DEM34-2

National Renewable Energy Laboratory
Innovation for Our Energy Future

Second-Generation Fuel Cell Stack Durability and Freeze Capability from National FCV Learning Demonstration

Fuel Cell Seminar 2009

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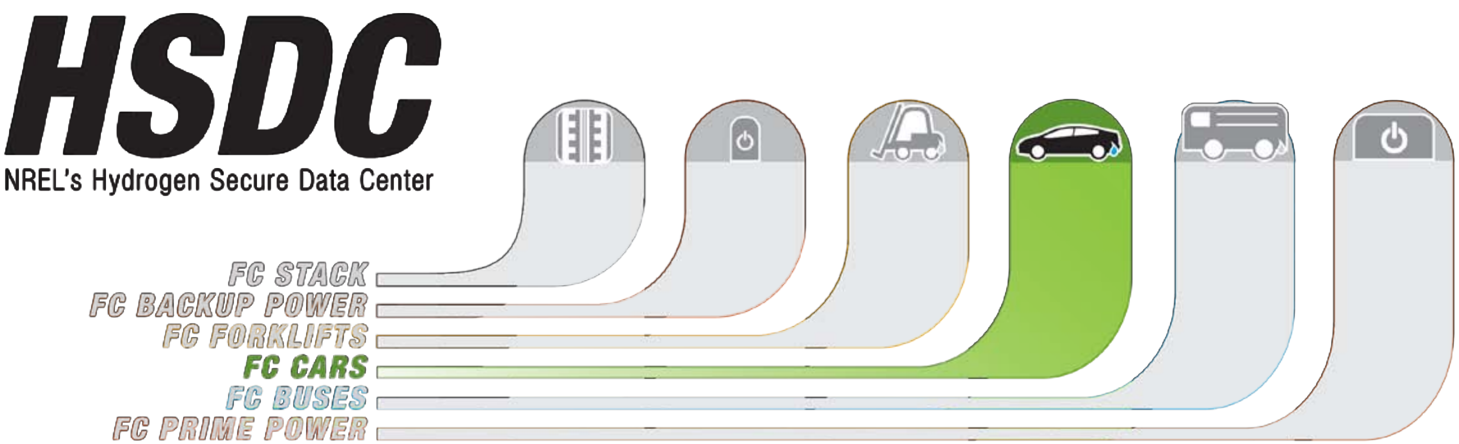
Outline and Context

- Project Objectives and Partners
- Vehicle/Station Deployment and Status
- Vehicle Analysis Results
- Infrastructure Analysis Results
- Summary



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 Project 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	Outside review	$2-3/gge

Solar Electrolysis Station, Sacramento, CA

Photo: NREL

Industry Partners:
Four Automaker/Energy-Supplier Teams

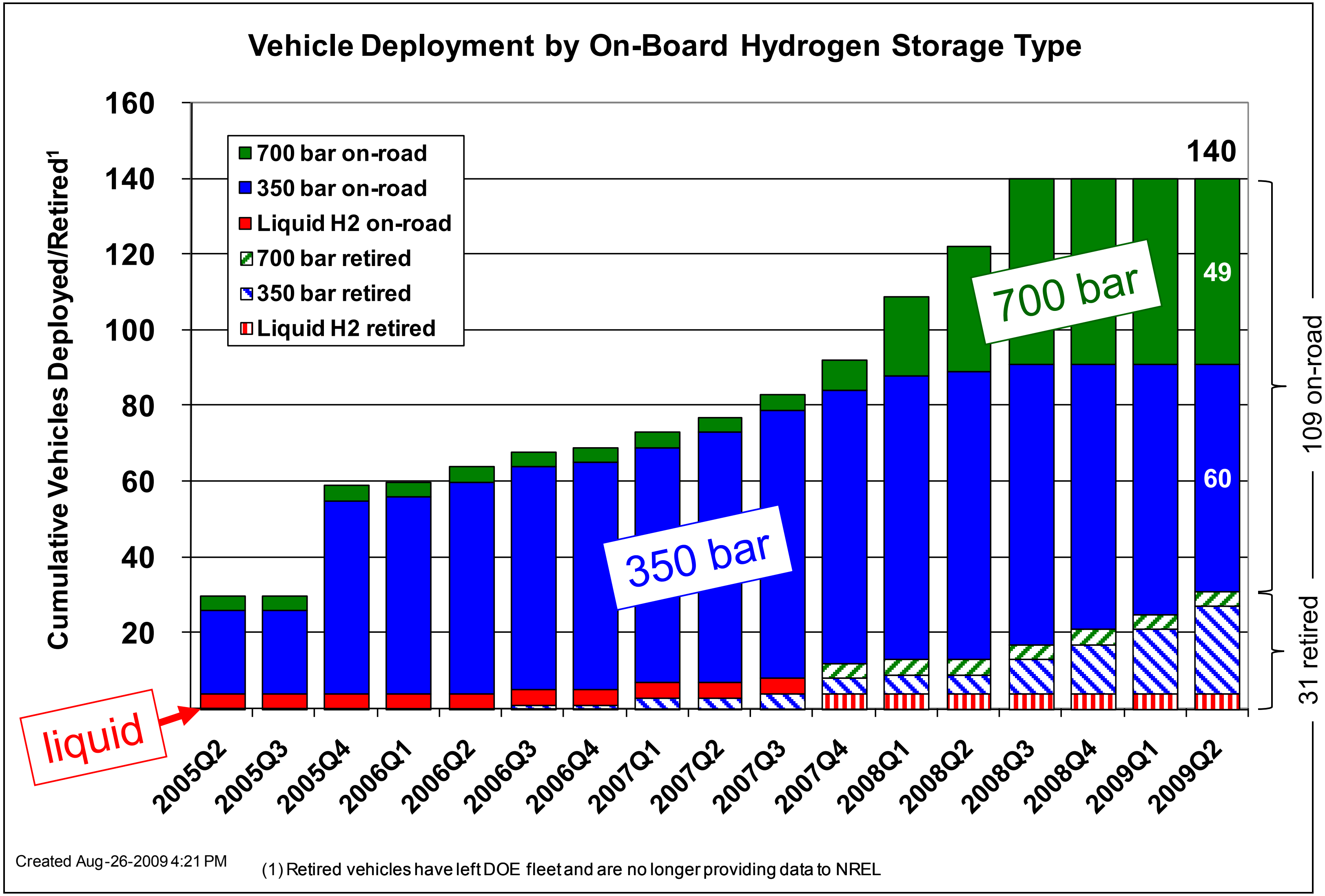
DAIMLER
bp

Ford
bp

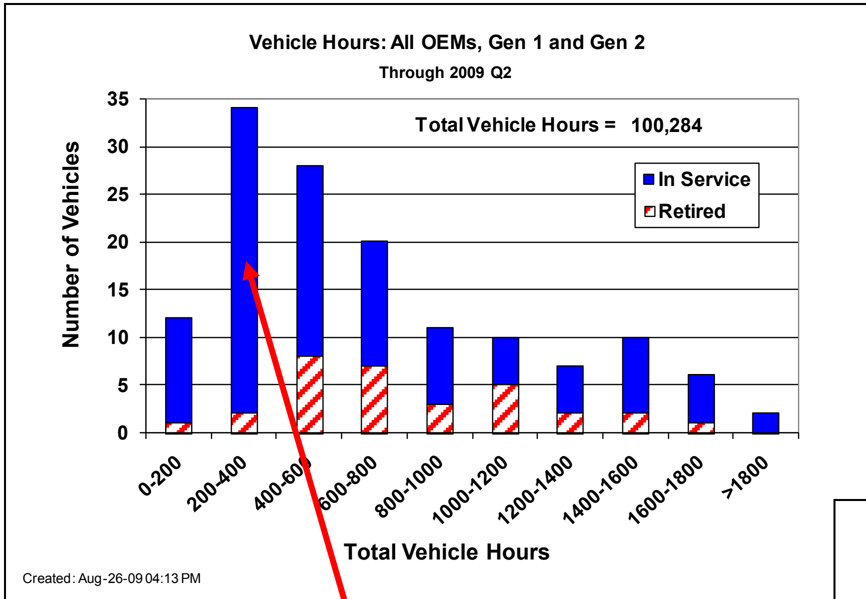
GM

Chevron
HYUNDAI
KIA
UTC Power
A United Technologies Company

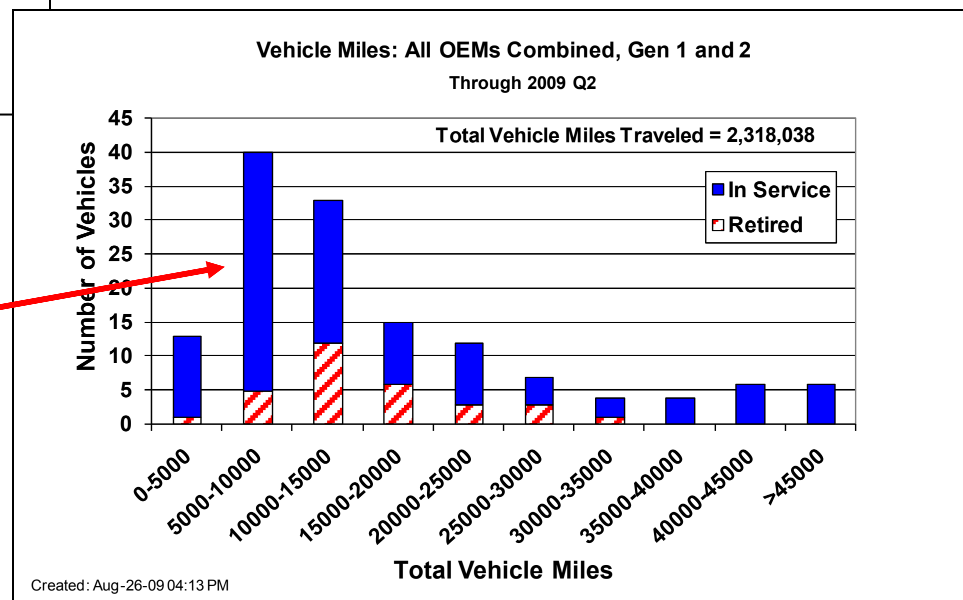
Vehicle Deployment Complete at 140 FCVs, Some Early Vehicles Retired



DOE Learning Demo Fleet Has Surpassed 100,000 Vehicle Hours and 2.3 Million Miles

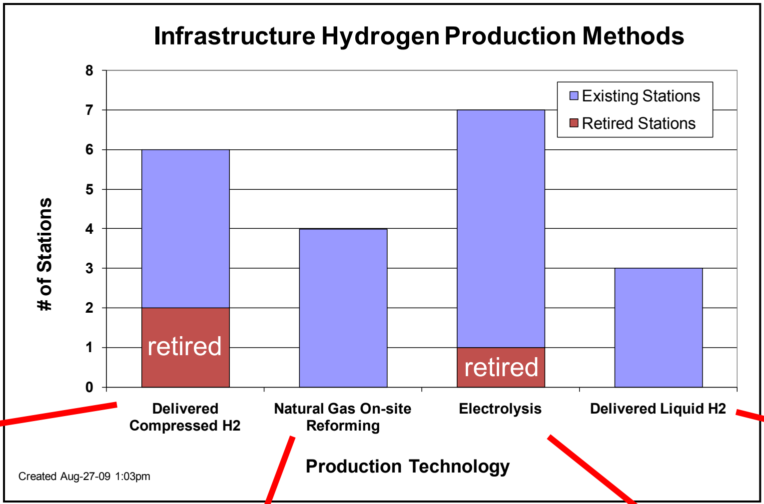


Some Gen 1 vehicles have now been retired (red bars)



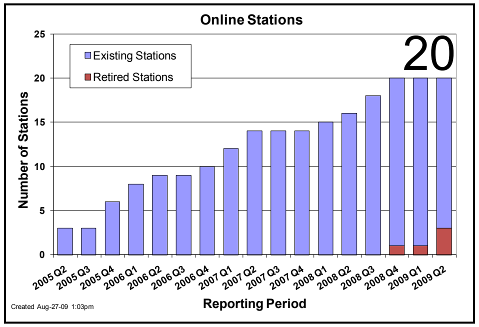
Gen 2 vehicles make up most of 2nd bulge at low hours/miles

Project Exploring 4 Types of Hydrogen Refueling Infrastructure: Delivered and Produced On-Site



Mobile Refueler
Sacramento, CA

Delivered Liquid, 700 bar
Irvine, CA

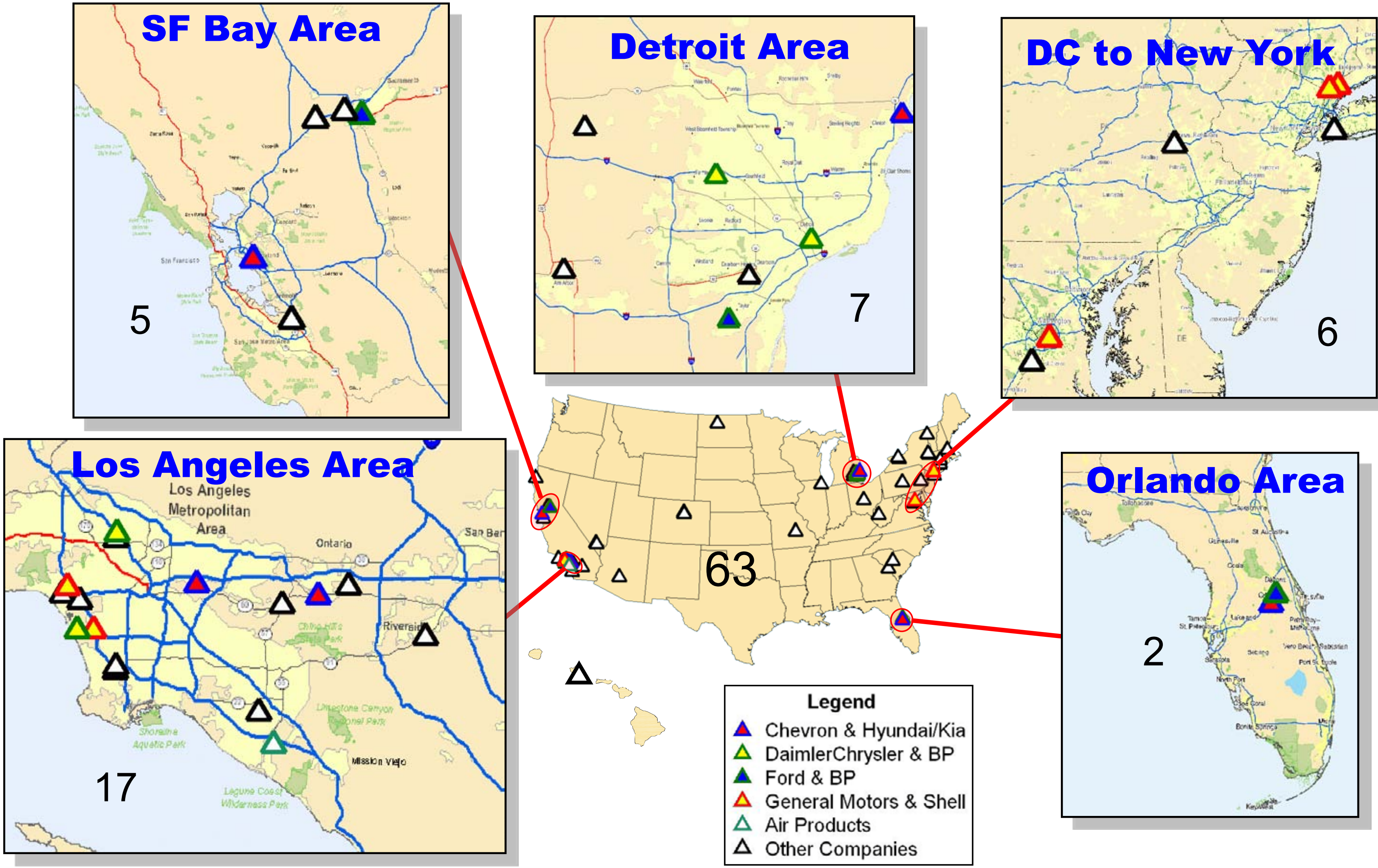


Steam Methane Reforming
Oakland, CA

Water Electrolysis
Santa Monica, CA

Total of 115,000 kg H_2 produced or dispensed

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



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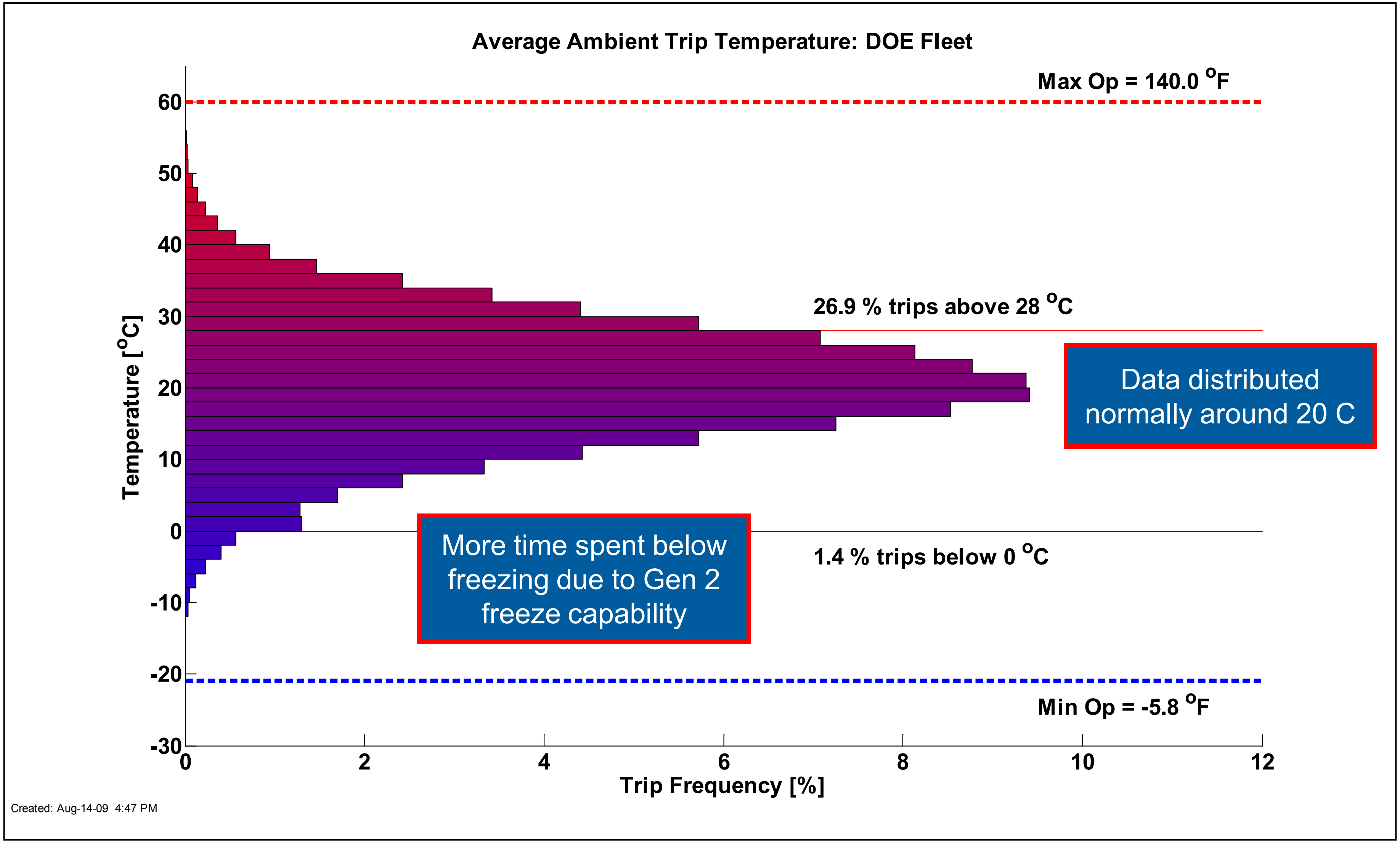
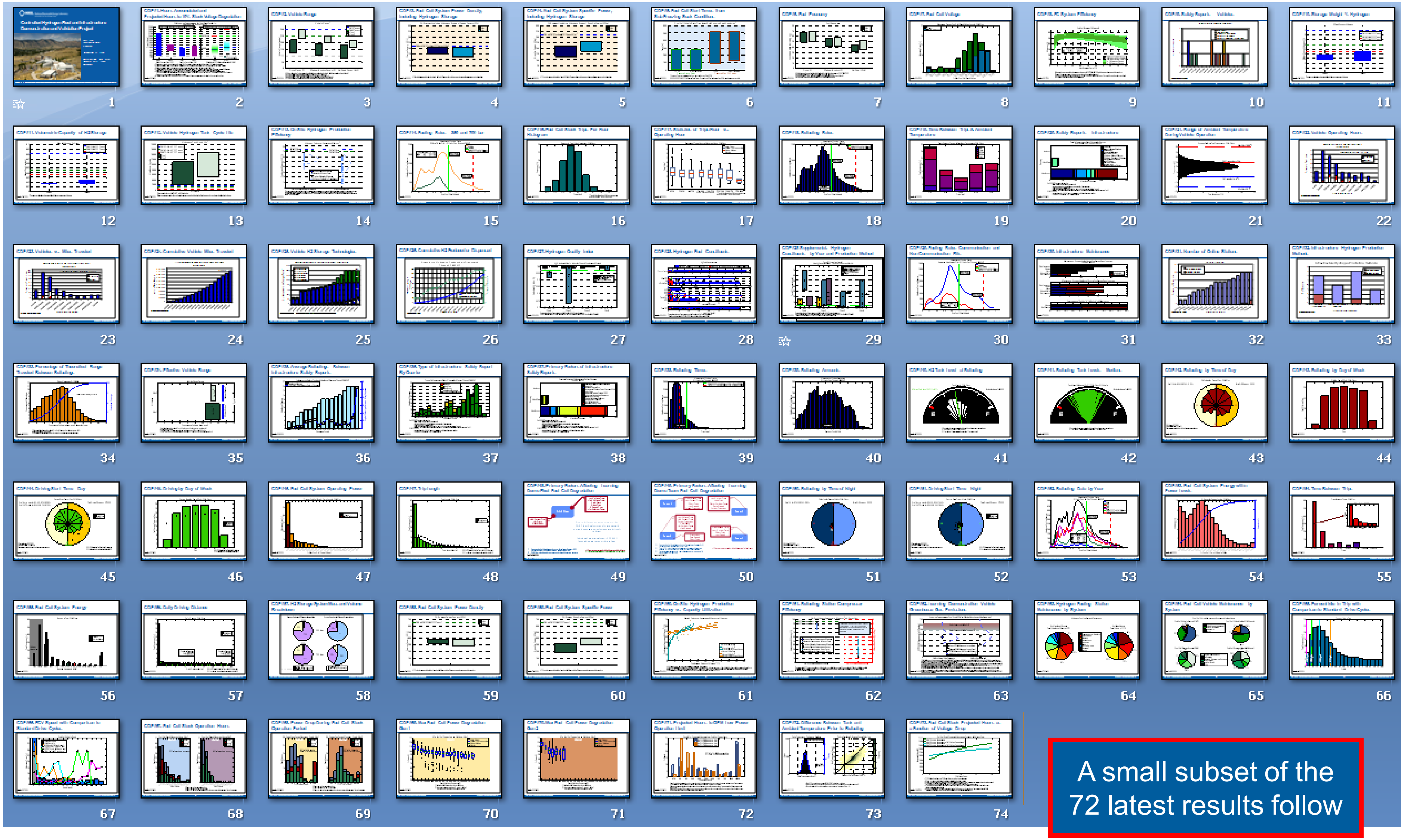
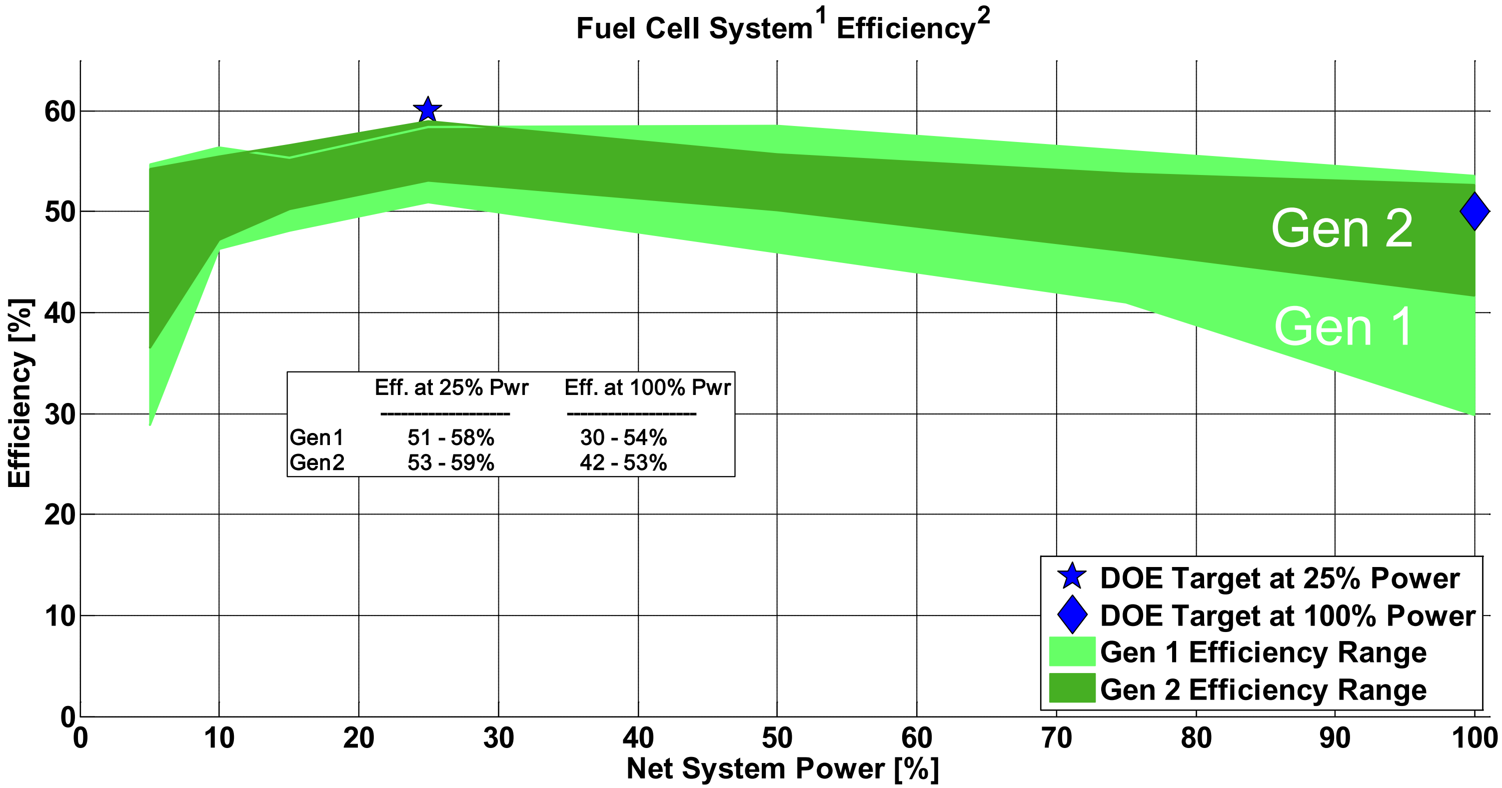
Average Ambient Temperature of Learning Demo Vehicles Spans Most Climates



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



While Improving Durability and Freeze Capability, FC System Efficiency Stays High



[1] Gross stack power minus fuel cell system auxiliaries, per DRAFT SAE J2615. Excludes power electronics and electric drive.

[2] Ratio of DC output energy to the lower heating value of the input fuel (hydrogen).

[3] Individual test data linearly interpolated at 5,10,15,25,50,75,and 100% of max net power. Values at high power linearly extrapolated due to steady state dynamometer cooling limitations.

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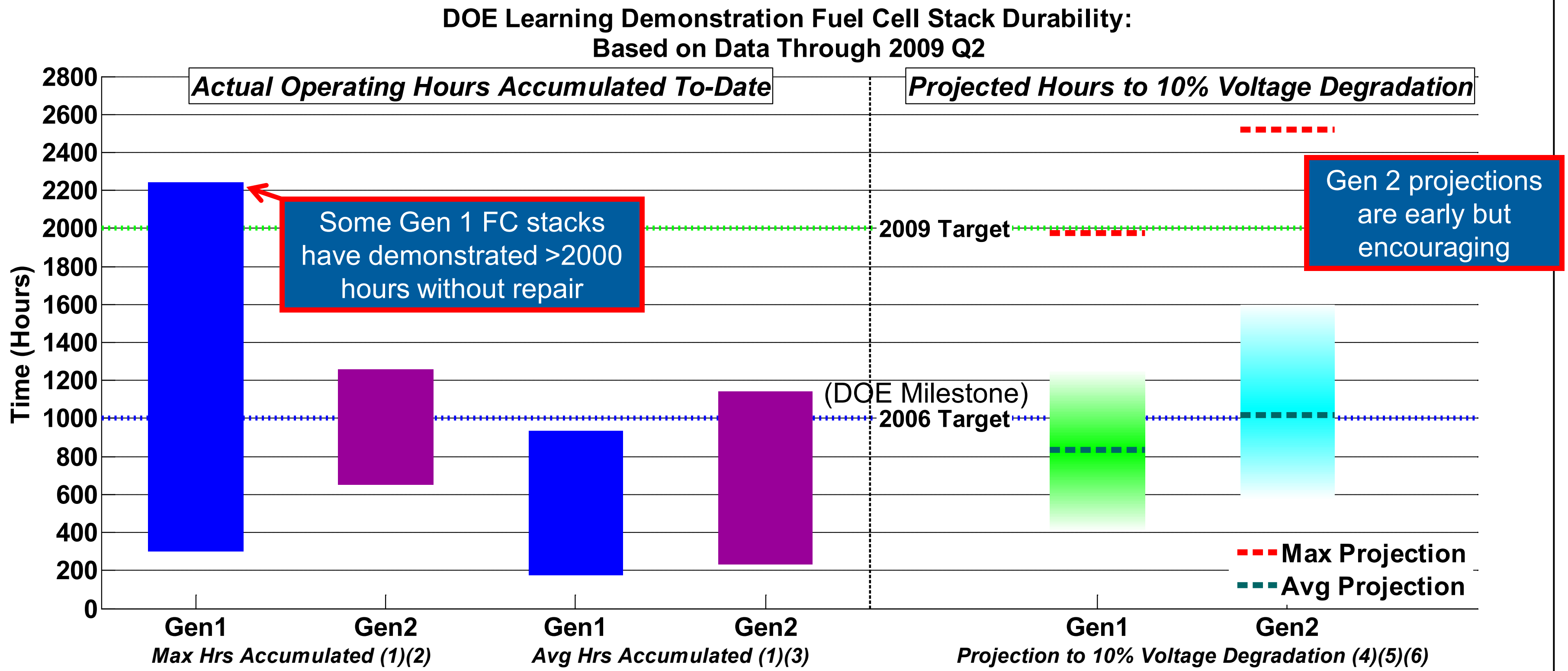
Gen 1 and Gen 2 Stack Operating Hours and Projected Time to *10%* Voltage Drop



(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 projection bars 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 2009 Q2 data, includes an upper projection limit based on demonstrated op hours.

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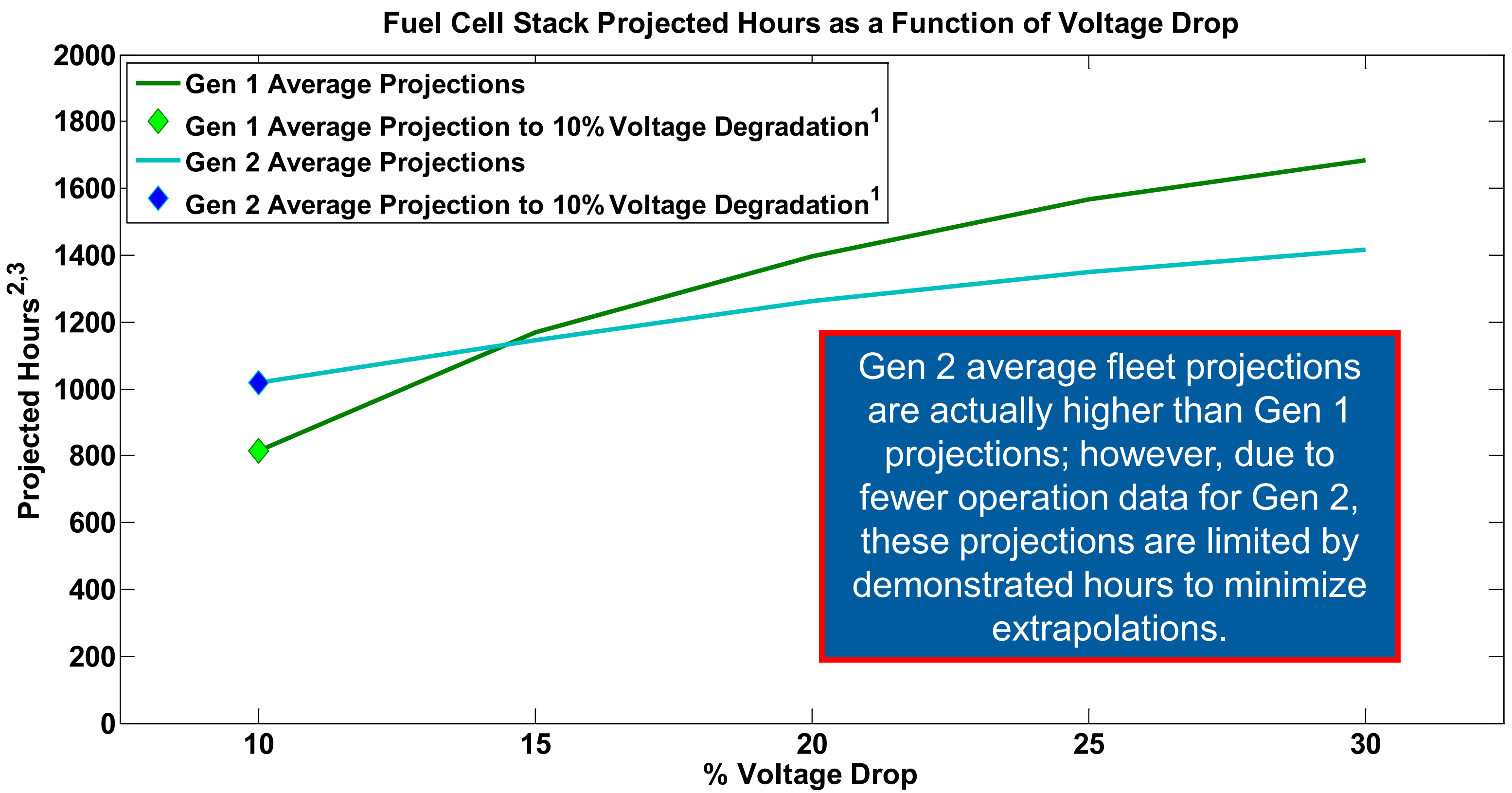
10% Voltage Drop Is One Metric – Sensitivity of Projections to % Voltage Drop



(1) 10% Voltage degradation is a DOE metric for assessing fuel cell performance.
(2) Projections using on-road data -- degradation calculated at high stack current.
(3) Curves generated using the Learning Demonstration average of each individual fleet average at various voltage degradation levels.
(4) The projection curves display the sensitivity to percentage of voltage degradation, but the projections do not imply that all stacks will (or do) operate at these voltage degradation levels.
(5) The voltage degradation levels are not an indication of an OEM's end-of-life criteria and do not address catastrophic stack failures such as membrane failure.
(6) All OEM Gen 2 average fleet projections are higher than Gen1 projections, however due to less operation data for Gen 2, these projections are limited by demonstrated operation hours to minimize extrapolations.

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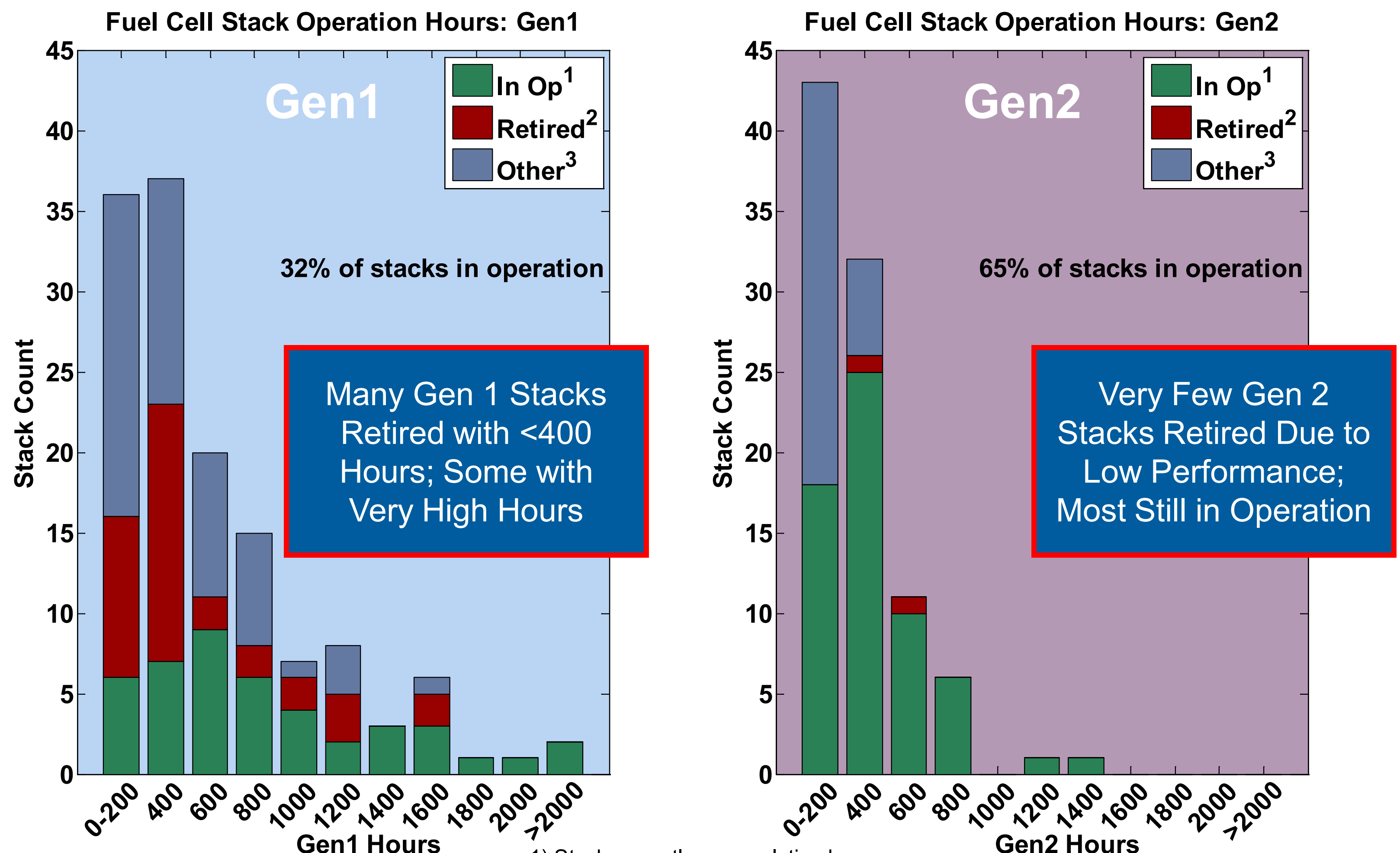
Fuel Cell Stack Operation Hours; Early in Gen 2 Life, But Results Encouraging



1) Stack currently accumulating hours
2) Stack removed for low performance
3) Stack not currently accumulating hours, but not removed because of low performance

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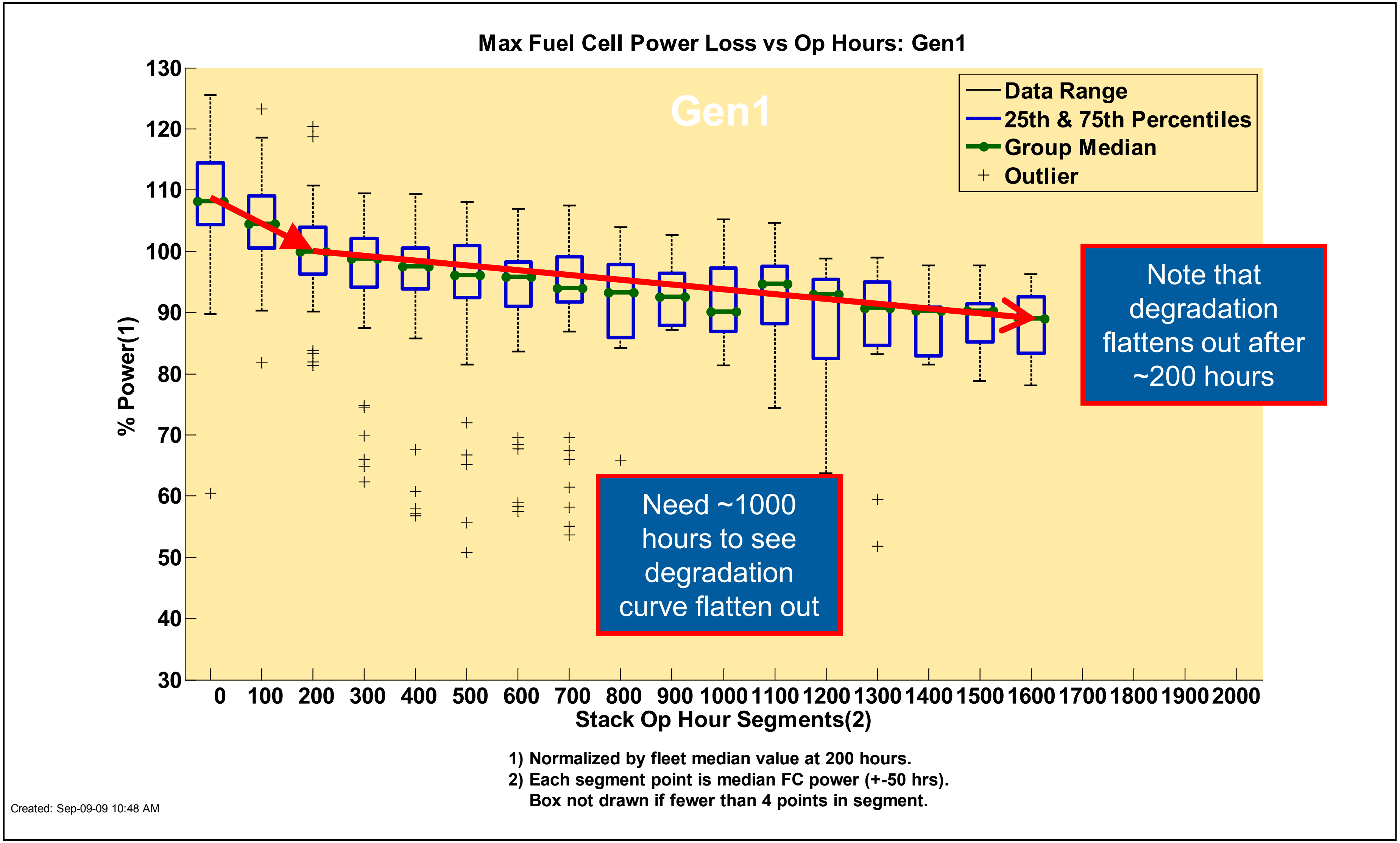
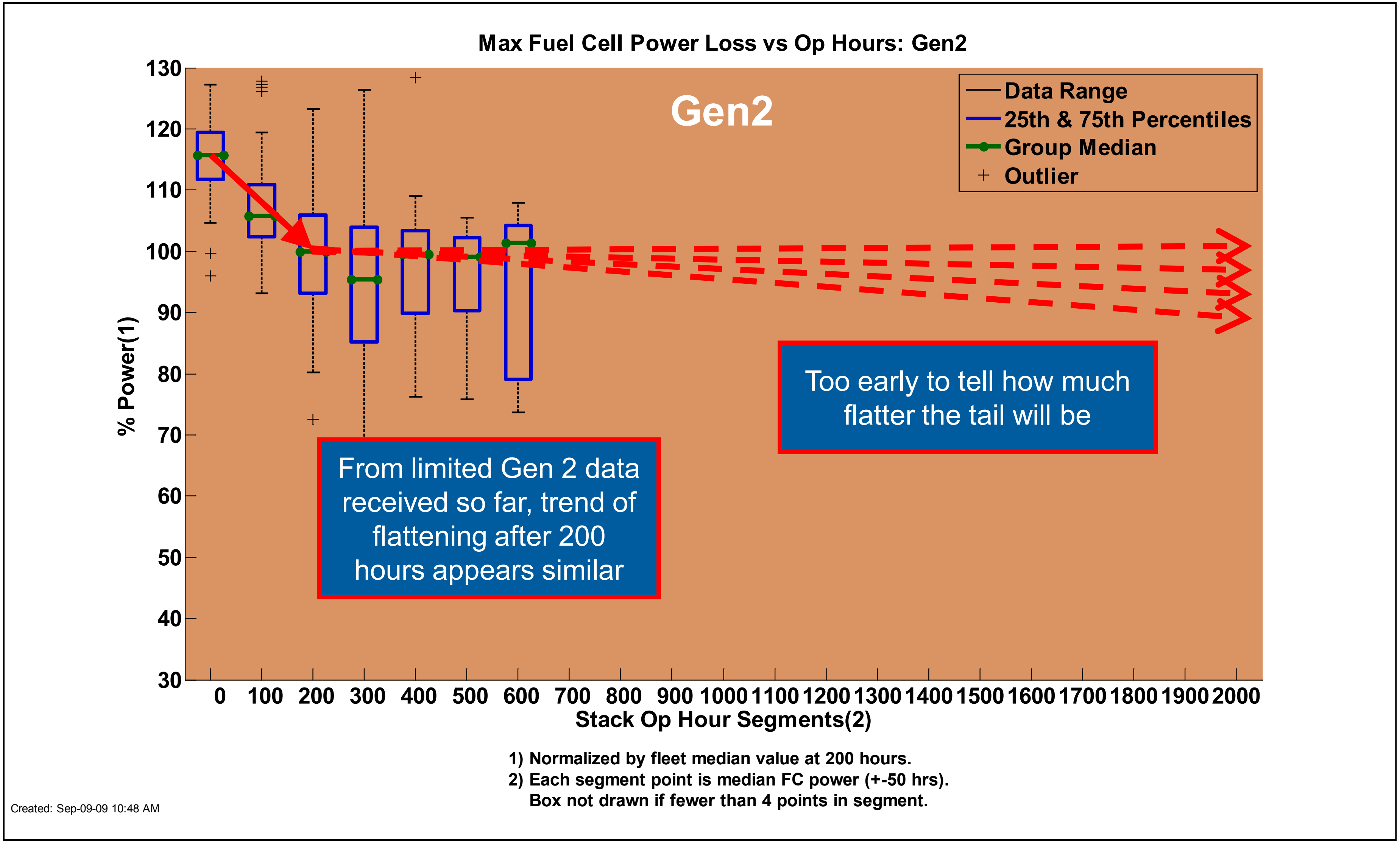
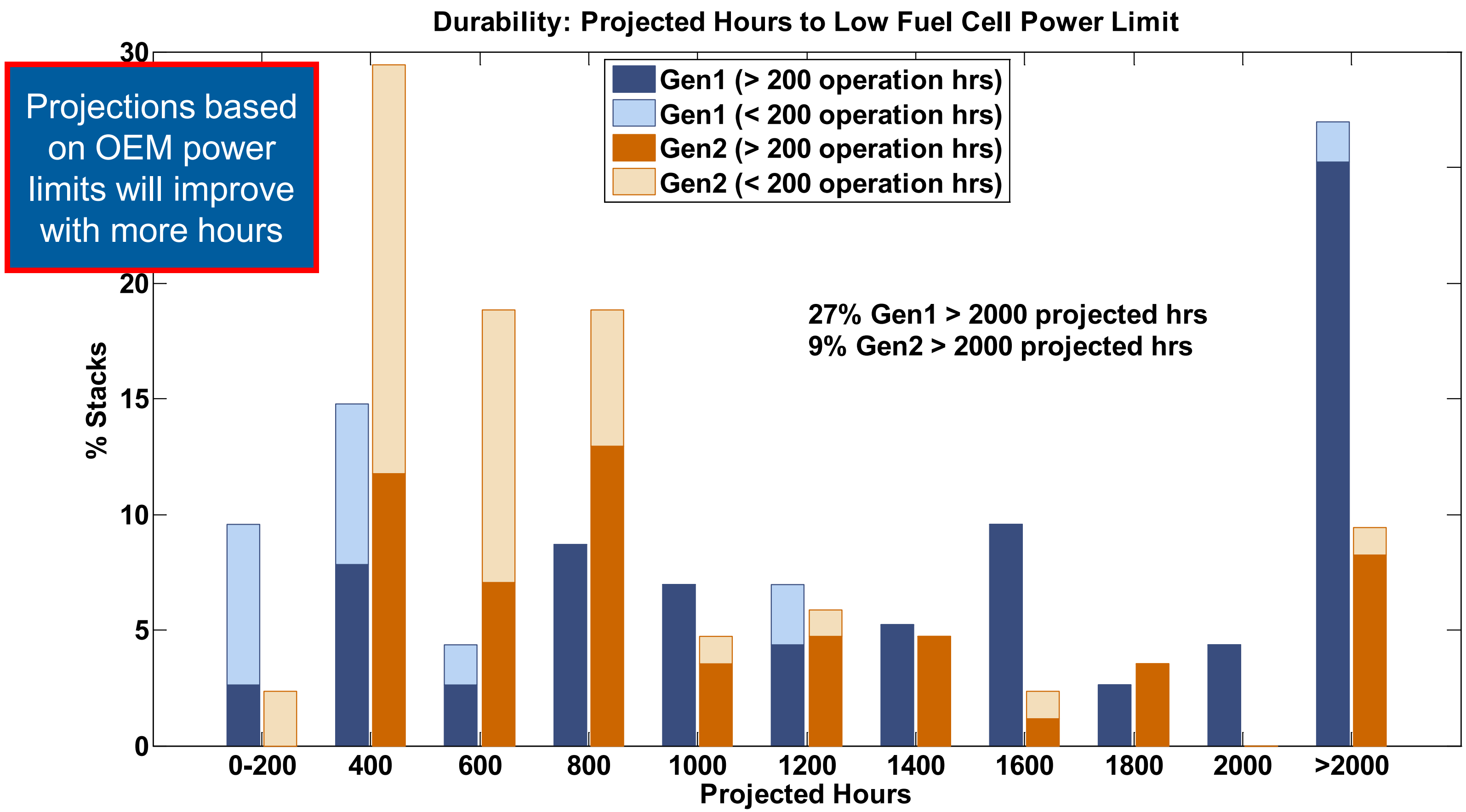
Max Fuel Cell Power Degradation – Gen 1



Max Fuel Cell Power Degradation – Gen 2



Projected Hours to OEM Low Power Operation Limit



1. Low fuel cell power limit is dependent on the fuel cell vehicle system and is unique to each company in this Learning Demonstration.
2. Acceptable low vehicle performance limit will be determined by retail customer expectations.
3. Power projection method based on the voltage degradation techniques, but uses max fuel cell power instead of voltage at a specific high current.
4. Stacks with less than 200 operation hours are in separate groups because the projection is based on operation data and with operation hours greater than 200 the degradation rate tends to flatten out.

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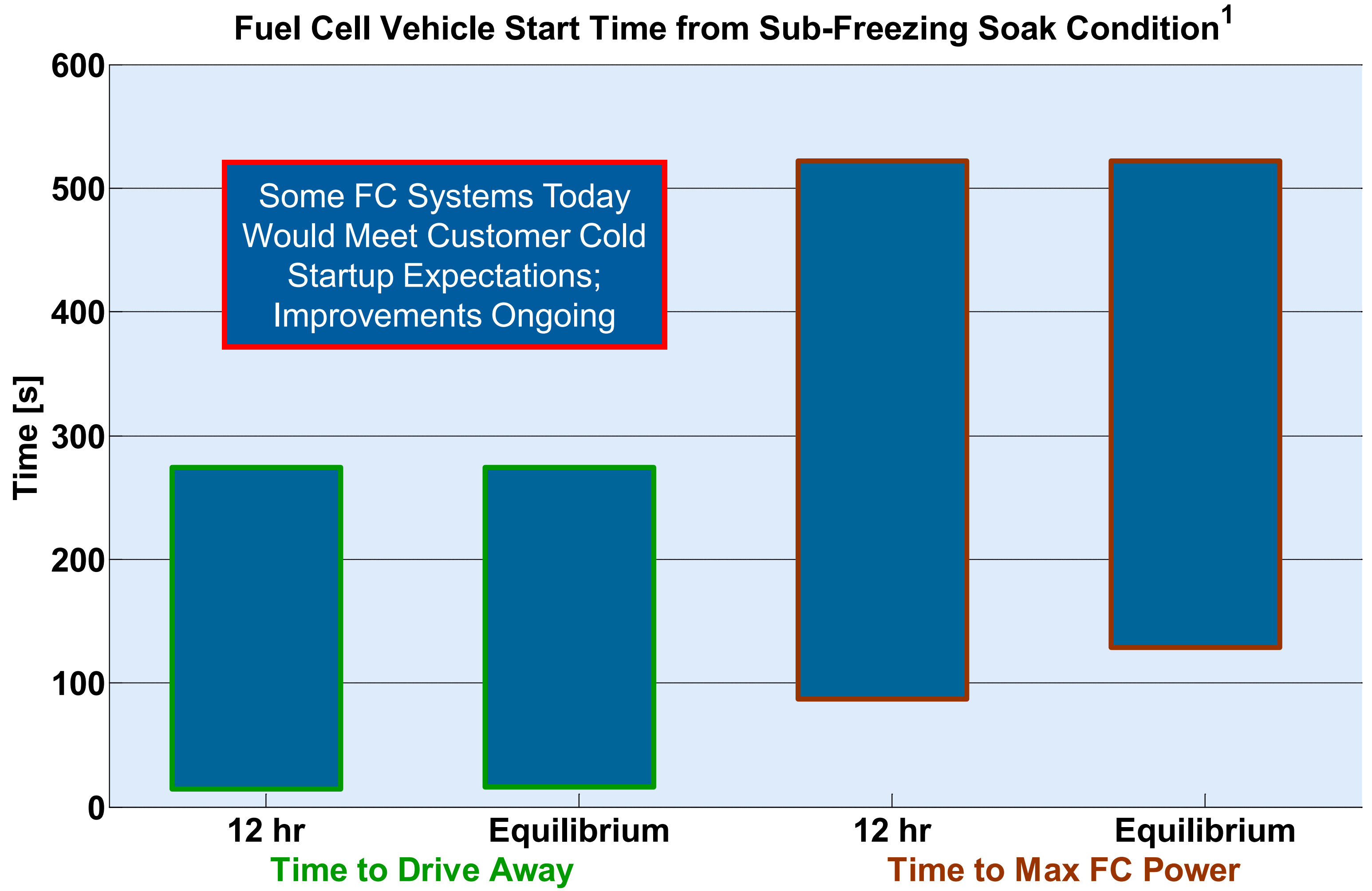
Fuel Cell Start Times from Sub-Freezing Soak Conditions



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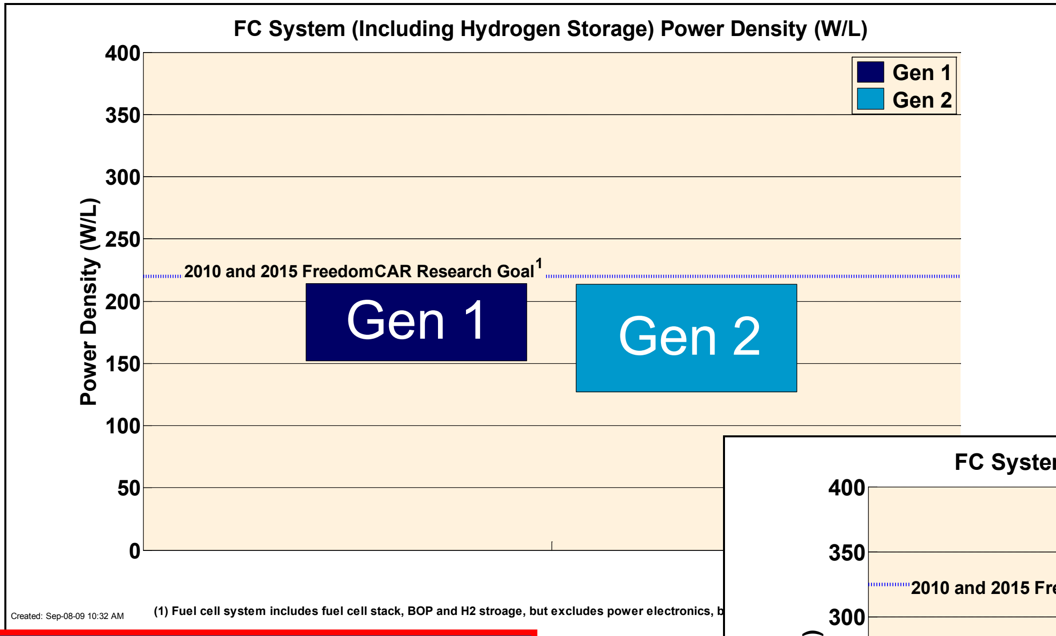
(1) Learning Demo soak temperature for freeze tests were between -9 and -20 °C

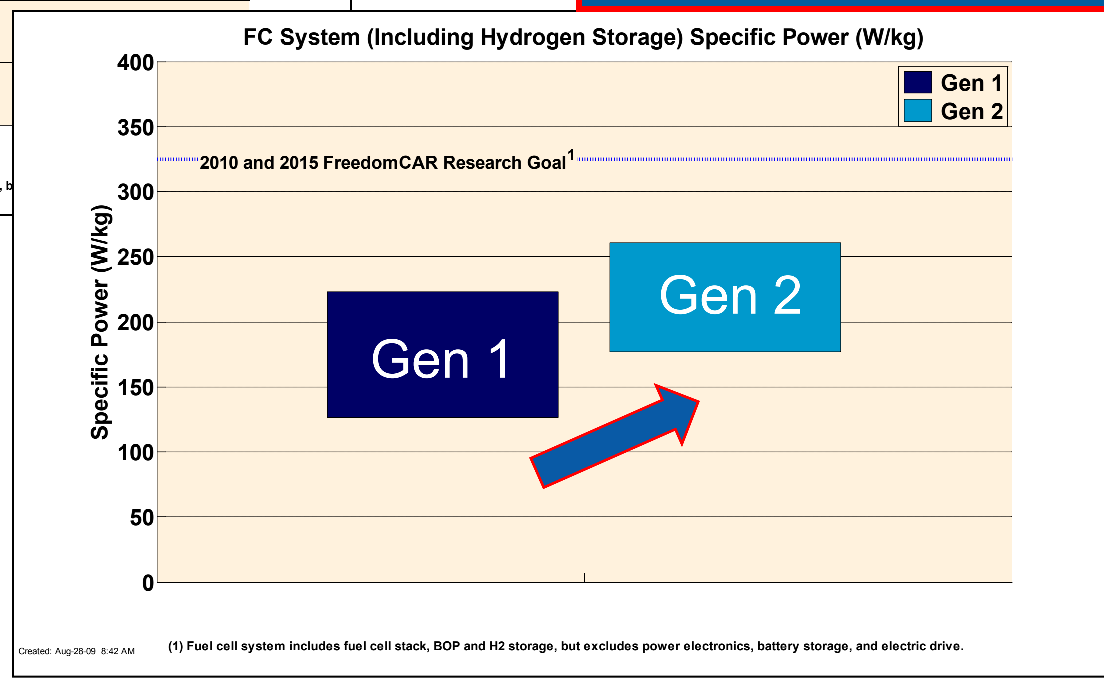
(2) 2010 & 2015 DOE MYPP Cold Start Up Time Target: 30 seconds to 50% of rated power from -20 °C (soak duration not specified).

Fuel Cell System (including H2 storage) Close to 2010 and 2015 W/L and W/kgTargets

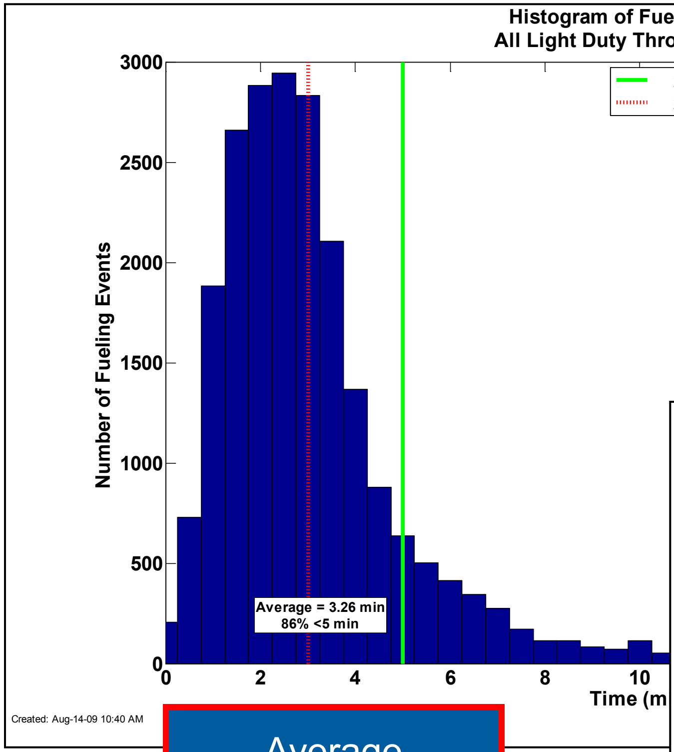


Power Density Held Similar Between Gen 1 and Gen 2 (…same size or larger)

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

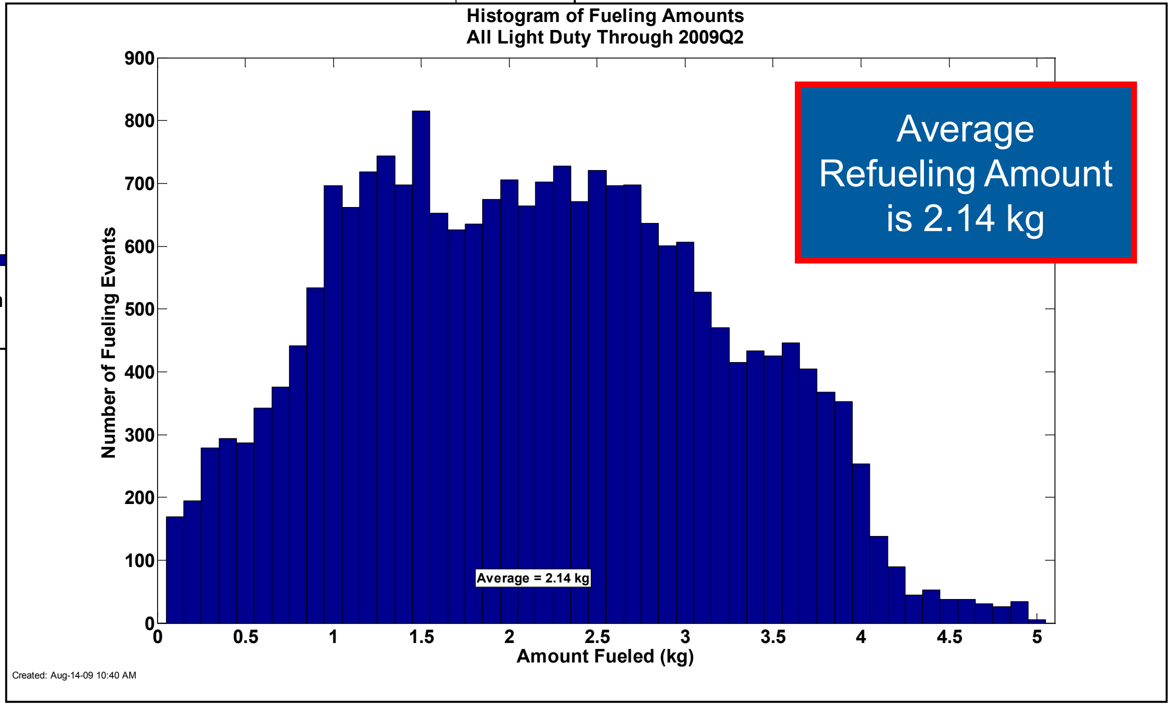


Refueling Times are Short; Amounts are Reflective of Demonstration-Sized Systems



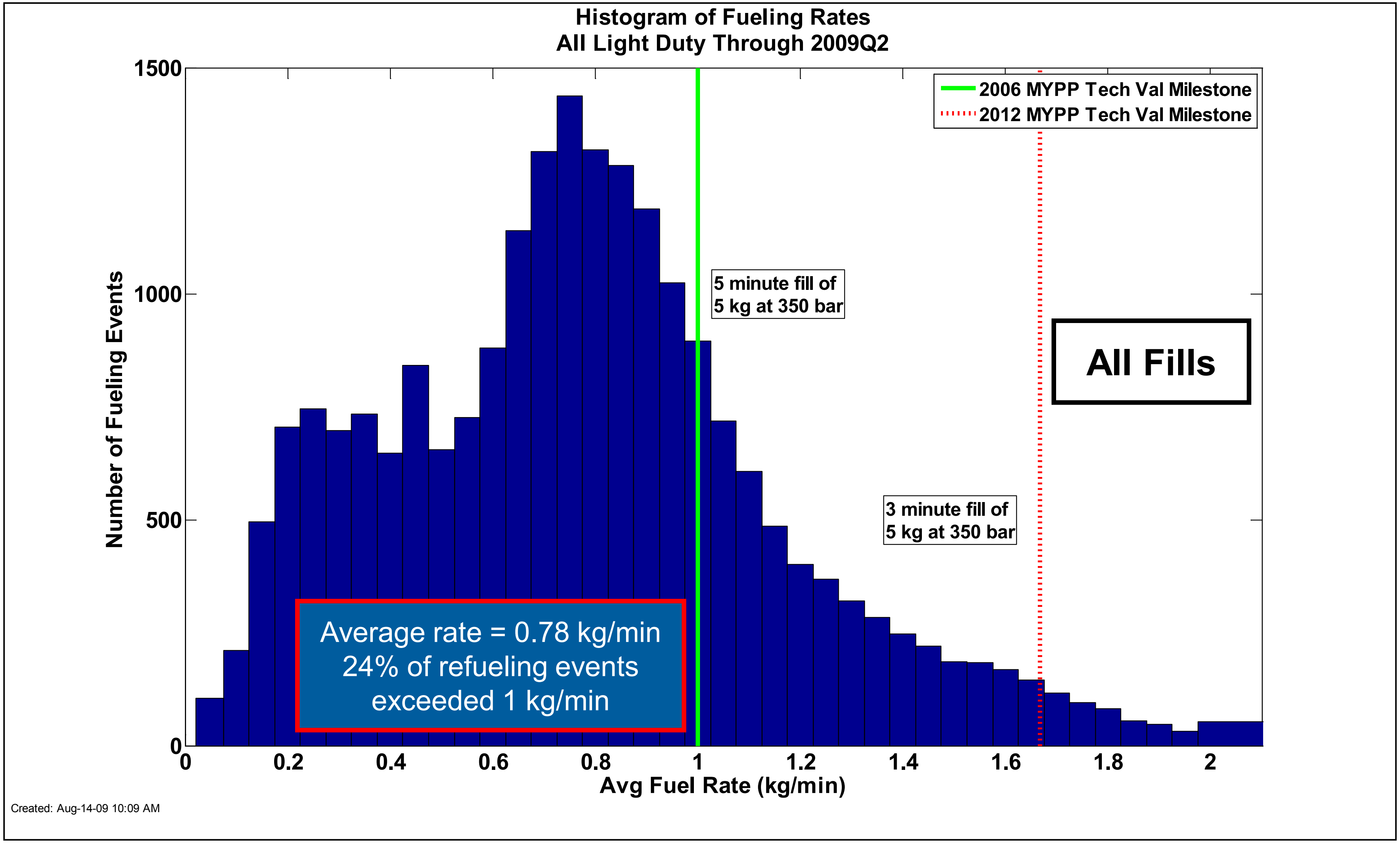
Average Refueling Time is 3.26 minutes

Results from 21,000 Refueling Events

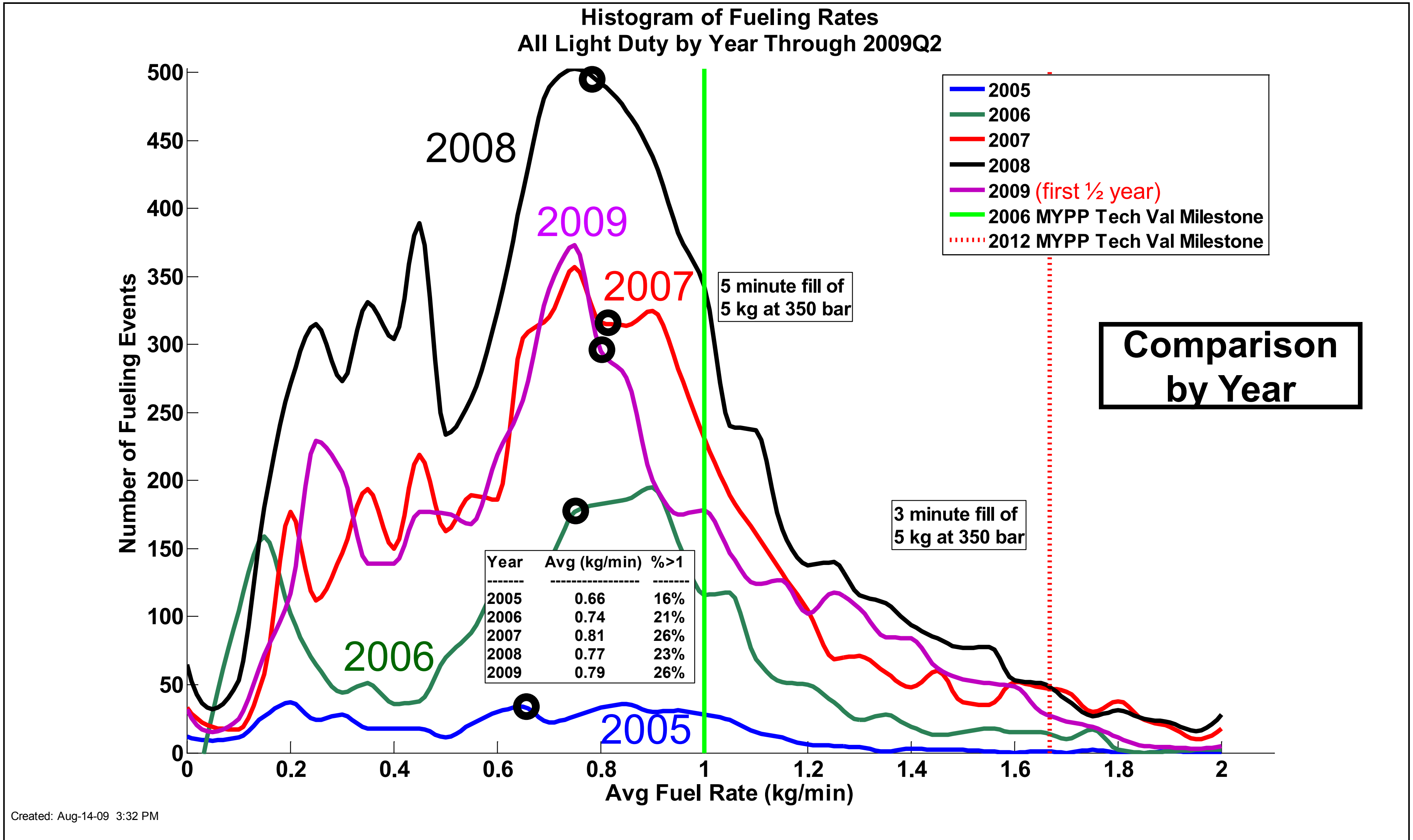


Average Refueling Amount is 2.14 kg

Actual Vehicle Refueling *Rates* from 21,000 Events: Measured by Stations or by Vehicles

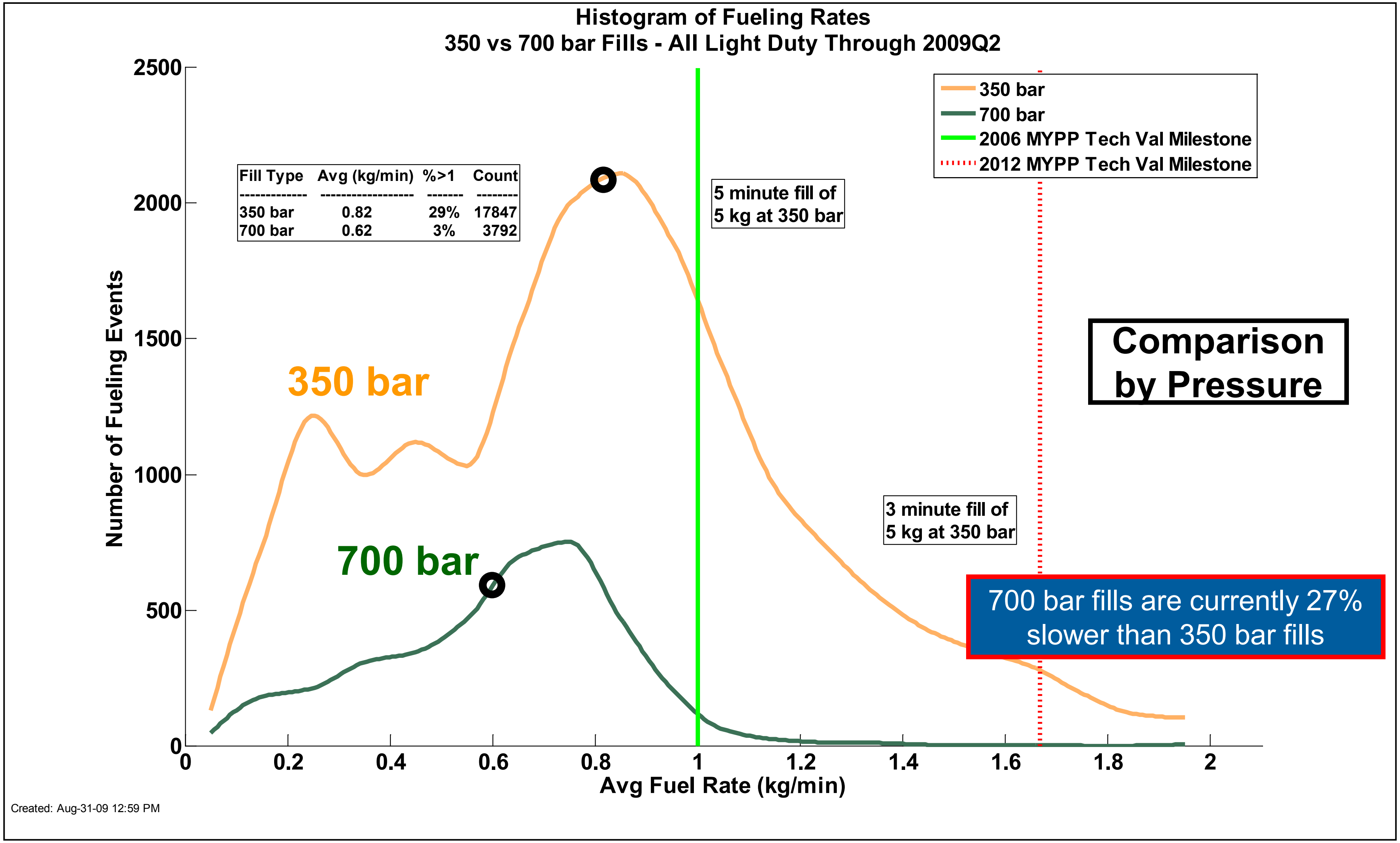


Refueling Rates by Year: ~1/4 Now Exceed 1 kg/min, 2009 to be Highest # of Fills

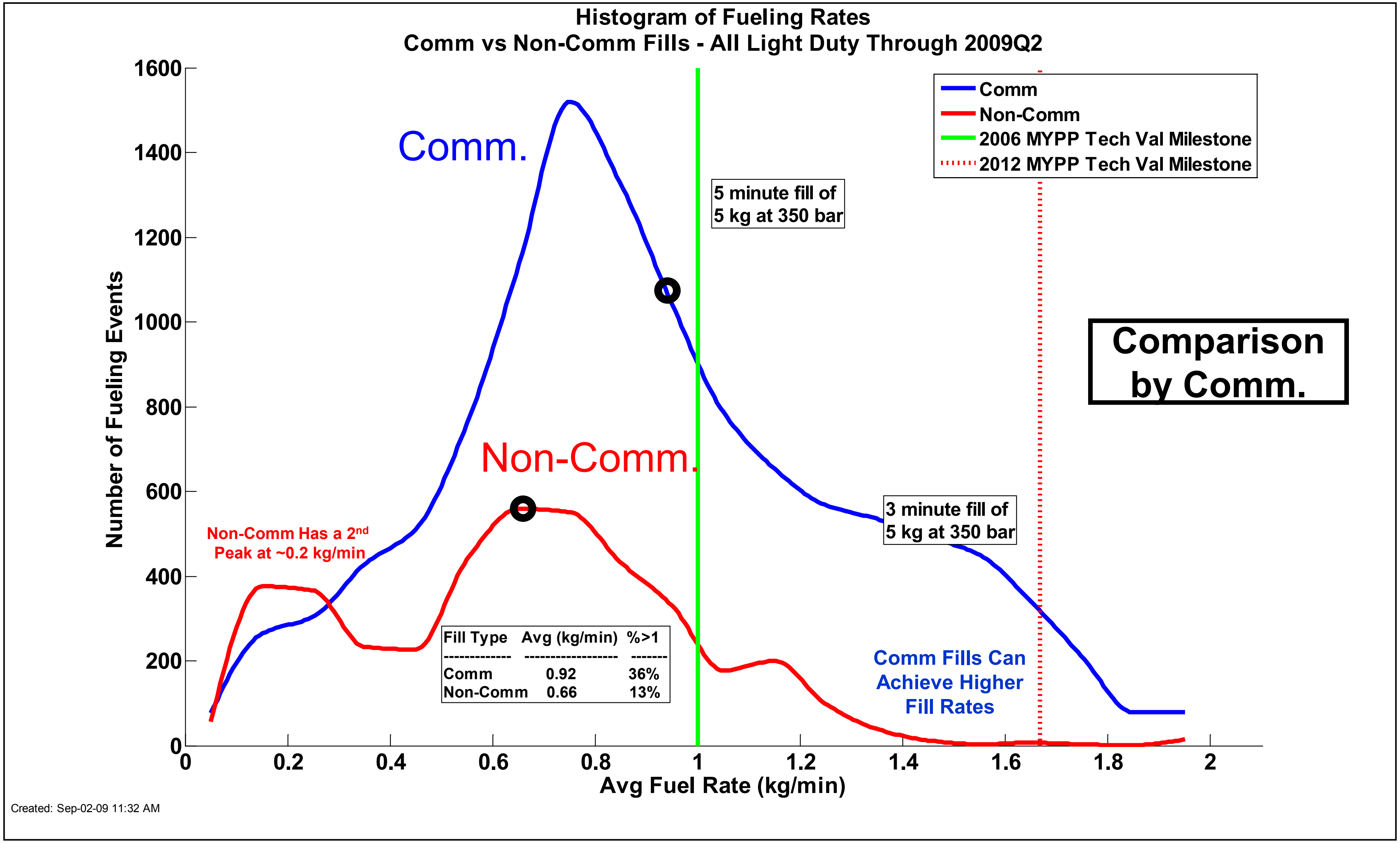


Year	Avg (kg/min)	%>1
2005	0.66	16%
2006	0.74	21%
2007	0.81	26%
2008	0.77	23%
2009	0.79	26%

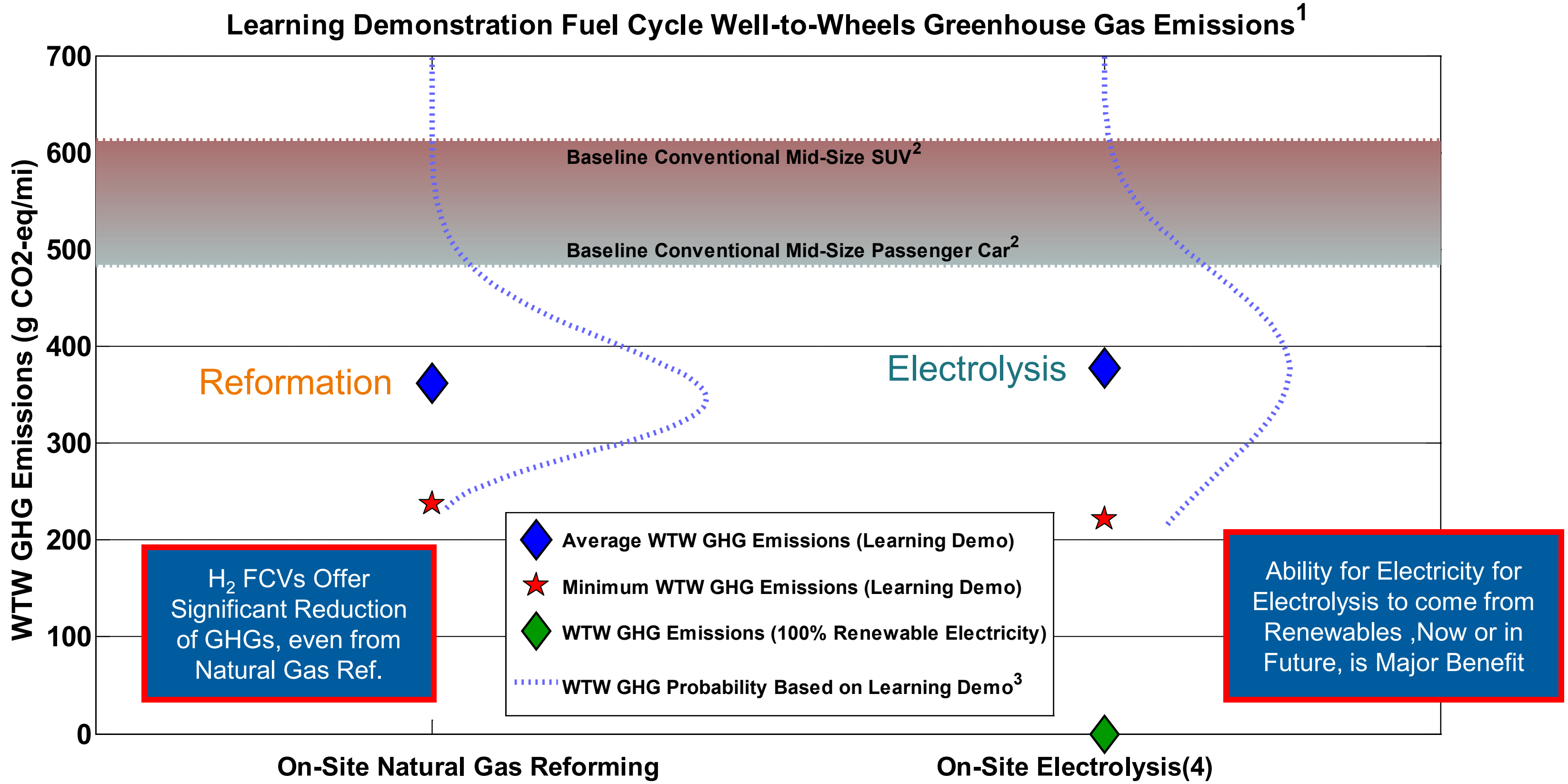
Comparison of Fueling Rates for 350 and 700 bar Pressure Fueling Events



Communication H_2 Fills Achieving 39% Higher Average Fill Rate than Non-Communication



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 1245 g/mile.

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Summary

- Learning Demo evaluation is ~80% complete
  - 140 vehicles and 20 stations deployed
  - 2.3 million miles traveled, 115,000 kg H_2 produced or dispensed
  - 346,000 individual vehicle trips analyzed
  - FC durability and vehicle range targets met with Gen 2 vehicles
  - Project to continue into 2010
- Emphasis from project has been on providing maximum value from the data collected during project
  - 72 results have been published, updates every 6 months
  - Current results are always available on our web page

- Vehicle/Station Status
  - 2nd generation vehicles have now been on road for >1 year
  - Station deployment nearing completion; some early stations retired
- Similar Evaluations Now Underway at NREL for FC Forklifts, Backup Power, Prime Power

Questions and Discussion

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

NREL's Renewable H2 Station Opened in September and is Ready to Fuel Vehicles

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