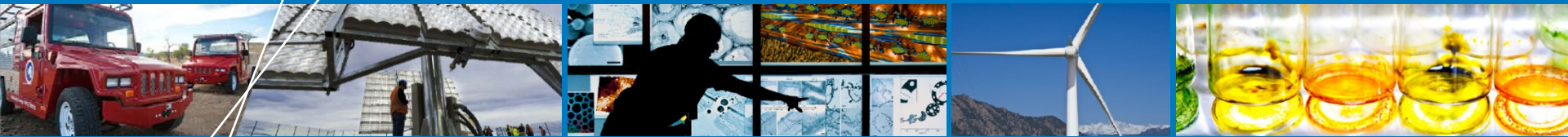


Stationary Fuel Cell Evaluation



2014 DOE Annual Merit Review

Genevieve Saur (PI), Jennifer Kurtz, Chris Ainscough, Michael Peters

National Renewable Energy Laboratory

June 19, 2014

Project ID # TV016

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

Overview

Timeline

Project start date: Oct. 2011

Project end date: Sep. 2014*

Percent complete: On-going

Barriers

B. Lack of Data on Stationary Fuel Cells in Real-World Applications

E. Codes & Standards

Budget

FY13 DOE Funding:\$200k

Planned FY14 DOE Funding:\$100k

Total DOE Project value:\$365k

Partners

- California Stationary Fuel Cell Collaborative, (review results)
- National Fuel Cell Research Center (UCI), (subcontractor)
- Five OEM data providers, developing others.

*Project continuation and direction determined annually by DOE

Relevance - Objectives

Independently assess, validate, and report operation targets and stationary fuel cell system performance under real operating conditions.



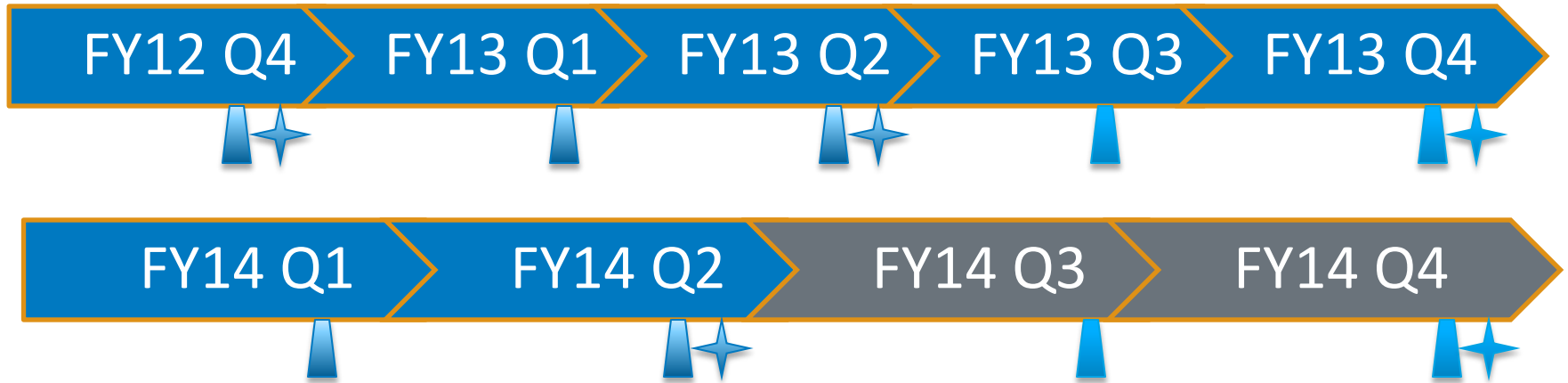
B. Lack of Data on Stationary Fuel Cells in Real-World Applications

Addressing the gap in knowledge as stationary fuel cell installations have increased dramatically

E. Codes & Standards

Providing data and context to C&S activities.

Approach - Milestones



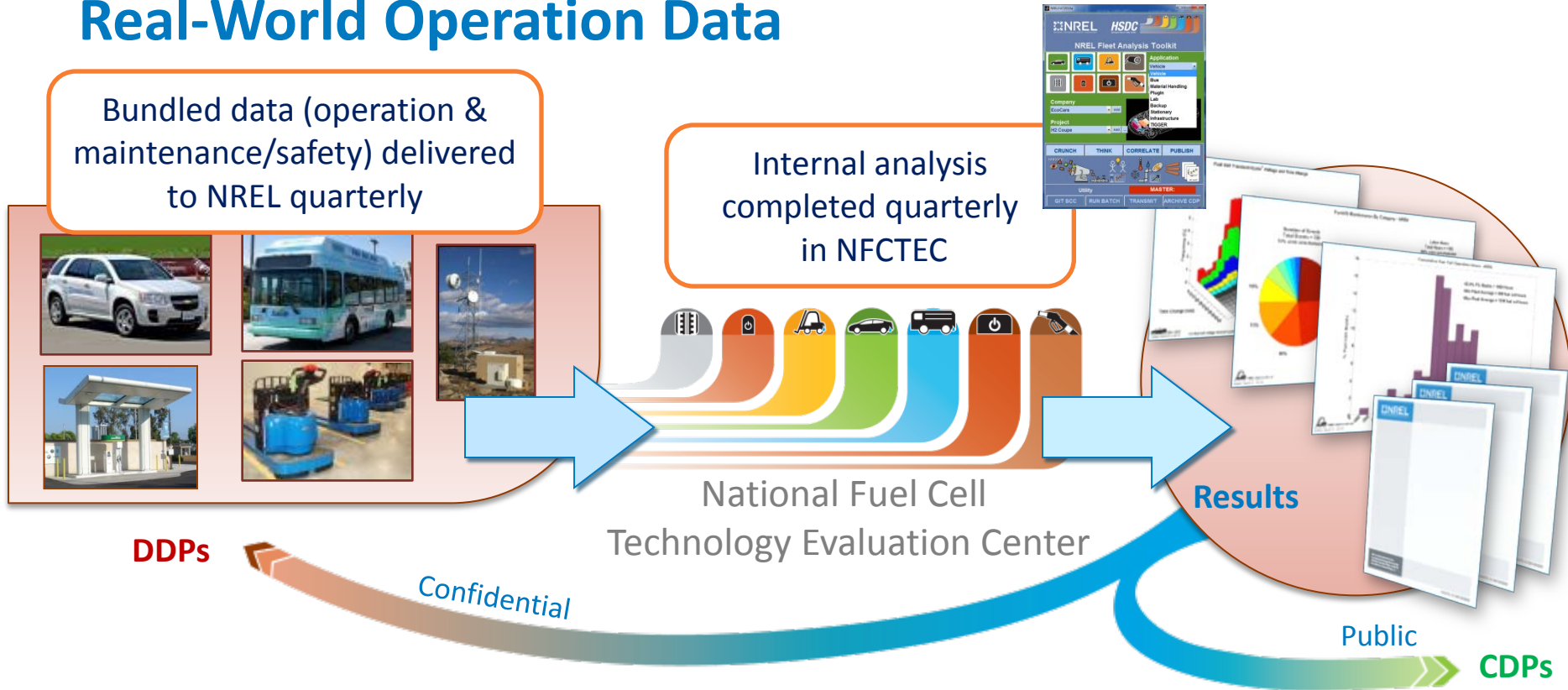
▲ Quarterly data analysis (based on available data)

★ Publication of technical stationary fuel cell composite data products

▲ ★ Scheduled

▲ ★ Completed

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



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

Approach - Stationary Fuel Cell Systems

- **Deployment and cost data**

- Publically available data from California SGIP (2001-present)
- Includes systems providing prime, continuous, or regular power to a site (not backup power)
- Includes multiple fuel cell types - proton exchange membrane (high and low temperature), solid oxide, phosphoric acid, and molten carbonate
- Includes fuel types for fuel cells (natural gas, biomass, digester gas, landfill gas)
- Small, kilowatt-scale to large, megawatt-scale
- Cost data for projects including incentives

- **Operations data**

- All data voluntary

- **28 total cdps**

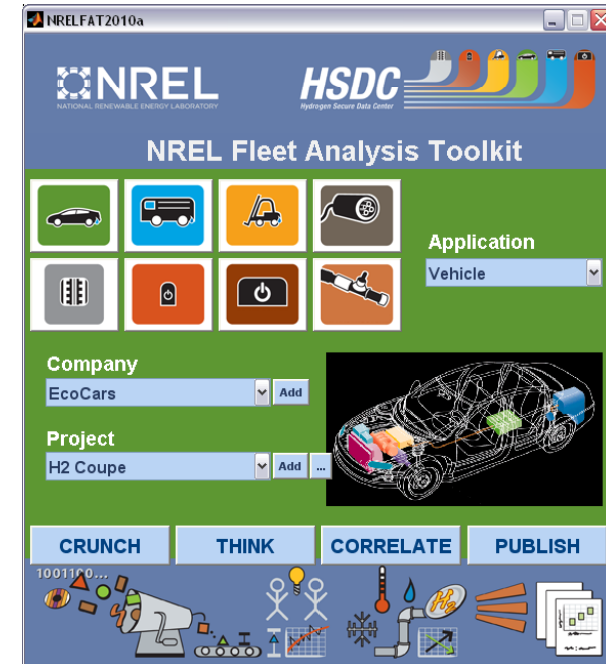
Approach - Data Processing, Analysis, and Reporting Tools

- **NREL Fleet Analysis Toolkit (NRELFAT)**

- Developed first under fuel cell vehicle Learning Demonstration
- Restructured architecture and interface to effectively handle new applications and projects and for flexible analysis
- Leverage analyses already created

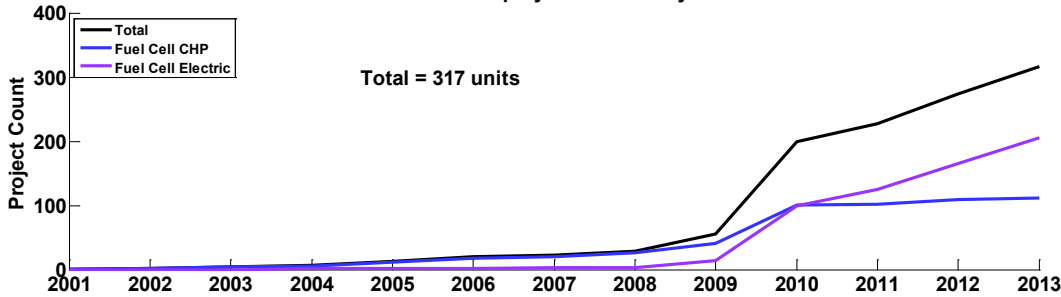
- **Report results**

- Detailed and composite results
- Target key stakeholders such as fuel cell and hydrogen developers, and end users

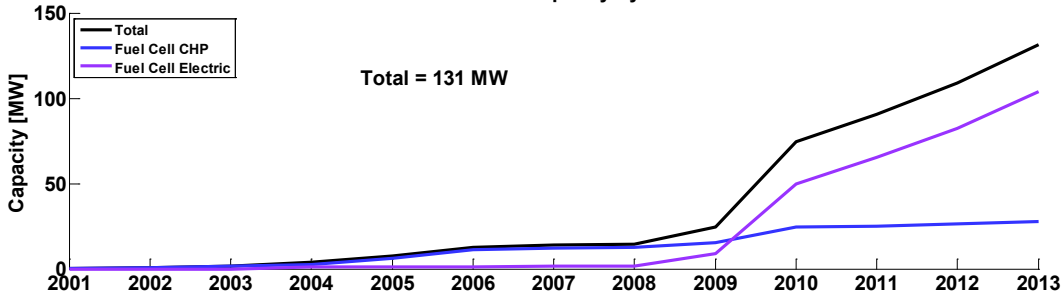


Accomplishments and Progress

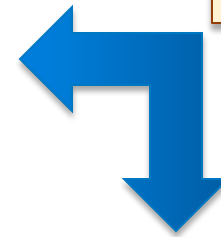
Cumulative Deployment Count by Year*



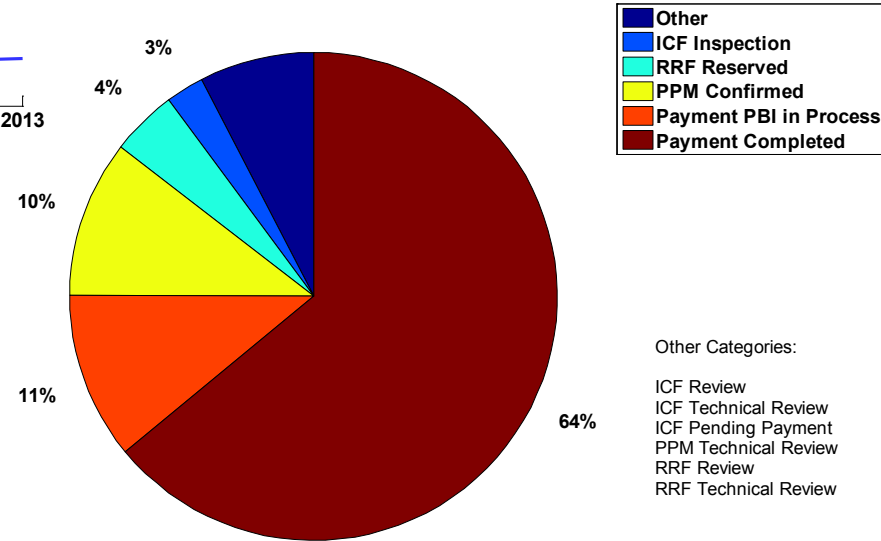
Cumulative Capacity by Year*



California SGIP has 317 fuel cell projects (CHP and electric) in various stages of development.



Deployment Count By Status*



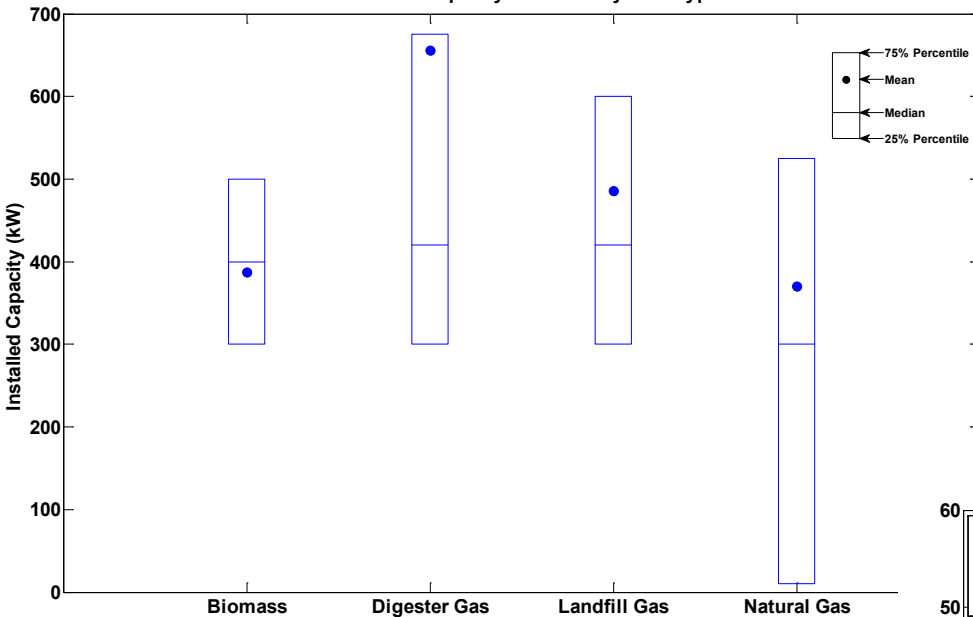
Fuel cell projects in the California SGIP account for 21% of projects with CHP potential technologies* (317 projects out of 1493) and 28% of the capacity (131 MW out of 460 MW).

* Technologies included: fuel cell, gas turbine, internal combustion engine, microturbine, pressure reduction turbine

Definitions: RRF = Reservation Request Form, is the first step in the SGIP incentive claim process.
 PPM = Proof of Project Milestone; the applicant must prove progress and commitment to the project.
 ICF = Incentive Claim Form is the step where the applicant, after meeting all SGIP requirements requests payment of the incentive.
 PBI = Performance Based Incentive is the way in which the incentive is paid out over time based on performance of the system.

Accomplishments and Progress

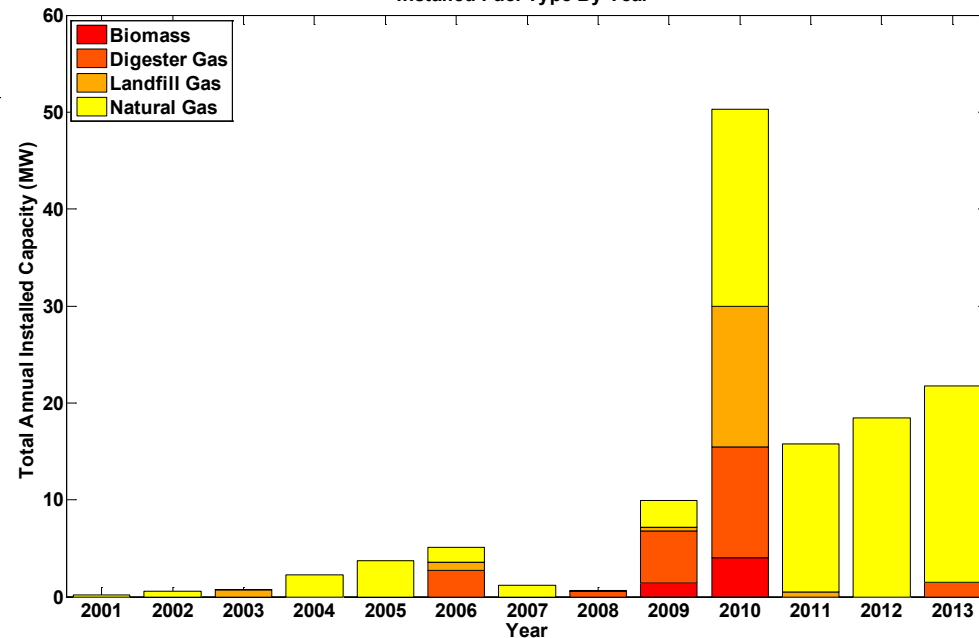
Installation Capacity Statistics by Fuel Type*



- Most of the recent projects since 2011 have been natural gas. There was a small resurgence of biomass projects in late 2013.
- Renewable fuels project have generally larger capacities by project.
- Digester gas has several large projects

74% of California SGIP fuel cell projects use natural gas and they account for 66% of the capacity

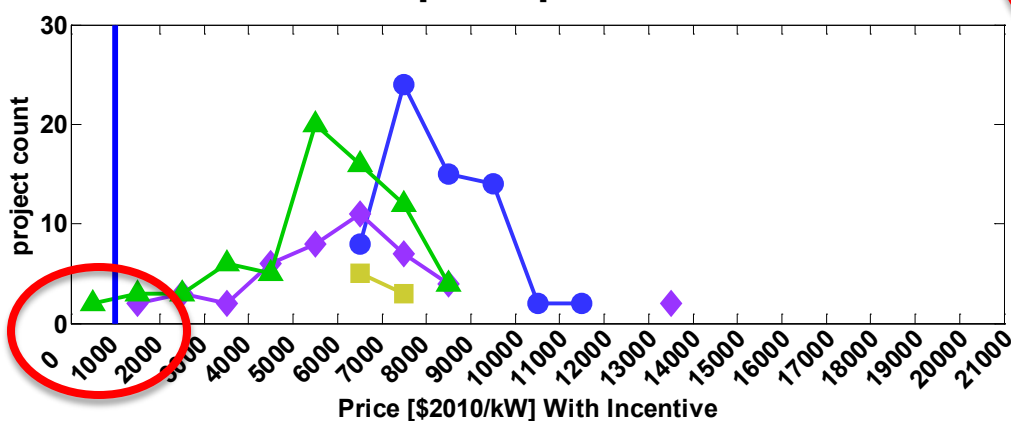
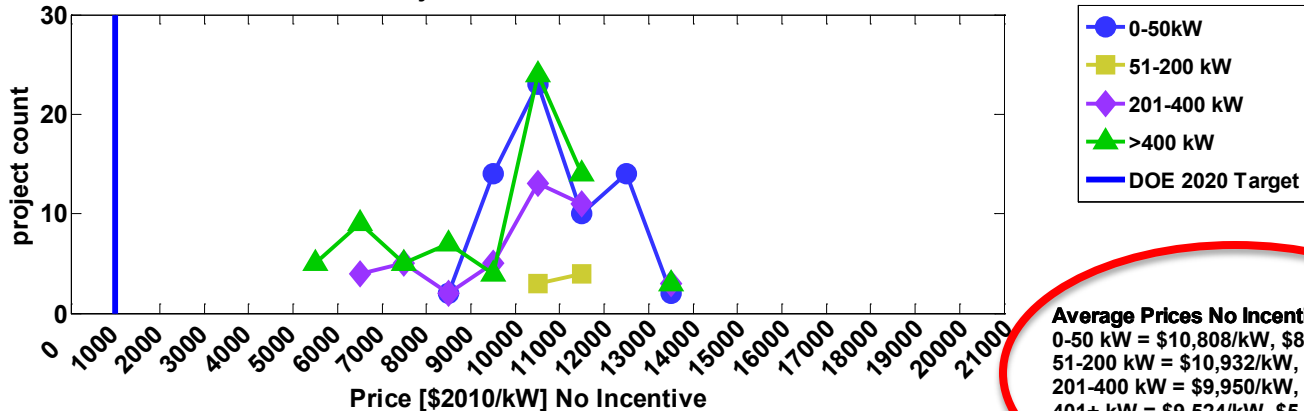
Installed Fuel Type By Year*



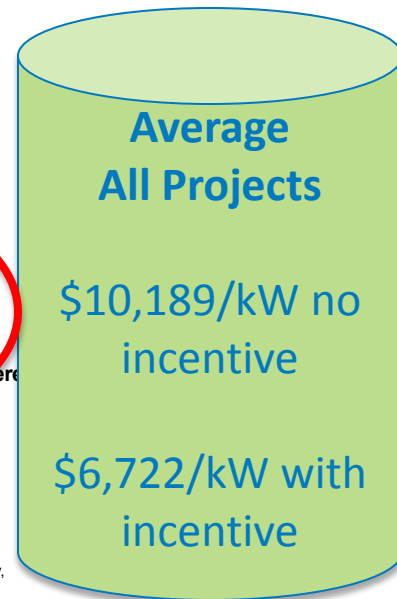
Accomplishments and Progress

- Larger projects generally have lower unit prices(\$/kW)
- Larger projects generally receive more incentives thereby lowering the average unit prices(\$/kW) more than smaller projects
- Few projects with incentives meet the DOE target of \$1,500/kW

Installed Eligible Cost Per kW By Capacity*
Adjusted To 2010 Dollars



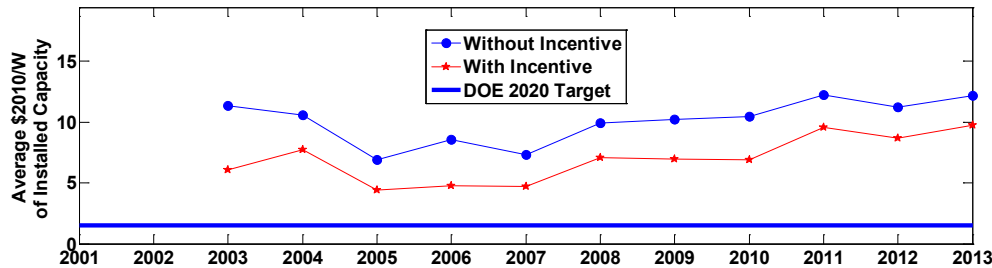
Average Prices No Incentive, Incentive
 0-50 kW = \$10,808/kW, \$8,299/kW
 51-200 kW = \$10,932/kW, \$6,725/kW
 201-400 kW = \$9,950/kW, \$6,046/kW
 401+ kW = \$9,524/kW, \$5,587/kW
 Data points with less than 2 projects filtered



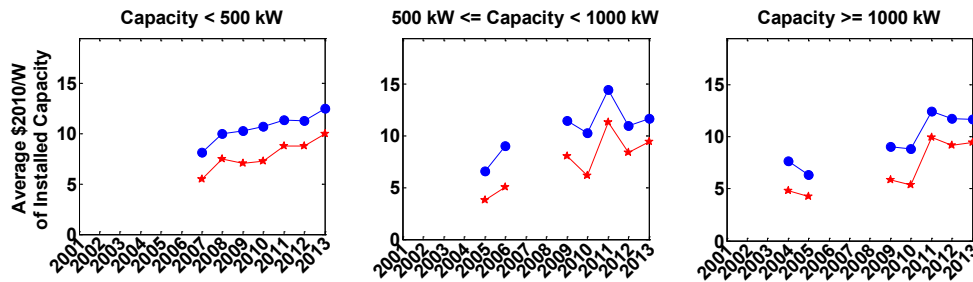
Eligible Costs May Include: Planning & Feasibility Study, Engineering & Design, Permitting, Self-Generation Equipment, Waste Heat Recovery Costs, Construction & Installation Costs, Gas & Electric Interconnection, Warranty, Maintenance Contract, Metering, Monitoring & Data Acquisition System, Emission Control Equipment Capital, Gasline Installation, Fuel Gas Clean-up Equipment, Electricity Storage Devices, Bond to Certify Renewable Fuel, Sales Tax, Fuel Supply (digesters, gas gathering, etc.), Thermal Load, & Other Eligible Costs

Accomplishments and Progress

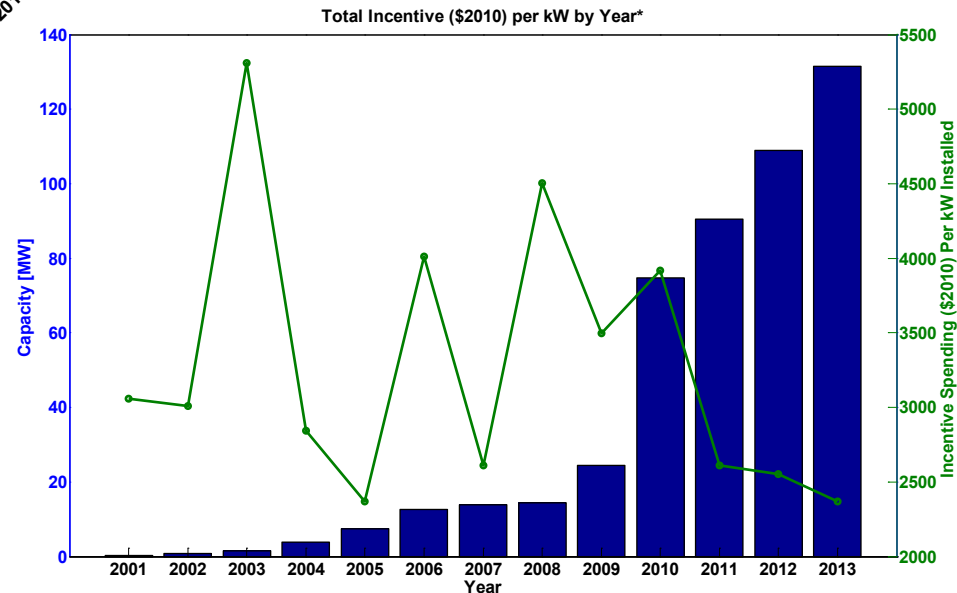
Average Eligible Cost \$2010/W Trend for Overall Deployments*



- The average unit prices for fuel cell projects has fluctuated very little, but more variation is seen when separated by size
- Total incentive spending in fuel cell projects have decreased since 2010 while project counts continues to increase steadily

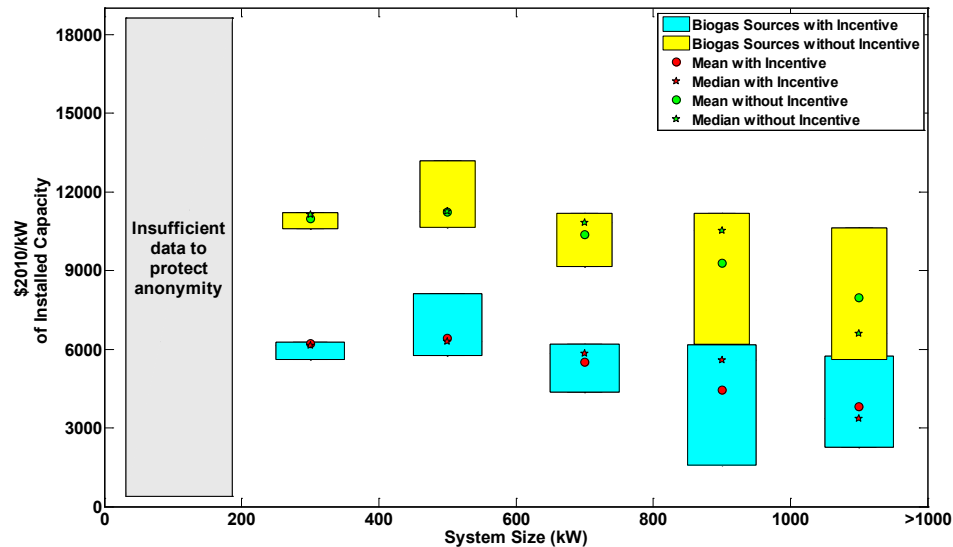


23 new fuel cell projects have been accepted into the California SGIP with a total capacity of 10 MW between Q2 2013 and Q4 2013



Accomplishments and Progress

Range of Installed Eligible Cost Per kW Biogas Sources by Capacity



Eligible Costs May Include: Planning & Feasibility Study, Engineering & Design, Permitting, Self-Generation Equipment, Waste Heat Recovery Costs, Construction & Installation Costs, Gas & Electric Interconnection, Warranty, Maintenance Contract, Metering, Monitoring & Data Acquisition System, Emission Control Equipment Capital, Gasline Installation, Fuel Gas Clean-up Equipment, Electricity Storage Devices, Bond to Certify Renewable Fuel, Sales Tax, Fuel Supply (digesters, gas gathering, etc.), Thermal Load, & Other Eligible Costs

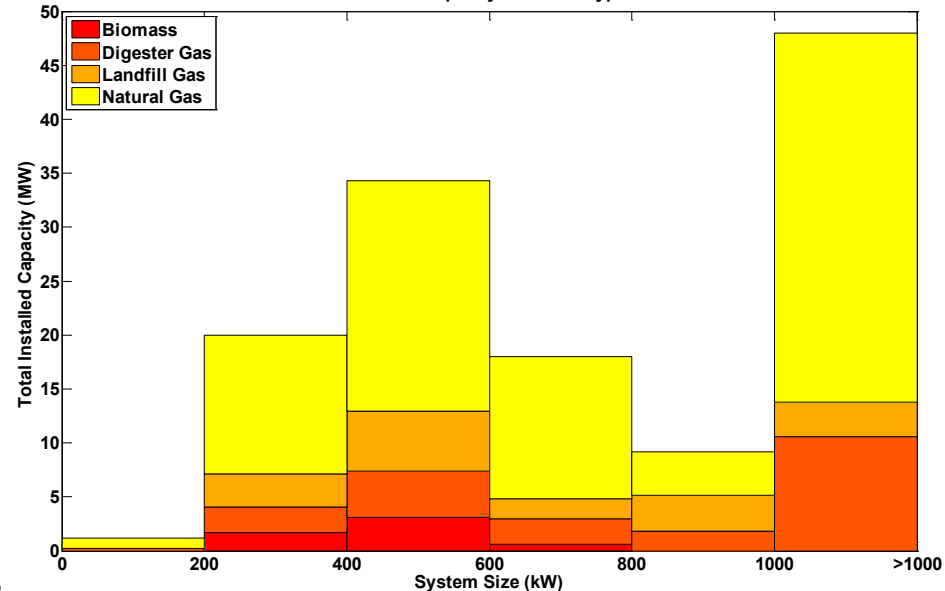
*Data from the Cal

- 25% of fuel cell sites have biogas fuel sources and account for 33% of the capacity
- The average and range of the cost (\$/kW) of biogas sourced fuel cell projects generally decreases with project size.

Biogas fuel cells

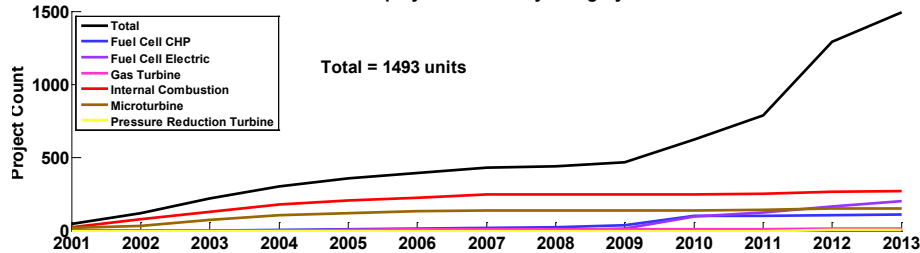
- ❖ 25% of 317 fuel cell sites have biogas fuel sources and account for 33% of 131 MW of the total fuel cell capacity
- ❖ 12% of 112 fuel cell CHP sites have biogas fuel sources for 45% of the 28 MW of total capacity

Installed Capacity And Fuel Type*

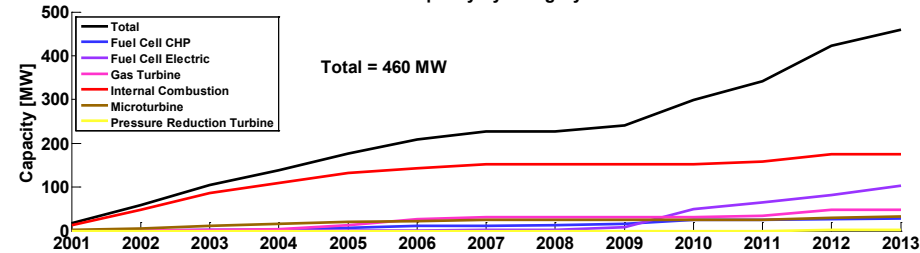


Accomplishments and Progress

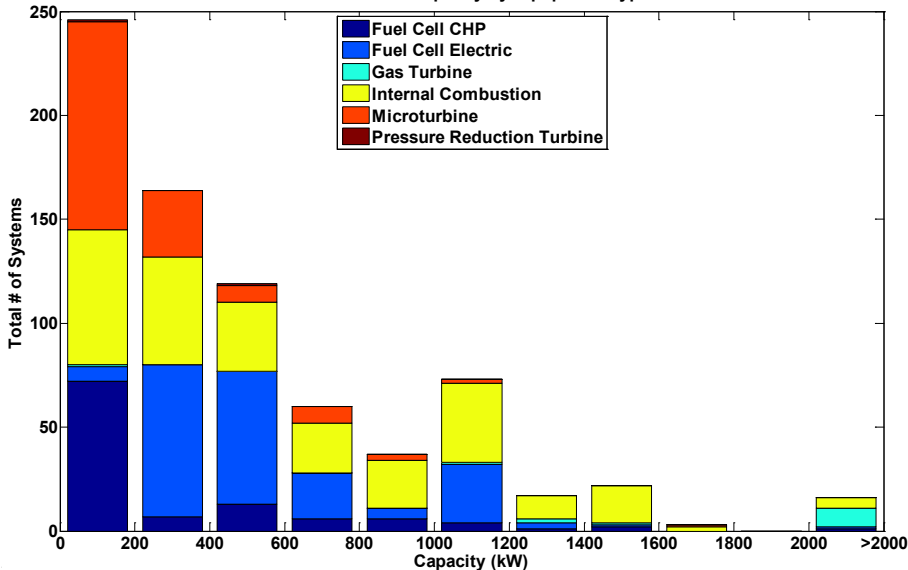
Cumulative Deployment Count by Category and Year*



Cumulative Capacity by Category and Year*

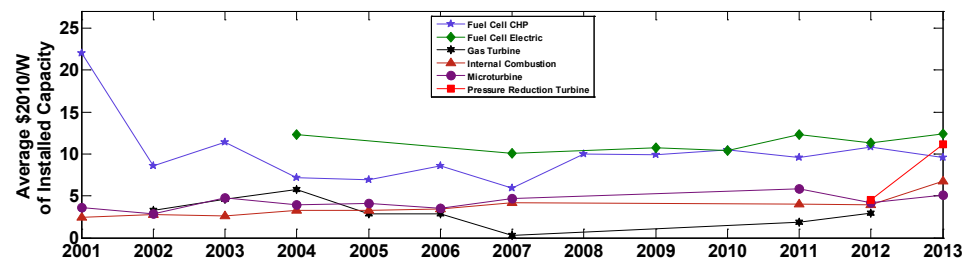


Distribution of Capacity by Equipment Type*

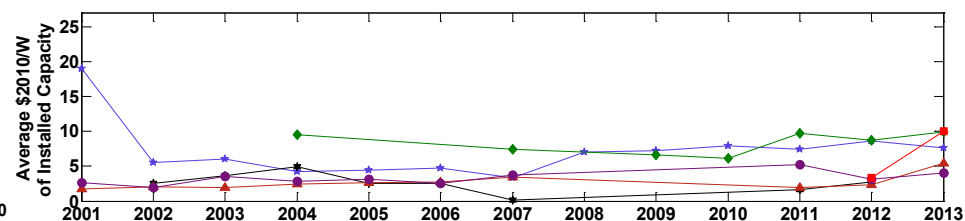


- Fuel cells mainly compete with internal combustion engines and microturbines in terms of capacity ranges
- Since 2010 fuel cells are making significant progress compared to other technologies by numbers of installations and capacity
- Fuel cells are generally more expensive than the competing technologies even with incentives

Average Eligible Cost \$2010/W Trend for Overall Deployments* Without Incentives

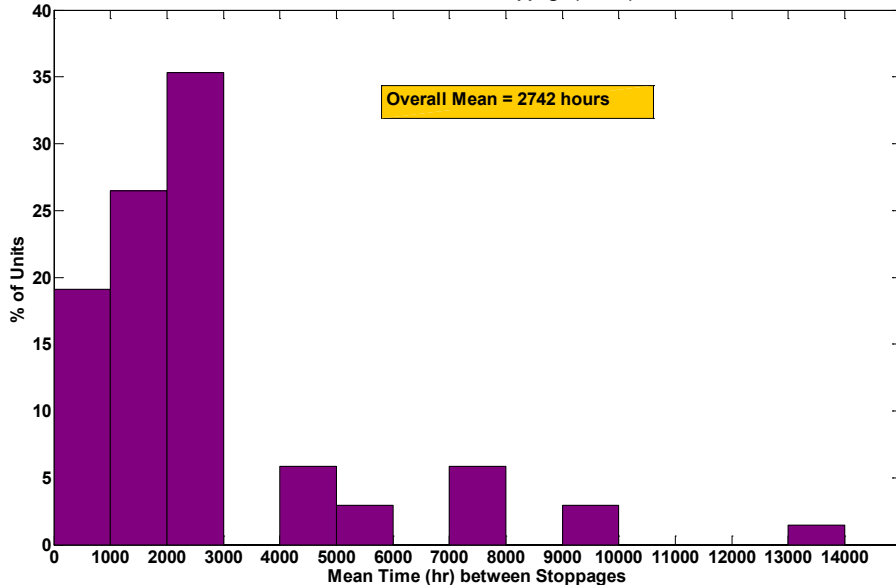


Average Eligible Cost \$2010/W Trend for Overall Deployments* With Incentives



Accomplishments and Progress

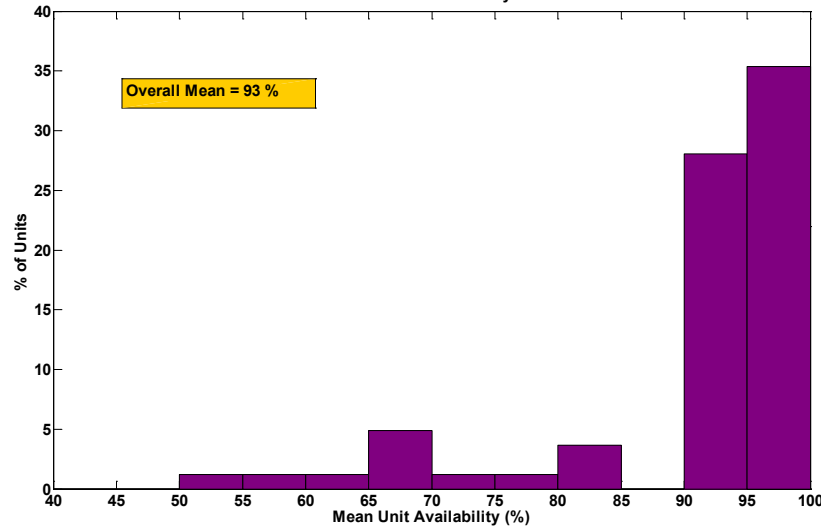
Mean Time Between Stoppage (hours)*



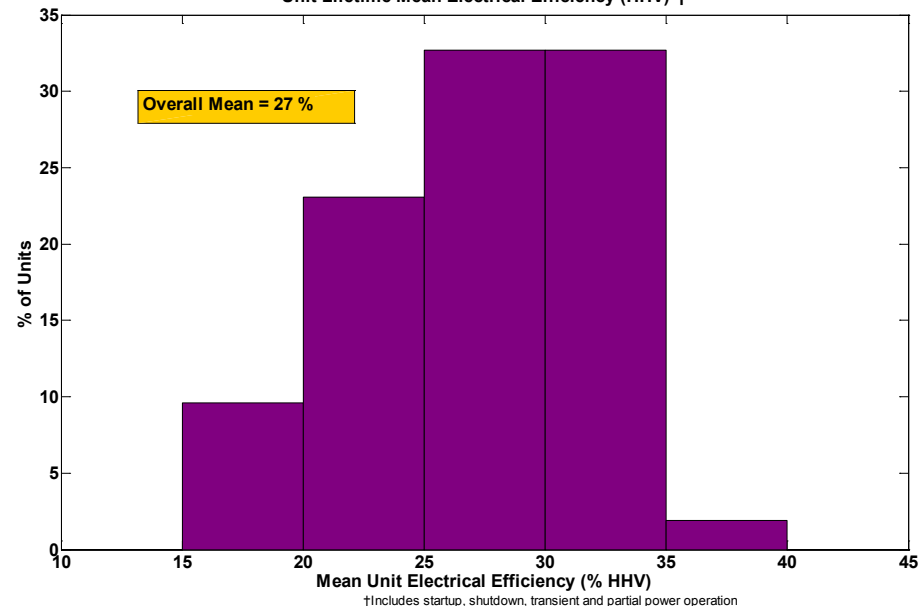
NREL has begun to collect operations data, additional data is expected in the Q4 results

* Unit refers to a single fuel cell system

Unit Mean Availability*



Unit Lifetime Mean Electrical Efficiency (HHV)*†



†Includes startup, shutdown, transient and partial power operation

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **“The pre-commercial days are over, so stationary fuel cells will need to compete with heat engines and the grid on cost and value.”**
 - Several new cdp's have been developed to compare fuel cells to other competing technologies from a size and cost standpoint.
- **However, few data are given about the operations of the systems themselves.**
 - 3 new cdp's have been developed to begin to address operational usage and key areas as efficiency and availability.
 - More data is expected and we are continuing to investigate additional data partners.
- **The data span a large set of power levels, combined heat and power (CHP)/non-CHP and other various technologies, so it is a bit hard to see trends, draw conclusions, etc.**
 - We have begun to create cdp's which separate sizes and CHP systems.

Collaborations

- **Partners for data delivered at the end of 2012**
 - National Fuel Cell Research Center
 - Five fuel cell OEMs
 - California Stationary Fuel Cell Collaborative
- **Communicating with several organizations to establish agreements for sharing data with NREL**
 - State and regional fuel cell organizations
 - Fuel cell developers

Remaining Challenges and Barriers

- **Develop additional state project partners for deployment numbers, cost trends, and operations data.**
- **Work with fuel cell companies to obtain data for assessing key DOE targets**
- **Analyze key deployment barriers and identify elements of successful deployment.**

Proposed Future Work

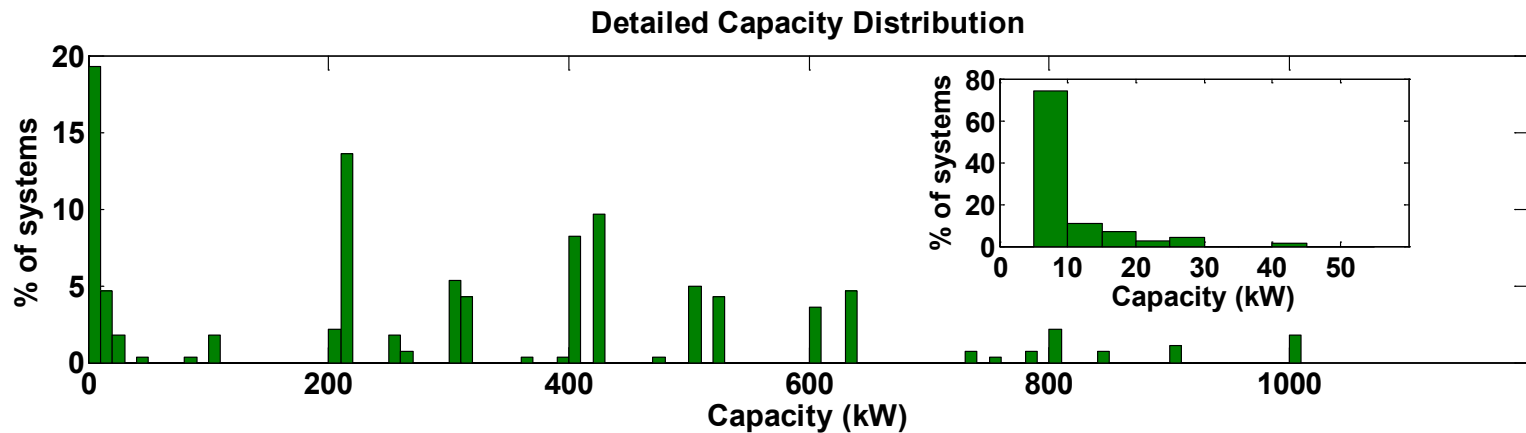
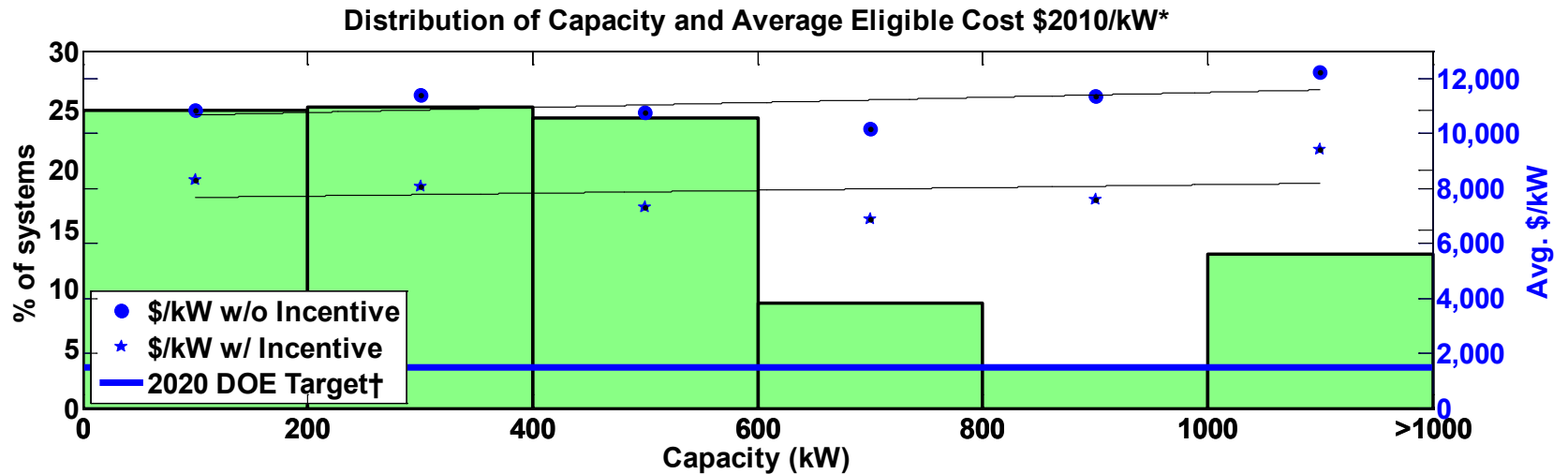
- **Q4 2014 milestone: Update all cdp's with current data**
- **Remainder of 2014:**
 - Continue to analyze current California SGIP deployment data
 - Collect additional operations data for updates to operations cdps
 - Expand analysis to include new cdps which address further segmentation of the data (CHP/non-CHP, competing technologies, fuel sources) and trends over time
 - Look into other data partners (state and federal programs)
 - Work with fuel cell OEMs for possibility of additional data sets

Summary

- NREL is leveraging a large pool of technology validation analyses and knowledge
- Stationary fuel cell deployment is increasing steadily, incentive expenditure (in California SGIP) is decreasing, but project prices are still generally higher for fuel cells.
- Natural gas is the leading fuel source, but a significant number of larger installations are using biogas fuel sources (23 biogas FC projects are ≥ 600 kW)
- Fuel cells continue to be installed in the California SGIP (23 new FC projects between Q2 2013 and Q4 2013)
- Larger projects tend to have lower unit cost (\$/kW) and often take advantage of more incentives.
- The mean availability of fuel cells systems is 93% with $\sim 35\%$ of systems over 95%.
- The mean electrical efficiency of fuel cells is 27% with $< 3\%$ of the systems analysed over 35% electrical efficiency (based on HHV).

Technical Back-Up Slides

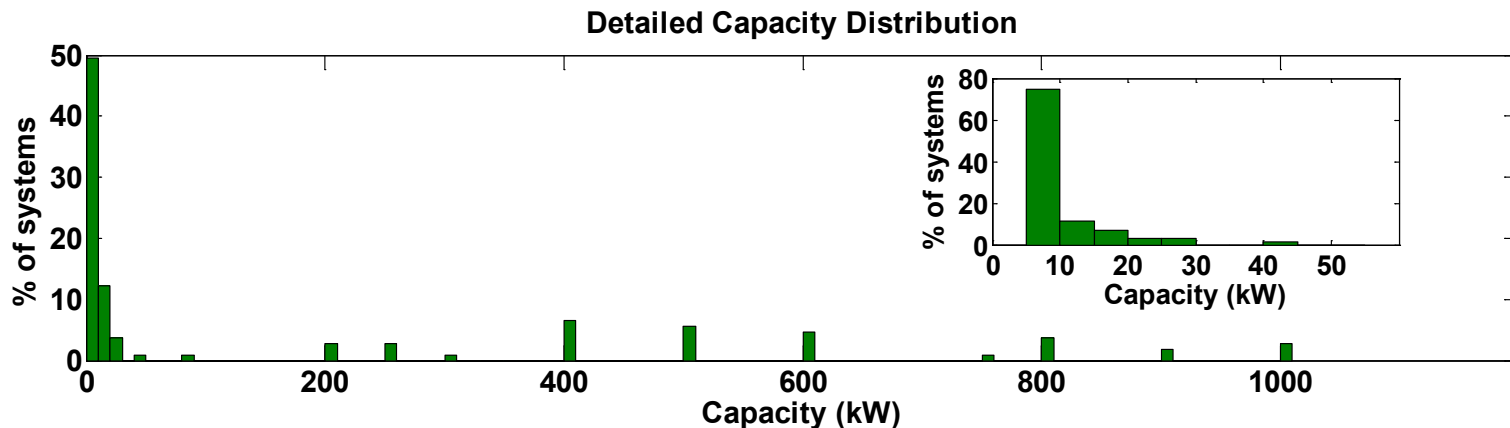
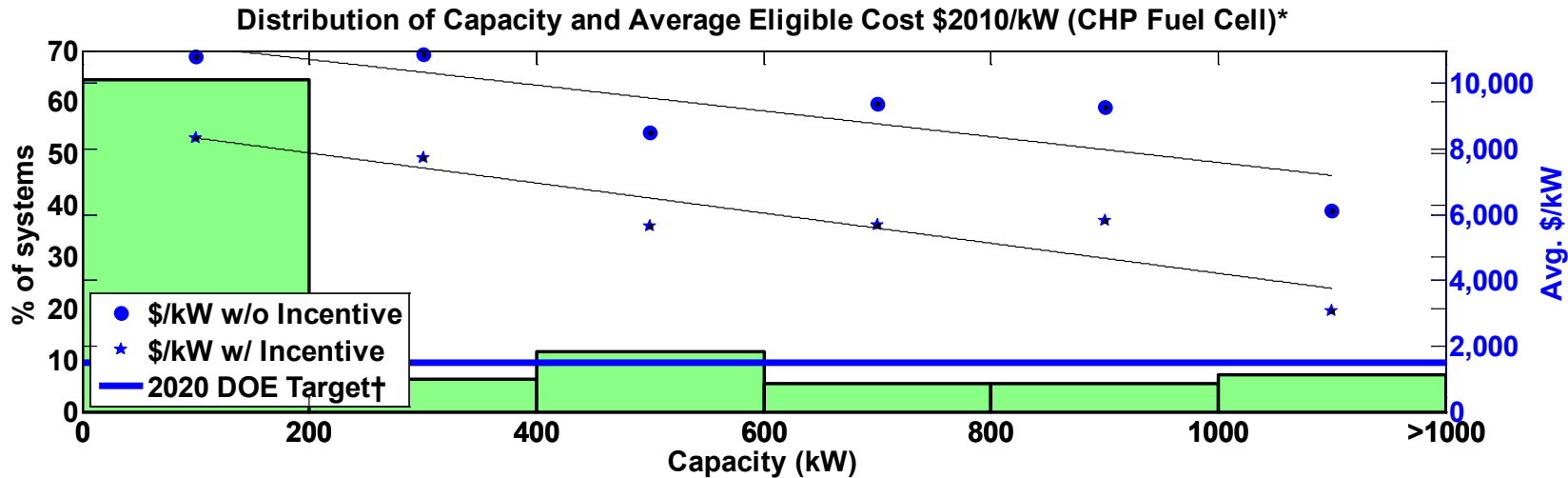
Fuel Cell Stationary Capacity and Average Prices



Eligible Costs May Include: Planning & Feasibility Study, Engineering & Design, Permitting, Self-Generation Equipment, Waste Heat Recovery Costs, Construction & Installation Costs, Gas & Electric Interconnection, Warranty, Maintenance Contract, Metering, Monitoring & Data Acquisition System, Emission Control Equipment Capital, Gasline Installation, Fuel Gas Clean-up Equipment, Electricity Storage Devices, Bond to Certify Renewable Fuel, Sales Tax, Fuel Supply (digesters, gas gathering, etc.), Thermal Load, & Other Eligible Costs

†for the year 2020, operating on natural gas.
 *Data from the California SGIP.

Distribution of Capacity and Eligible Cost (CHP Fuel Cells)

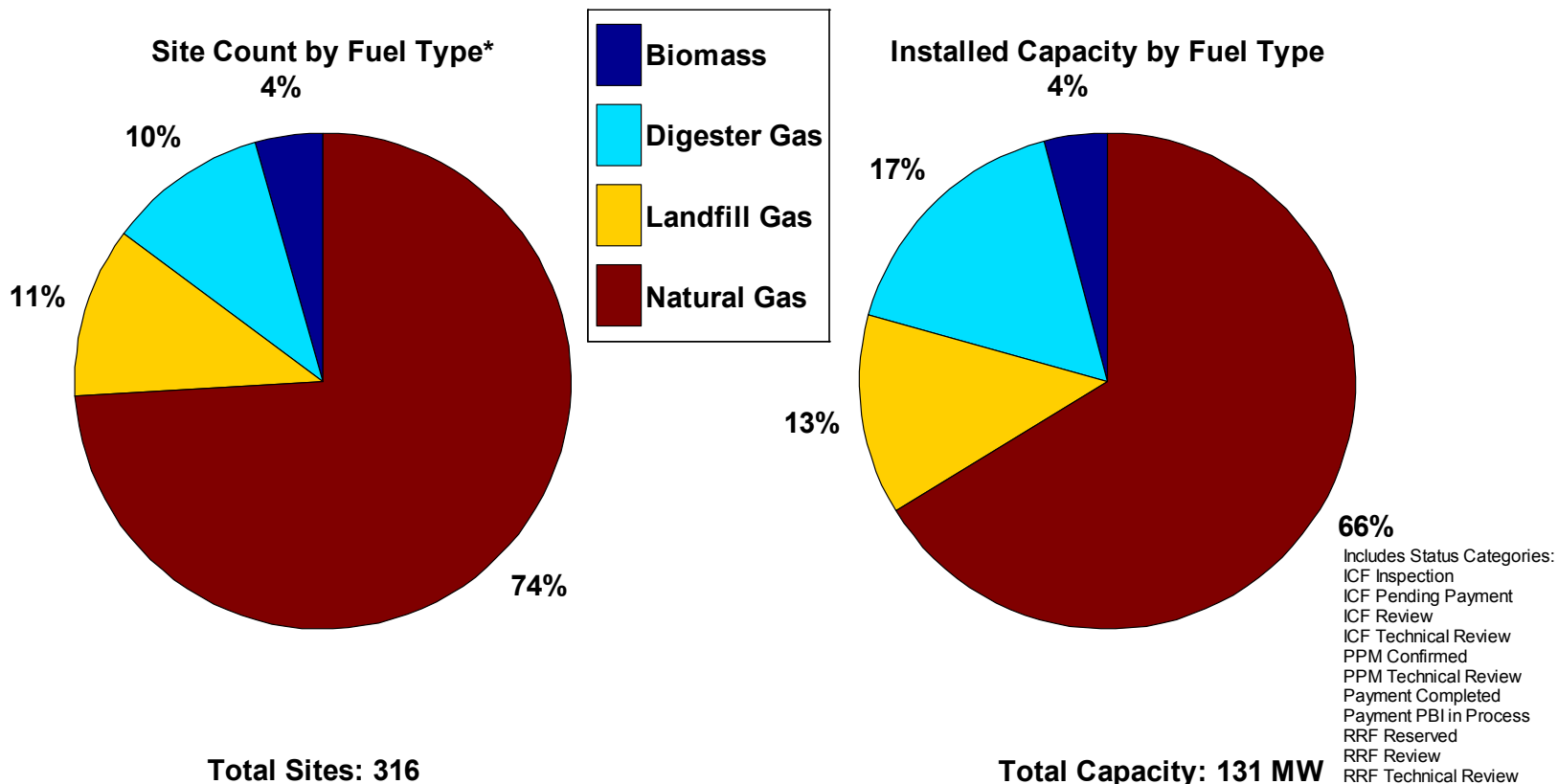


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†for the year 2020, operating on natural gas.
*Data from the California SGIP.

Stationary Fuel Cell System Count and Capacity by Fuel Type

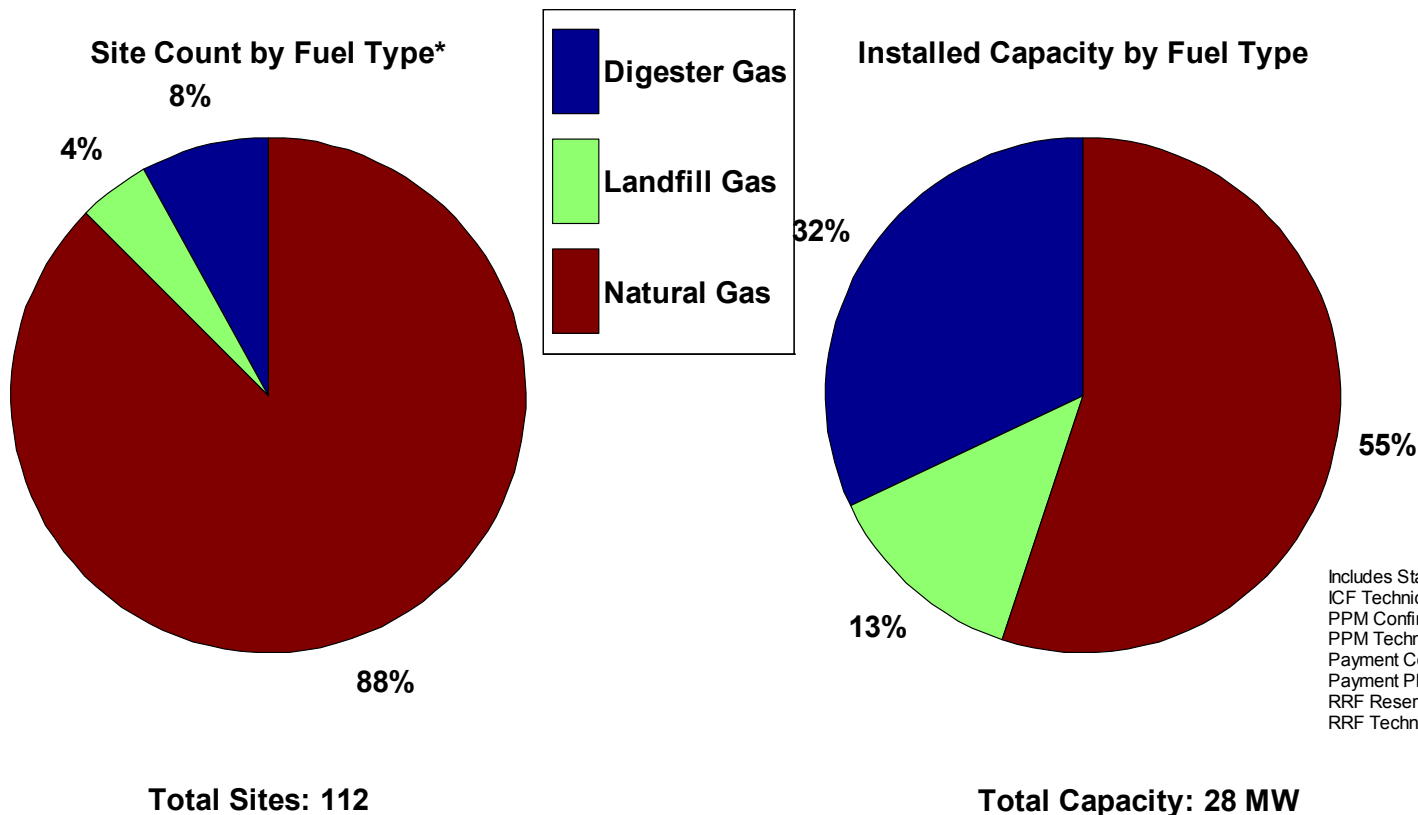
Installations by Fuel Type
(All Fuel Cell Systems)



Definitions: RRF = Reservation Request Form, is the first step in the SGIP incentive claim process.
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Installations By Fuel Type (CHP Fuel Cells)

Installations by Fuel Type
(CHP Fuel Cell Systems)

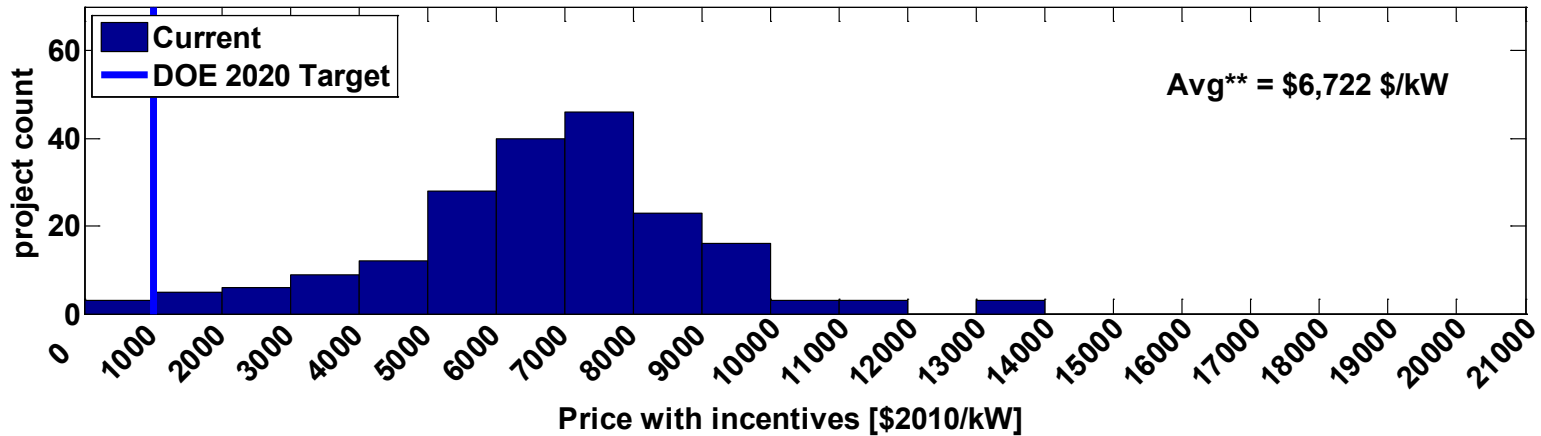
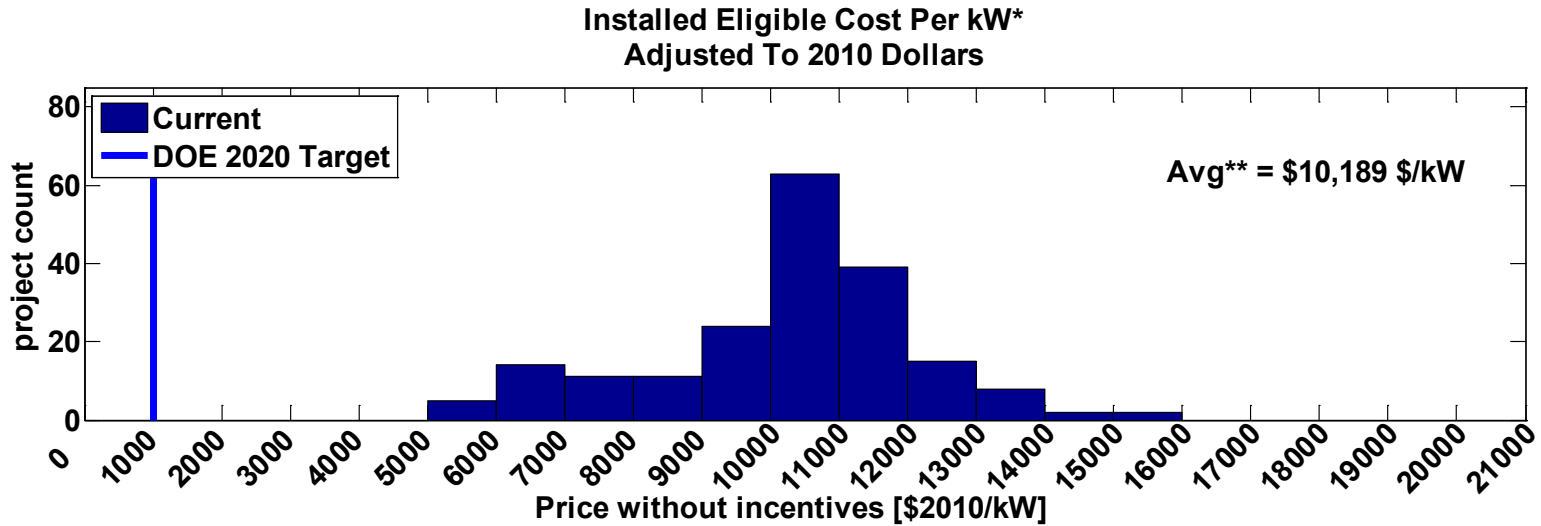


Includes Status Categories:
ICF Technical Review
PPM Confirmed
PPM Technical Review
Payment Completed
Payment PBI in Process
RRF Reserved
RRF Technical Review

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PPM = Proof of Project Milestone; the applicant must prove progress and commitment to the project.
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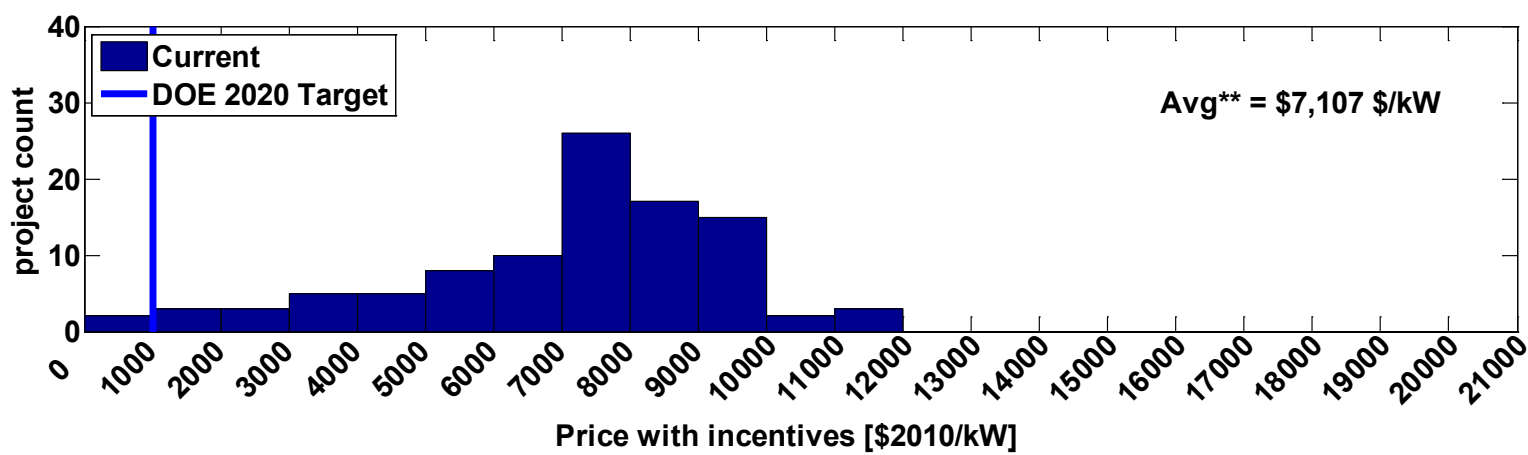
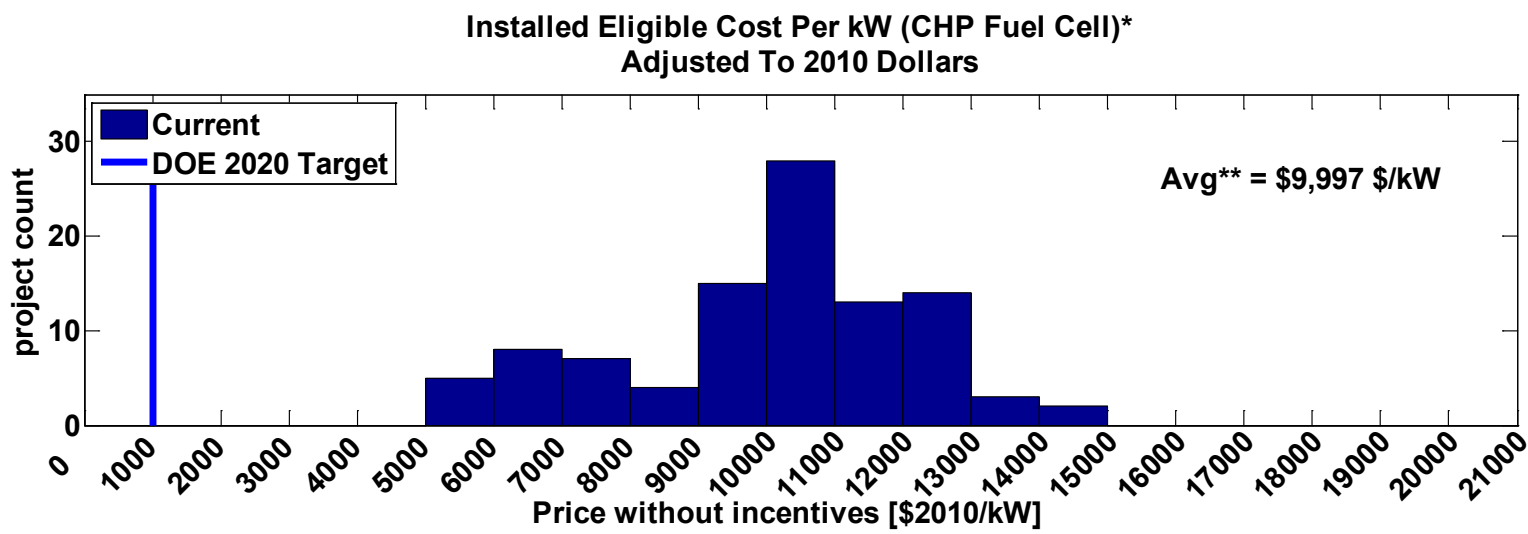
Distribution of Stationary Fuel Cell Install Price with and without Incentives



Eligible Costs May Include: Planning & Feasibility Study, Engineering & Design, Permitting, Self-Generation Equipment, Waste Heat Recovery Costs, Construction & Installation Costs, Gas & Electric Interconnection, Warranty, Maintenance Contract, Metering, Monitoring & Data Acquisition System, Emission Control Equipment Capital, Gasline Installation, Fuel Gas Clean-up Equipment, Electricity Storage Devices, Bond to Certify Renewable Fuel, Sales Tax, Fuel Supply (digesters, gas gathering, etc.), Thermal Load, & Other Eligible Costs

**Data points with less than 2 projects filtered.
*Data from the California SGIP.

Distribution of Eligible Cost with and w/o Incentives (CHP Fuel Cells)

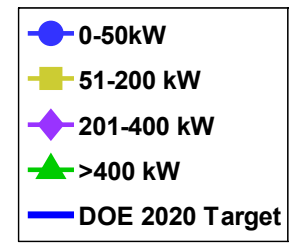
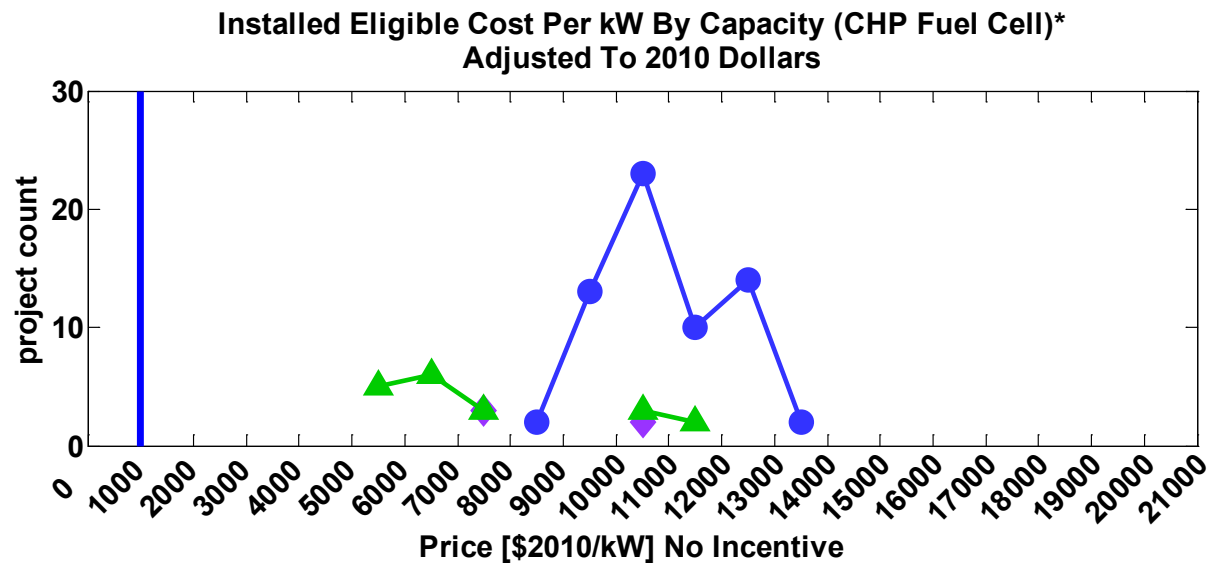


NREL cdp_stat_23
Created: Apr-16-14 9:37 AM | Data Range: 2001Q2-2013Q3

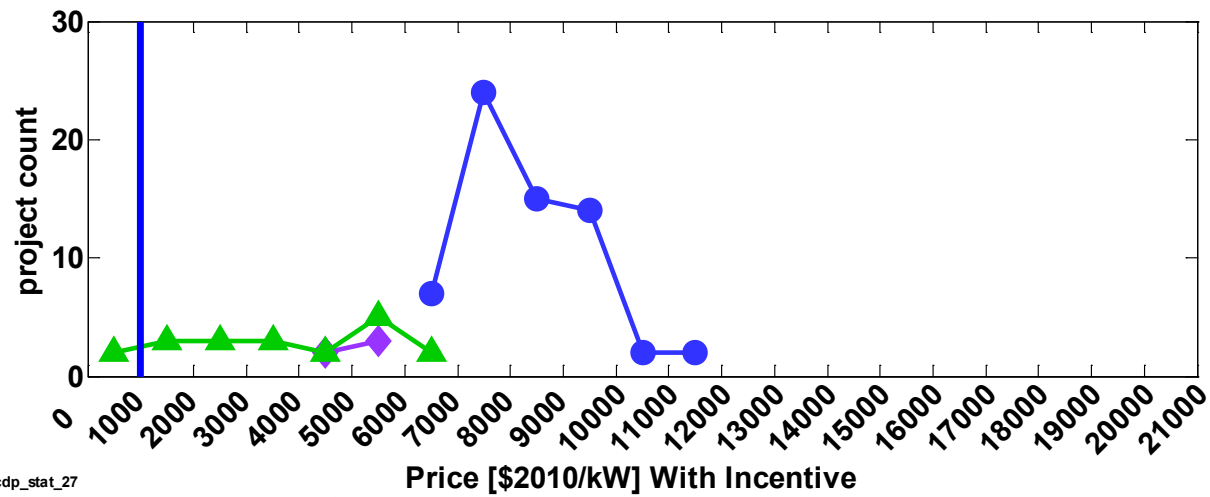
Eligible Costs May Include: Planning & Feasibility Study, Engineering & Design, Permitting, Self-Generation Equipment, Waste Heat Recovery Costs, Construction & Installation Costs, Gas & Electric Interconnection, Warranty, Maintenance Contract, Metering, Monitoring & Data Acquisition System, Emission Control Equipment Capital, Gasline Installation, Fuel Gas Clean-up Equipment, Electricity Storage Devices, Bond to Certify Renewable Fuel, Sales Tax, Fuel Supply (digesters, gas gathering, etc.), Thermal Load, & Other Eligible Costs

**Data points with less than 2 projects filtered.
*Data from the California SGIP.

Installed Eligible Cost per kW By Capacity (CHP Fuel Cell)



Average Prices No Incentive, Incentive
 0-50 kW = \$10,830/kW, \$8,320/kW
 51-200 kW = \$NaN/kW, \$NaN/kW
 201-400 kW = \$8,817/kW, \$5,330/kW
 401+ kW = \$7,582/kW, \$3,647/kW
 Data points with less than 2 projects filtered.



Eligible Costs May Include: Planning & Feasibility Study, Engineering & Design, Permitting, Self-Generation Equipment, Waste Heat Recovery Costs, Construction & Installation Costs, Gas & Electric Interconnection, Warranty, Maintenance Contract, Metering, Monitoring & Data Acquisition System, Emission Control Equipment Capital, Gasline Installation, Fuel Gas Clean-up Equipment, Electricity Storage Devices, Bond to Certify Renewable Fuel, Sales Tax, Fuel Supply (digesters, gas gathering, etc.), Thermal Load, & Other Eligible Costs

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