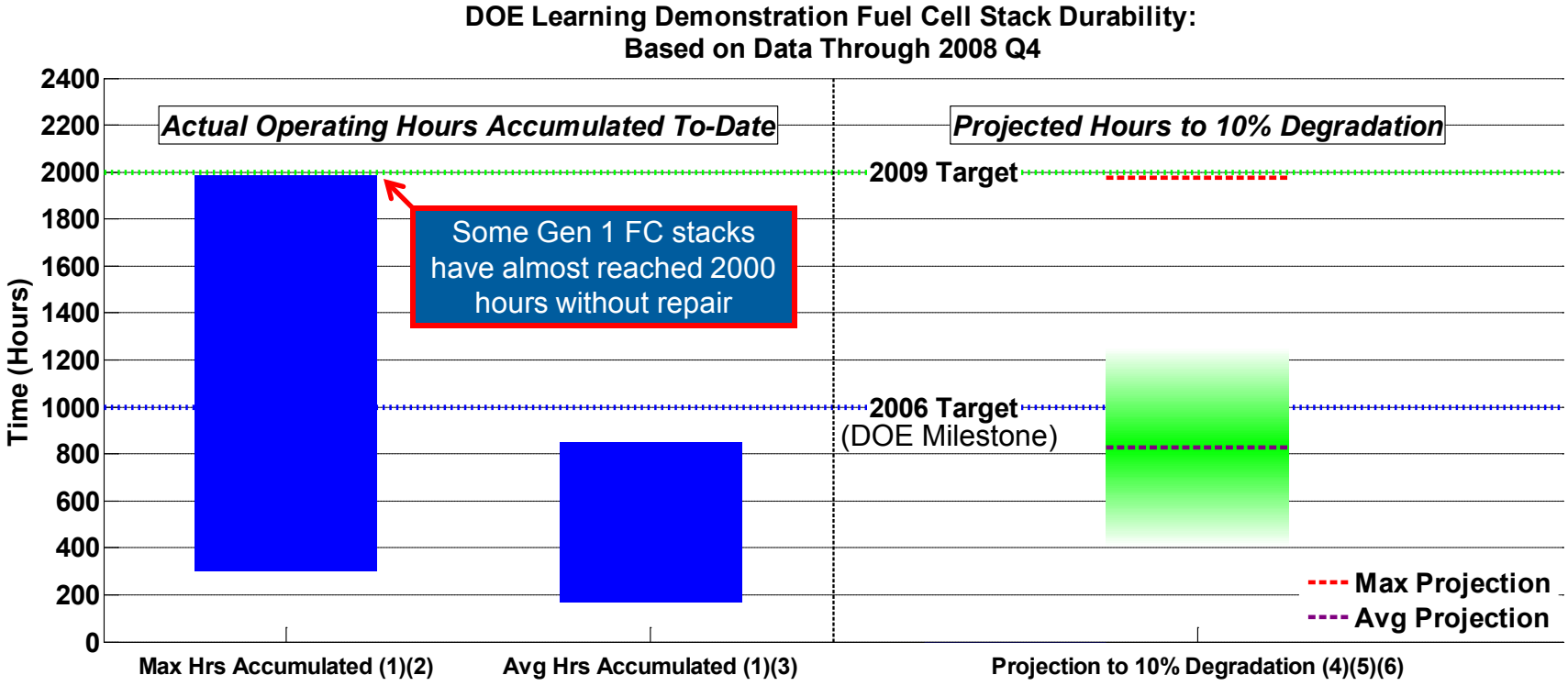


1. ***FC Stack*** voltage & current polarization fit
2. ***FC Stack*** voltage decay estimate using robust, improved **segmented linear fit** instead of linear fit (follows non-linear decay trends & early voltage decay)
3. ***Fleet*** weighted average using FC Stack operating hour projections and weights (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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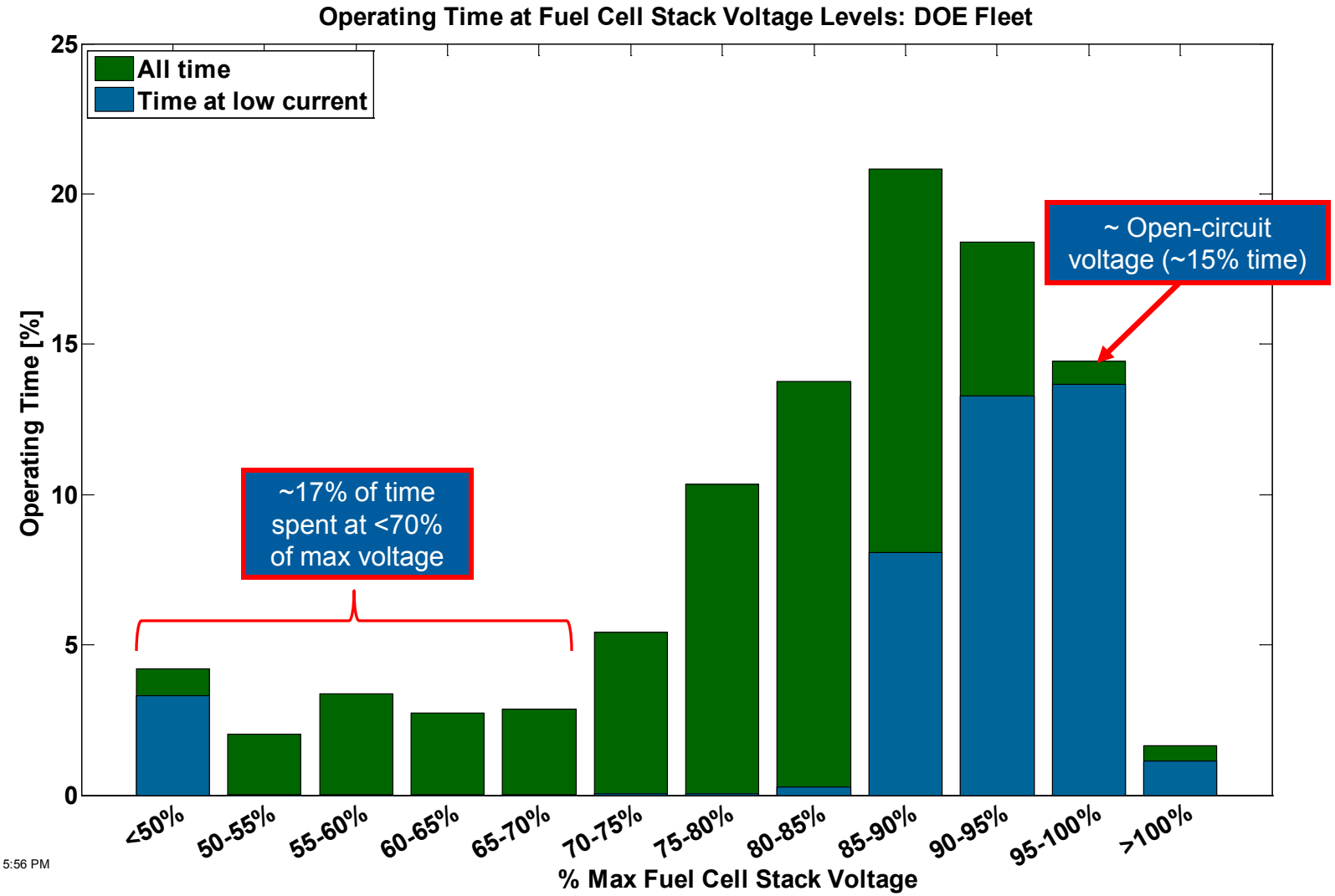
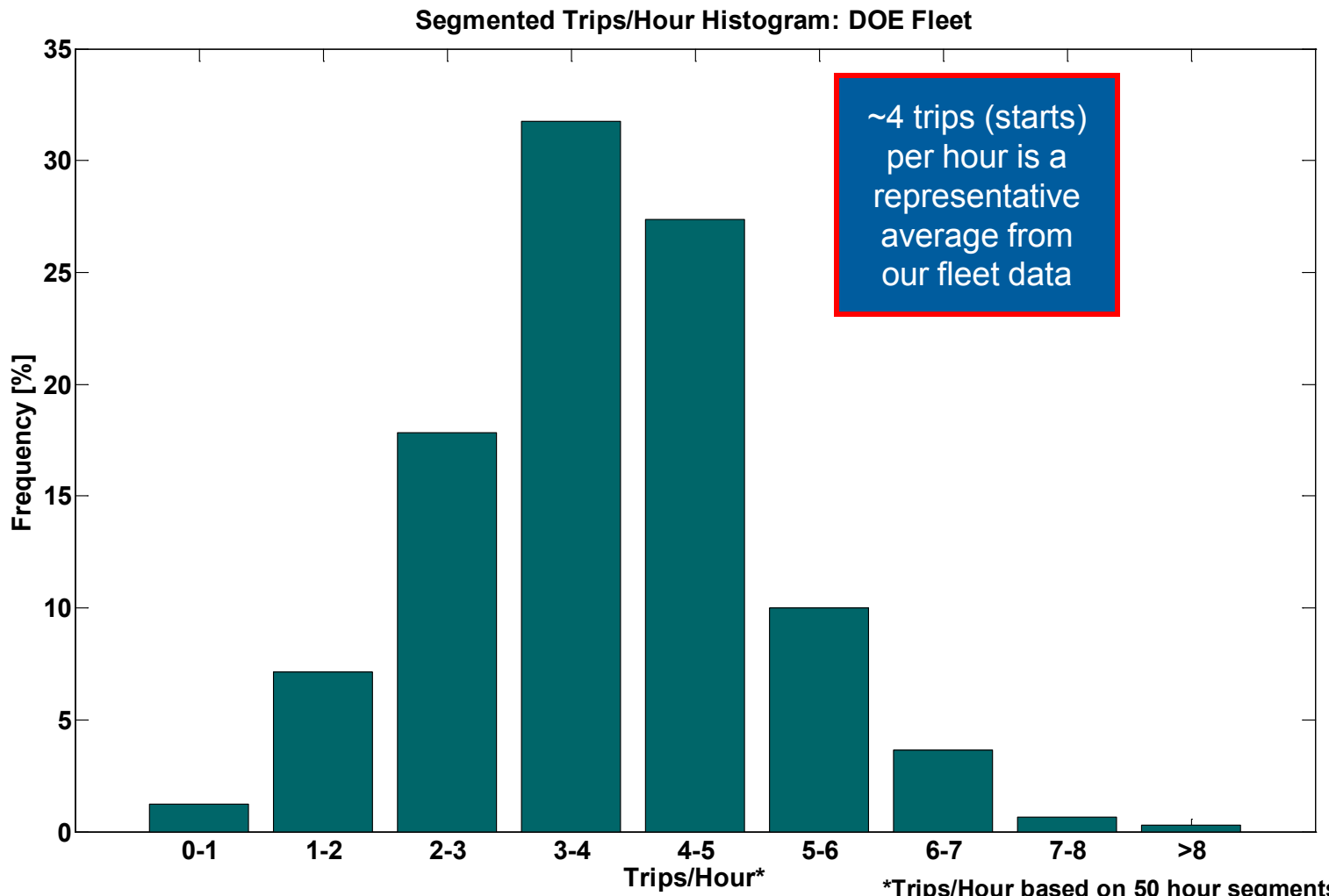
More data required to make Gen 2 projections (late 2009)

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



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



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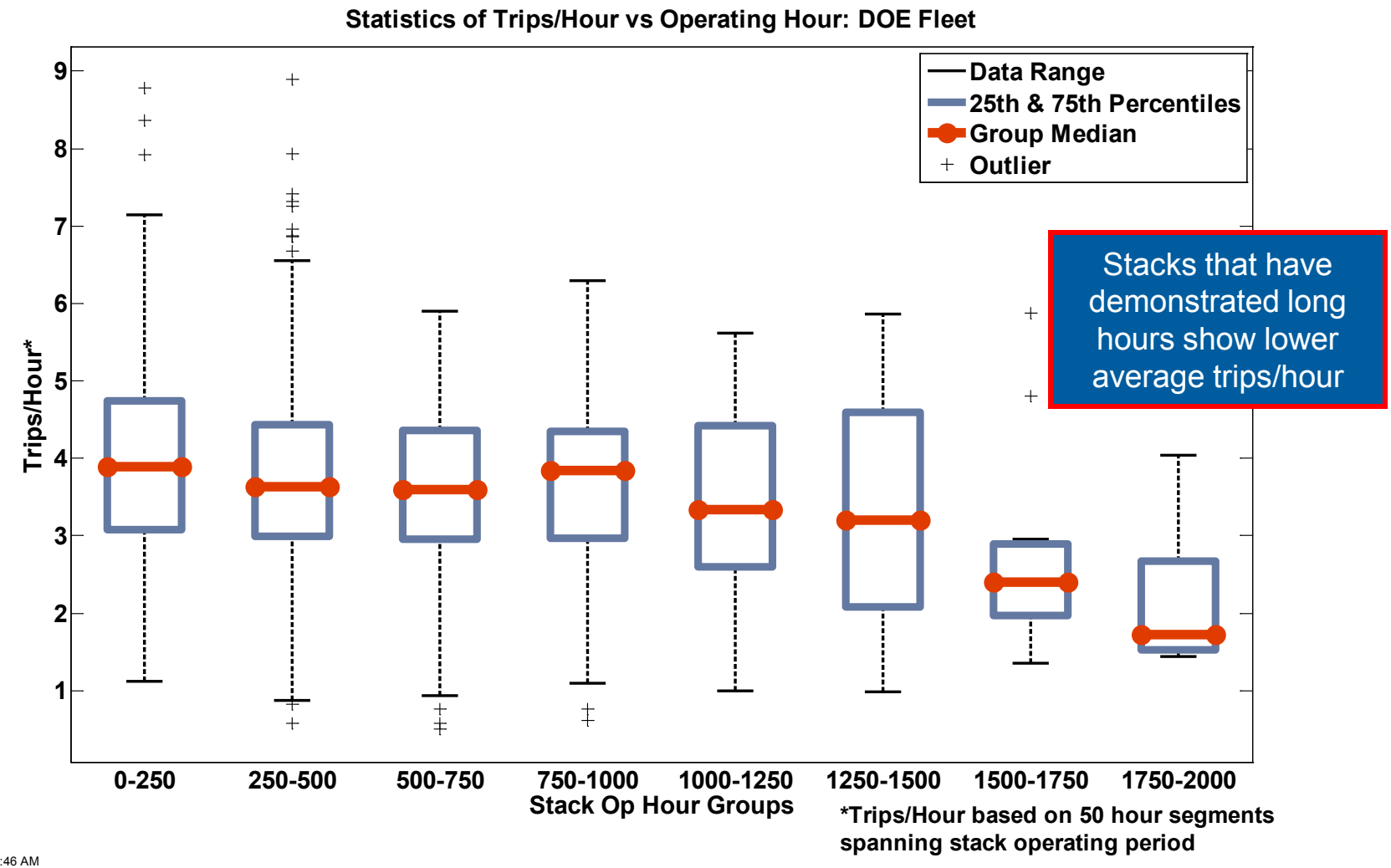
*Trips/Hour based on 50 hour segments spanning stack operating period

Average Trips/Hour as a Function of Stack Operating Hour



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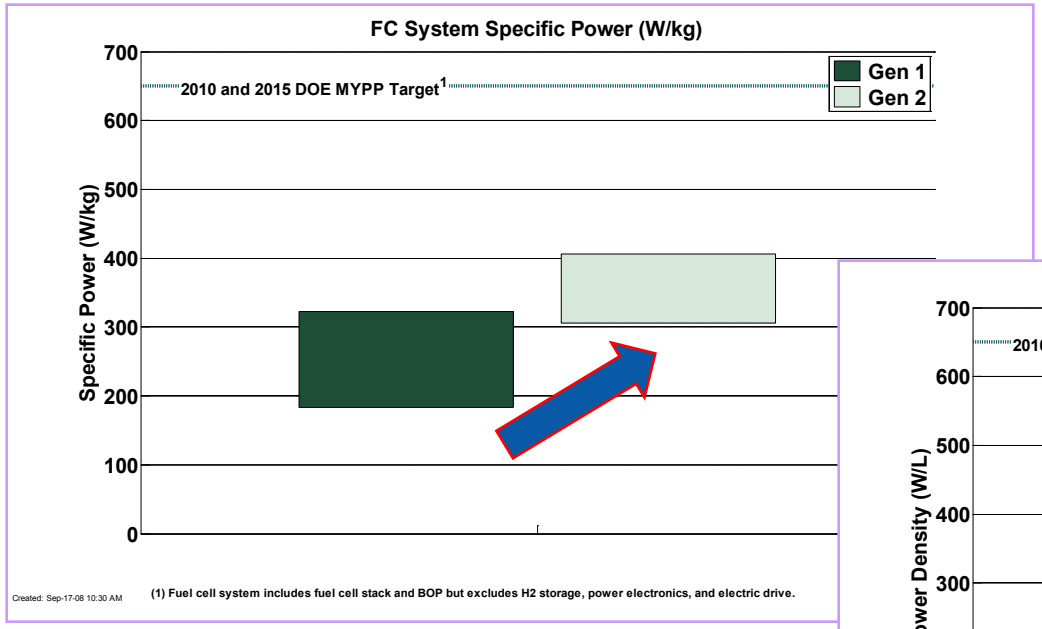
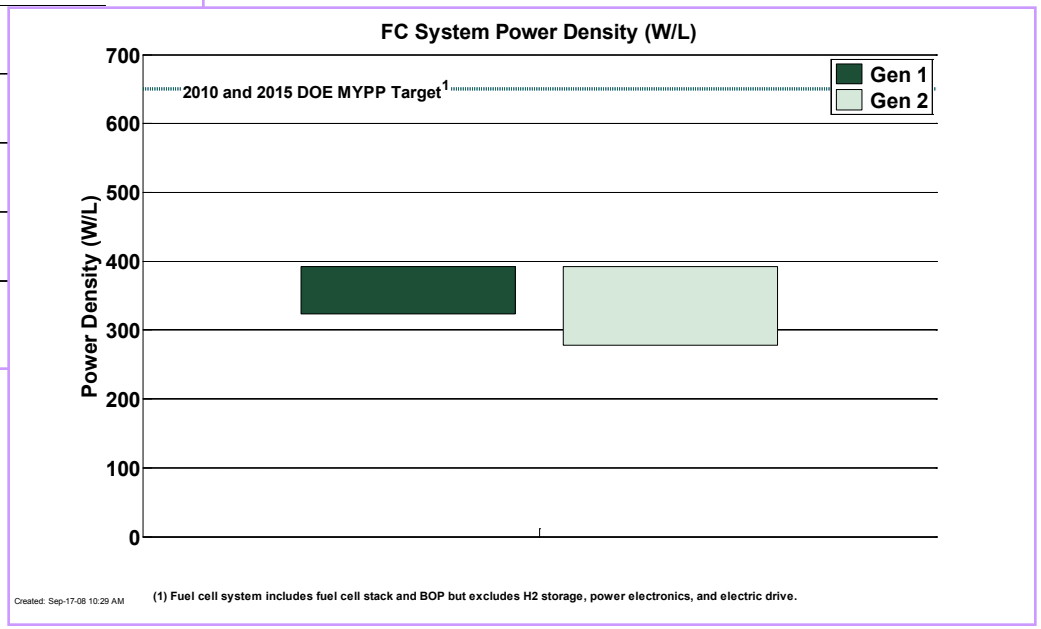
Comparison of FC System Specific Power and Power Density Between Gen 1 to Gen 2



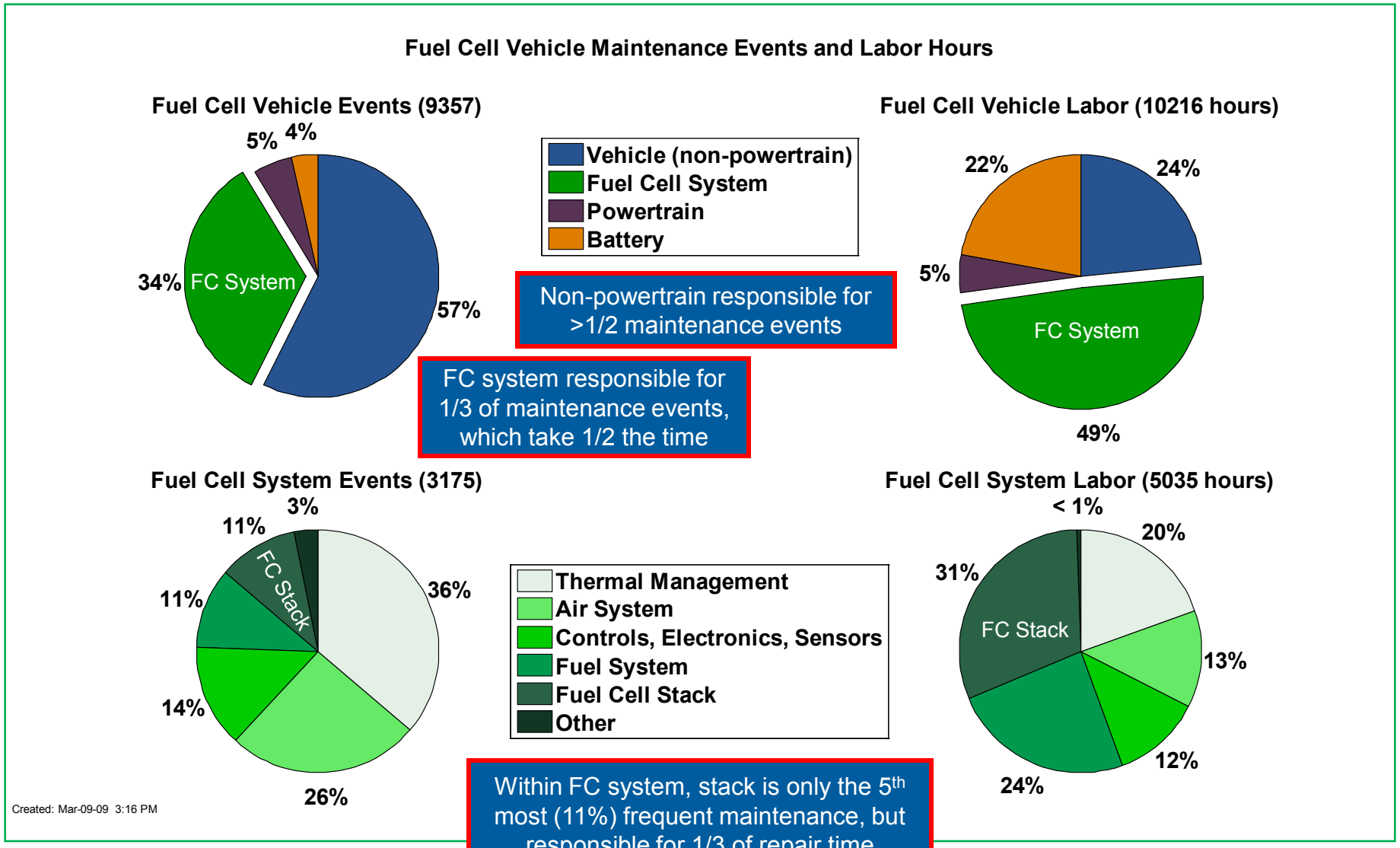
Freeze Capability of Gen 2 Systems May Have Increased Volume

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



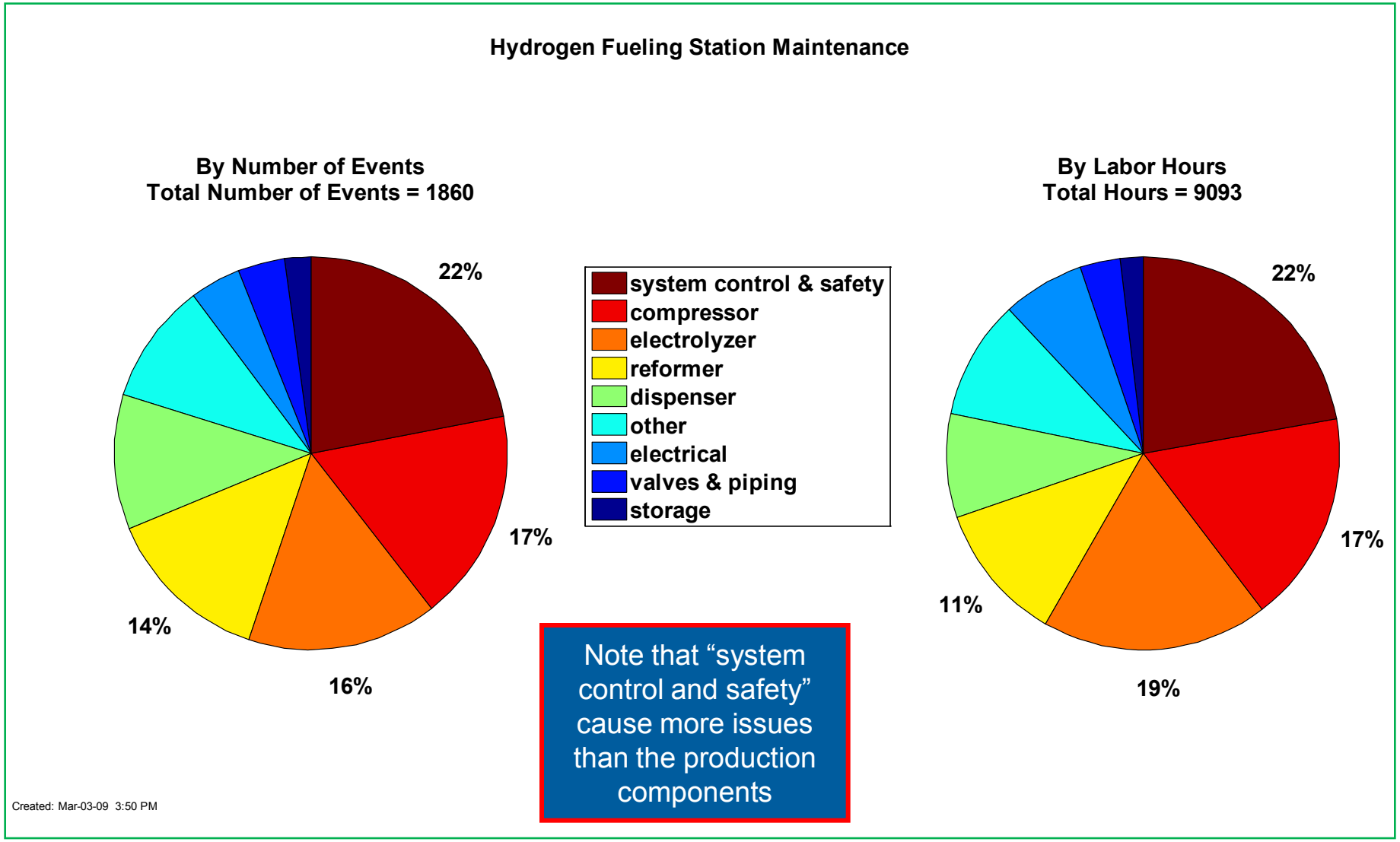
Power Density Did Not Improve Between Gen 1 and Gen 2 (…same size or larger)

New Analysis of Vehicle Maintenance Data Highlights Areas for Improvement



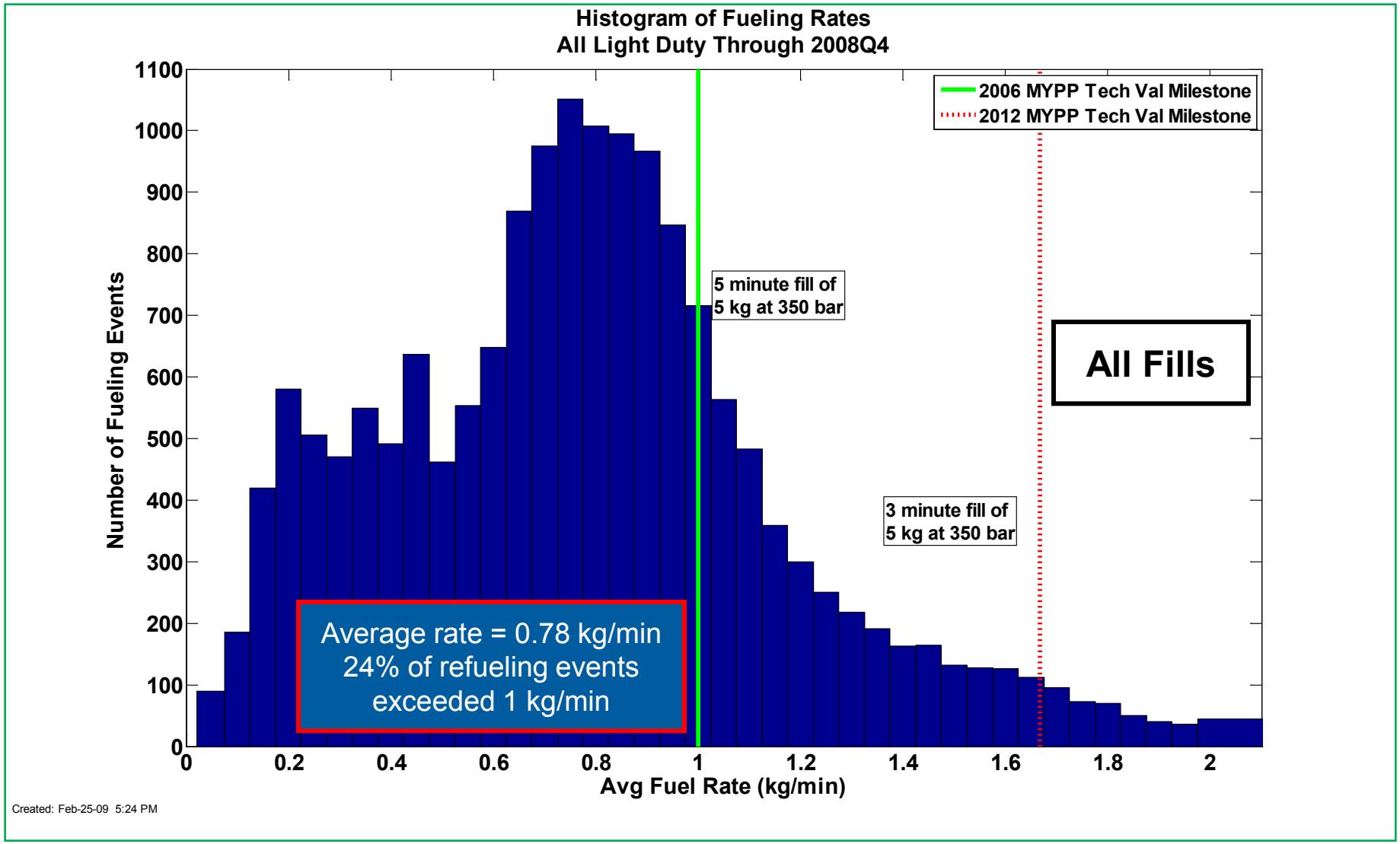
Within FC system, stack is only the 5th most (11%) frequent maintenance, but responsible for 1/3 of repair time

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

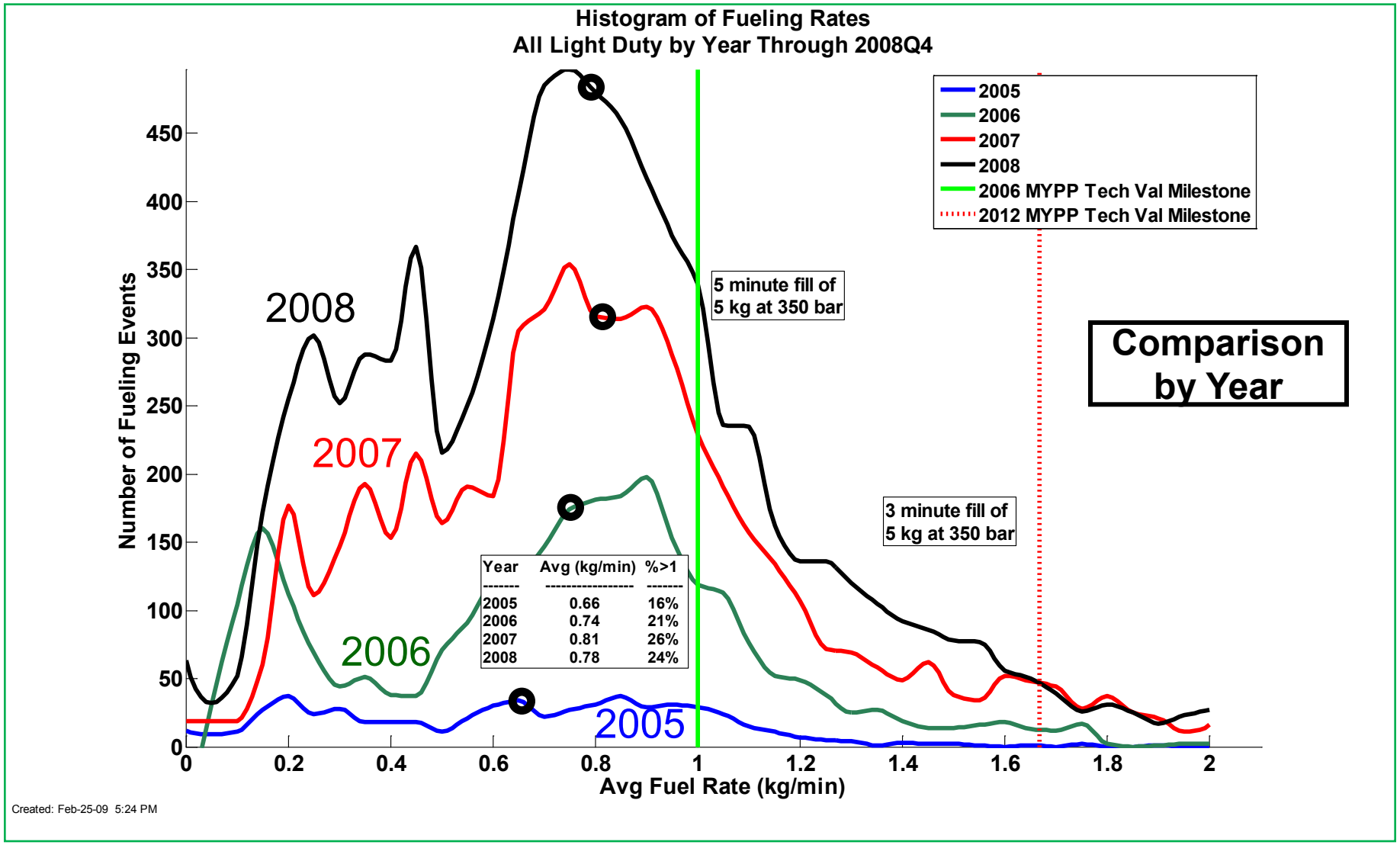


Note that "system control and safety" cause more issues than the production components

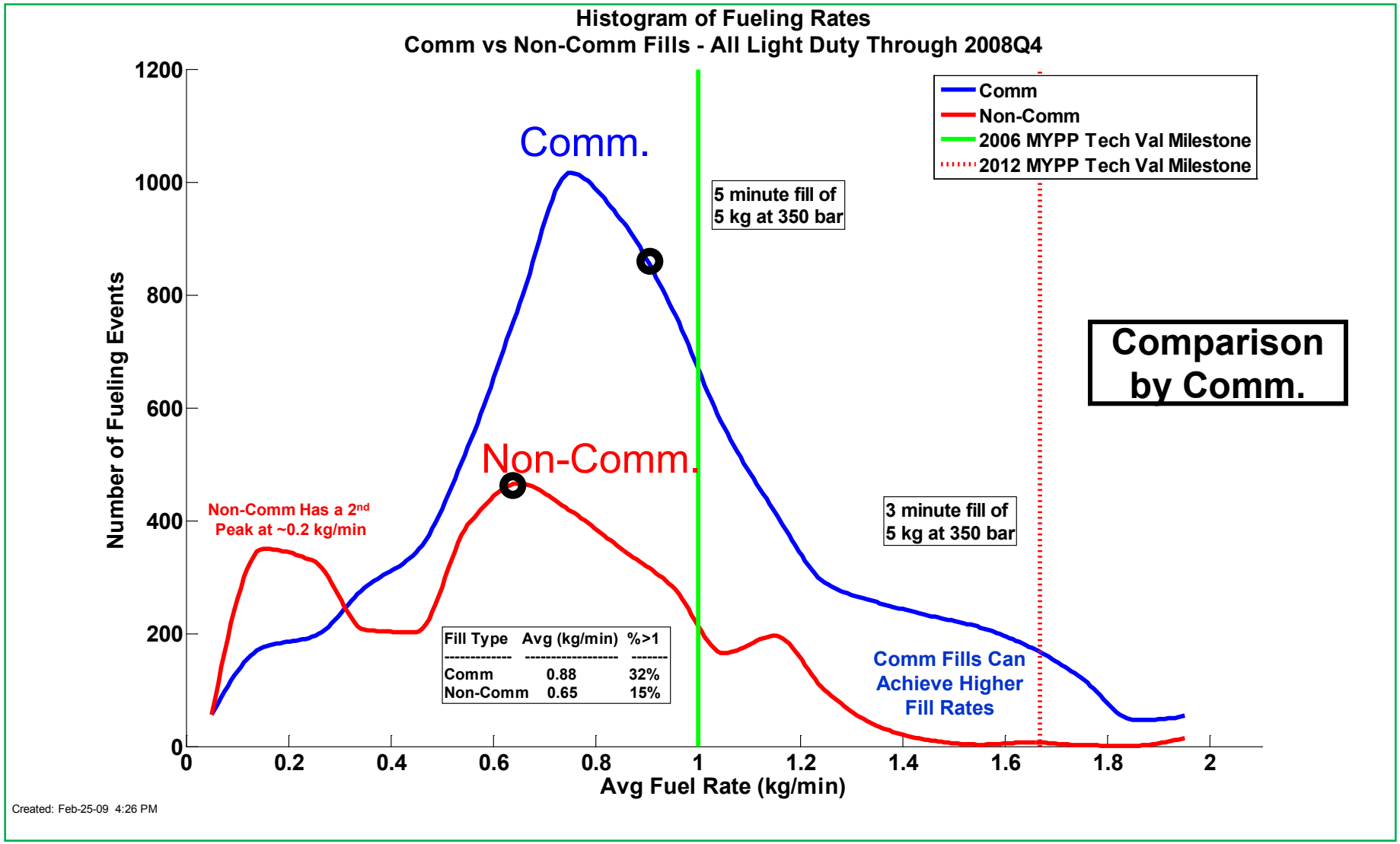
Actual Vehicle Refueling *Rates* from 16,000 Events: Measured by Stations or by Vehicles



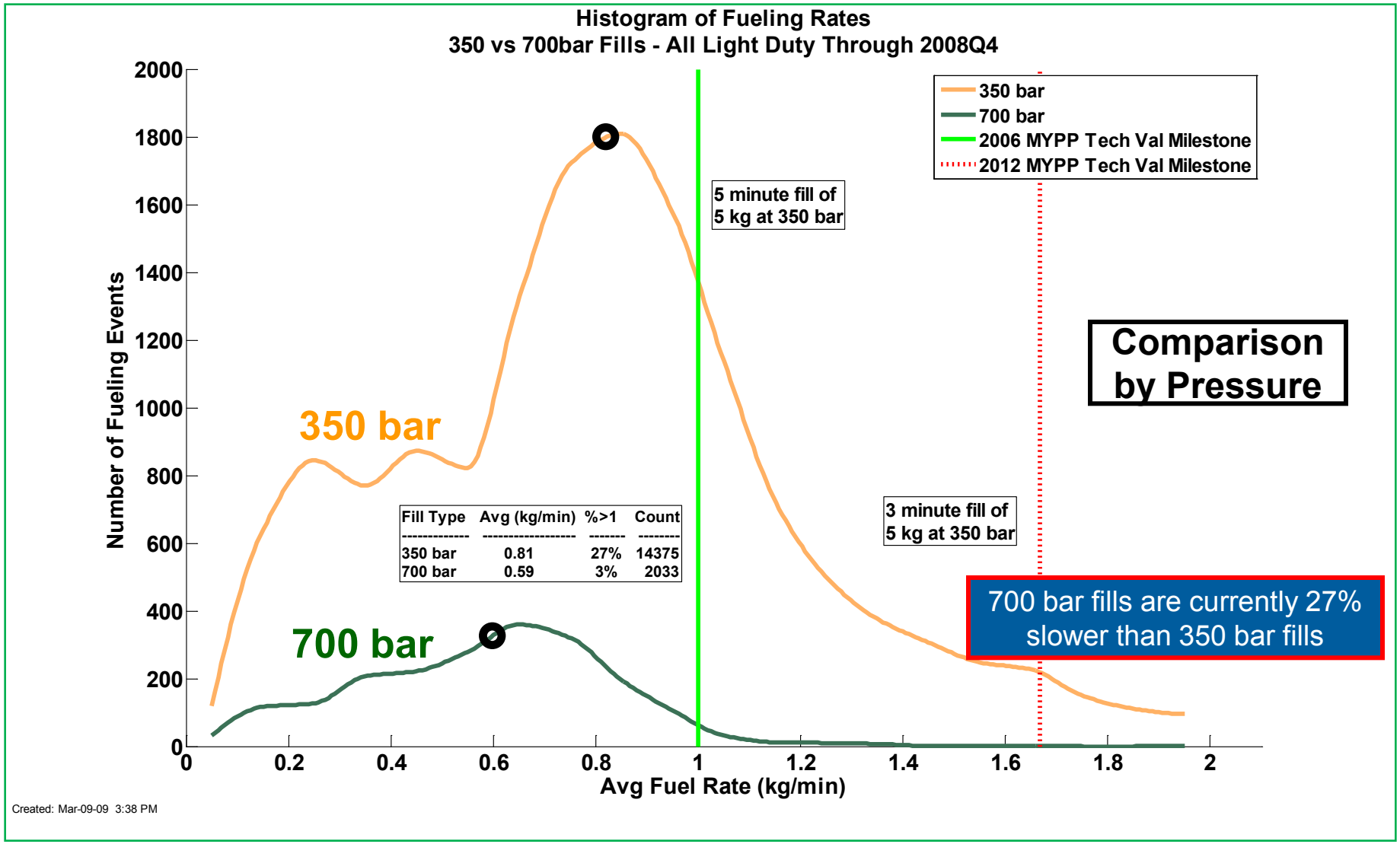
Refueling Rates by Year: Highest Number of Fills in 2008; ~1/4 Now Exceed 1 kg/min



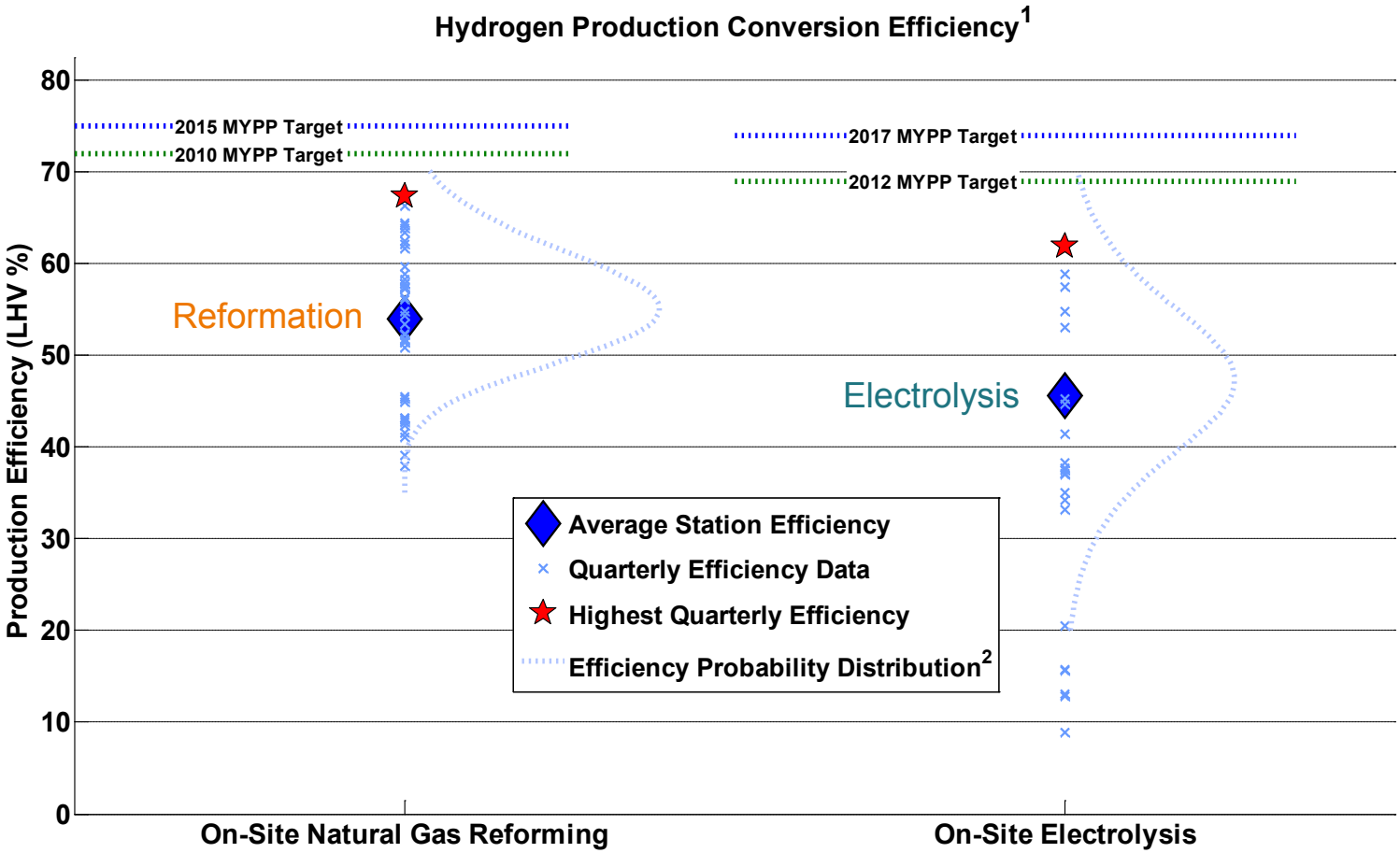
Communication H_2 Fills Achieving 35% Higher Average Fill Rate than Non-Communication



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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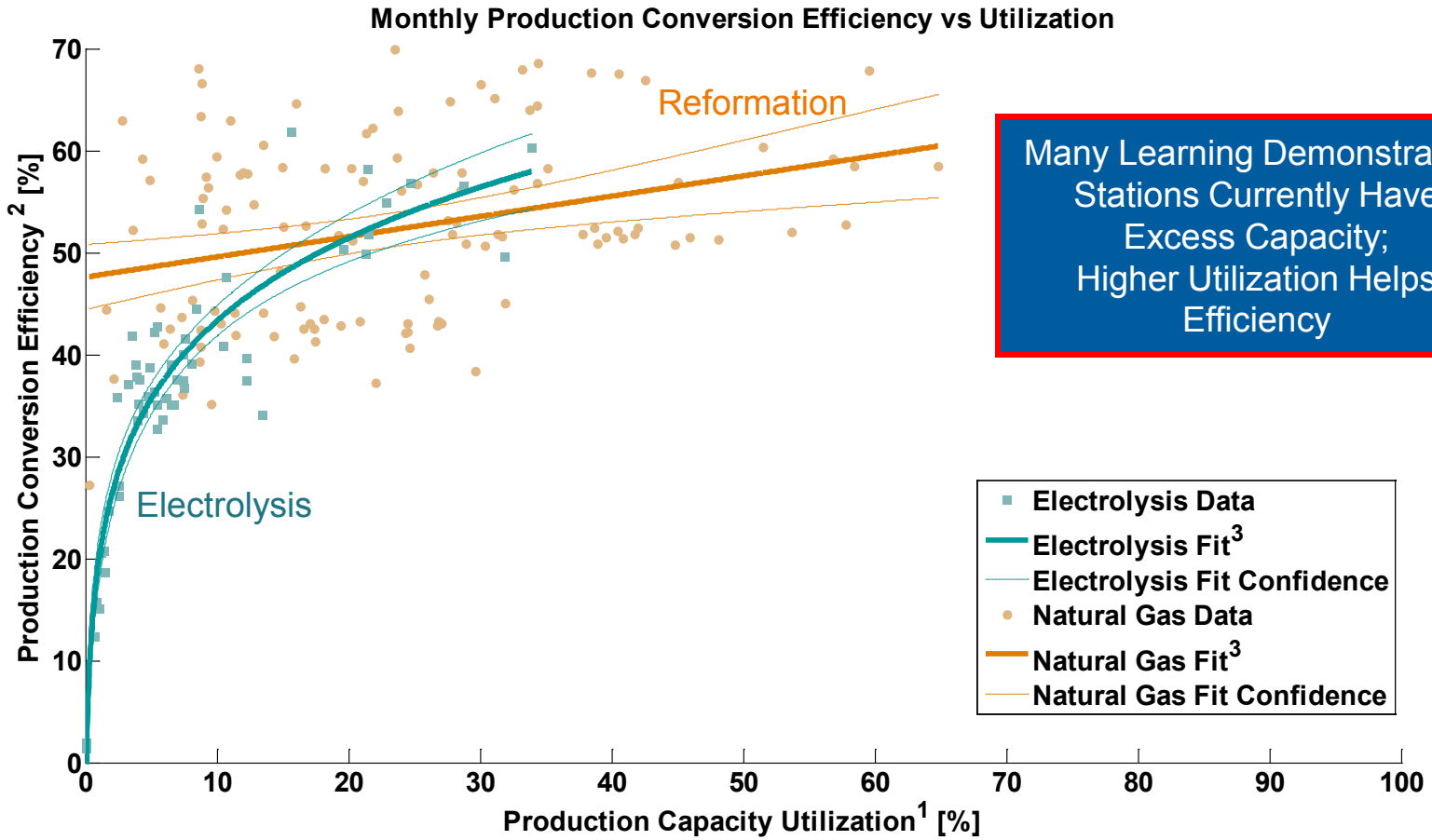
On-Site Hydrogen Production Efficiency vs. Capacity Utilization



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

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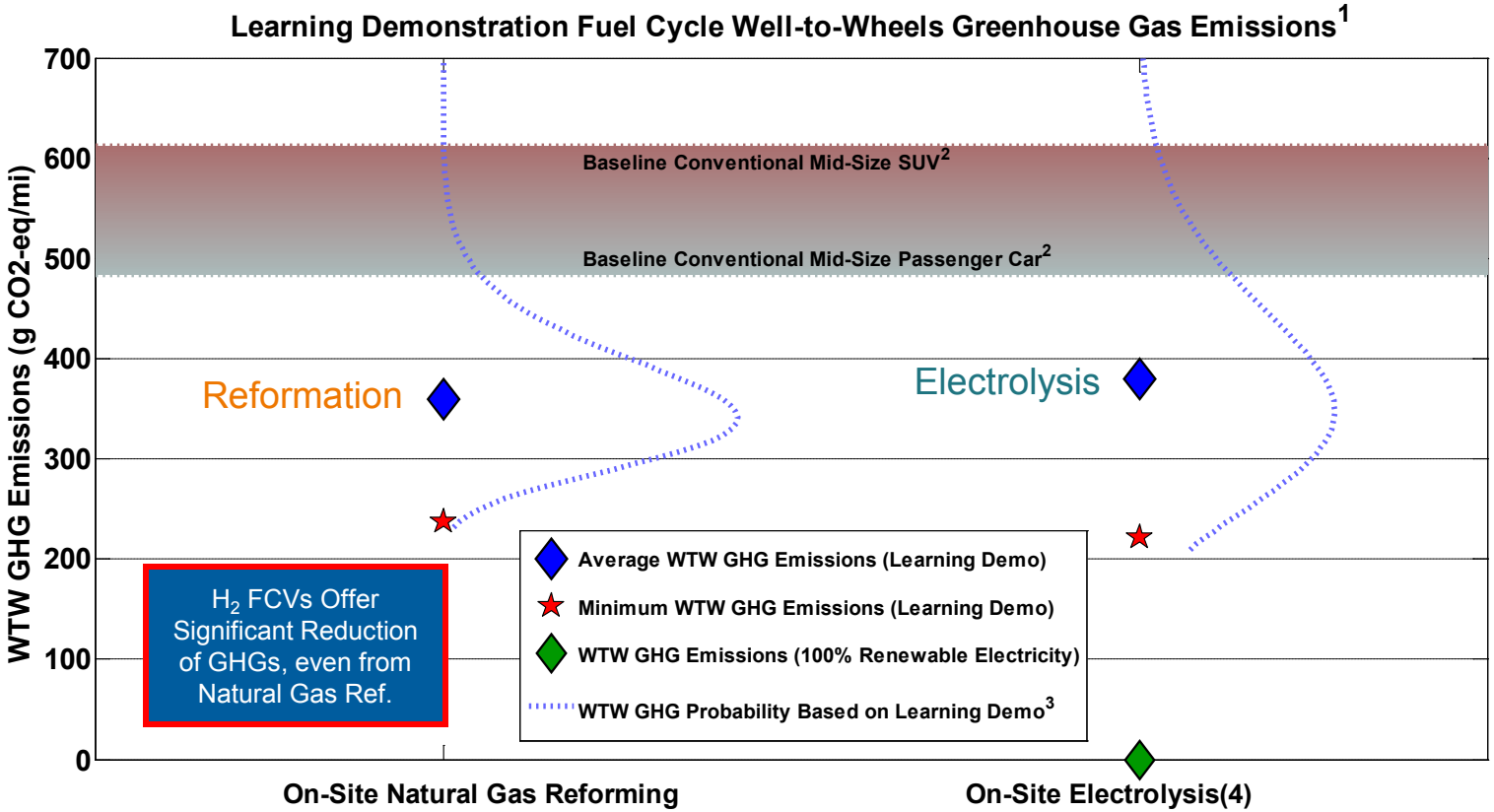
Learning Demonstration Vehicle Greenhouse Gas Emissions Using Actual Production Efficiencies and Fuel Economies



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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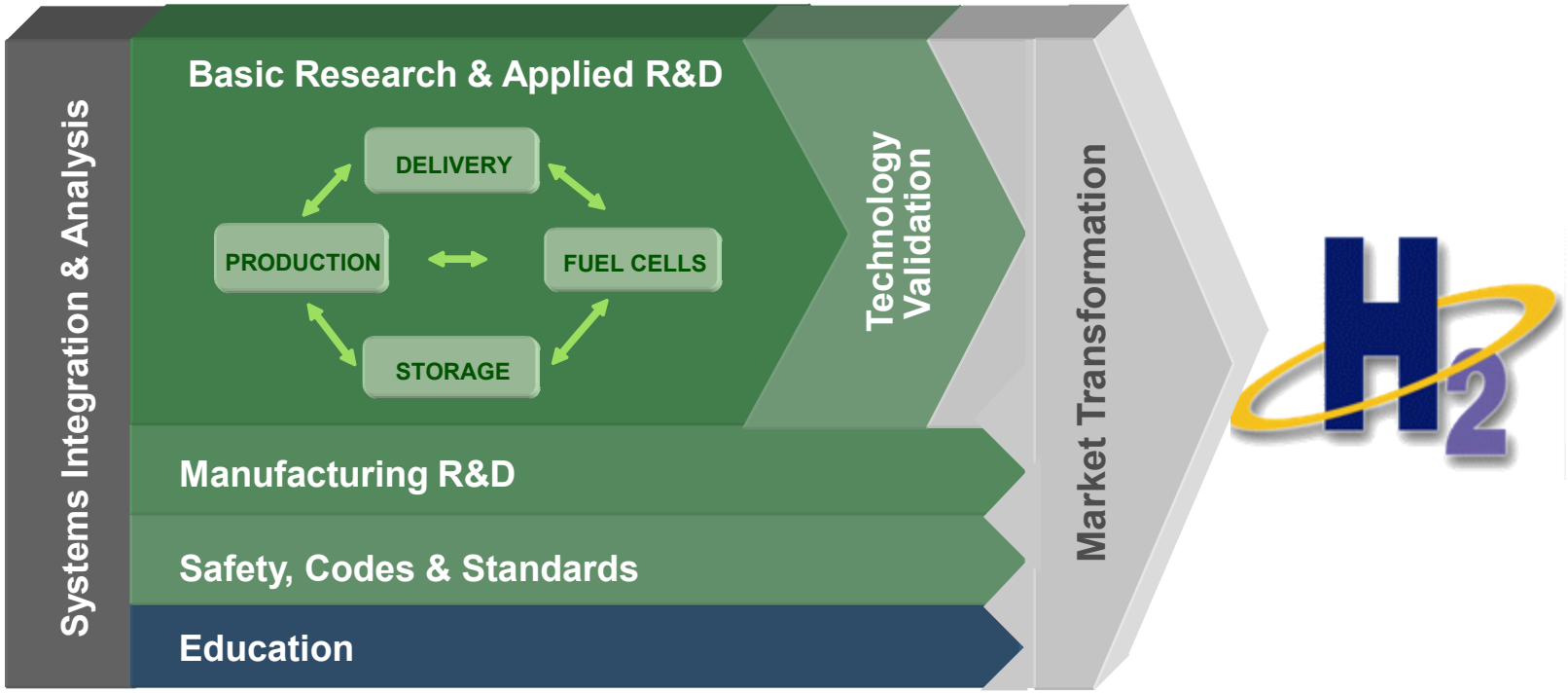
Summary

- 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 NHA presentation
  - All but 2 updated since last NHA
    - H_2 production efficiency, compressor efficiency, vehicle GHG emissions
    - 350 vs. 700 bar refueling rates
    - Several new FC stack usage statistics
    - Ambient temperature distribution
    - H_2 fueling station maintenance by system
    - Fuel cell vehicle maintenance by system
  - All new results live on web site today
- Roll-out of 2nd generation vehicles is now complete
- Station deployment nearing completion

Questions and Discussion



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