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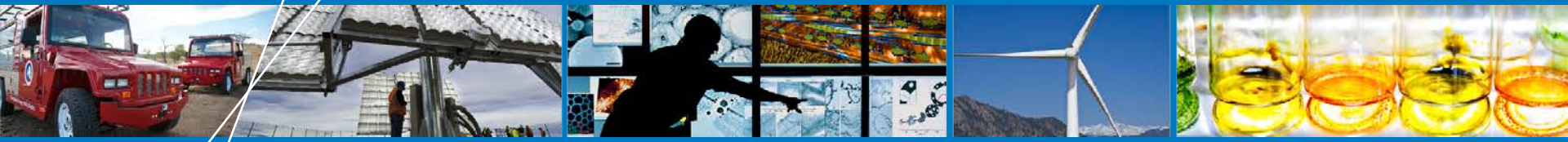
Forklift and Backup Power Data Collection and Analysis



2014 DOE Annual Merit Review

Jennifer Kurtz, Sam Sprik, Matt Post, Mike Peters

June 19, 2014

Project ID# TV021

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

Overview

Timeline	Barriers
Project start date: October 2012* Project end date: September 2015 Percent complete: 60%	Commercialization of fuel cells in key early markets
Budget	**Partners**
FY13 DOE funding: $270k Planned FY14 DOE funding: $100k Total project funding: $695k	See Collaboration slide

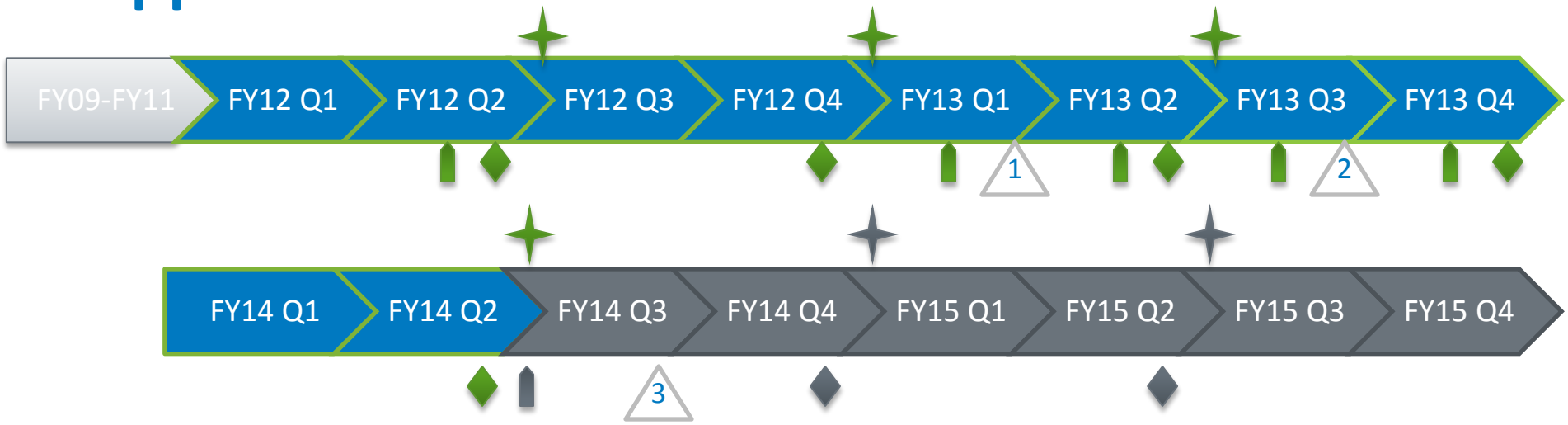
*Previous evaluations funded with ARRA ($1,000k FY09 – FY11)

Relevance: Objectives

Assess the technology status in real-world operations, establish performance baselines, report on fuel cell and hydrogen technology, and support market growth by evaluating performance relevant to the markets' value proposition.

- **Assess technology**
  - Perform independent technology assessment in real-world operation conditions
  - Focus on fuel cell system and hydrogen infrastructure: performance, operation, and safety
  - Leverage data processing and analysis capabilities developed under the fuel cell vehicle Learning Demonstration project
  - Evaluate material handling equipment (MHE) and backup power
  - Analysis includes up to 1,000 fuel cell systems deployed with ARRA funds
- **Support market growth**
  - Provide analyses and results relevant to the markets' value proposition
  - Report on technology status to fuel cell and hydrogen communities and other key stakeholders like end users

Approach: Milestones



- Quarterly deployment composite data products*
- Quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure*
- Bi-annual technical composite data products*
- 1 Hydrogen Safety Panel Final Report (FY13 Q1)
- 2 Interim draft report of status and performance of fuel cell MHE and backup power systems
- 3 Final report of status and performance of fuel cell backup power

*Gray markers indicate future work

Approach: NFCTEC Analysis and Reporting of Real-World Operation Data

Bundled data (operation & 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)

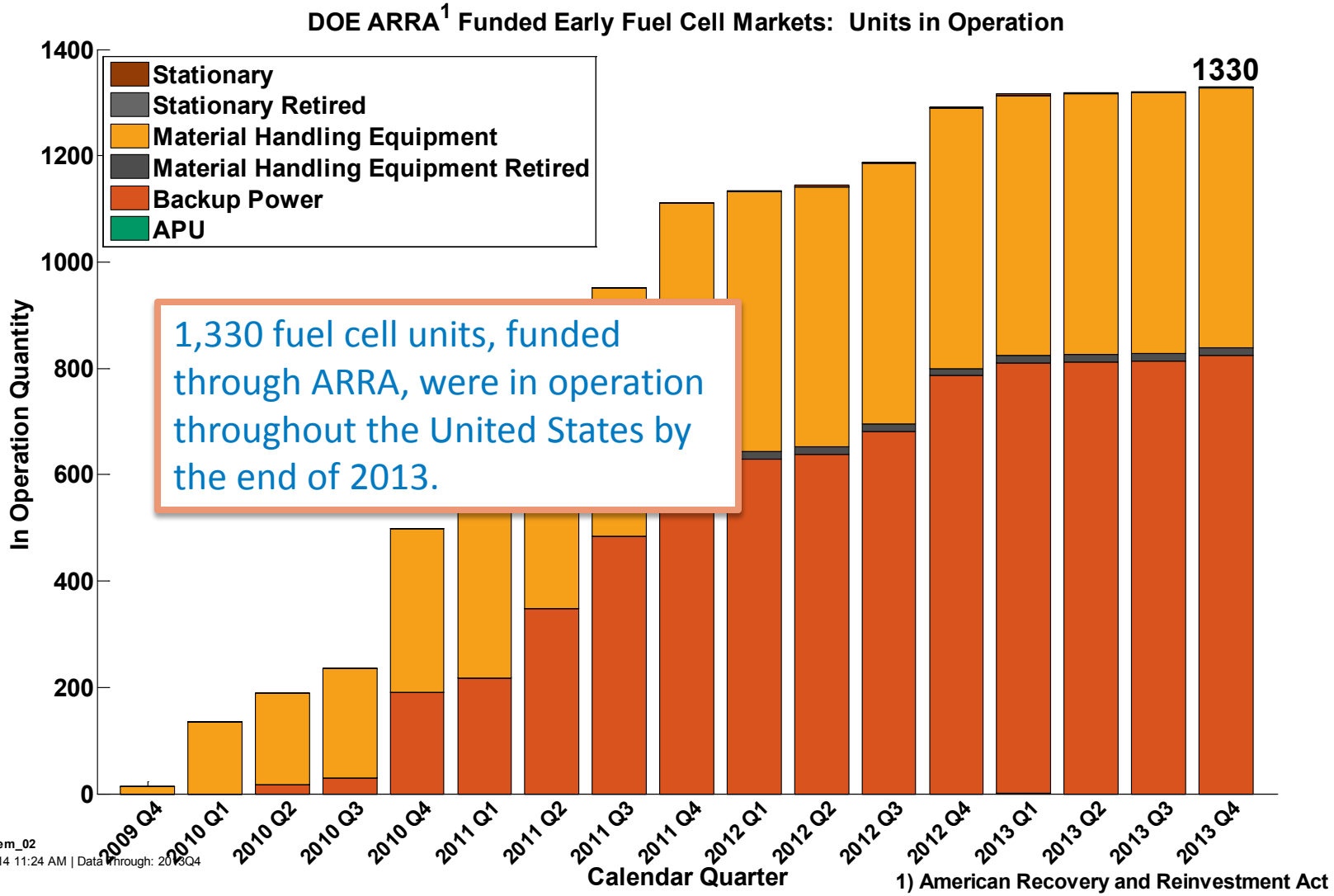
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

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

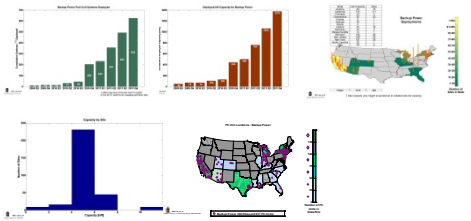
Accomplishments: Deployment Update



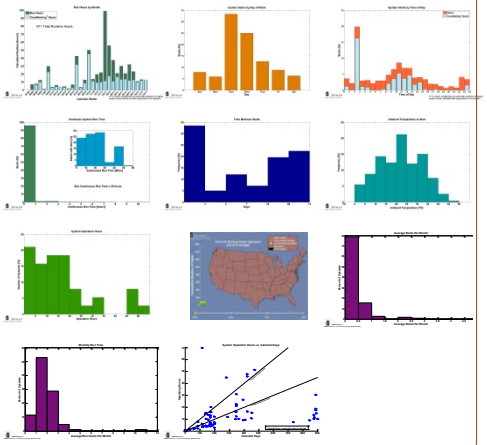
Accomplishments: 32 Backup Power CDPs – Count and Category

BACKUP POWER

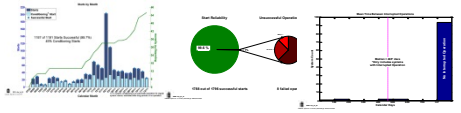
Deployment
(1, 2, 3, 14, 19)



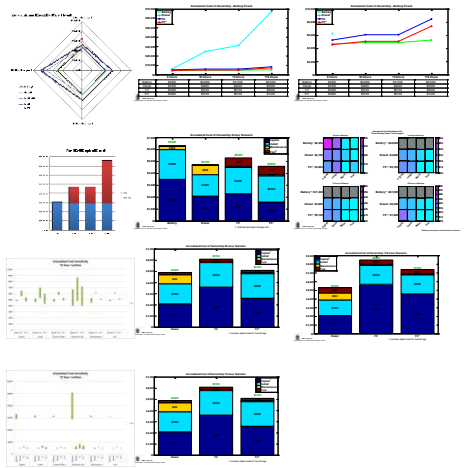
Fuel Cell Operation
(5, 7, 8, 9, 11, 12, 13, 15, 16, 17, 21)



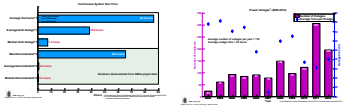
Fuel Cell Reliability
(4, 10, 29)



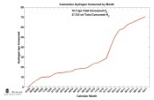
Cost of Ownership
(22 – 28, 30 - 32)



U.S. Grid Outage Stats
(18, 20)



Infra. Operation
(6)



Accomplishments: Backup Power Operation Summary 2009 Q1 – 2013 Q4

BACKUP POWER

1.99
Installed capacity in MW

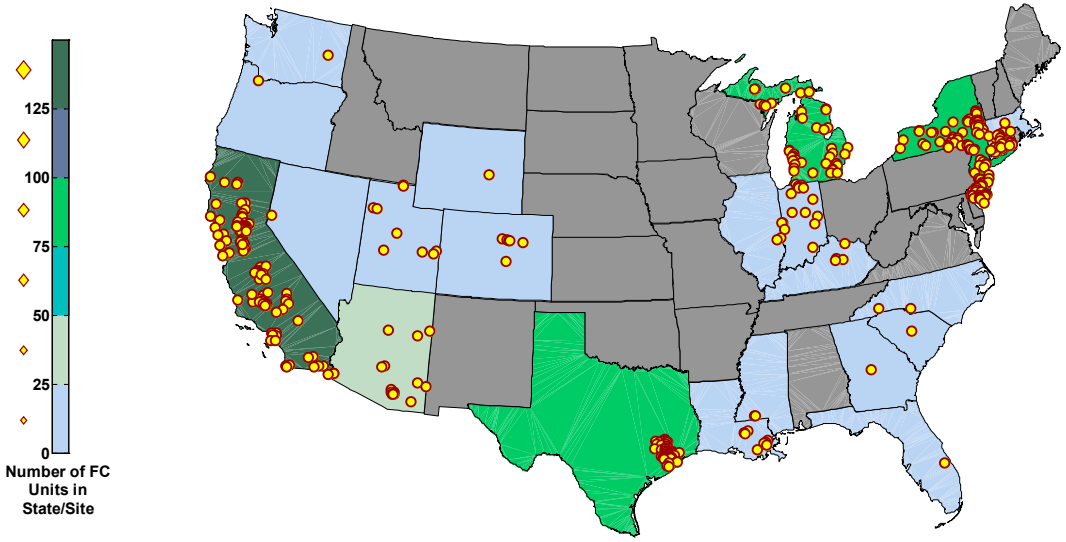
Systems are operating reliably in 23 states. Reasons for unsuccessful starts include an e-stop signal, no fuel, and other system failures.

99.5%
Successful starts

852
Systems in operation*

4–6
Average site capacity in kW

2,578
Start attempts



65
Continuous run hours demonstrated

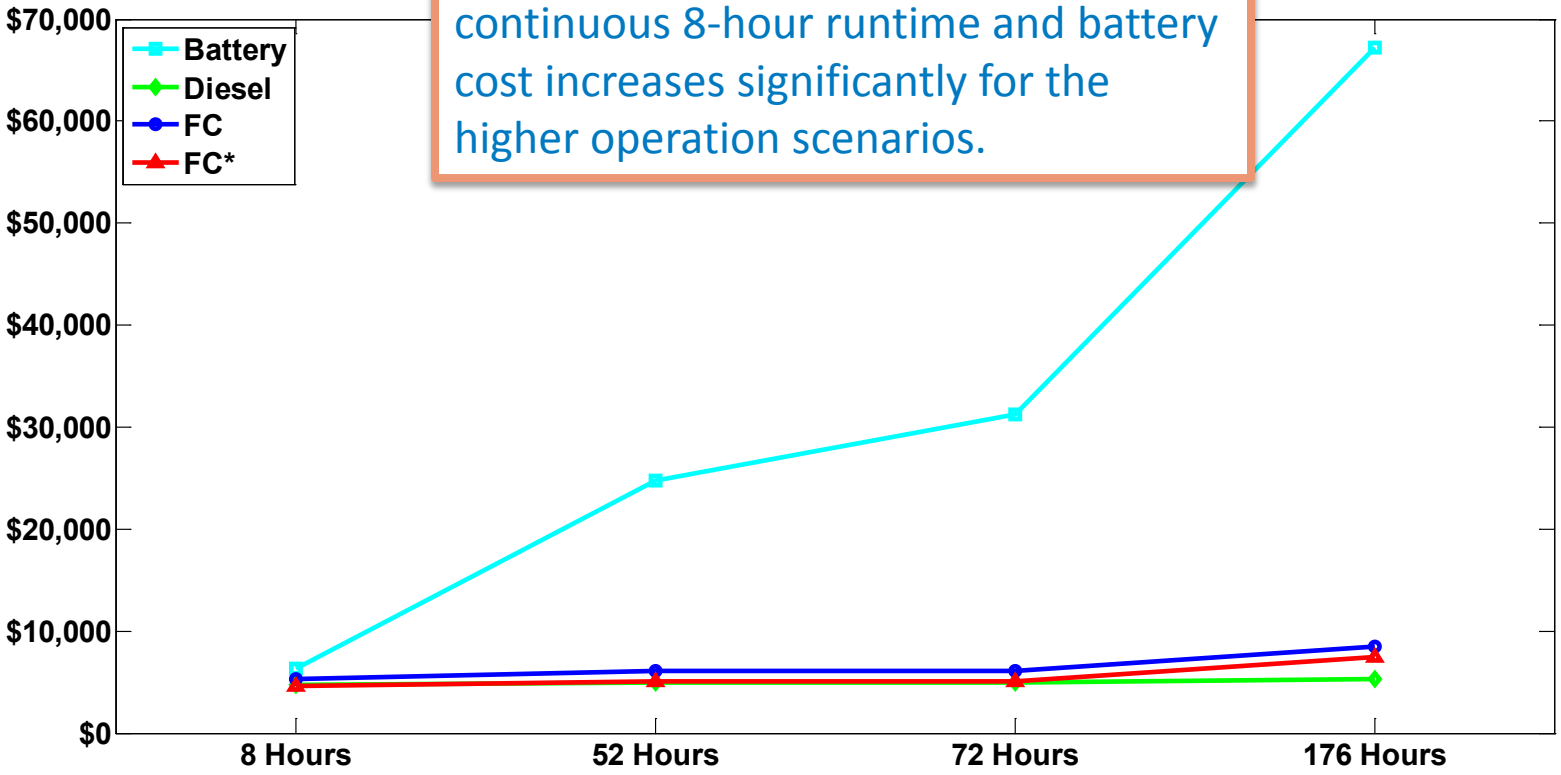
1,749
Operation hours

*Not all systems have detailed data reporting to NREL

Accomplishments: Backup Power Cost of Ownership Summary

BACKUP POWER

Technologies are comparable at continuous 8-hour runtime and battery cost increases significantly for the higher operation scenarios.



Battery	$6300	$24800	$31300	$67200
Diesel	$4700	$4900	$4900	$5300
FC	$5300	$6100	$6100	$8500
FC*	$4600	$5100	$5100	$7400

NREL cdp_bu_23

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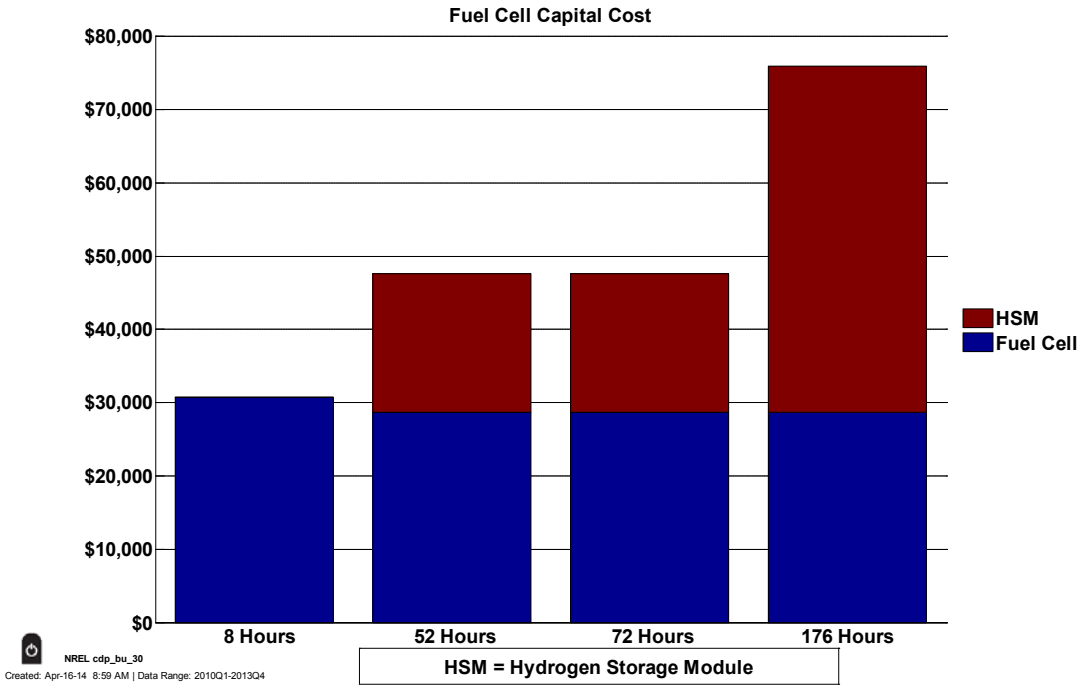
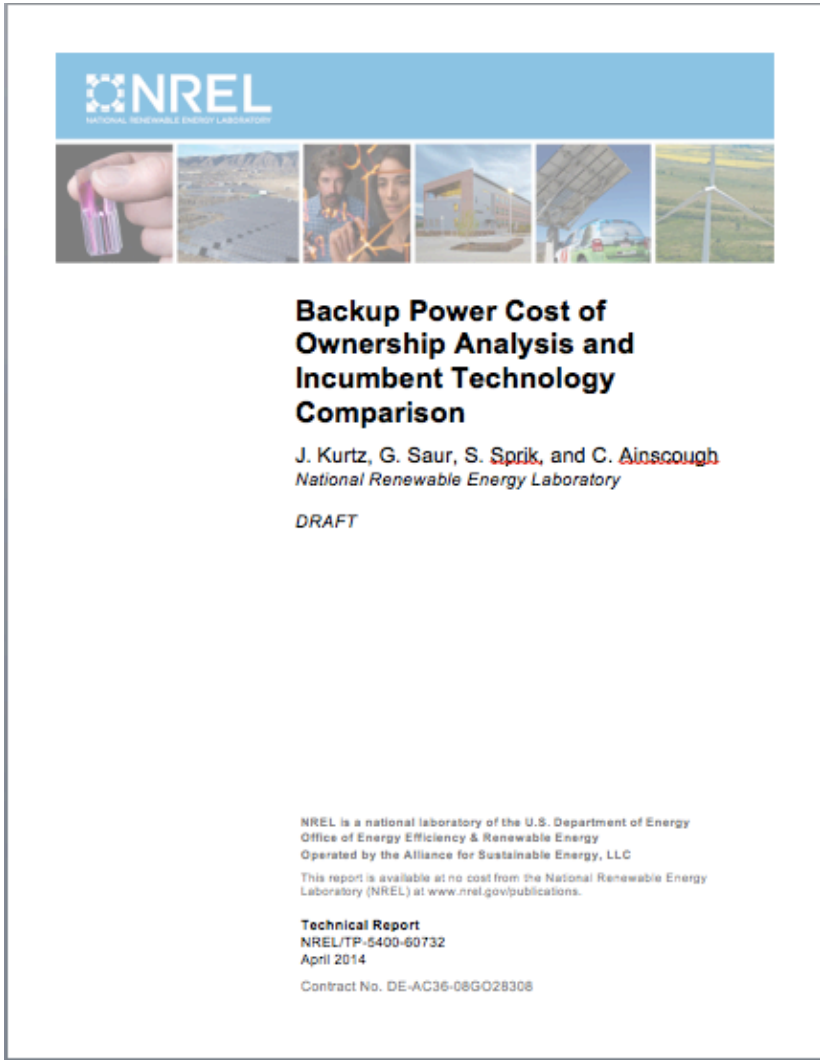
FC* includes incentives

Accomplishments: Detailed Analysis Report of Assumptions, Inputs, and Results

BACKUP POWER

Expect report describing details of the backup power cost of ownership to be published April/May 2014.





NREL

Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison

J. Kurtz, G. Saur, S. Sprik, and C. Ainscough
National Renewable Energy Laboratory

DRAFT

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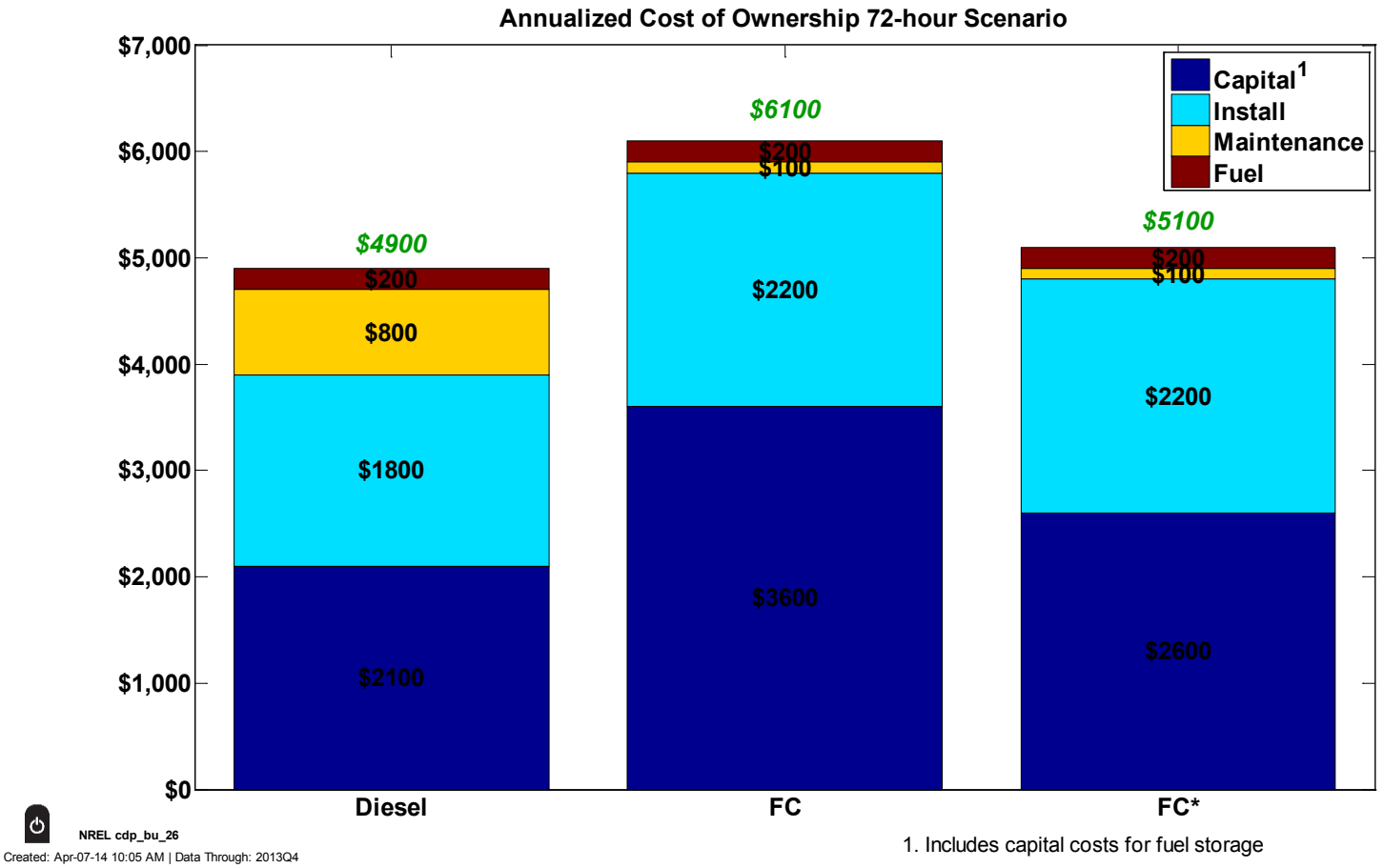
Technical Report
NREL/TP-5400-60732
April 2014

Contract No. DE-AC36-08GO28308

Accomplishments: 72-Hour Runtime Scenario Breakdown

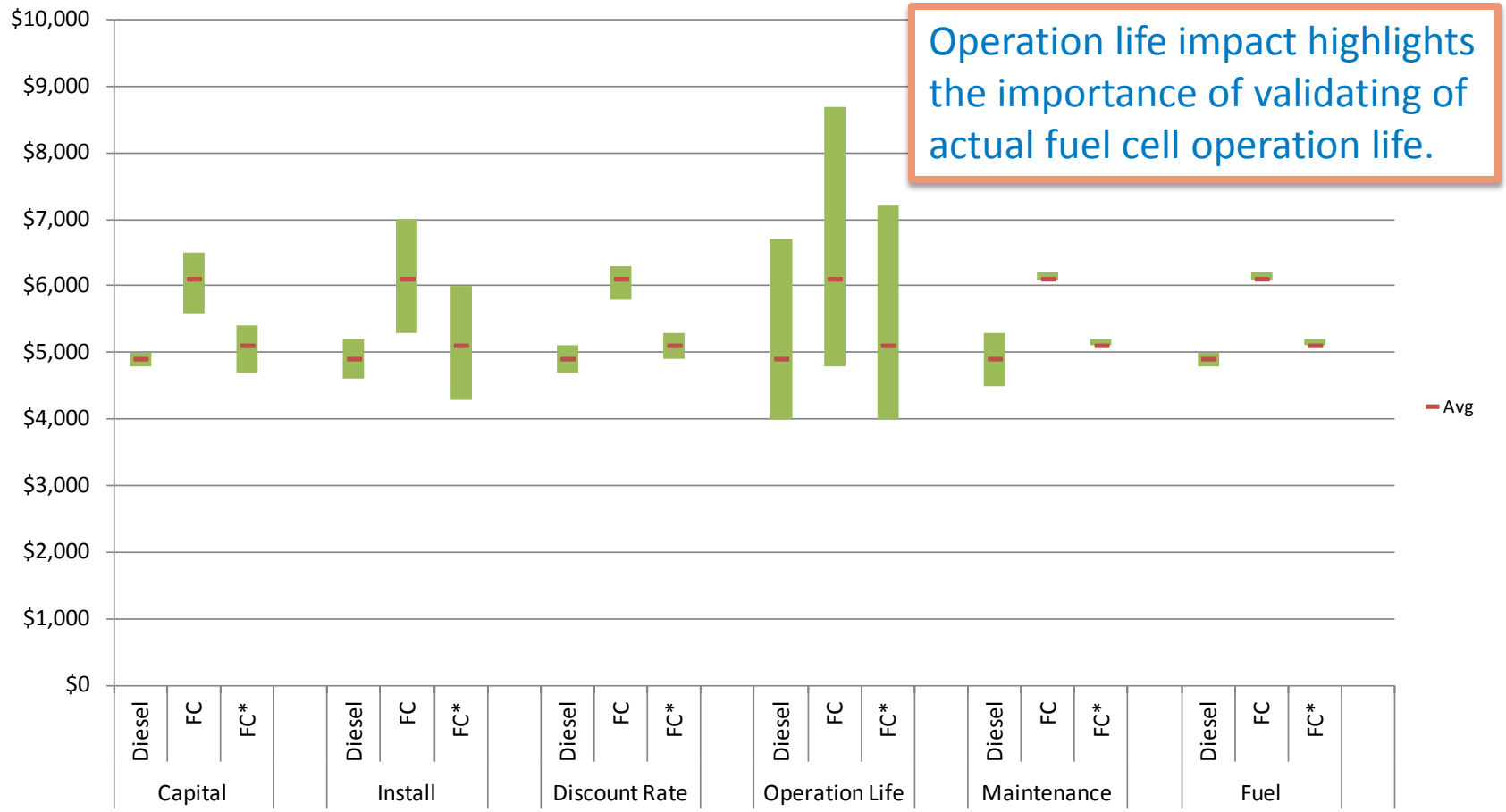
BACKUP POWER



Fuel cell system with incentives can be cost competitive with diesel generators.

Accomplishments: 72-Hour Runtime Scenario Sensitivity Study

BACKUP POWER



Operation life impact highlights the importance of validating of actual fuel cell operation life.

Metrics studied for sensitivity are capital cost, installation cost, discount rate, operation life, maintenance cost, and fuel cost.

Sensitivity ranges are based on ranges of input data but do not necessarily represent the minimum and maximum inputs.

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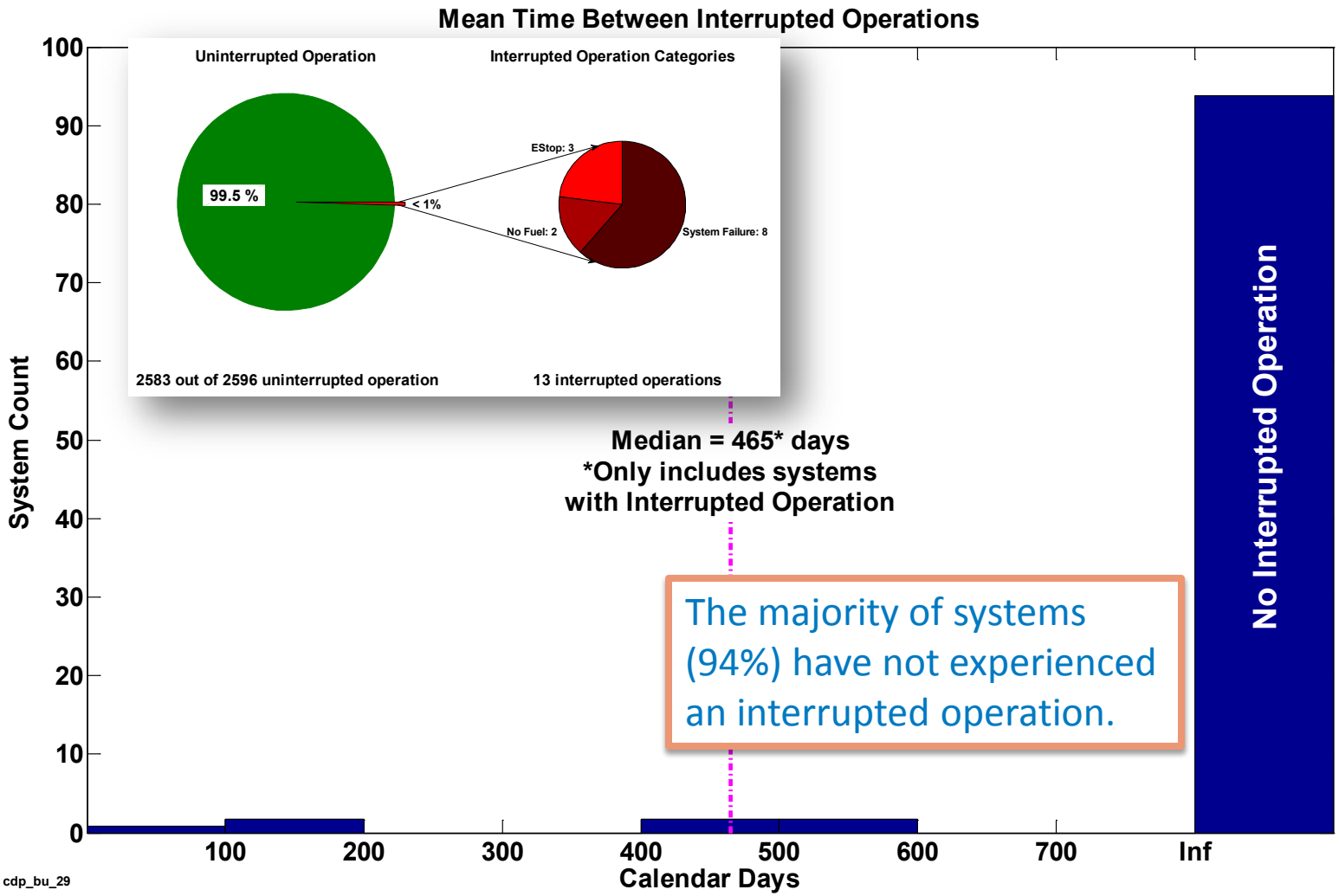
Accomplishments: Mean Time Between Interrupted Operations



The majority of systems (94%) have not experienced an interrupted operation.

NREL cdp_bu_29

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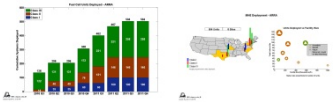
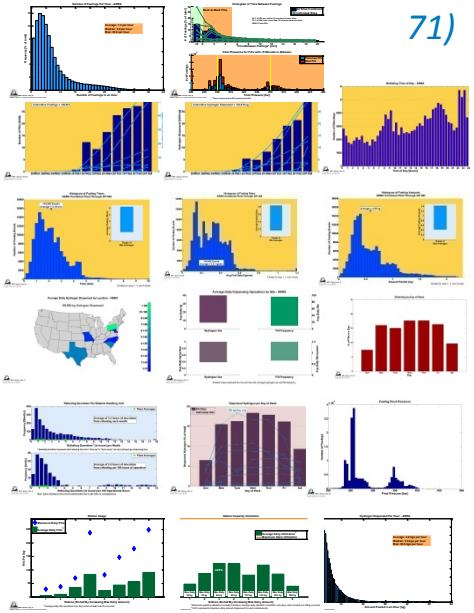
Accomplishments: 75 MHE & Infrastructure CDPs – Count and Category

FORKLIFTS

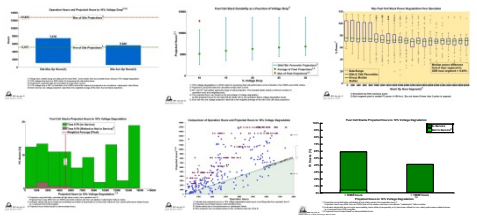
Deployment & Site Overview *(1, 40)*



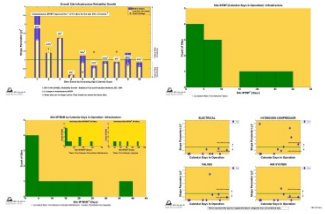
Infra. Operation *(3, 4, 5, 6, 9, 10, 21, 22, 35, 37, 42, 62, 65, 68, 69, 70, 71)*



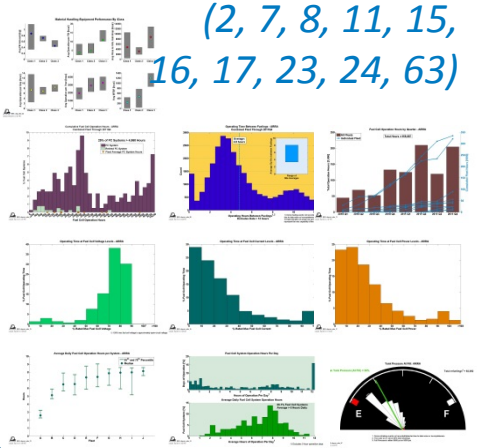
Fuel Cell Durability *(32, 33, 34, 38, 39, 73)*



Infra. Reliability *(45, 48, 49, 50)*

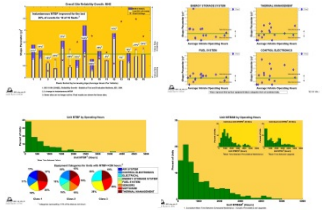


Fuel Cell Operation *(2, 7, 8, 11, 15, 16, 17, 23, 24, 63)*

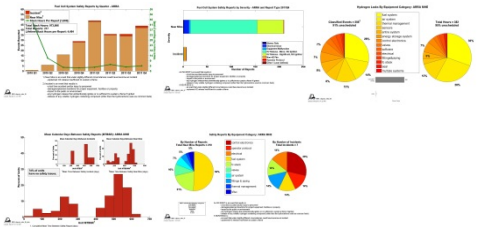


FC Maintenance *(12, 13, 14, 43, 54, 61)*

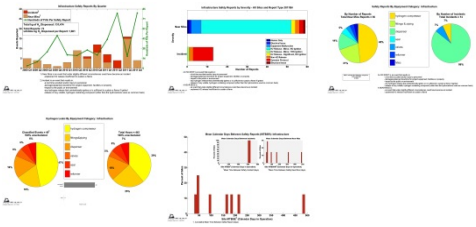
Fuel Cell Reliability *(28, 29, 30, 31)*



Fuel Cell Safety *(26, 27, 53, 56, 57)*



Infra. Safety *(25, 41, 46, 51, 55)*



Infra. Maintenance *(18, 19, 20, 44, 47, 52, 66, 67, 72,76,77)*

Cost of Ownership *(58, 59, 60,64)*

Accomplishments: MHE Operation Summary 2009 Q4 – 2013 Q4

FORKLIFTS

Validation of MHE is based on real-world operation data from high-use facilities.

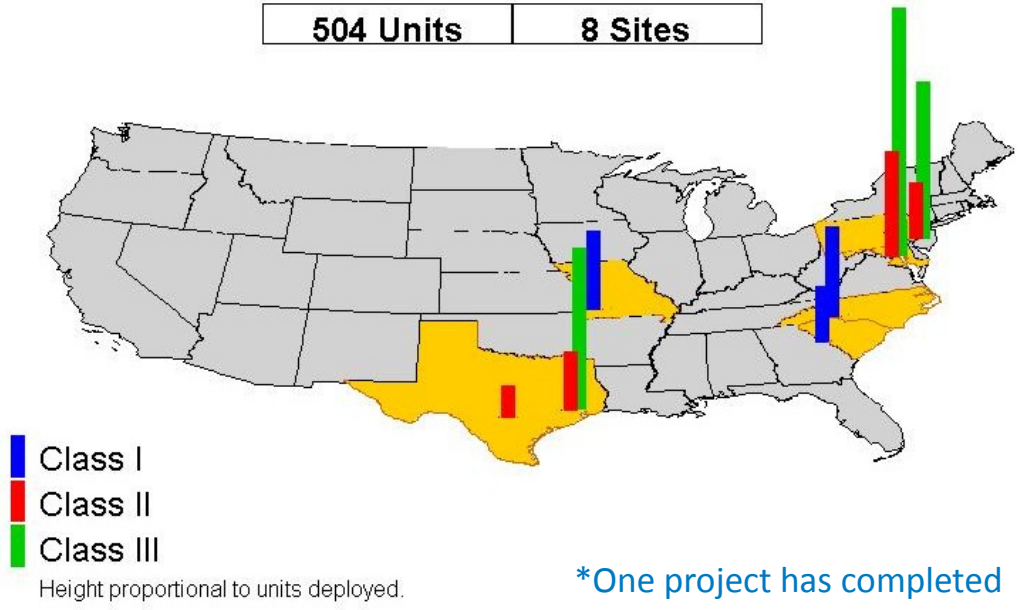
2,005,680
Operation hours

329,834
Hydrogen fills

490
Units in operation*

4.4
Average operation hours between fills

275,520
Hydrogen dispensed in kg

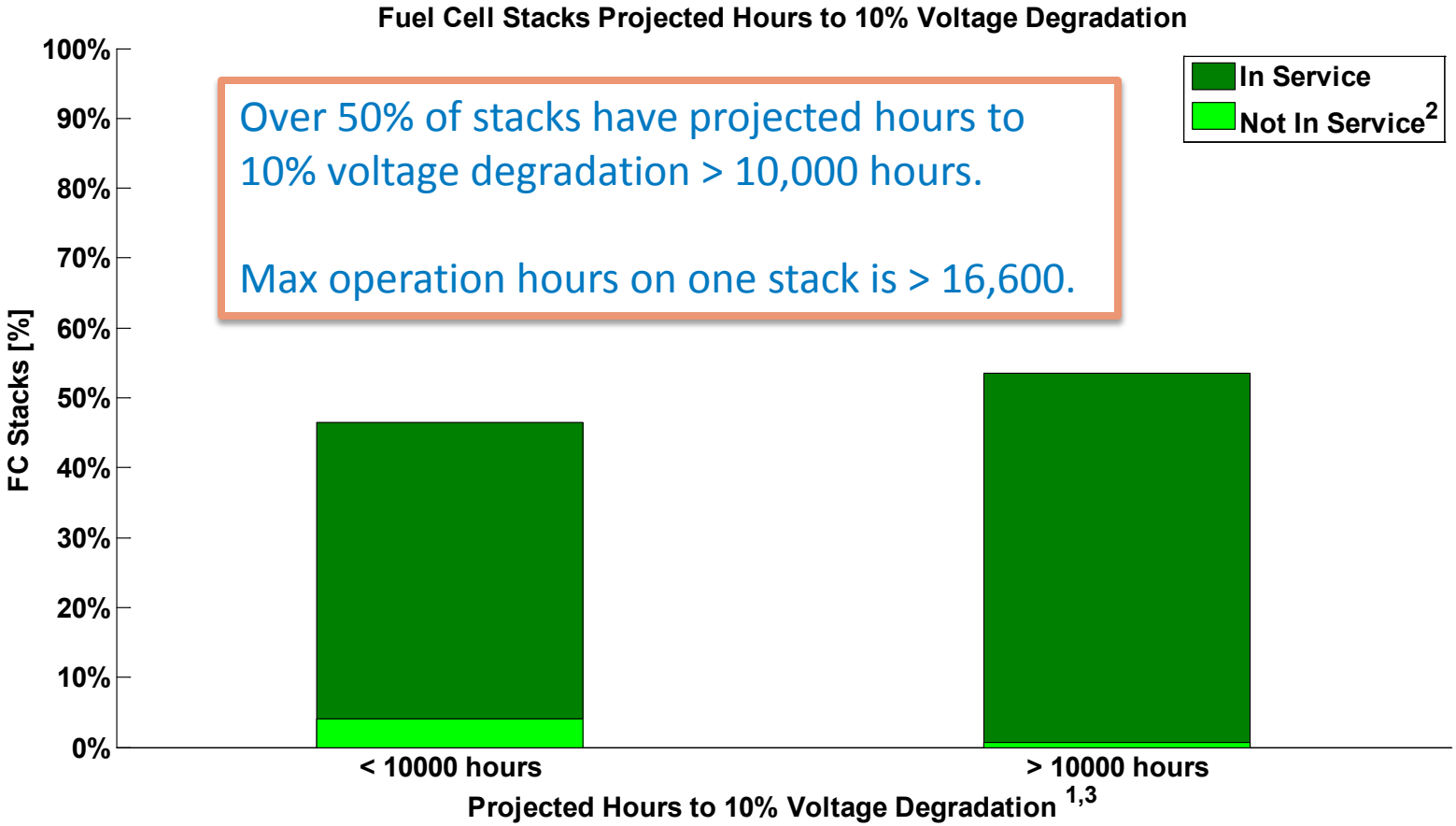


0.7
Average fill amount in kg

2.3
Average fill time in minutes

*One project has completed

Accomplishments: Study of FC Voltage Degradation Against 10,000 Hours



1) Projection using field data, calculated at high stack current, from operation hour 0.
Projected hours may differ from an OEM's end-of-life criterion and does not address "catastrophic" failure modes.
2) Indicates stacks that are no longer accumulating hours either a) temporarily or b) have been retired for non- stack performance related issues or c) removed from DOE program.
3) Projected hours limited based on demonstrated hours.

NREL cdp_mhe_97

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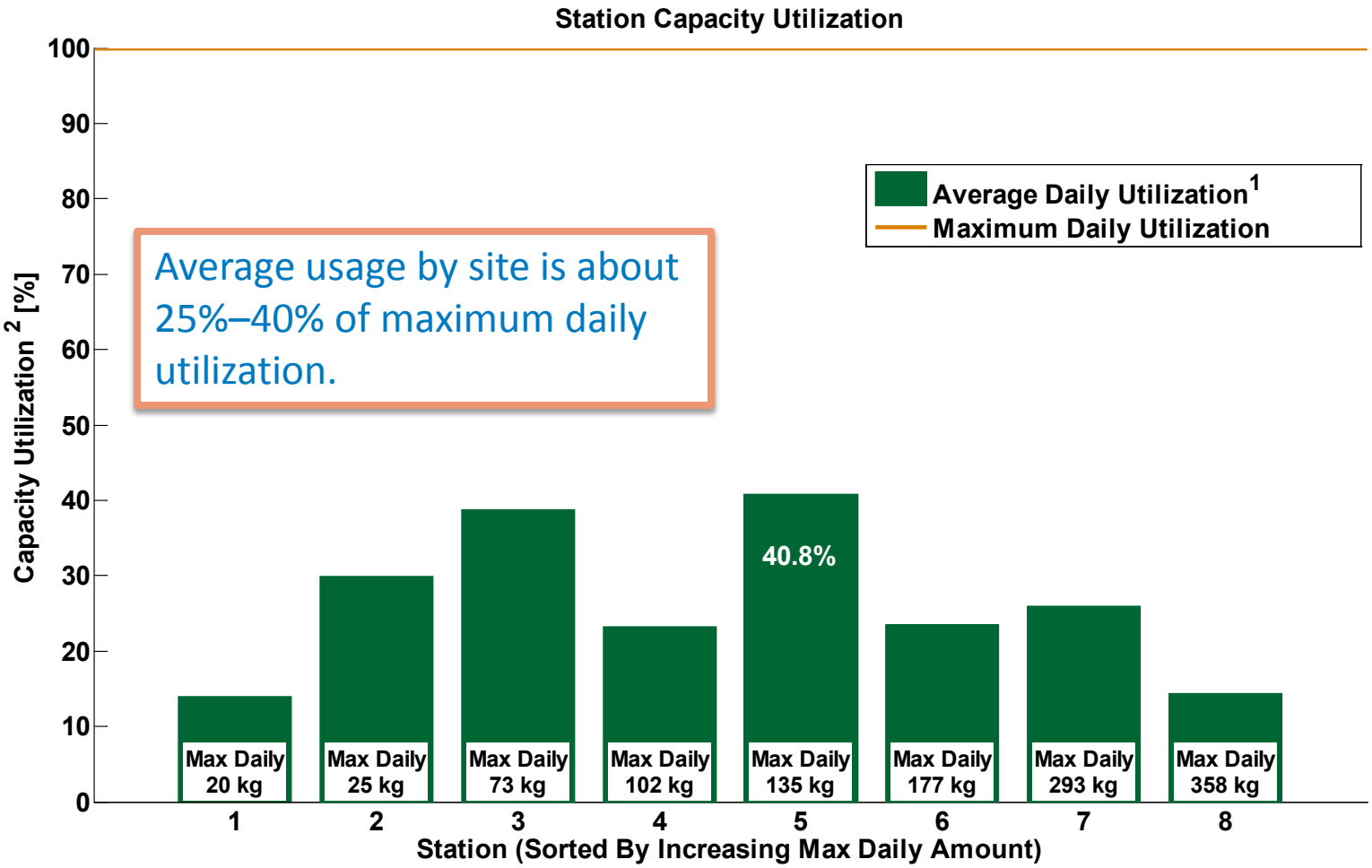
Accomplishments: Study of Infrastructure Usage by Daily Fills

FORKLIFTS



NREL cdparra_mhe_71

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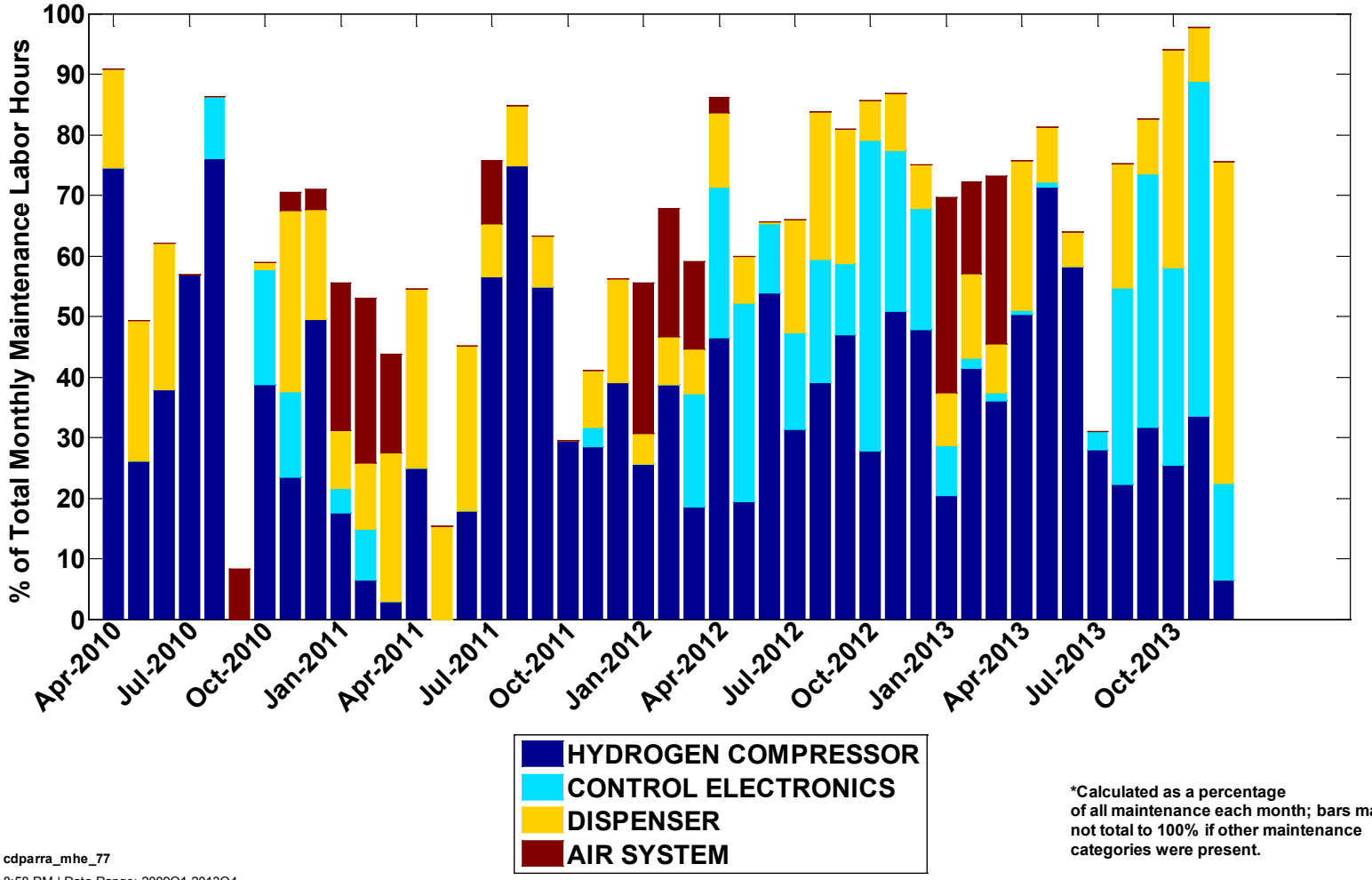
[1]Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occurred

[2]100% represents maximum daily amount dispensed for each individual site

Accomplishments: Equipment Percentage of Monthly Repair Labor Hours

FORKLIFTS

Compressors are consistently a leading category for monthly maintenance hours. Control electronics is not as consistent but is also a leading maintenance category.



*Calculated as a percentage of all maintenance each month; bars may not total to 100% if other maintenance categories were present.

NREL cdparra_mhe_77

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Accomplishments: Response to Previous Year Reviewer's Comments

"…a cost-of-ownership stack-up plot … would be a valuable addition for the backup power systems."

- Completed a backup power cost of ownership analysis
- Includes 8, 52, 72, and 176-hour runtime scenarios
- Includes a sensitivity analysis for the 72-hour runtime scenario

"It would be helpful to depict time-dependent performance trends, a risk-assessment of key issues and possible resolution paths for identified issues."

- Including time-based results (e.g. CDPARRA-MHE-77 Maintenance categories over time
- Identified additional investigations with maintenance data that utilize the CDPs for understanding and R&D gap identification (e.g. control electronics and sensor maintenance events)

Collaborations

Data Sharing and Analysis Partners

- Air Products
- FedEx
- GENCO
- Nuvera Fuel Cells*
- Plug Power
- ReliOn*
- Sprint
- Sysco Houston

ARRA Market Impact Study

Other collaboration activities include site visits and detailed analysis discussions

*Project completed

Other

- Technical Monitor of Hydrogen Safety Panel reviews of ARRA projects
  - Review of safety plans for each site
  - Conduct safety review site visits for up to six sites (three MHE and one backup site visits completed)
- Quantitative Risk Assessment & Process Hazard Assessment Data Input
  - Carl Rivkin (NREL)
- Hydrogen production & delivery
  - Data shared for RD&D needs workshop
- Market transformation
  - Data shared for MHE and backup power fact sheets

Future Work

Remaining FY14 tasks:

- Complete quarterly analysis of operation and maintenance data for fuel cell MHE systems and hydrogen infrastructure (two cycles)
- Complete final report on backup power status and performance for project completion
- Publish bi-annual technical composite data products for voluntarily supplied MHE data (operation through June 2014)
  - Update existing set of CDPs
  - Add to the CDPs pertaining to the market value proposition performance metrics
- Share detailed data with individual project partners for identification of successes and gaps with the early market technology validation

FY15:

- Complete quarterly analysis and technical CDPs, as voluntary data is supplied
- Complete final report of status and performance for fuel cell MHE systems for project close out

Project Summary

***Relevance*:** Assess the technology status in real world operations, establish performance baselines, report on fuel cell and hydrogen technology, and support market growth by evaluating performance relevant to the markets' value proposition for early fuel cell markets.

***Approach*:** Leverage capabilities established under other technology validation activities (NRELFAT) and industry collaborations. Aggregate data for concise reporting on large data sets from multiple project partners.

***Accomplishments*:** Published the eighth set of technical CDPs on performance, operation, and safety for MHE and backup power, with 14 new CDPs added. All results and publications are available on NREL's technology validation website that also includes monthly highlights.

***Collaborations and Future Work*:** Prepare for backup power project close out in FY14 and continue MHE validation with voluntarily supplied data with the close collaboration of the fuel cell and hydrogen developers and end users.

NFCTEC Contacts

Website

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

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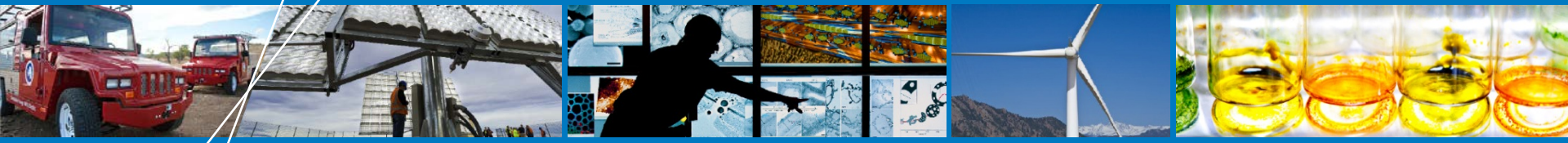

Technical Back-Up Slides

Backup Power Cost of Ownership Key Assumptions

Table 1. Key Assumptions[a] by Technology

	Battery	Diesel Generator	Fuel Cell
Capacity [kW]	4–6	25–35 (operated at 6)	4–6
Lifetime [9]	5	15	15
Fuel Storage Capacity	NA	Onsite tank capable of 176-hour scenario	Leased bottles for 8-hour scenario Fill-in-place hydrogen storage capable of 72-hour scenario
Efficiency	90%	~20%[b]	47%
Fuel Cost	6.67 cents per kW (EIA average industrial) [5]	$3.89 per gallon[c] [6]	$10 per kg + $100 fee (8-hour scenario) $8 per kg + $50 fee (all other scenarios)
Maintenance	4 visits per year	2–12 visits per year	1 visit per year
Federal Incentive	NA	NA	$15,000[d]
Discount Rate	1.5%	1.5%	1.5%
Fuel Storage	NA	Not separated in provided data	$600/year for a 6 cylinder rent (8-hour scenario) $18,900 capital for 72-hour storage module (all other scenarios)

[a] Assumptions are based on the average of provided data from suppliers and end users, unless otherwise referenced.
[b] Diesel generator spec sheet references [7][8]
[c] A delivery fee would also be included for the diesel fuel. That fee was not provided in the diesel cost estimates and is not included in this analysis.
[d] The incentive is 30% of the up-front costs (includes capital and install), capped at $3,000/kW capacity. This analysis assumes an average capacity of 5 kW [10].

Backup Power Cost of Ownership Inputs

Table 1. Capital, Permitting and Installation, Maintenance, and Fuel Costs[a] for All Technology and Runtime Scenarios

Runtime Scenario	Technology	Capital Cost[b]	Permitting & Installation Cost	Annual Maintenance Cost	Annual Fuel Cost
8 hour	Battery[c]	$16,800	$12,000	$300.00	$2.00
	Diesel generator	$28,300	$24,000	$800.00	$27.00
	Fuel cell	$30,700	$29,300	$100.00	$23.00
	Fuel cell*[d]	$21,500	$29,300	$100.00	$23.00
52 hour (~2 days)	Battery[c]	$70,200	$45,000	$700.00	$12.00
	Diesel generator	$28,300	$24,000	$800.00	$178.00
	Fuel cell	$47,600	$29,300	$100.00	$170.00
	Fuel cell*[d]	$34,200	$29,300	$100.00	$170.00
72 hour (3 days)	Battery[c]	$88,600	$57,000	$900.00	$17.00
	Diesel generator	$28,300	$24,000	$800.00	$246.00
	Fuel cell	$47,600	$29,300	$100.00	$216.00
	Fuel cell*[d]	$34,200	$29,300	$100.00	$216.00
176 hour (~1 week)	Battery[c]	$192,000	$120,000	$2000.00	$42.00
	Diesel generator	$28,300	$24,000	$800.00	$602.00
	Fuel cell	$76,000	$29,300	$100.00	$455.00
	Fuel cell*[d]	$61,000	$29,300	$100.00	$455.00

[a] Costs are based on the averages of provided data from suppliers and end users, unless otherwise referenced.
[b] Capital costs assume the system has enough capability to operate continuously for each runtime scenario.
[c] Battery installation and maintenance are assumed to scale with the battery capital costs because of the increase in support equipment (e.g., cabinets and cooling). The cost to recharge a depleted battery string is included here. Additional costs will be required to maintain the battery charge when not in use.
[d] There are two fuel cell systems scenarios, with (*) and without federal tax credits [10] for fuel cell purchases.

Table 1. 72-hour Sensitivity Ranges

Runtime Scenario	Technology	Low	High
Capital	Battery	$78,000	$98,000
	Diesel generator	$27,000	$30,000
	Fuel cell	$41,000	$54,000
	Fuel cell*[a]	$29,000	$39,000
Install	Battery	$53,000	$60,000
	Diesel generator	$20,000	$28,000
	Fuel cell	$19,000	$41,000
	Fuel cell*[a]	$19,000	$41,000
Discount Rate	All	1.0%	2.0%
Operation Life	Battery	3	8
	Diesel generator	10	20
	Fuel cell	10	20
	Fuel cell*[a]	10	20
Maintenance	All	Half	1.5
Fuel/Electricity	Battery	$0.05/kWh	$0.1/kWh
	Diesel	$3.00/gal	$5.00/gal
	Hydrogen	$5.00/kg	$11.00/kg

[a] Fuel cell system with incentives.