NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Fuel Cell Electric Vehicle Evaluation

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DOE 2017 Annual Merit Review

Washington, DC

Project ID TV001

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

Overview

Timeline and Budget

- Project start date: 10/2012*
- FY16 DOE funding: $300k
- FY17 DOE funding: $200k
- Total DOE funds received to date: $1,765k

Barriers

- Lack of current controlled and on-road hydrogen fuel cell vehicle data

Partners

- Project partners include:
  - Daimler
  - Hyundai
  - Honda
  - GM
  - Nissan
  - Toyota
  - Electricore

*Project continuation determined annually by DOE

FCEV Evaluation Objectives, Relevance, and Targets

FY17 Objectives

Analysis and reporting on FCEV, fuel economy, range, and fueling behavior

- Objectives
  - Data analysis and reporting of hydrogen fuel cell electric vehicles (FCEV) operating in real-world setting
  - Identify current status and evolution of the technology
  - Publish performance status and progress from multiple FCEV models
- Relevance
  - Objectively assess progress toward targets and market needs
  - Provide feedback to hydrogen research and development
  - Publish results for key stakeholder use and investment decisions

NFCTEC Analysis and Reporting

Data collection, analysis, aggregation, and reporting consistent with FY16 approach

Bundled data (operation and maintenance/safety) delivered to NREL quarterly

Internal analysis completed quarterly in NFCTEC

National Fuel Cell Technology Evaluation Center

Results

DDPs

Confidential

Public

CDPs

Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data

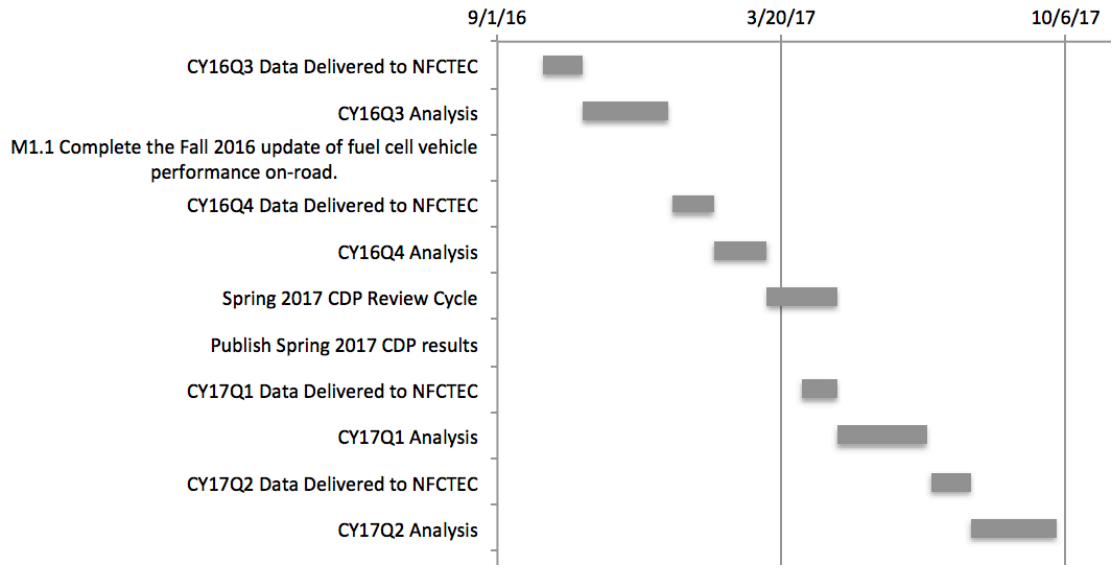
www.nrel.gov/hydrogen/proj_tech_validation.html

On-road FCEVs & Partners Supplying Data

Range of FCEV Model Years

OEMs supplying data for both pre-commercial and commercial vehicles on the road. Reduction in number of partners from FY16 is based on award completion and on-road vehicles.

Schedule & Milestones



Tasks	Start	End	Days	Status
CY16Q3 Data Delivered to NFCTEC	10/3/16	10/31/16	28	Completed
CY16Q3 Analysis	10/31/16	12/30/16	60	Completed
M1.1 Complete the Fall 2016 update of fuel cell vehicle performance on-road.	12/30/16	12/30/16	0	Completed
CY16Q4 Data Delivered to NFCTEC	1/2/17	1/31/17	29	Completed
CY16Q4 Analysis	1/31/17	3/10/17	38	Completed
Spring 2017 CDP Review Cycle	3/10/17	4/28/17	49	Completed
Publish Spring 2017 CDP results	5/31/17	5/31/17	0	In progress
CY17Q1 Data Delivered to NFCTEC	4/3/17	4/28/17	25	In progress
CY17Q1 Analysis	4/28/17	6/30/17	63	Not started
CY17Q2 Data Delivered to NFCTEC	7/3/17	7/31/17	28	Not started
CY17Q2 Analysis	7/31/17	9/29/17	60	Not started

Regular project activities include:

Quarterly analysis

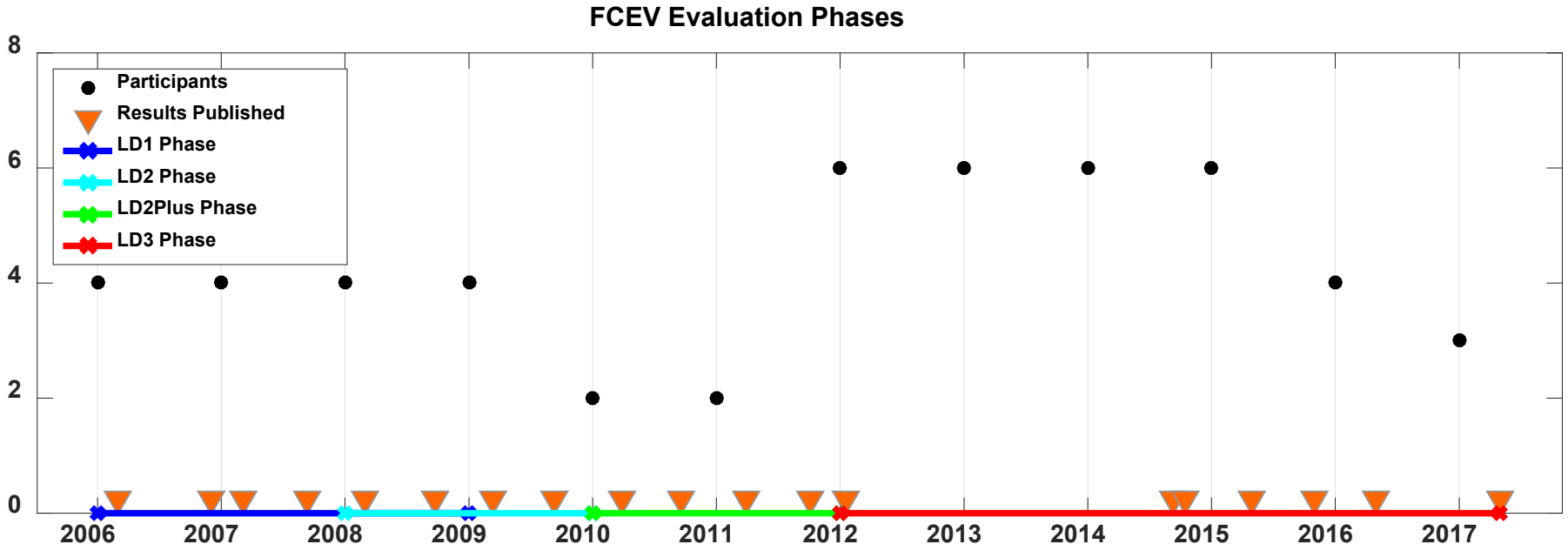
Annual technical CDPs (Change from FY16 approach)

Detailed data and analysis reviews with project partners

Publishing and presenting results

Collaborating with infrastructure evaluation

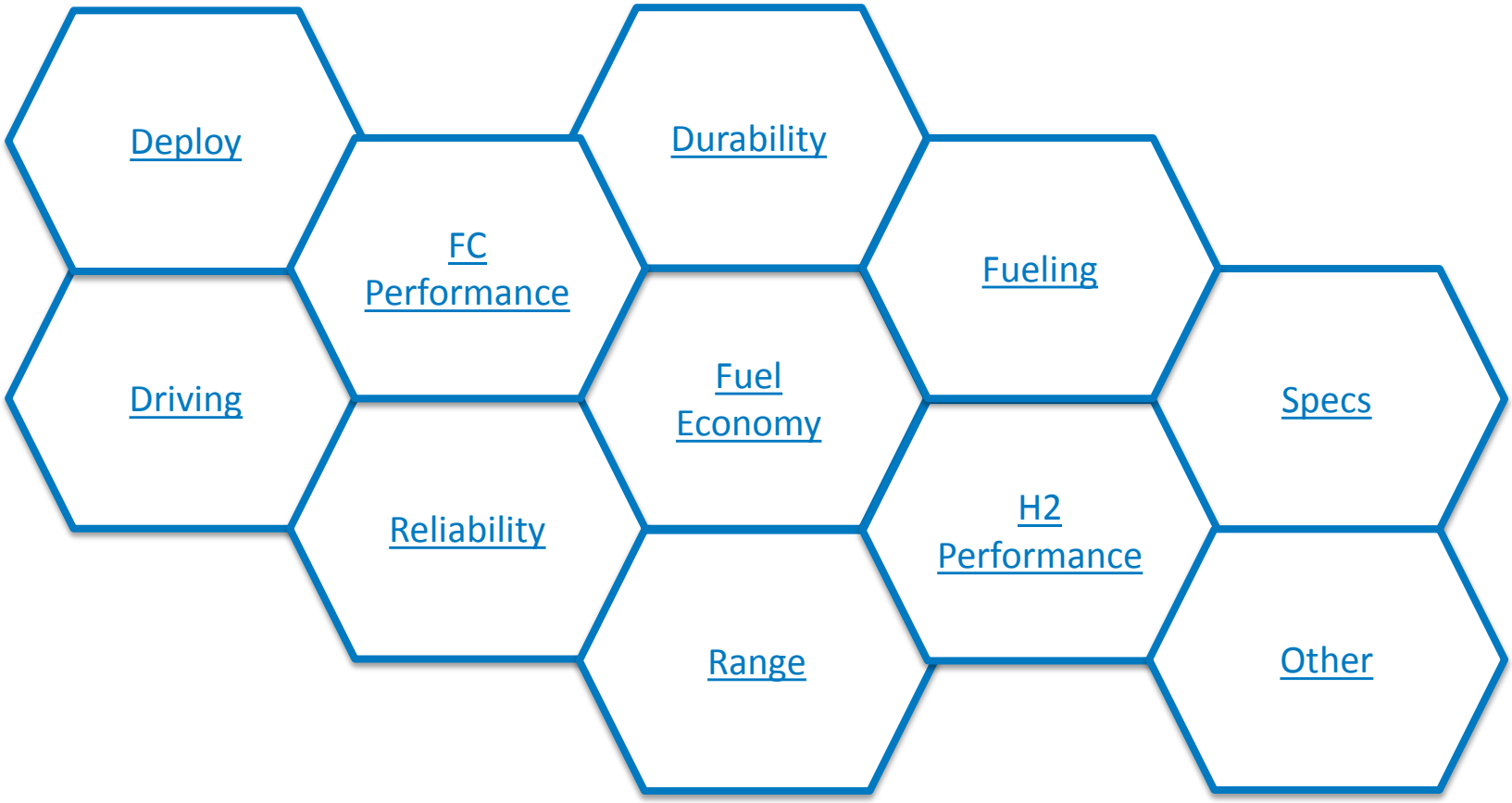
Historical FCEV Evaluation Phases, Partners, and Publications



Current evaluation has 3 OEMs delivering data from FCEVs currently on-road. The data is varied between OEMs and the analysis is focused on FCEV operation to provide technology status and support hydrogen station operation and improvement. Not all analysis topics are published because of data limitations.

Updated

Analysis Categories



Analyzed data through 12/2016
All results are not included here or published. All published results available online at www.nrel.gov/hydrogen/proj_tech_validation.html

Updated

FCEV Deployment and Operation Through 2016CYQ4

42
FCEVs total

51
Average on-road fuel economy miles/kg

> 296,300
Max FCEV odometer miles

7
FCEVs retired

> 2,377,000
miles traveled

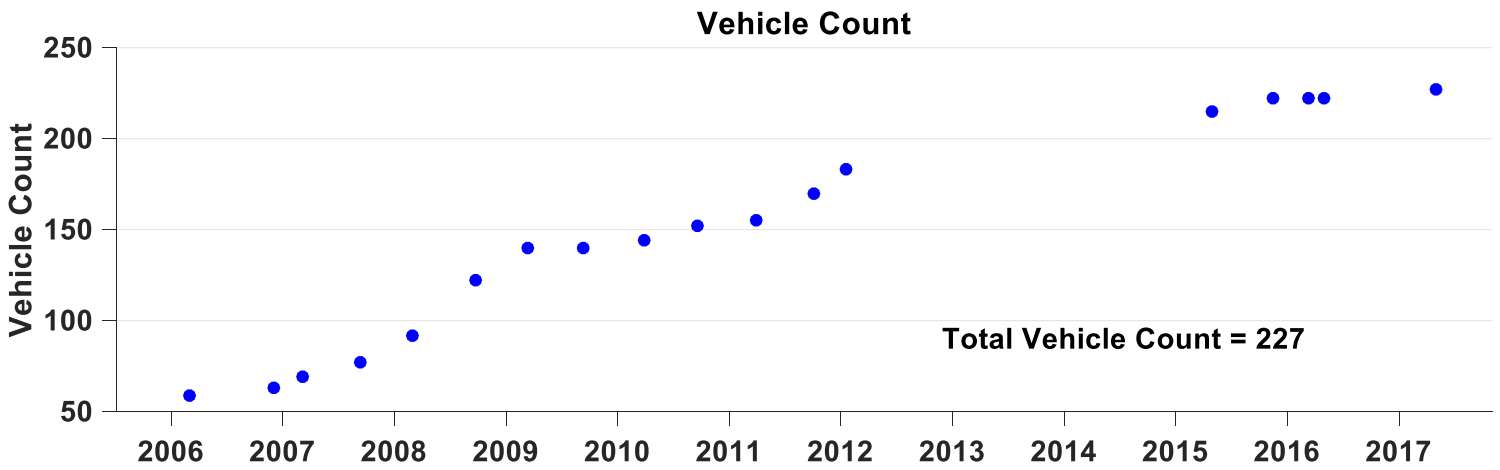
> 72,780
Fuel cell operation hours

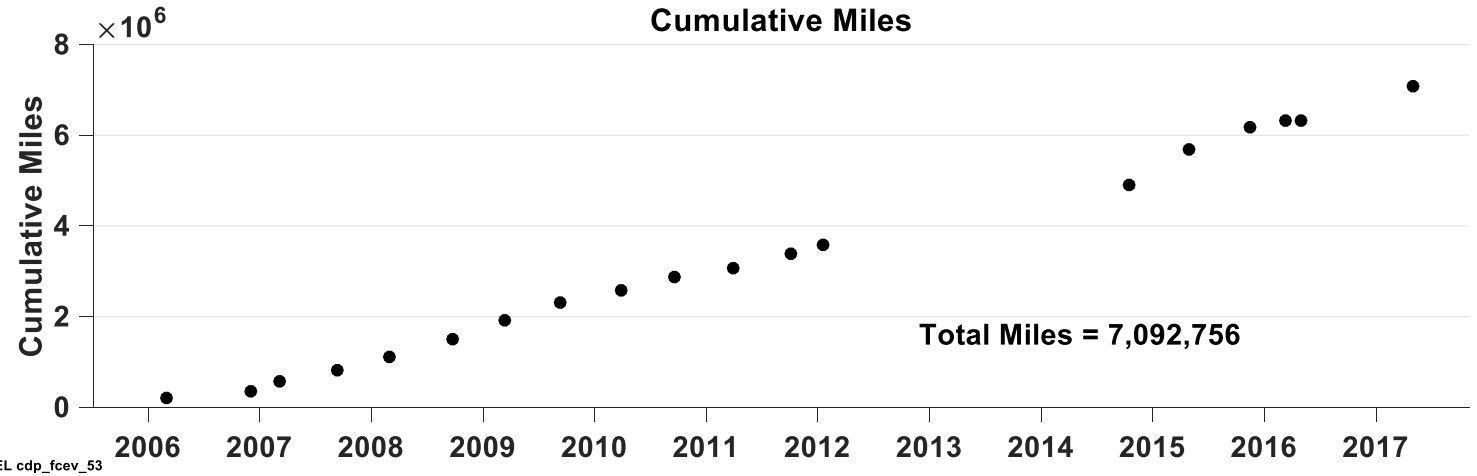
Summary of FCEV operation from the current 3 OEM fleets. **Summary operation statistics support the status reporting project objective.** Summary statistic are from more detailed aggregated results that show distribution of available data. Durability analysis was completed but not published because of data aggregation limits.

>5,600
Max fuel cell operation hours

Updated

Analyzed FCEVs and Miles Traveled Since 2006





NREL cdp_fcev_53
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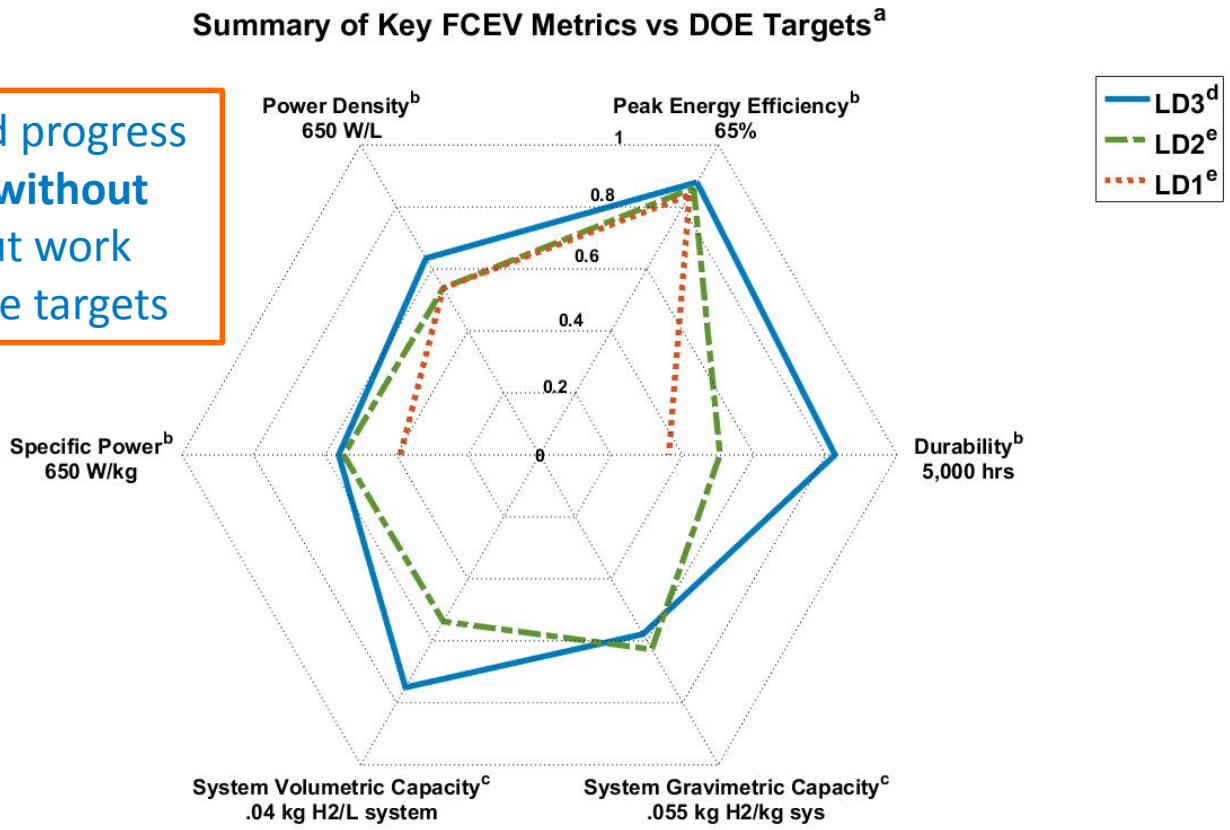
Included Vehicles: Partial

We are able to benchmark current performance, as well as progress since 2006, with the data set that includes 227 vehicles and over 7 million miles traveled.

Updated

Progress Toward Targets

FCEVs have made good progress toward DOE targets **without losing efficiency**, but work remains to achieve the targets



a. Results are a fraction of the 2020 targets in the Fuel Cell Technolgies Office Multi-Year Research, Development, and Demonstration (MYRDD) Plan (https://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22)
b. MYRDD Fuel Cell section 3.4 (last updated September 2016), table 3.4.3.
c. MYRDD Hydrogen Storage section 3.3 (last updated May 2015), table 3.3.3.
d. Current results are available at http://www.nrel.gov/hydrogen/proj_fc_vehicle_evaluation.html (Updated 4/2017)
e. National Fuel Cell Vehicle Learning Demonstration Final Report (http://www.nrel.gov/hydrogen/pdfs/54860.pdf)

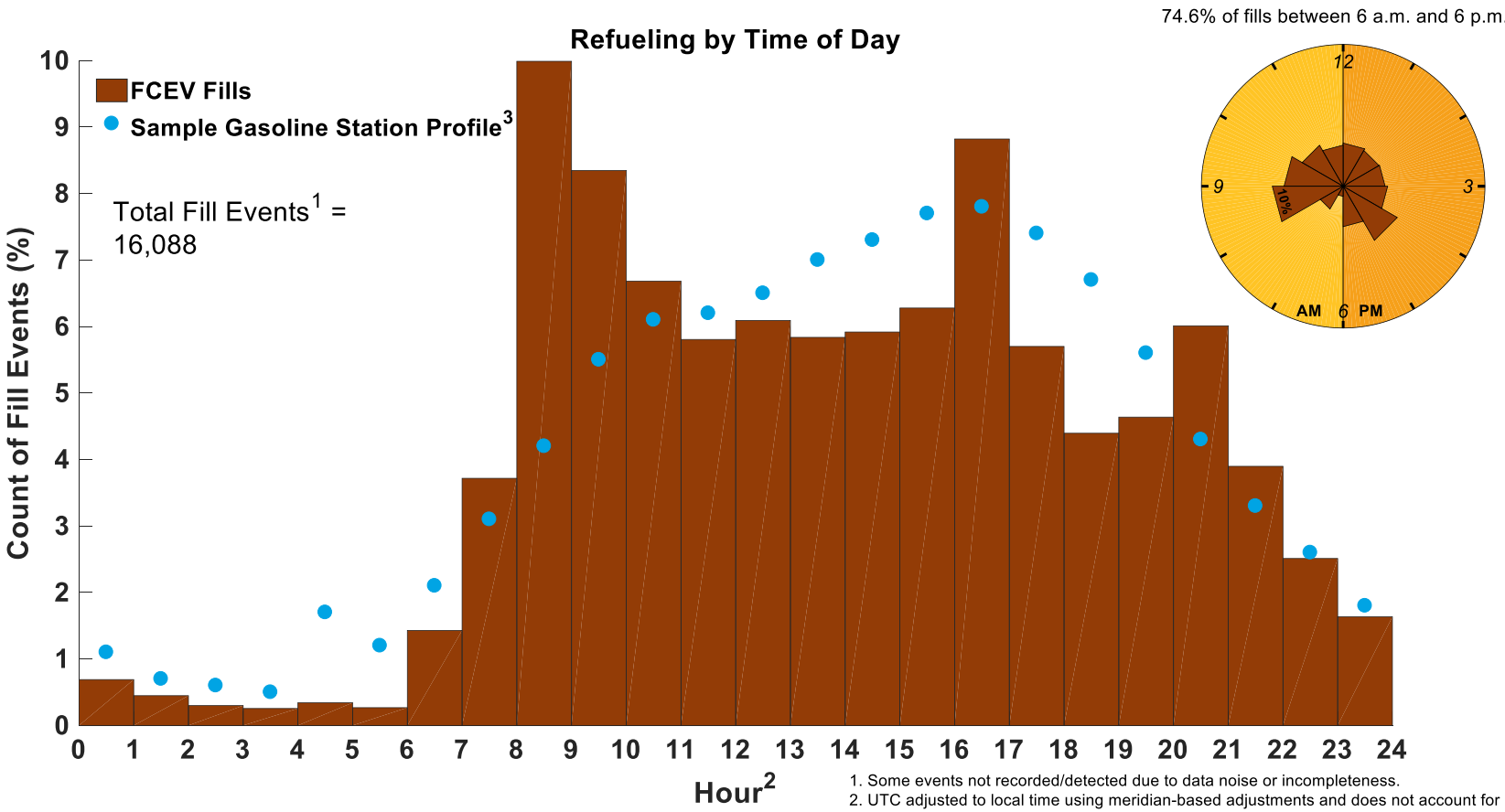
NREL cdp_fcev_96
Created: May-05-17 12:01 PM | Data Range: 2009Q1-2016Q4
Included Vehicles: Partial

New

Data-based Fueling Demand Profiles – Fill Times

Accomplishment

Utilize fueling data to develop a model for predictive fueling demand that can be integrated with hydrogen stations for operation and control improvements and optimization – **in progress**



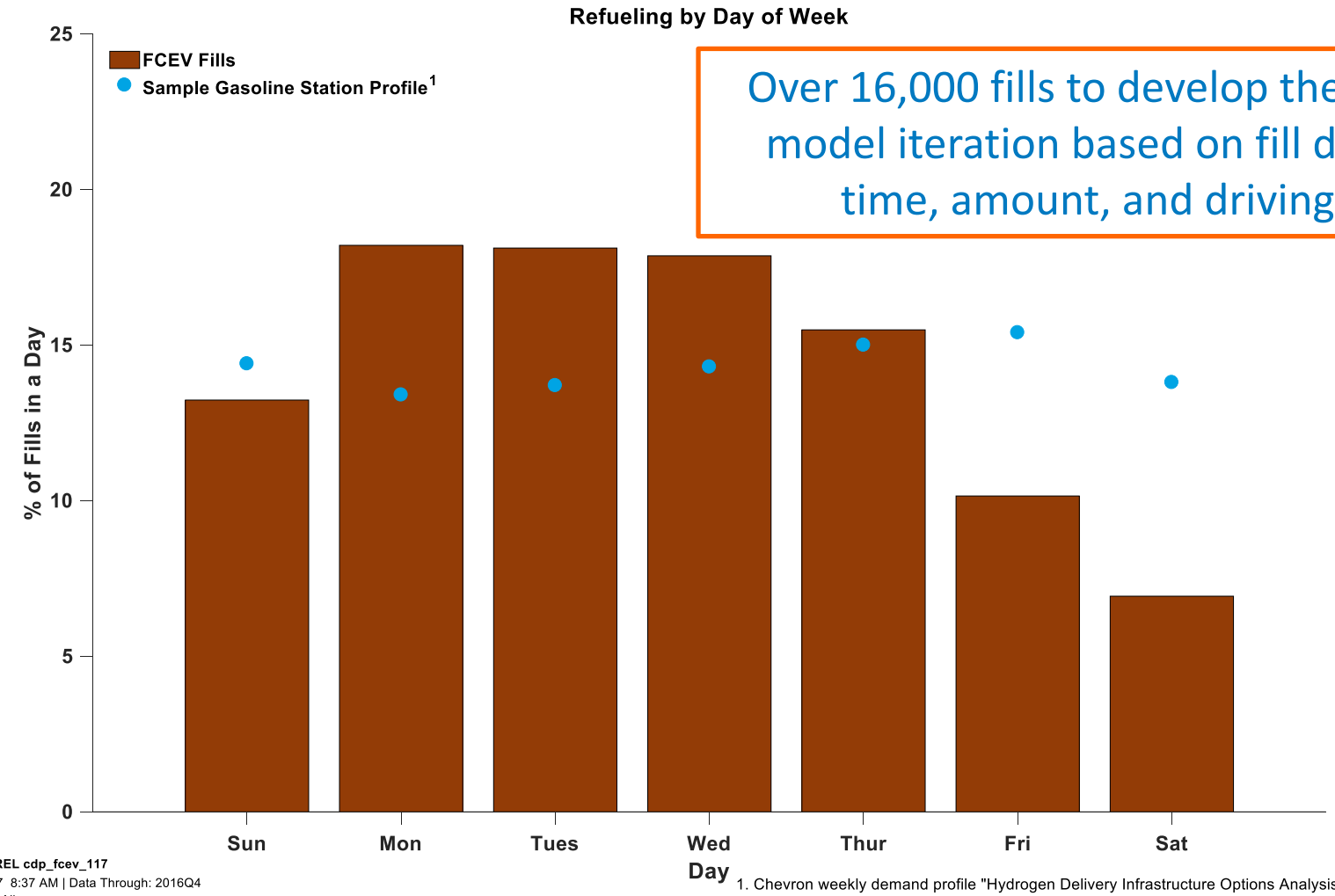
1. Some events not recorded/detected due to data noise or incompleteness.
2. UTC adjusted to local time using meridian-based adjustments and does not account for statutory deviations from the meridian-based system.
3. Friday Chevron profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

NREL cdp_fcev_116
Created: May-03-17 3:53 PM | Data Range: 2009Q1-2016Q4
Included Vehicles: All

Updated

Data-based Fueling Demand Profiles – Fill Days

Accomplishment



Over 16,000 fills to develop the first model iteration based on fill days, time, amount, and driving

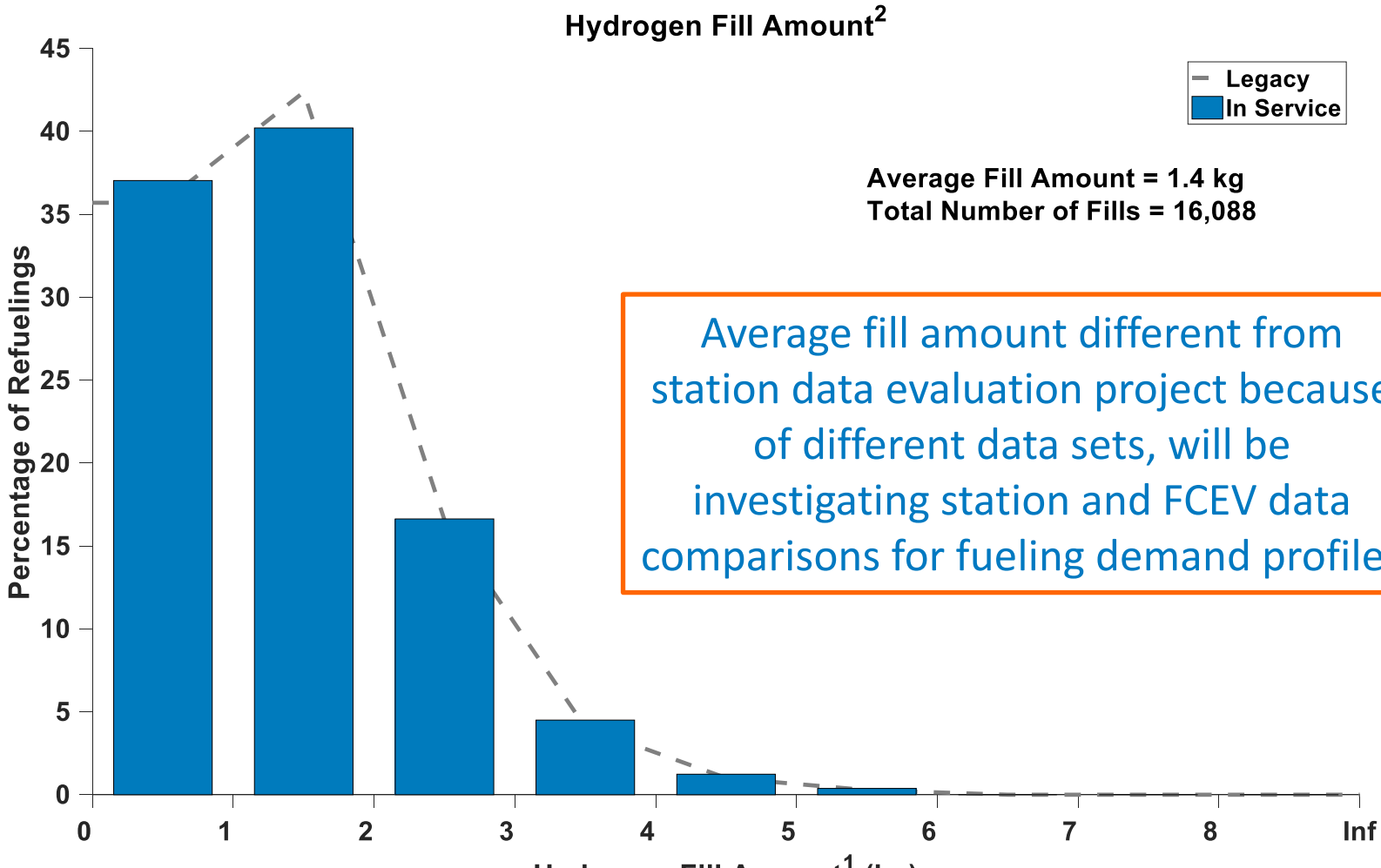
NREL cdp_fcev_117
Created: Apr-13-17 8:37 AM | Data Through: 2016Q4
Included Vehicles: All

1. Chevron weekly demand profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen, 2008.

Updated

Data-based Fueling Demand Profiles – Fill Amounts

Accomplishment



Average fill amount different from station data evaluation project because of different data sets, will be investigating station and FCEV data comparisons for fueling demand profiles

NREL cdp_fcev_108
Created: Apr-13-17 8:38 AM | Data Through: 2016Q4
Included Vehicles: All

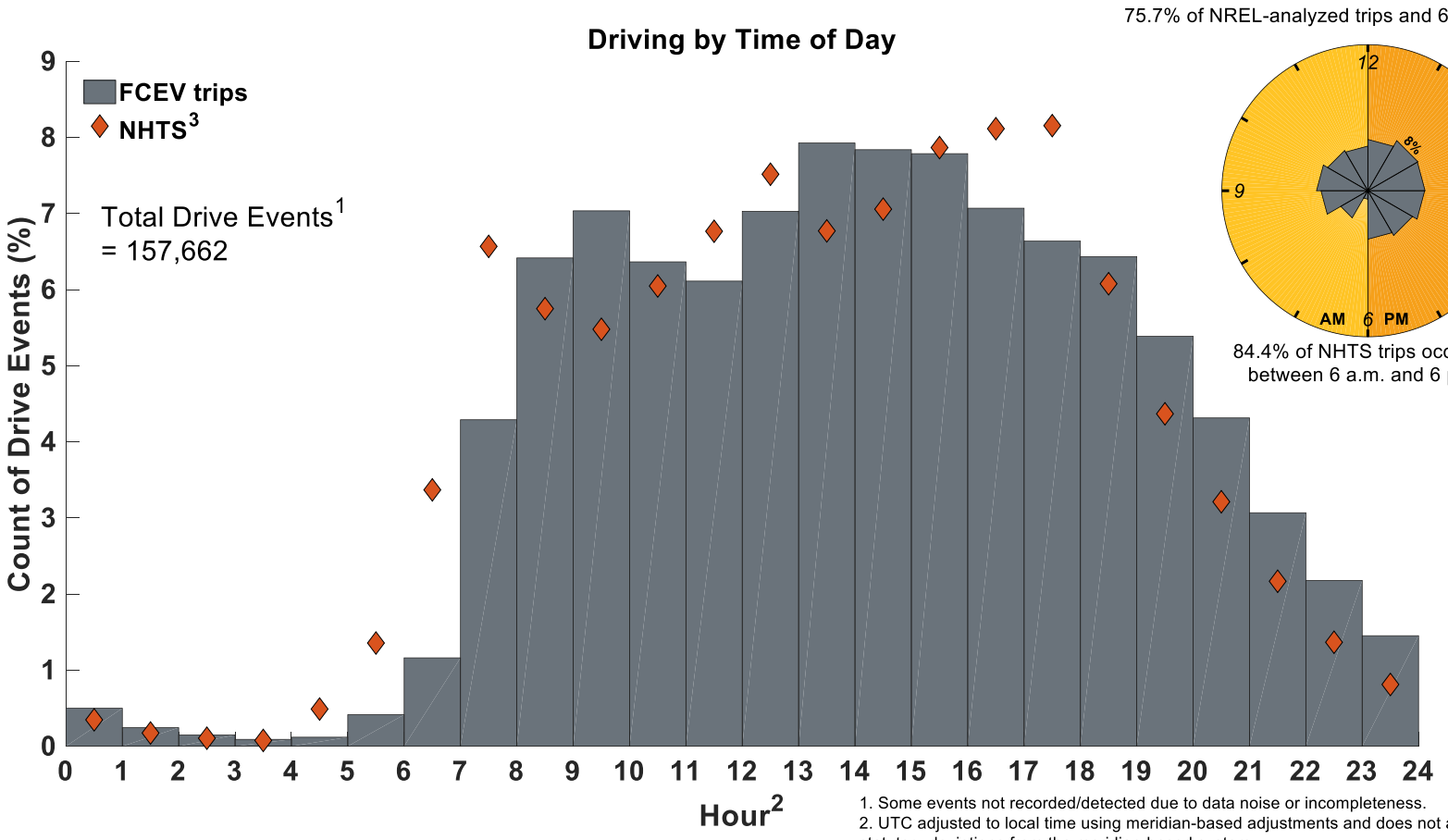
1. Data comes from fcev onboard sensors, includes fills from 2012 to 2014
2. Tanks range from 3.8 to 6.3 kg

Updated

Data-based Fueling Demand Profiles – Driving Times

Accomplishment

Driving data (over 157,000 trips) compared with standard gasoline vehicle driving trends. Driving times are similar. Driving data support what the vehicle does between fueling to support the predictive fueling demand.



75.7% of NREL-analyzed trips and 6 a.m. and 6 p.m.

84.4% of NHTS trips occurred between 6 a.m. and 6 p.m.

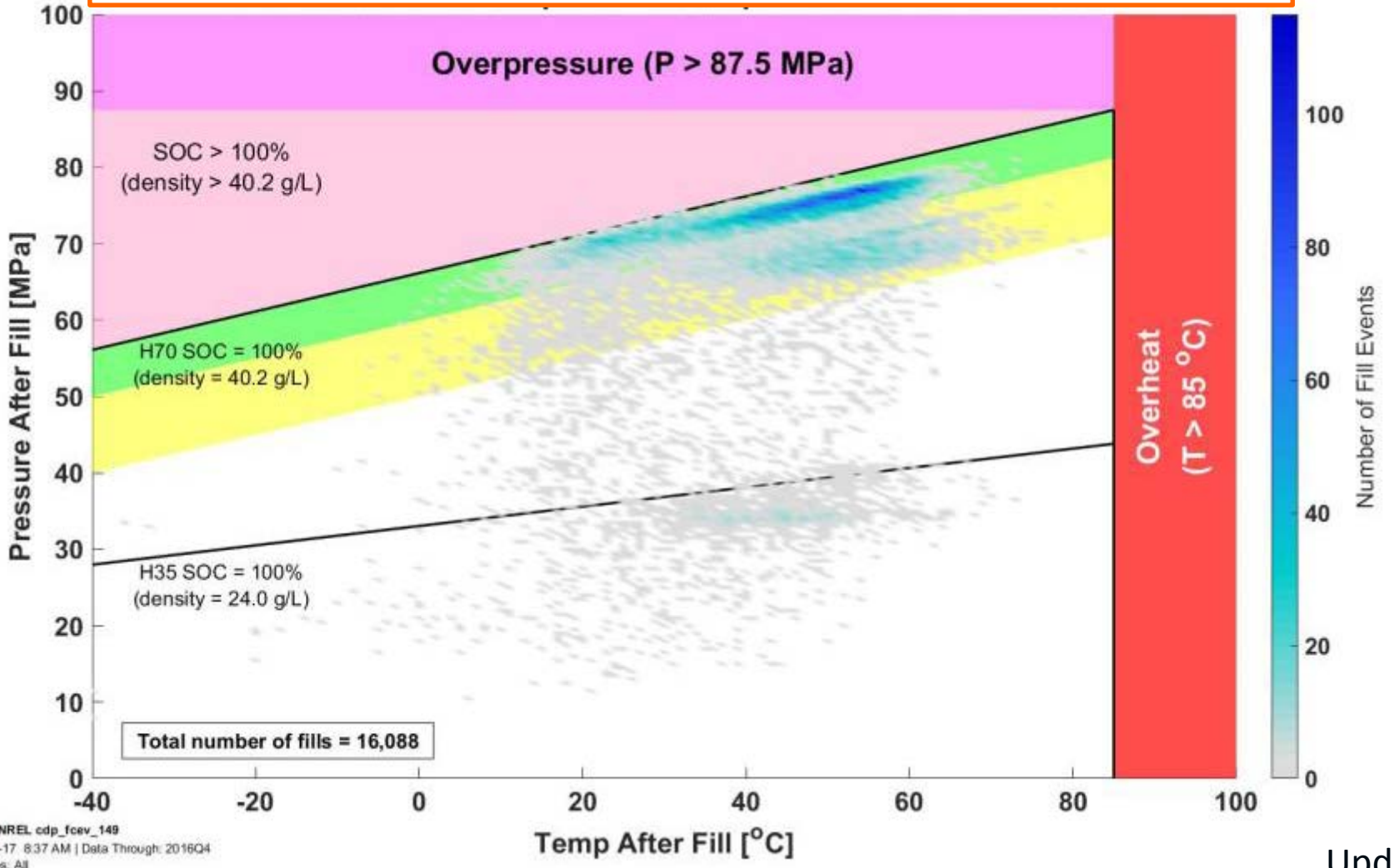
1. Some events not recorded/detected due to data noise or incompleteness.
2. UTC adjusted to local time using meridian-based adjustments and does not account for statutory deviations from the meridian-based system.
3. 2009 NHTS Data Includes Car, Truck, Van, & SUV day trips
ASCII.csv Source: http://nhts.ornl.gov/download.shtml#2009

NREL cdp_fcev_118
Created: May-03-17 3:52 PM | Data Range: 2009Q1-2016Q4
Included Vehicles: All

Updated

Fill Pressures and Temperatures Compared to SAE J2601 Limits

On-board tank fueling data supports understanding of station fueling performance, from the perspective of the vehicle.



Updated

Accomplishments and Progress:
Responses to Previous Year Reviewers' Comments

- ". . . work with newer vehicles . . . ", "Bringing in newer vehicles would add to the project's value . . ."
  - This year we expanded the range of vehicles from which we collect data from 2012 to 2016 – then-current model year vehicles.
- "The main weakness is in trying to make the connection between what is seen here and what is happening in the private sector . . . [to] demonstrate the progress (or lack of progress) made in FCEV development."
  - See CDP 96 for a look at status compared to DOE targets.
- "Data should be collected for the driver-refueling interface"
  - Information on dispensers (the main driver-refueling interface) is collected in our sister infrastructure project, TV-017.

Collaborations

- Three participating OEMs – Daimler, Honda, Hyundai. These OEMs:
  - Supply data
  - Review detailed data analysis and approve published results
  - Review current and future analysis topics.

Detailed view of a typical data cycle with OEMs before every publication of analysis results

- Industry working groups (CaFCP, H2USA, & FCHEA)
  - Participation and briefings

Technology Transfer Activities

- None to date

Remaining Challenges and Barriers

- Relationship between vehicle, station, and driver
  - Station reliability and availability remains a challenge, even as the station network grows.
  - To alleviate this, we need to develop a predictive fueling model to inform decisions regarding station operation optimization, availability, and locations.
- Additional progress is needed to meet the 2020 DOE targets for power density, specific power, volumetric and gravimetric H2 storage capacity, and durability.
- Improve feedback of analysis results to inform R&D
- Availability of on-road vehicle data – although some new-vehicle data are available at NFCTEC, they are insufficient to publish results from new vehicles alone.

Proposed Future Work

- Develop and validate predictive FCEV fueling demand model based on fill and drive data for hydrogen station operation optimization to decrease operation and maintenance costs and in support of research projects like electrolyzer grid integration and vehicle-to-grid
- Continue building relationship with OEMs for additional on-road FCEVs for status, validation of the predictive FCEV fueling demand model, and FCEV-to-station interface needs
- Publish results (online, reports, & conferences) to meet a project objective of data dissemination
- Spring 2018
  - Complete quarterly analysis of CY17 data
  - Publish analysis results dependent on number of on-road vehicles (5/2018)

Any proposed future work is subject to change based on funding levels.

Summary

"For more than 10 years, NREL has been a trusted analysis partner. NREL turns our raw data into business intelligence. This gives us insight into how our vehicles are progressing toward targets, and how we compare against our peers. NREL has robust security procedure to keep our data safe and provide us useful results on a regular basis." FCEV OEM Partner

- Relevance
  - Independent validation of FCEV on-road performance against DOE and industry targets
- Approach
  - Collaborate with industry partners to receive new vehicle data
  - Continue to develop core NFCTEC and analysis capability and tools
  - Leverage 8+ years of analysis and experience from the Learning Demonstration
- Technical Accomplishments and Progress
  - Analyzed data from three OEMs
  - Performed detailed reviews of individual OEM data results
  - Published results via 20 CDPs that cover topics such as deployment, fuel cell performance, fuel economy, range, driving, fueling, and specifications.
- Collaborations
  - Working closely with industry partners to validate methodology and with other key stakeholders to ensure relevance and accuracy of results
- Future Work
  - Develop predictive FCEV fueling demand in support of research projects like electrolyzer grid integration and vehicle-to-grid.
  - Continue building relationship with OEMs for additional on-road FCEVs for status and FCEV-to-station interface needs
  - Publish results (online, reports, & conferences) to meet a project objective of data dissemination

Summary of Key FCEV Metrics

	Vehicle Performance Metrics	DOE Target (Year 2020)[a]	LD3[b]	LD2+[c]	LD2[c]	LD1[c]
Durability	Max Fuel Cell Durability Projections (hours)	5,000	4,130	--	2,521	1,807
	Average Fuel Cell Durability Projection (hours)		2,442	1,748	1,062	821
	Max Fuel Cell Operation (hours)		5,648	1,582	1,261	2,375
Efficiency	Adjusted Dyno (Window Sticker) Range (miles)		200 - 320	--	196 - 254	103 - 190
	Median On-Road Distance Between Fuelings (miles)		122	98	81	56
	Fuel Economy (Window Sticker) (mi/kg)		53 (median)	--	43 - 58	42 - 57
	Fuel Cell System Efficiency at 1/4 Power	65	57% (average)	--	53% - 59%	51% - 58%
	Fuel Cell System Efficiency at Full Power		43% (average)	--	42% - 53%	30% - 54%
Specs	Specific Power (W/kg)	650	240 - 563		306 - 406	183 - 323
	Power Density (W/L)	650	278 - 619		300 - 400	300 - 400
Storage	System Gravimetric Capacity (kg H2/kg system)	5.5%	2.5% - 3.7%		2.5% - 4.4%	
	System Volumetric Capacity (kg H2/L system)	0.04	0.018 - 0.054		0.018 - 0.025	

a. Fuel Cell Technolgies Office Multi-Year Research, Development, and Demonstration Plan (https://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22)
b. Current results are available at http://www.nrel.gov/hydrogen/proj_fc_vehicle_evaluation.html (Updated 4/2017)
c. National Fuel Cell Vehicle Learning Demonstration Final Report (http://www.nrel.gov/hydrogen/pdfs/54860.pdf)

NREL cdp_fcev_96
Created: May-05-17 12:02 PM | Data Range: 2009Q1-2016Q4
Included Vehicles: Partial

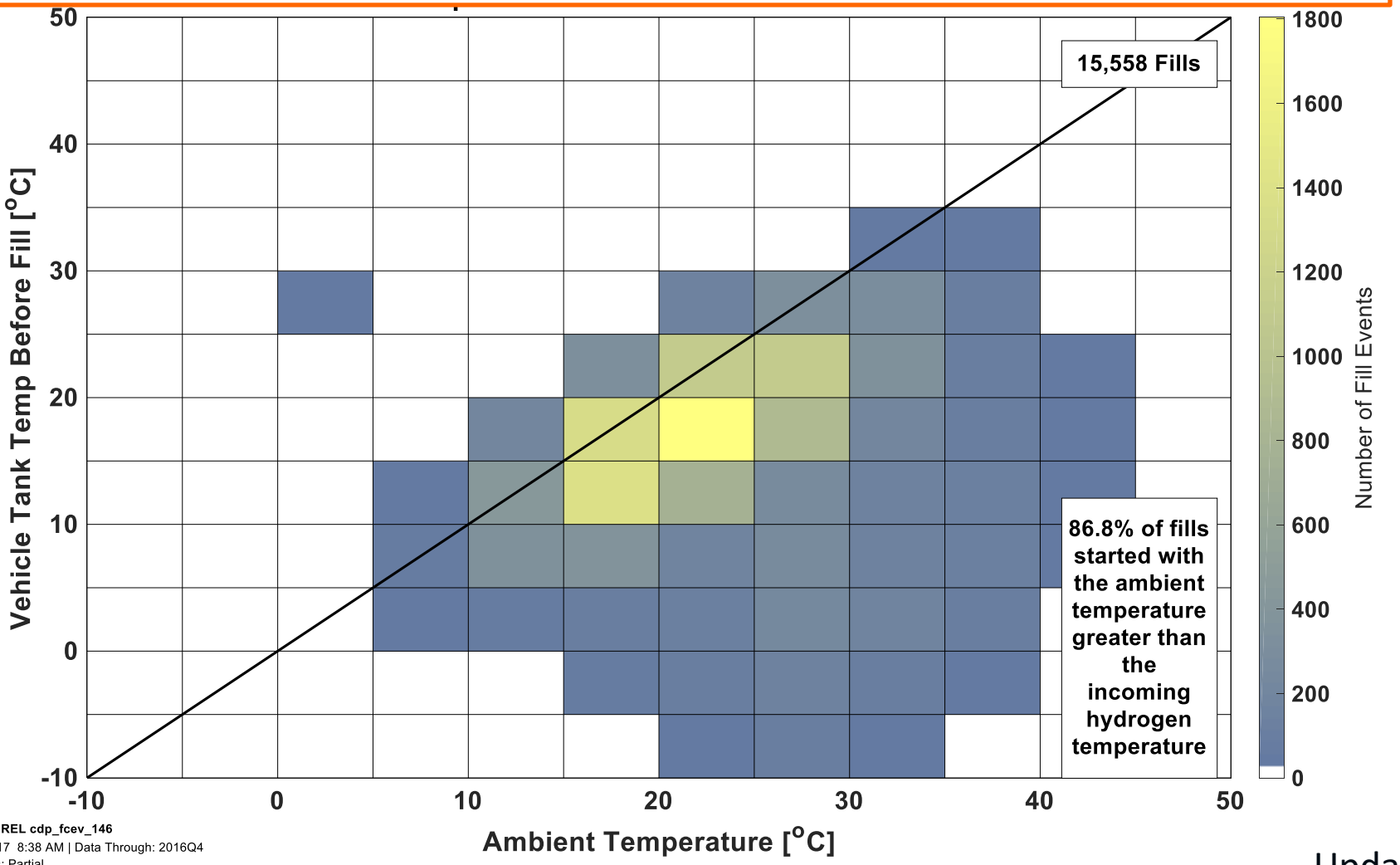
Updated

Technical Back-Up Slides

(Include this “divider” slide if you are including back-up technical slides **[maximum of five]**. These back-up technical slides will be available for your presentation and will be included in the USB drive and Web PDF files released to the public.)

Tank & Ambient Temperature before Fills

Temperature data is used to understand the actual range of tank temperatures with the expected extreme temperature conditions at a fill.

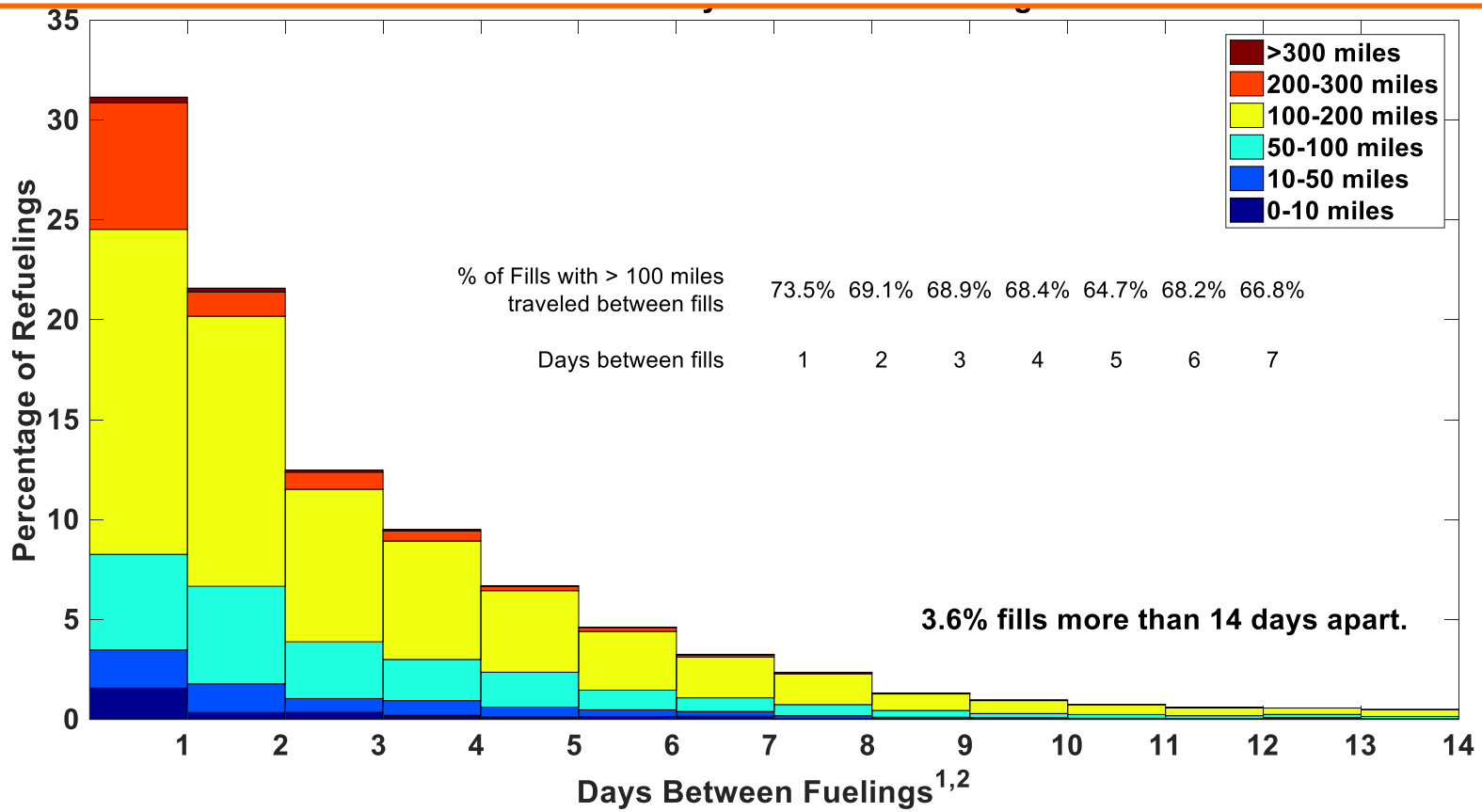


NREL cdp_fcev_146
Created: Apr-13-17 8:38 AM | Data Through: 2016Q4
Included Vehicles: Partial

Updated

Calendar Days Between Refueling

Only 3% of fills happen more than 14 days apart; 100 miles are traveled ~70% of the time with 1-2 days between fills which indicates high daily miles traveled.



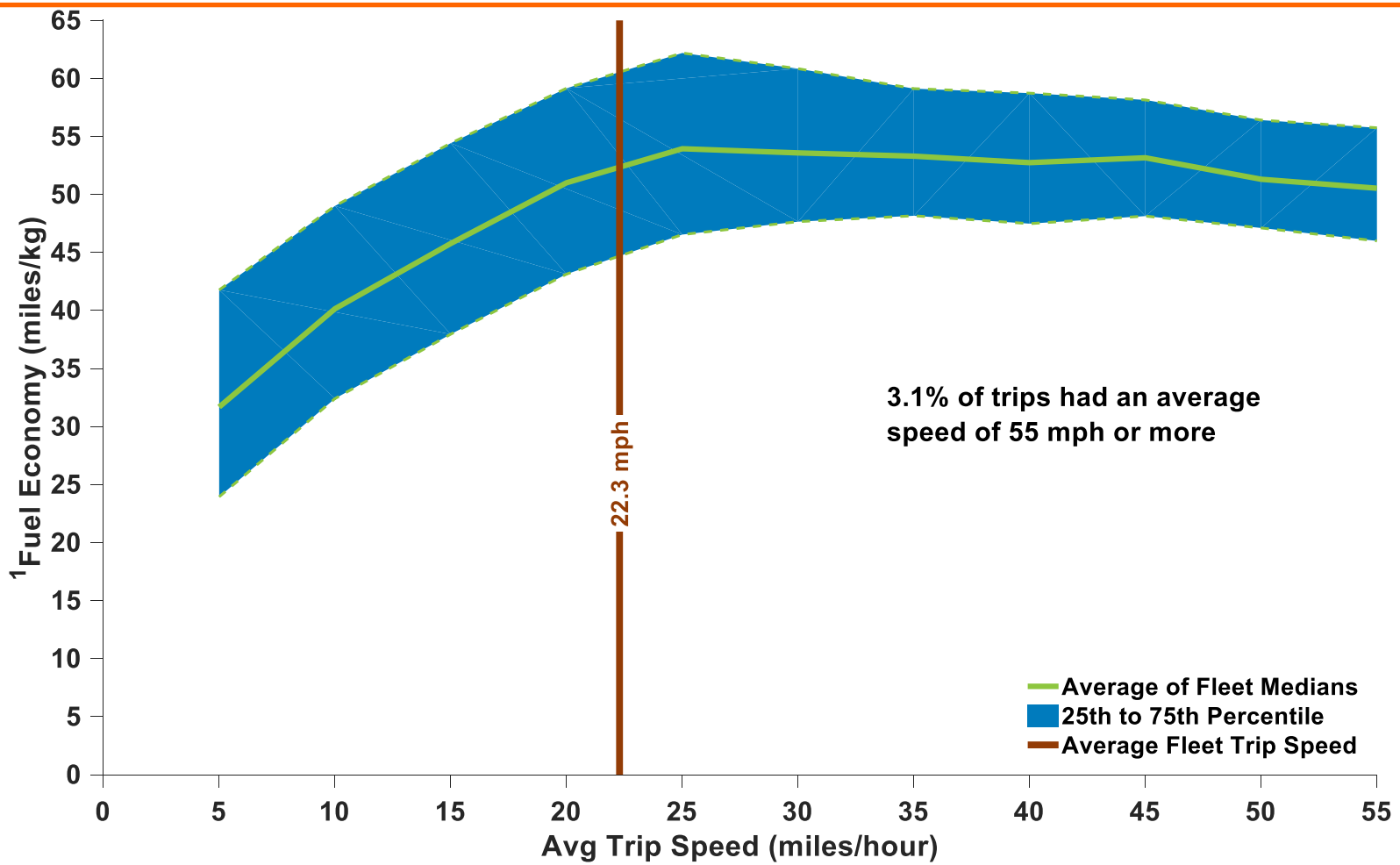
1. Data includes fills from 2012 - 2015. Fills < 1 hour apart are excluded.
2. Some vehicles included in the data have scheduled driving aimed at accumulating high miles and operation time over a variety of conditions. These vehicles typically fill at least once a day. These vehicles are operated on public roads and driving is typical for the region.

NREL cdp_fcev_106
Created: Apr-13-17 8:37 AM | Data Through: 2016Q4
Included Vehicles: All

Updated

Effect of Average Trip Speed on Fuel Economy

The impact of average trip speed on fuel economy follows an expected trend, where the peak on-road fuel economy is when average trip speed is between 20 – 25 mph.



NREL cdp_fcev_141

Created: Apr-13-17 8:37 AM | Data Through: 2016Q4

Included Vehicles: All

1. Data binned every 5 mph for calculating median and percentiles.

Updated