NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Electric Vehicle Evaluation

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National Renewable Energy Laboratory
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DOE Hydrogen and Fuel Cells Program
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID # TV001

Overview

Timeline and Budget

- Project start date: 10/2012*
- FY17 DOE funding: $200K
- FY18 planned DOE funding: $120K
- Total DOE funds received to date: $1,885k

Barriers

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

Partners

- Daimler
- Hyundai
- Honda
- GM
- Nissan
- Toyota
- Electricore

*Project continuation determined annually by DOE

Relevance

- Objectives
  - Analyze and report data on hydrogen fuel cell electric vehicles (FCEVs) operating in a 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.

FY18 Objectives
Analyze and report on FCEV fuel economy, range, and fueling behavior.

Approach: NFCTEC Analysis and Reporting

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

Data collection, analysis, aggregation, and reporting consistent with FY17 approach

Internal analysis completed quarterly in NFCTEC

National Fuel Cell Technology Evaluation Center

Results

DDPs

Confidential

Public

CDPs

Detailed Data Products (DDPs)

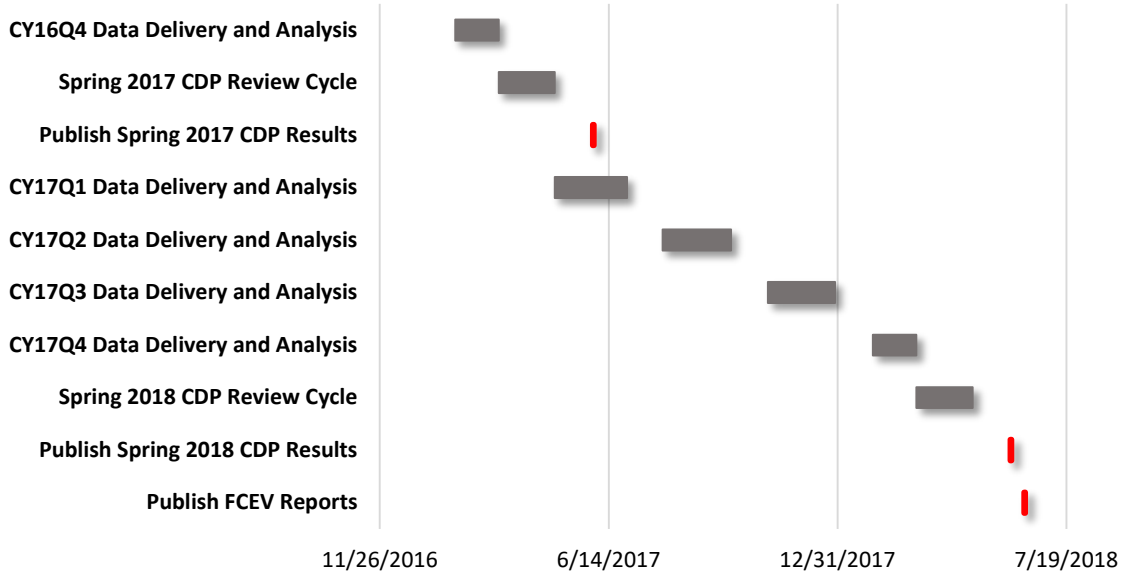
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

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/technology-validation.html

Approach: Schedule and Milestones

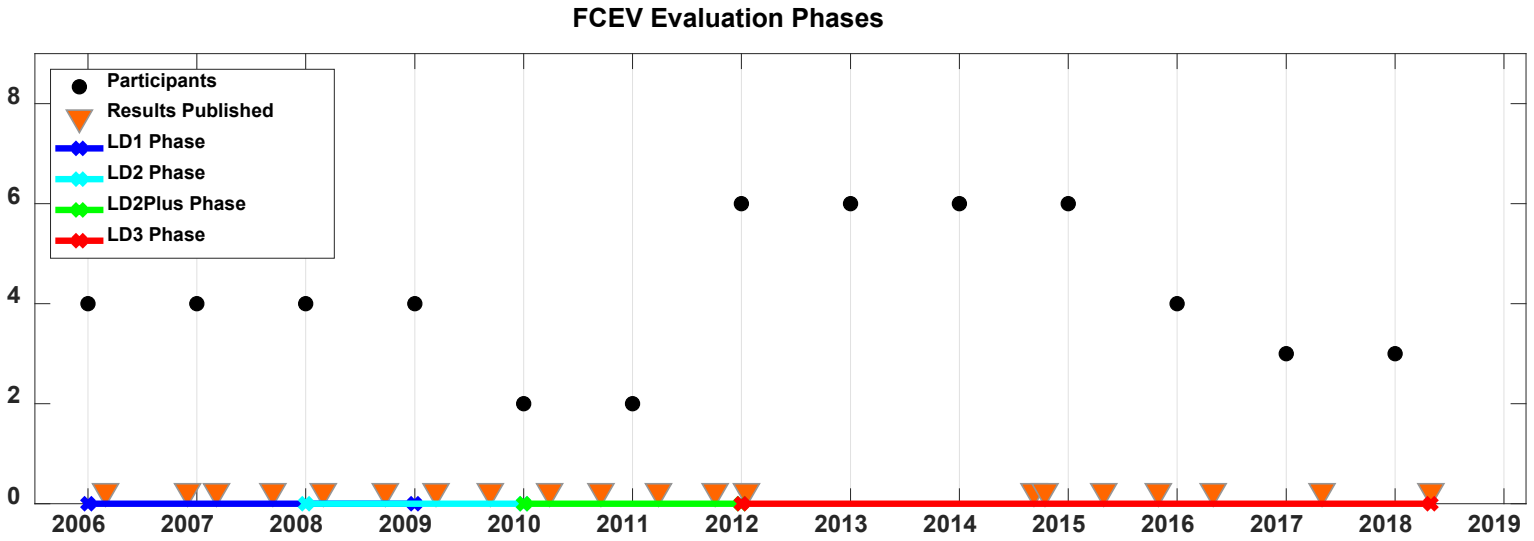


Task	Start	End	Days	Status
CY16Q4 Data Delivery and Analysis	1/31/2017	3/10/2017	38	Complete
Spring 2017 CDP Review Cycle	3/10/2017	4/28/2017	49	Complete
Publish Spring 2017 CDP Results	5/31/2017	5/31/2017	1	Complete
CY17Q1 Data Delivery and Analysis	4/28/2017	6/30/2017	63	Complete
CY17Q2 Data Delivery and Analysis	7/31/2017	9/29/2017	60	Complete
CY17Q3 Data Delivery and Analysis	10/31/2017	12/29/2017	59	Complete
CY17Q4 Data Delivery and Analysis	1/31/2018	3/10/2018	38	Complete
Spring 2018 CDP Review Cycle	3/10/2018	4/28/2018	49	In Progress
Publish Spring 2018 CDP Results	5/31/2018	5/31/2018	1	In Progress
Publish FCEV Reports	6/12/2018	6/12/2018	1	In Progress

Regular project activities include:

- Quarterly analysis
- Annual technical CDPs
- Detailed data and analysis reviews with project partners
- Publishing and presenting results
- Collaborating with infrastructure evaluation

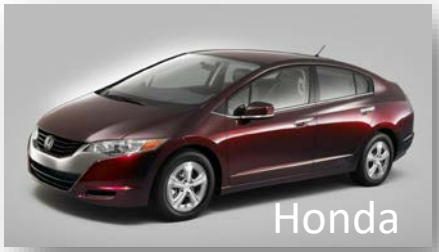
Accomplishments and Progress: Historical FCEV Evaluation Phases, Partners, and Publications

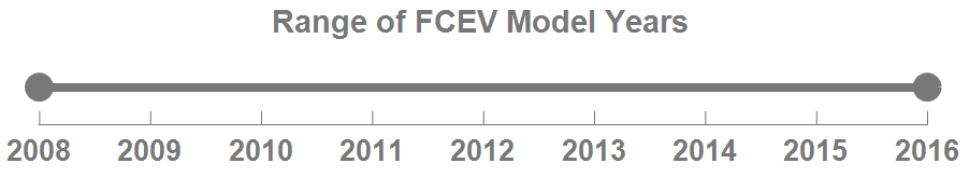


"LD" - Indicates Learning Demonstration Phase

Current evaluation includes three OEMs delivering data from FCEVs currently on-road. The data are 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 due to data limitations.

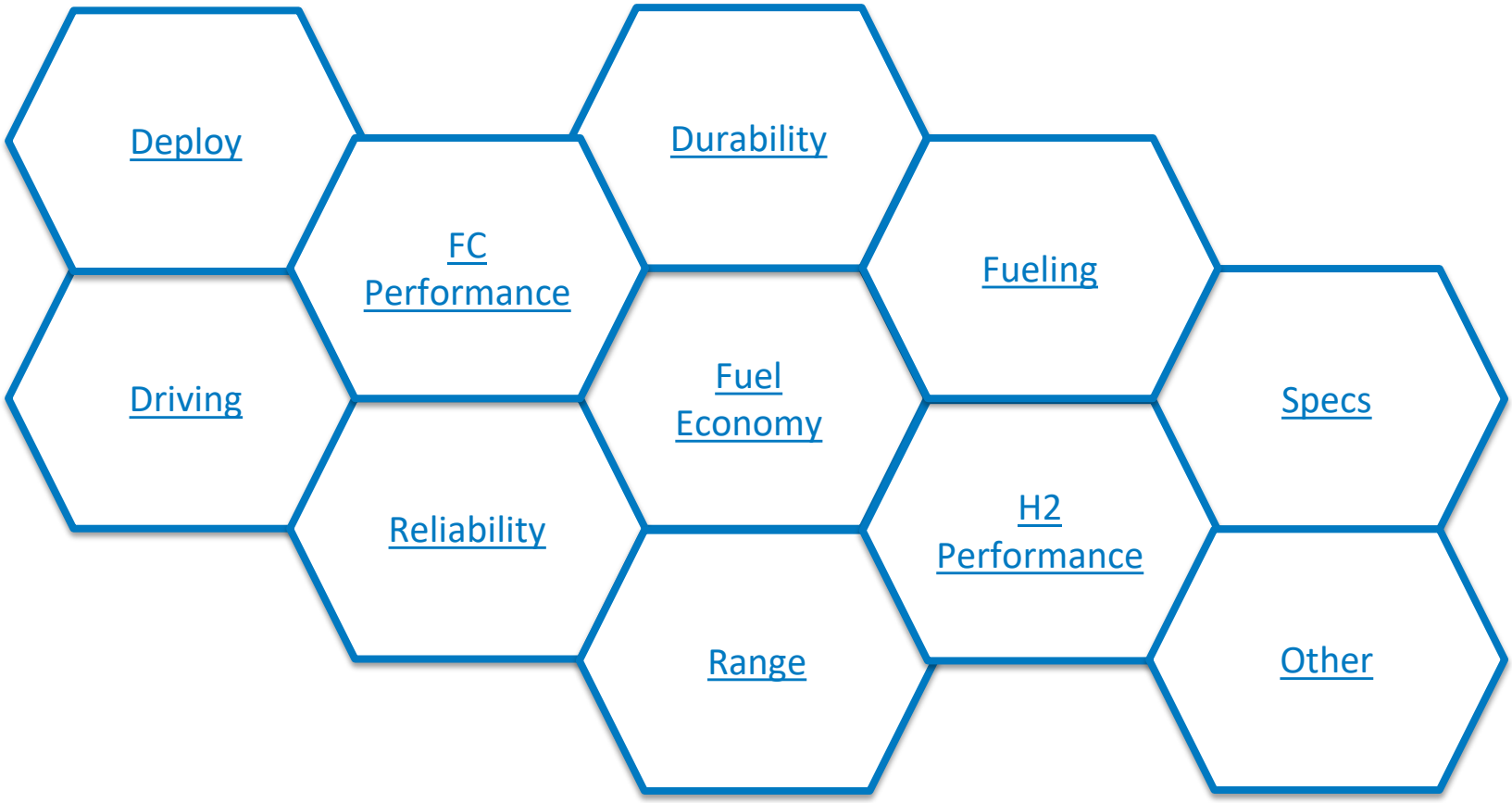
Approach: On-Road FCEVs and Partners Supplying Data





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

Accomplishments and Progress: Analysis Categories



Analyzed data through 12/2017. Not all results are included here or published.
All published results are available online:
www.nrel.gov/hydrogen/technology-validation.html.

Accomplishments and Progress: FCEV Deployment and Operation Through CY2017Q4

54
FCEVs total

51
Average on-road fuel economy miles/kg

>296,830
Max FCEV odometer miles

9
FCEVs retired

>2,675,280
miles traveled

>83,466
Fuel cell operation hours

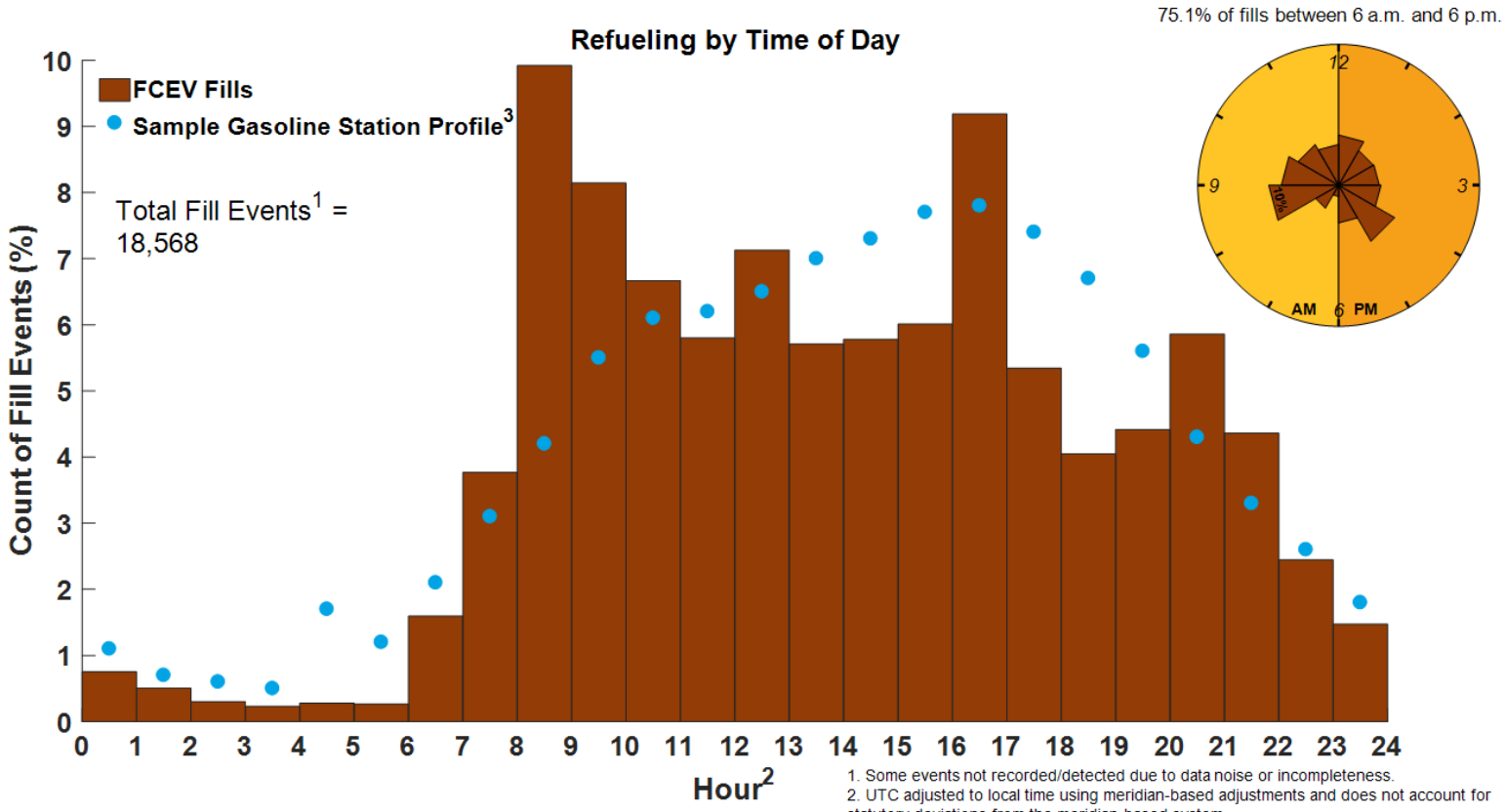
Current performance benchmarked since 2006 includes 230 vehicles and more than 7.39 million miles traveled.

>5,648
Max fuel cell operation hours

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

Accomplishments and Progress: Predictive Fueling Demand Model

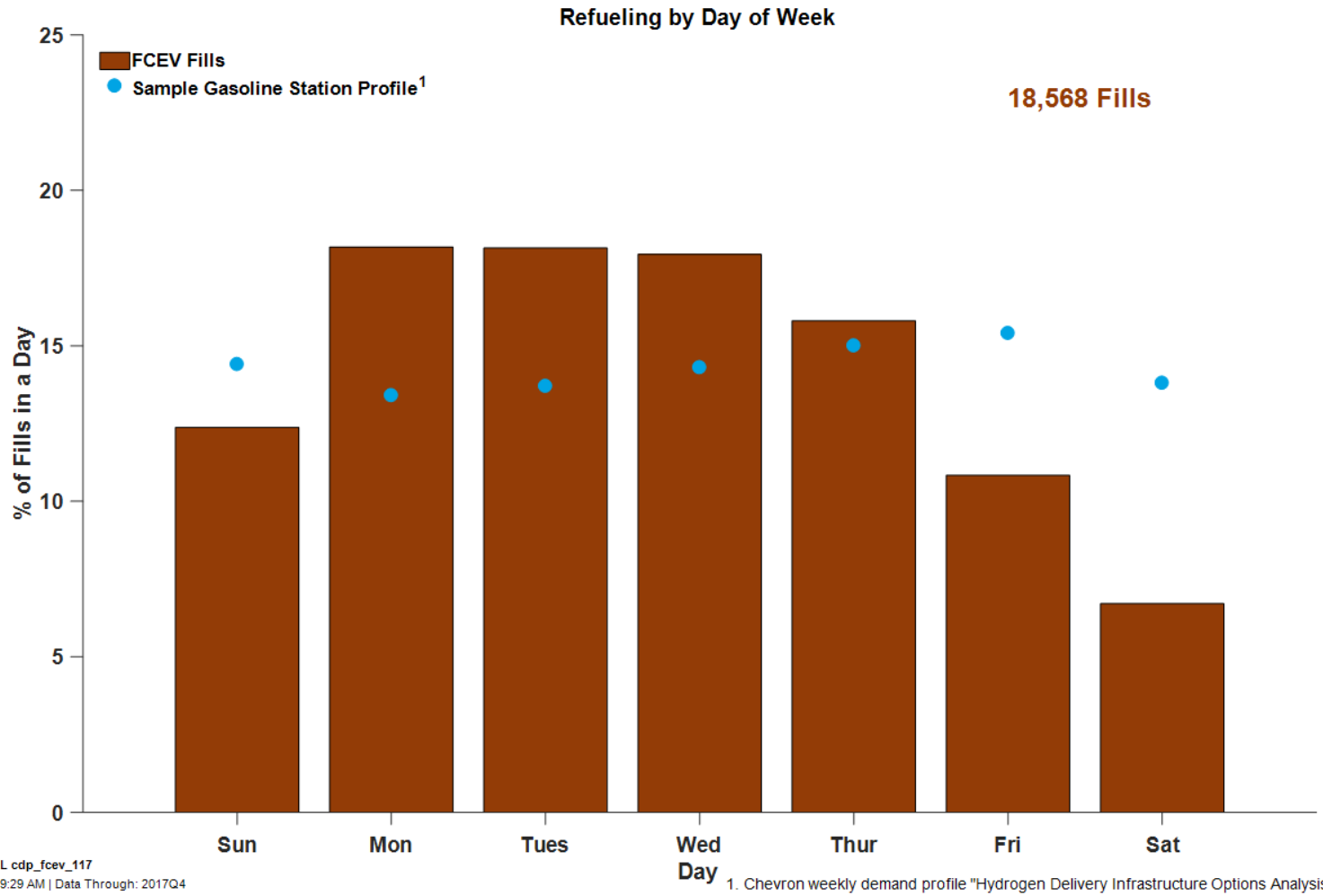
NREL utilized fueling data to develop a model for predictive fueling demand that can be integrated with hydrogen stations for operation and control improvements as well as optimization.



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.

Accomplishments and Progress: Predictive Fueling Demand Model

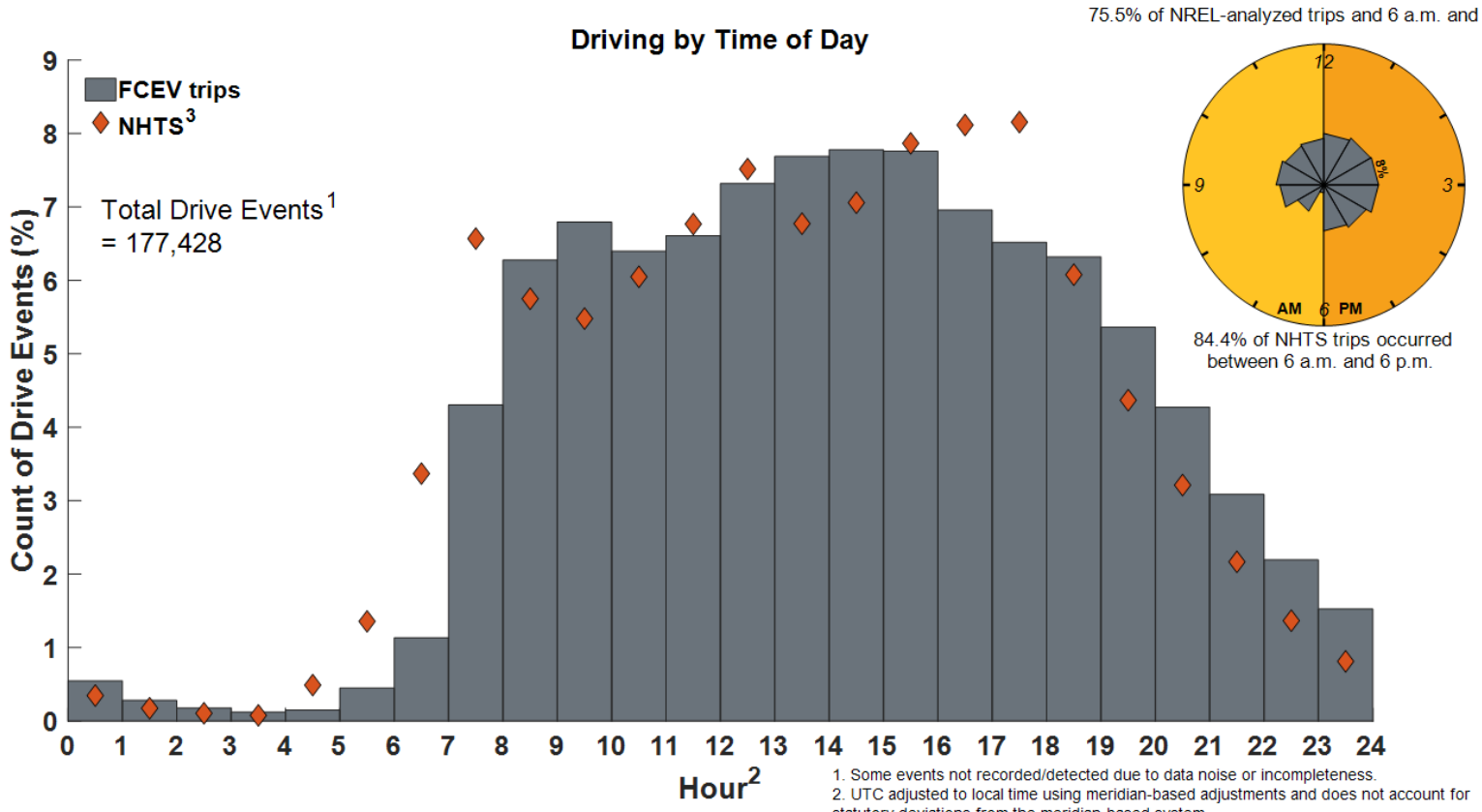
Data from more than 18,568 fills were used to develop the first model iteration based on fill days, time, amount, and driving.



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

Accomplishments and Progress: Predictive Fueling Demand Model

FCEV driving data are shown in comparison with standard gasoline vehicle driving trends (over 177,428 trips). The similarity in driving times and trends help support the predictive hydrogen refueling demand.



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
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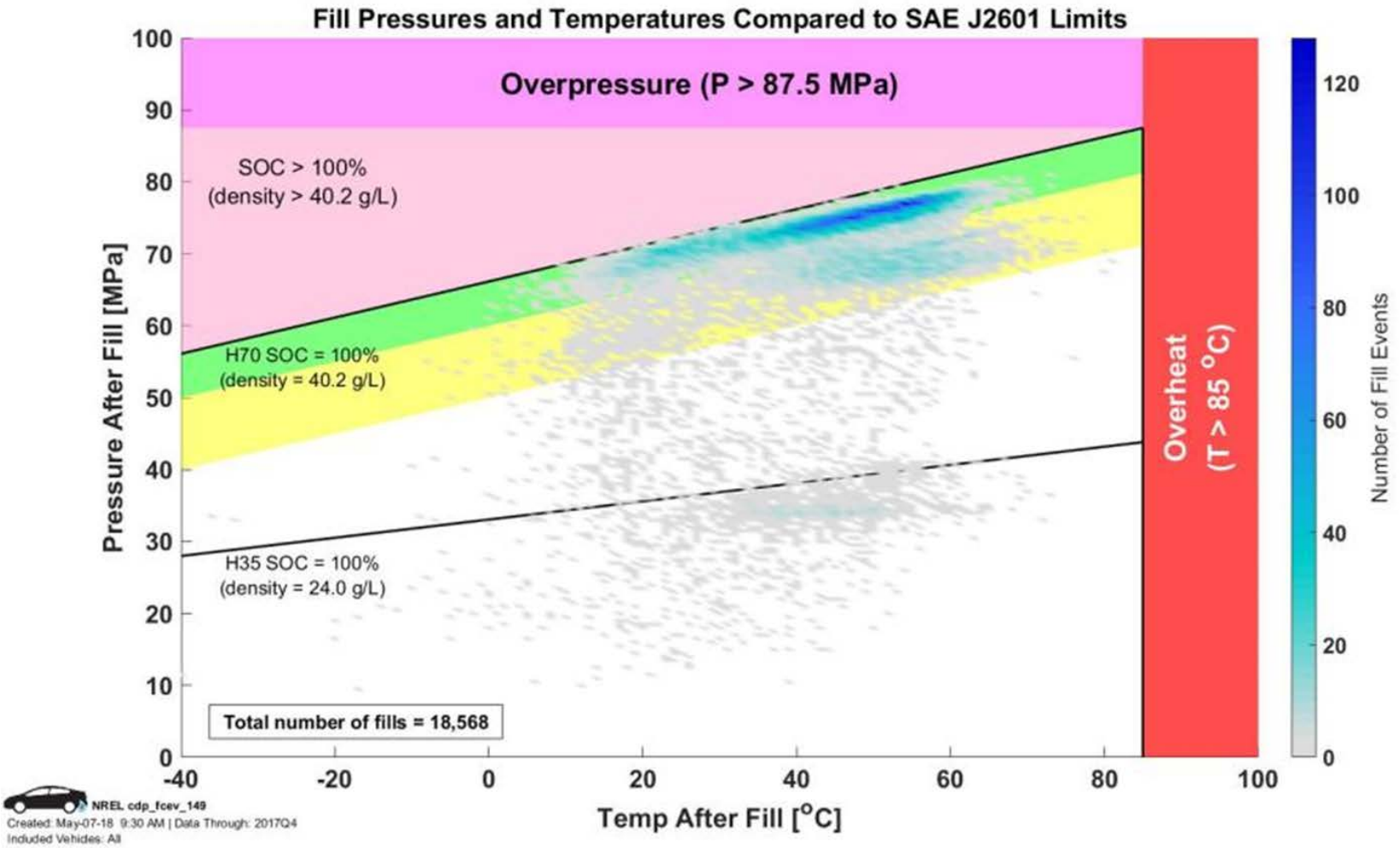
Included Vehicles: All

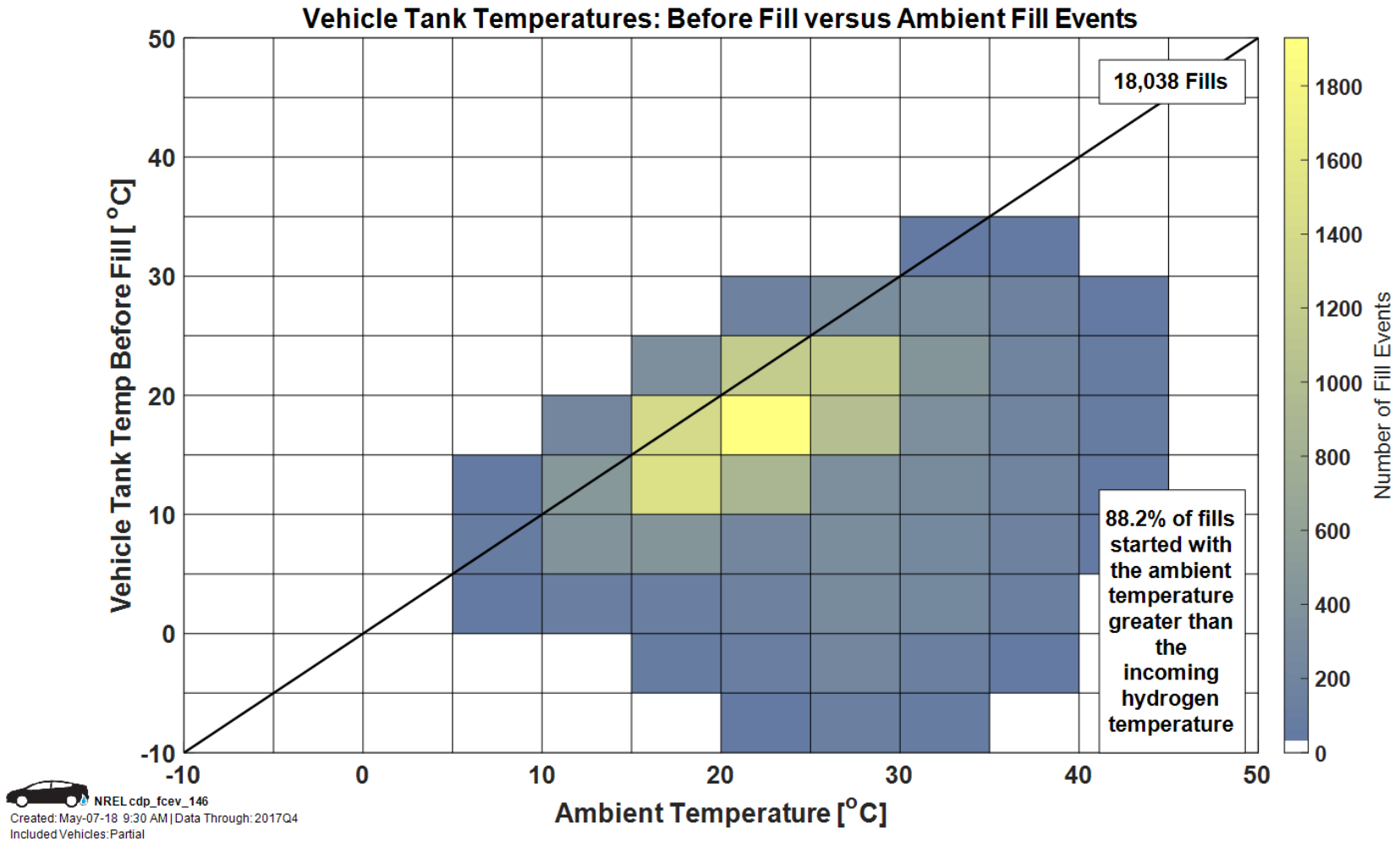
Accomplishments and Progress: Predictive Fueling Demand Model

On-board tank refueling data support understanding of station fueling performance from the perspective of the vehicle.



Accomplishments and Progress: Predictive Fueling Demand Model

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



Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- "The collaboration does not include the one OEM that sells FCEVs, and one of the OEMs included has reported plans for new models (but does not sell or lease the new models)."
  - NREL maintains open dialogue with FCEV OEMs. Availability of FCEV data is determined by OEM participation interest and diversity of vehicles operating on the road.
- "A potential downside is the age of this project and whether the industry needs it as much now as in the past 10 years (even though not all DOE targets are met). The fact that there are fewer participants may be a testament to this fact."
  - Lack of operating FCEV fleets have dictated the decline of OEM participants and availability of data. This particular project is completing the high fidelity analysis work and shifting into tracking commercial vehicle deployment and specifications.
- "The project could have been a much better project if there had been more analysis. The slide 11 spider chart demonstrated that the NREL team can analyze, and its "Remaining Challenges & Barriers" and "Proposed Future Work" sections advise that NREL wants to analyze. It would have been nice to see more analysis in this presentation."
  - NREL performs analysis on a variety of FCEV refueling events. Due to lack of diversity in the data, not all analysis can be publicly disseminated in order to preserve anonymity. More CDPs are published than what is in this presentation. A full list of CDPs and analysis is available at <https://www.nrel.gov/hydrogen/fuel-cell-vehicle-evaluation.html>.

Collaboration and Coordination

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

(~8 weeks excluding data processing and analysis)

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

- Industry working groups (California Fuel Cell Partnership, H2USA, and Fuel Cell and Hydrogen Energy Association)
  - Participation and briefings

Remaining Challenges/Barriers and Proposed Future Work

- **Remaining Challenges/Barriers**
  - Lack of current controlled and on-road hydrogen fuel cell vehicle data.
- **Future Work**
  - Complete quarterly analysis of received CY18 data.
  - Publish analysis results of on-road vehicle evaluations (Spring 2018).
  - Disseminate data analysis through reports, white papers, and online content.
  - Utilize available fueling data for a predictive fueling models to inform decisions regarding station operation optimization, availability, and locations.
  - Shift focus of controlled demonstration from reporting on pre-competitive technologies to reporting on the current market status of commercially available FCEVs, production figures, market analysis, and geographic distribution.
    - Interact directly with OEMs, leveraging existing relationships and agreements.
    - Work closely with state, federal, and local government agencies (California Air Resources Board, California Energy Commission, U.S. Environmental Protection Agency, DOE, U.S. Department of Transportation, etc.).

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

Technology Transfer Activities

- None to date. However, this project helps inform industry on the status of FCEV technology and support research, development, and hydrogen station operation and improvement.

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 procedures 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 and other strategic sources of data to validate methodology and with other key stakeholders to ensure relevance and accuracy of results.
- **Future Work**
  - Shift focus from reporting on pre-competitive technologies to reporting on current market status of commercially available FCEVs.

Summary

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)		124	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 5/2017)

c. National Fuel Cell Vehicle Learning Demonstration Final Report (http://www.nrel.gov/hydrogen/pdfs/54860.pdf)

NREL cdp_fcev_175

Created: May-07-18 11:49 AM | Data Through: 2017Q4

Included Vehicles: Partial

Thank You

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Publication Number: NREL/PR-5400-xxxxx

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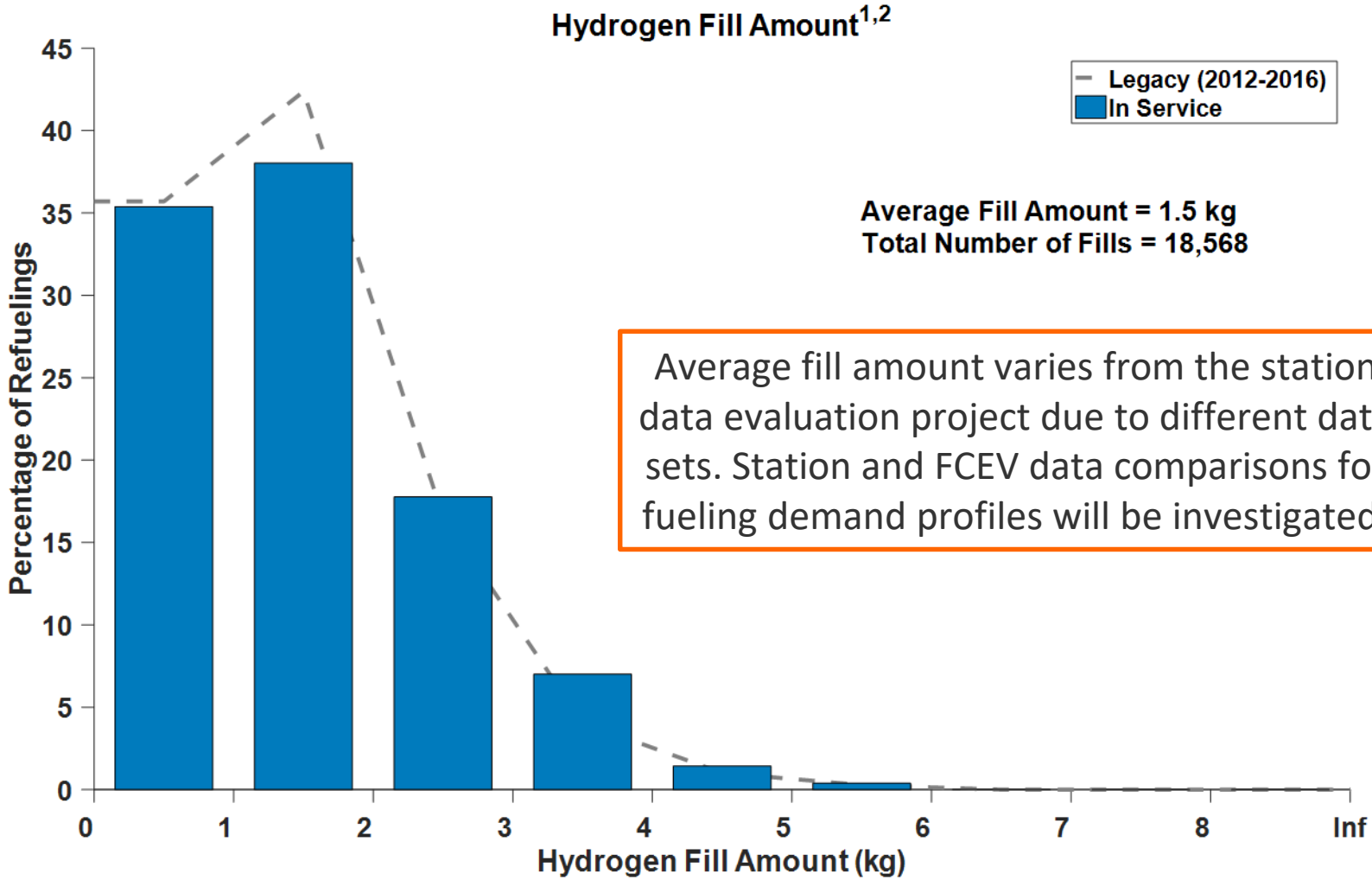
Technical Back-Up Slides

Hydrogen Fill Amount



Average fill amount varies from the station data evaluation project due to different data sets. Station and FCEV data comparisons for fueling demand profiles will be investigated.

NREL cdp_fcev_108
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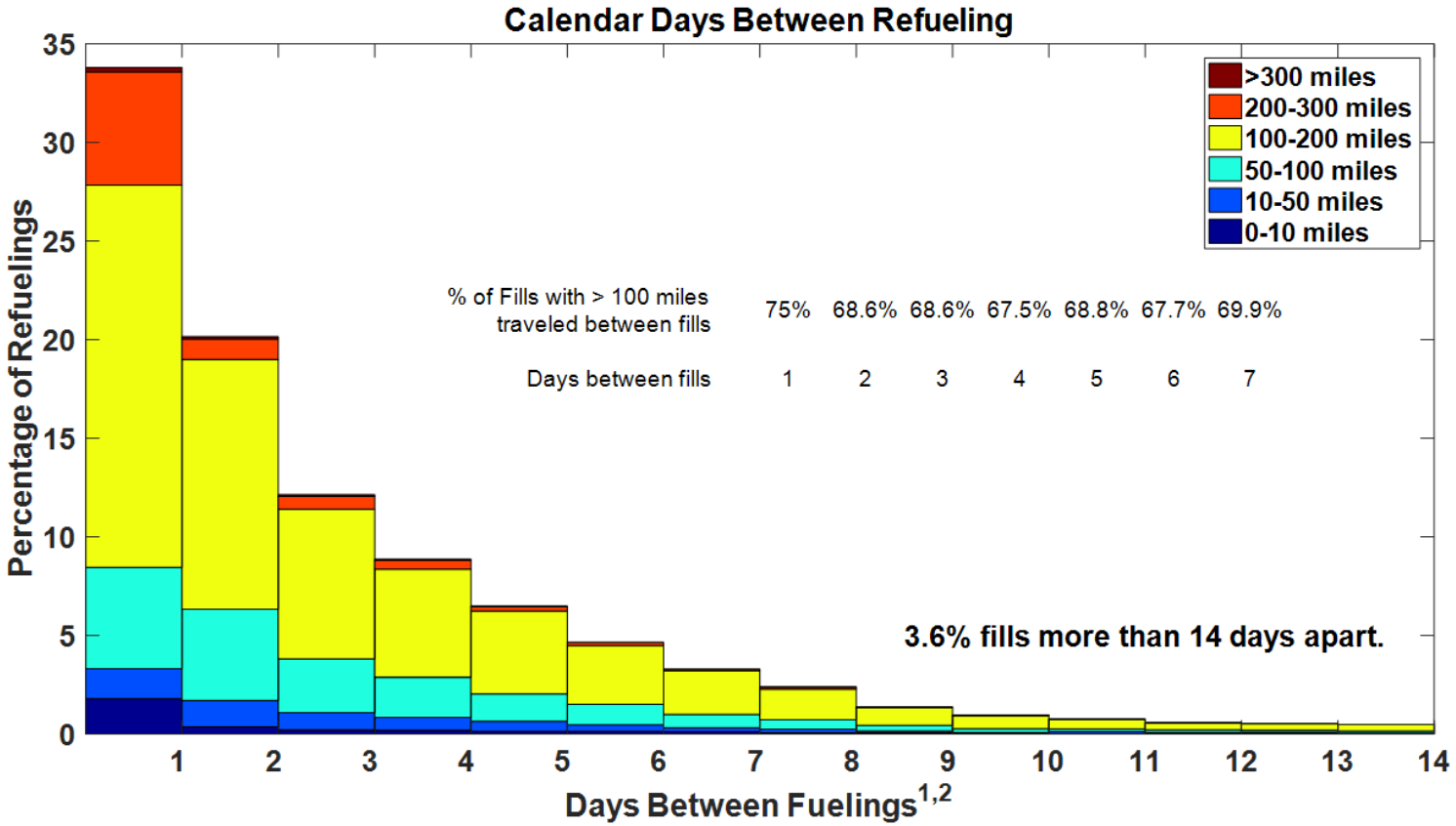
Included Vehicles: All

1. Data comes from fcev onboard sensors, includes fills from 2012 to 2018
2. Tanks range from 3.8 to 6.3 kg

Calendar Days Between Refueling

Only 3.6% 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.

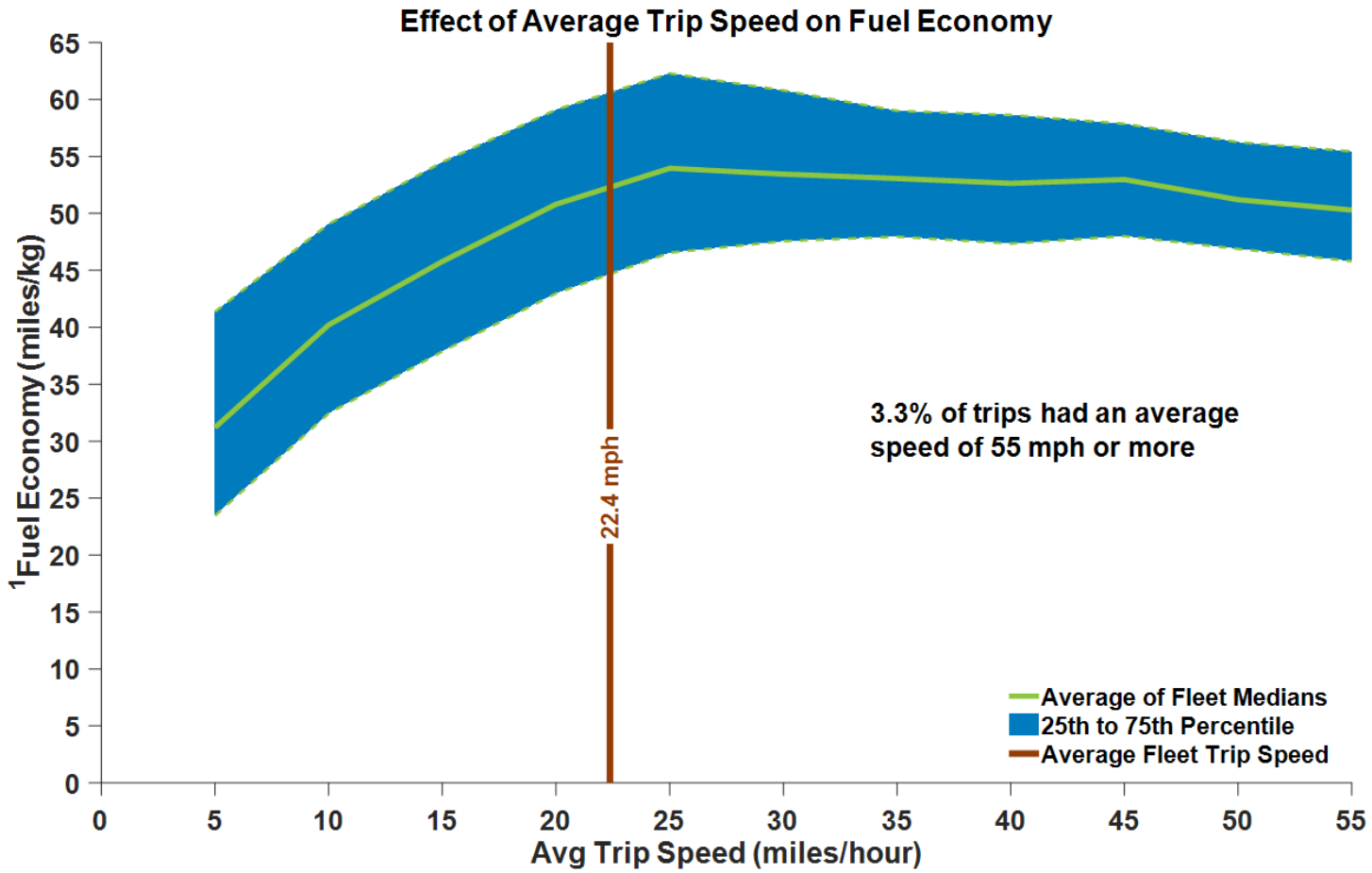


1. Data includes fills from 2012 - 2017. Fills < 1 hour apart are excluded.
2. Some vehicles included in the data have scheduled driving aimed at accumulating high miles and operation time over a variety of conditions. These vehicles typically fill at least once a day. These vehicles are operated on public roads and driving is typical for the region.

NREL cdp_fcev_106
Created: May-07-18 9:28 AM | Data Through: 2017Q4
Included Vehicles: All

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 20–25 mph.

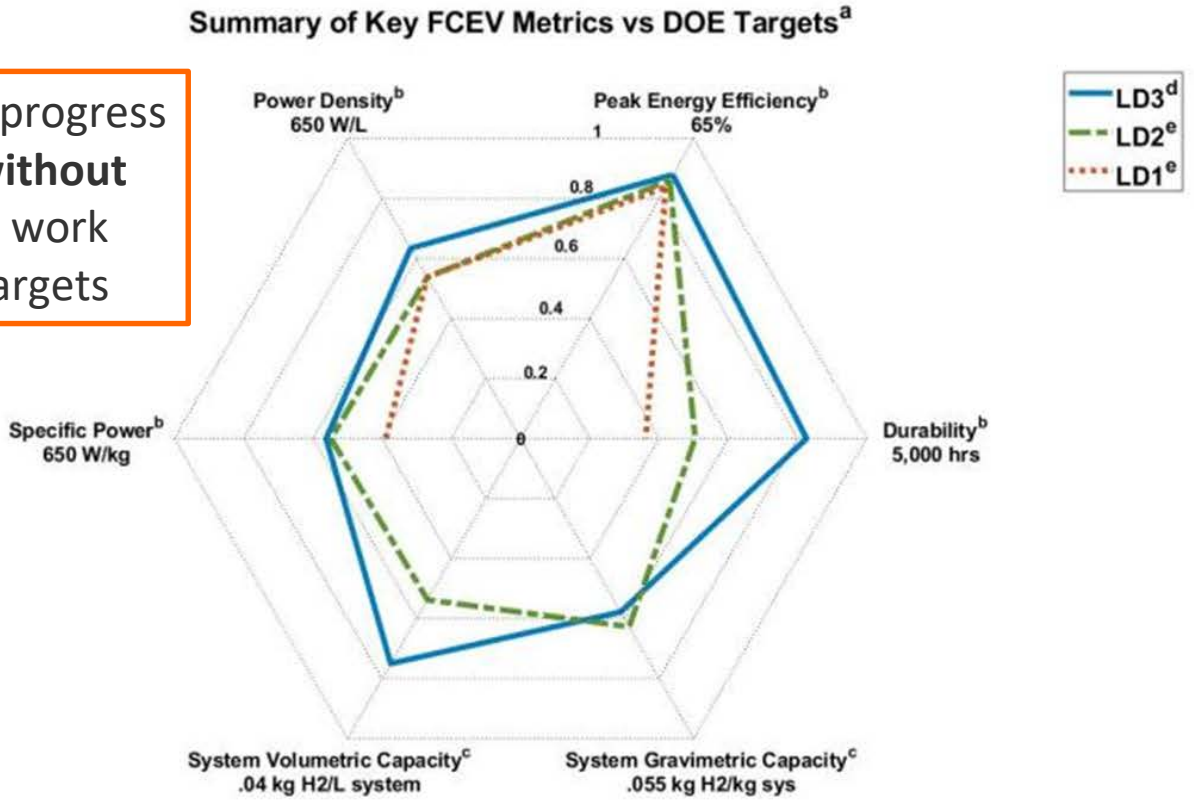


NREL cdp_fcev_141
Created: May-07-18 9:30 AM | Data Through: 2017Q4
Included Vehicles: All

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

Key FCEV Metrics vs. DOE Targets

FCEVs have made good progress toward DOE targets **without losing efficiency**, but work remains to achieve 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 May 2017), 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 4/2018)
e. National Fuel Cell Vehicle Learning Demonstration Final Report (http://www.nrel.gov/hydrogen/pdfs/54860.pdf)

NREL cdp_fcev_174
Created: May-07-18 11:49 AM | Data Through: 2017Q4
Included Vehicles: Partial