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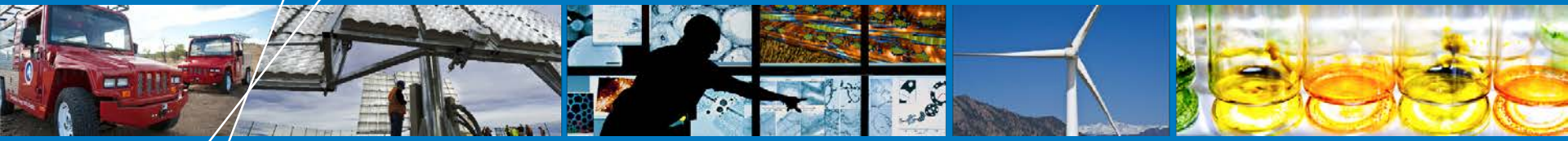
Stationary Fuel Cell Evaluation



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National Renewable Energy Laboratory

June 11, 2015

Project ID TV016

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

Overview

Timeline and Budget

- Project start date: October 2011
- Project end date: Sept 2015*
- FY14 DOE funding: $100k
- FY15 planned DOE funding: $100
- Total DOE funds received to date: $465k

* Project continuation and direction determined annually by DOE

** Separately funded project

Barriers

- B. Lack of Data on Stationary Fuel Cells in Real-World Applications
- E. Codes & Standards

Partners

- California Stationary Fuel Cell Collaborative (review results)
- National Fuel Cell Research Center (UCI) (subcontractor)
- Five OEM data providers
- Connecticut Department of Transportation (data provider through TIGGER)**

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: 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

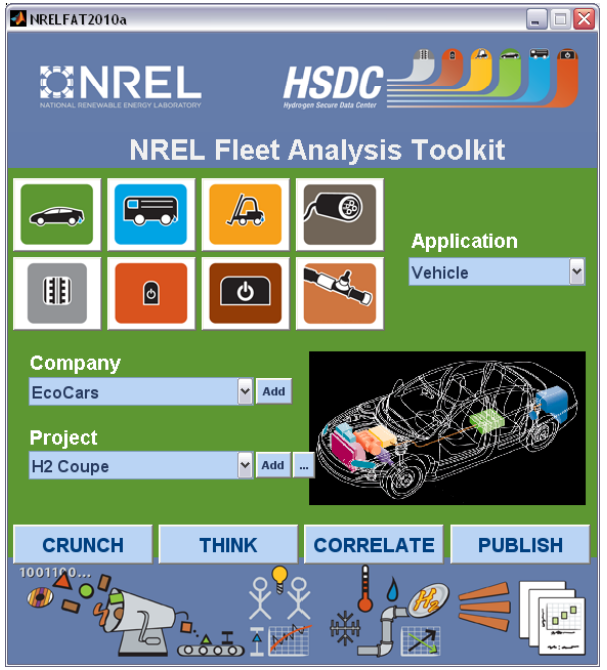
Approach – Data Sources and Scope

➢ **Project is reliant on voluntary data sharing – partner development is ongoing.**

- **Deployment and cost data**
  - Publically available data from California SGIP (Self Generation Incentive Program) (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 voluntarily supplied
- **33 total CDPs**
  - Quarterly data analysis (based on available data), biannual publications

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

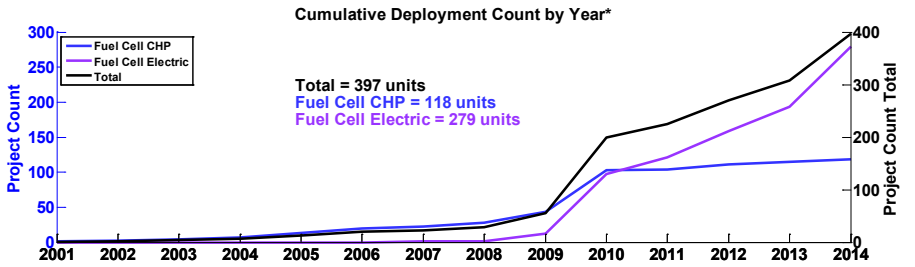


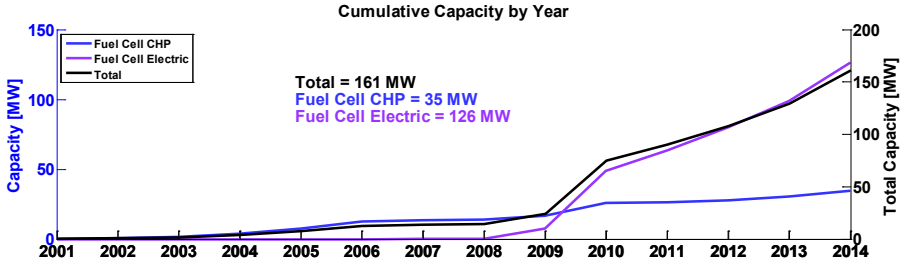
- **Report results**
  - Detailed and composite results
  - Target key stakeholders such as fuel cell and hydrogen developers, and end users

➢ Public results available at

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

Accomplishments: CA SGIP - Deployment





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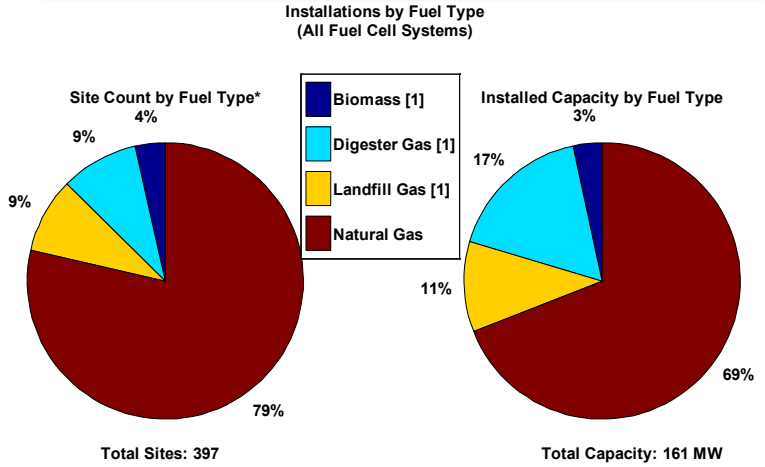
*Data from the CA SGIP.

California SGIP - Deployment

- Deployment of fuel cells in the California SGIP have been ramping up more rapidly than in the past several years, 25% increase in 2014.
- Natural gas sites dominate, but renewable fuels have a greater capacity compared to the number of projects.

- The California SGIP will continue run through at least January 1, 2019.
- Renewable fuels exclude those defined as conventional in Section 2805 of the California Public Utilities Code and are categorized here as gas derived from biomass, digester gas, or landfill gas.



[1] The renewable fuels exclude those defined as conventional in Section 2805 of the California Public Utilities Code and are categorized here as gas derived from biomass, digester gas, or landfill gas.
Definition of Included Status:
[2] Includes CA SGIP projects in Reservation Request Form (RRF) phases.
[3] Includes CA SGIP projects in Proof of Project Milestone (PPM) phases.
[4] Projects are in operation and pending confirmation of incentive claims, including CA SGIP Incentive Claim Form (ICF) phases.
[5] Includes projects that are receiving perfomance based incentives, includes CA SGIP Performance Based Incentives (PBI) In Progress.
[6] Includes installed projects with unknown operation status, includes CA SGIP Payment Completed and Payment Recalled status.

Includes Status Categories:
Application Review [2]
Project Execution Review [3]
Incentive Claim Review [4]
Project In Operation [5]
Project Completed [6]

*Data from the CA SGIP.

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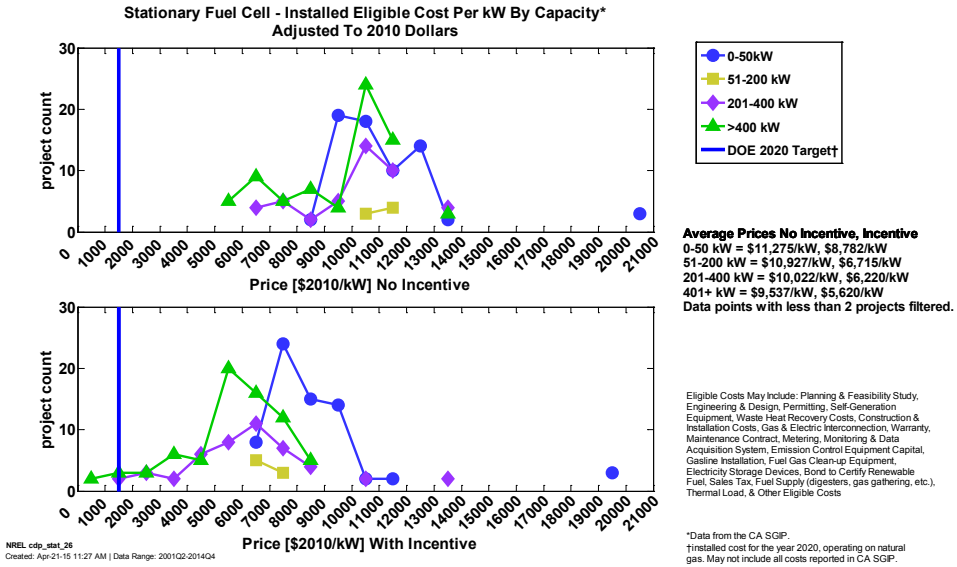
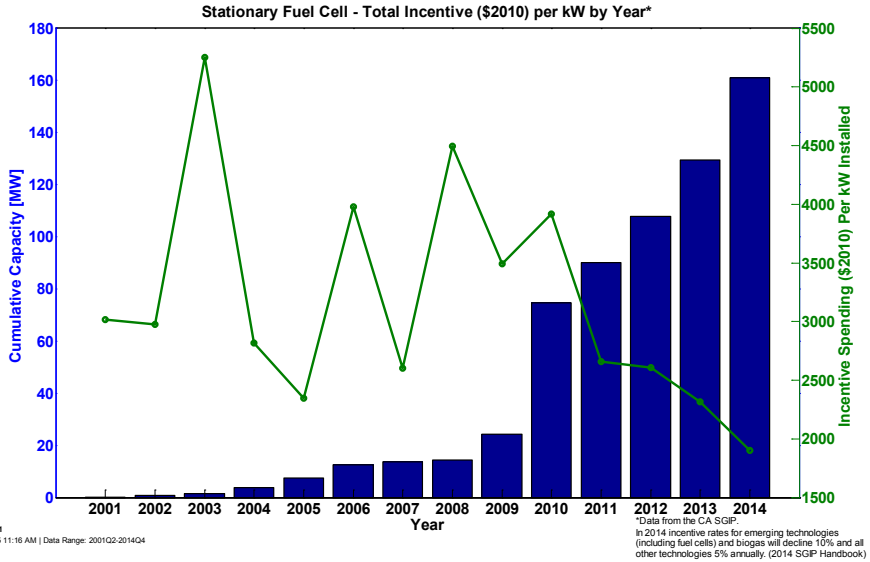
Accomplishments: CA SGIP – Fuel cell costs



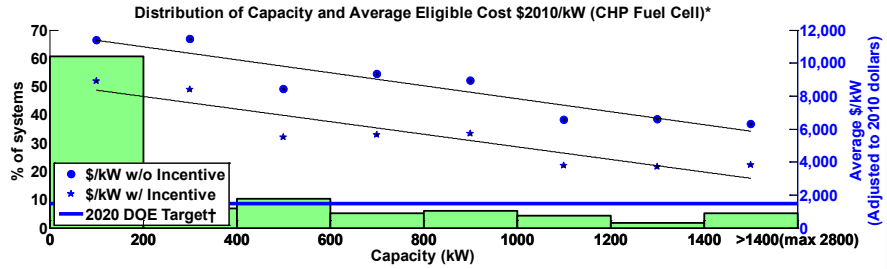
- **A few larger (>200 kW) projects meet the DOE target of $1,500/kW* with incentives**
- Fuel cell incentive spending as $/kW has steadily declined since 2010
- Larger projects generally cost less on a per kilo-watt basis than smaller projects.

Project Size (kW)	Cost without Incentive ($/kW)	Cost with Incentive ($/kW)
0-50	11,275	8,782
51-200	10,927	6,715
201-400	10,022	6,220
> 400	9,537	5,620



* DOE target may **not** include all costs reported in CA SGIP.

Accomplishments: CA SGIP – CHP Costs



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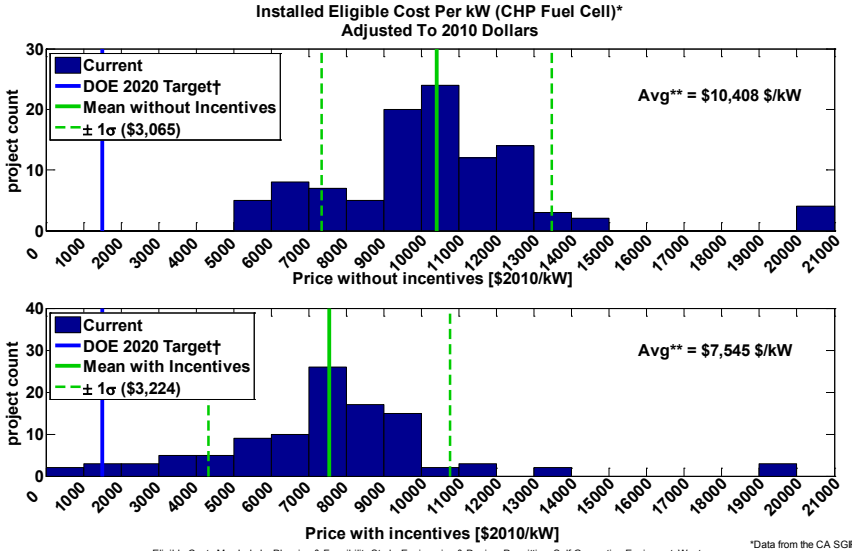
Eligible Costs May Include: Planning & Feasibility Study, Engineering & Design, Permitting, Self-Generation Equipment, Waste Heat Recovery Costs, Construction & Installation Costs, Gas & Electric Interconnection, Warranty, Maintenance Contract, Metering, Monitoring & Data Acquisition System, Emission 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 CA SGIP.
†installed cost for the year 2020, operating on natural gas. May not include all costs reported in CA SGIP.

- **A few larger (>400 kW) projects meet the DOE target of $1,500/kW* with incentives**
- Costs decline with size of project

Project Size (kW)	Cost without Incentive ($/kW)	Cost with Incentive ($/kW)
0-50	11,303	8,809
201-400	9,165	5,316
> 400	7,608	3,706



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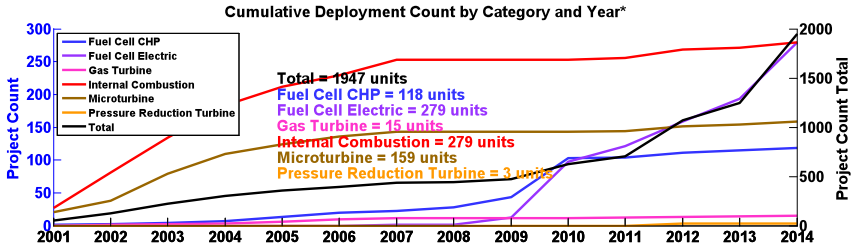
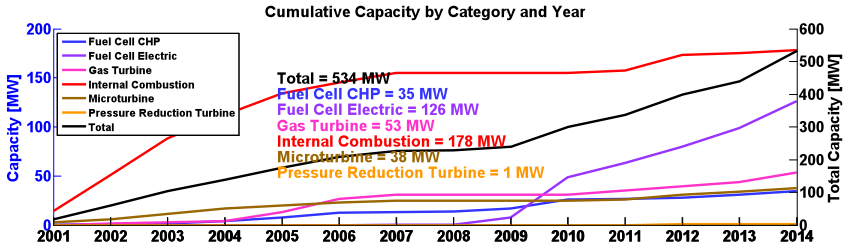
*Data from the CA SGIP.
**Data bins with less than 2 projects filtered.
†installed cost for the year 2020, operating on natural gas. May not include all costs reported in CA SGIP.

* DOE target may **not** include all costs reported in CA SGIP.

Accomplishments: CA SGIP – Competing Technologies





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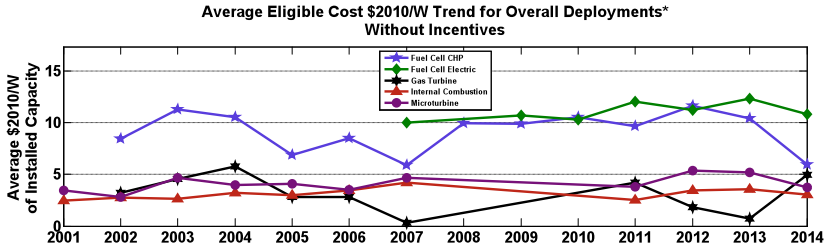
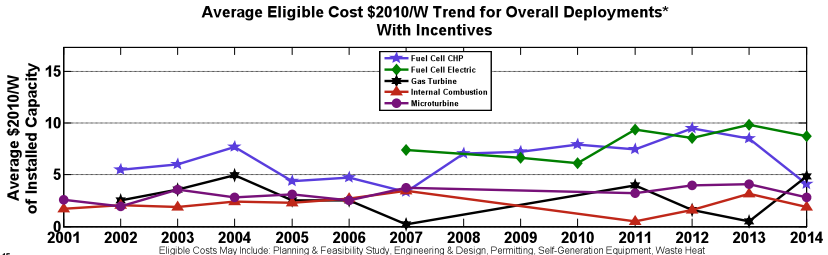
*Data from the CA SGIP.





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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

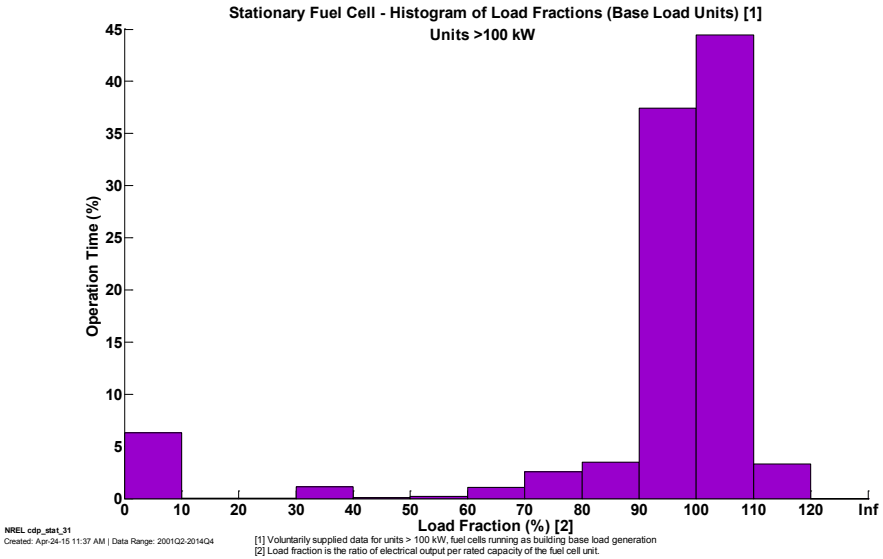
*Data from the CA SGIP.

California SGIP – Competing Technologies

- Fuel cells (CHP and electric) have exceeded the deployment of internal combustion engines
- In 2014 fuel cell CHP projects have dropped to close to the costs of gas turbines and below with incentives

Accomplishments: Load Profile (>100 kW units)

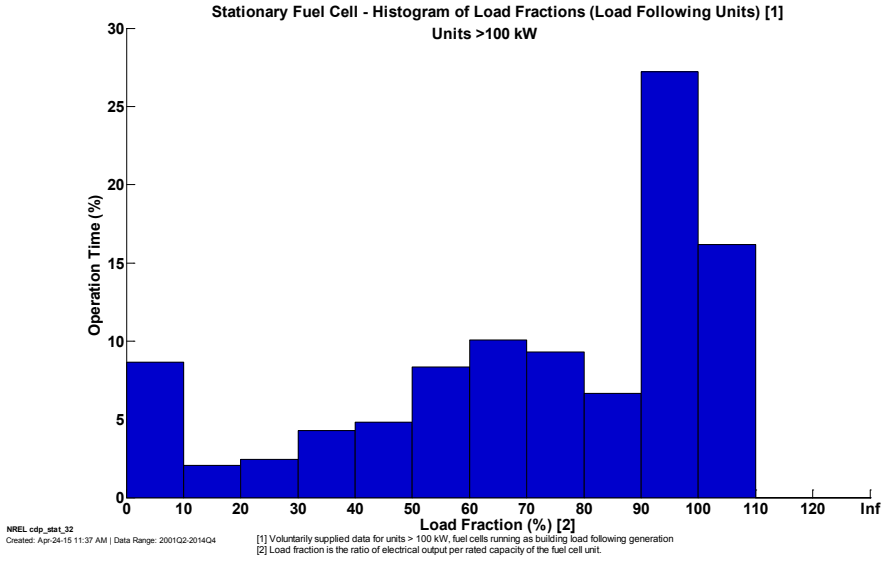
Histogram of Load Profile – Base Load Units



How stationary fuel cells are used changes the operation profiles.

- At base load most operation is 90-100% load fraction of rated capacity
- Some fuel cells may even be operated for significant time above rated capacity

Histogram of Load Profile – Load Following Units

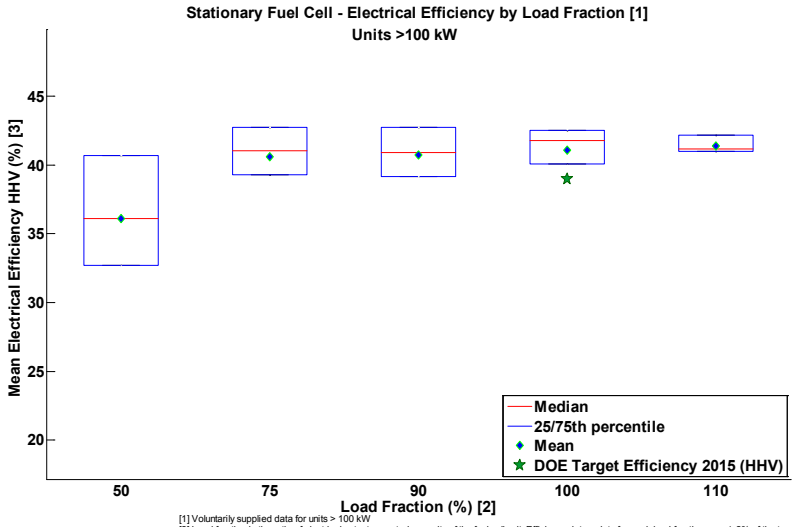


Fuel cell sizing

- For base load the fuel cells are sized for minimum load.
- For load following the fuel cells may be sized for near peak load.

Accomplishments: Mean Electrical Efficiency

Electrical Efficiency – Units > 100 kW



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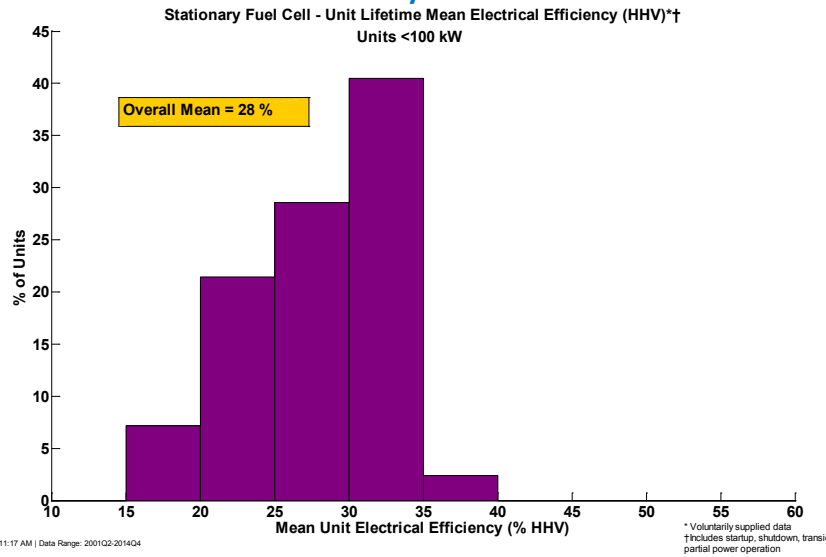
[1] Voluntarily supplied data for units > 100 kW
[2] Load fraction is the ratio of electrical output per rated capacity of the fuel cell unit. Efficiency data points for each load fraction are +/- 2% of the target load fraction.
[3] Mean efficiencies by unit are calculated as the percentage of electrical power output to higher heating value of fuel input. The natural gas higher heating value used is 48.956 MJ/kg and the lower heating value used is 44.294 MJ/kg.

- **Electrical efficiency for fuel cells > 100 kW are exceeding the 2015 DOE technology validation target of 43% LHV (39% HHV)**
- Electrical efficiency for units < 100 kW is improving, but does not meet target

Sizing

- Commercial are > 100 kW
- Residential are 0-10 kW

Electrical Efficiency – Units < 100 kW



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* Voluntarily supplied data
†Includes startup, shutdown, transient and partial power operation

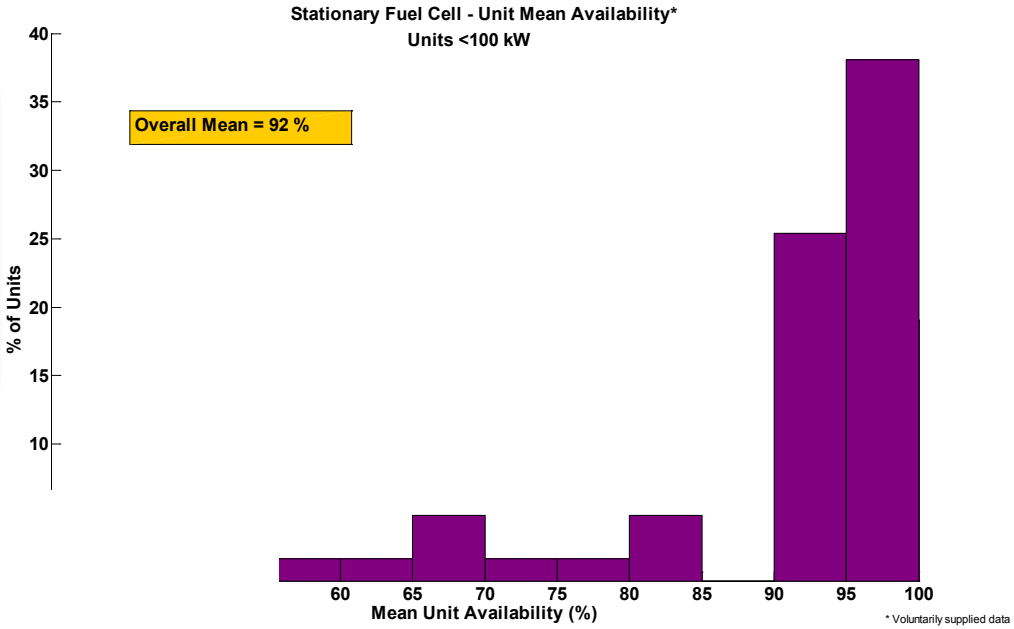
Accomplishments: Availability and MTBS* (<100 kW units)

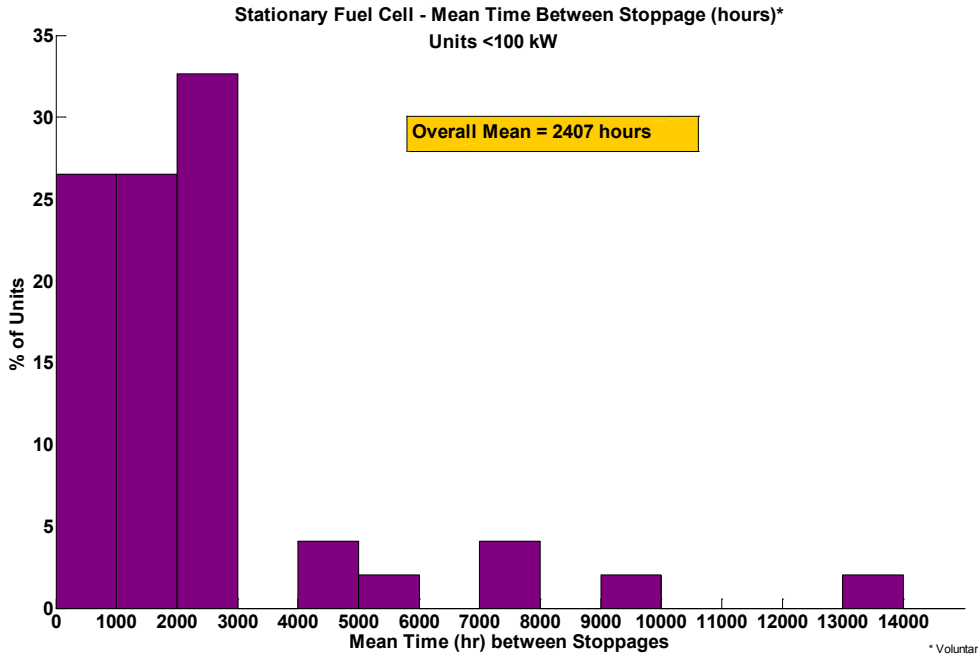
Availability (<100 kW units)

- Mean availability is 92%
- ~60% of units are > 90% availability

MBTS* (<100 kW units)

- Overall MBTS is 2407 hours
- >80% are 3000 or less





* Mean Time Between Stoppages

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **What is the purpose of collecting data?**
  - The purpose is to look at the current state of the technology for stationary fuel cells for the consideration by fuel cell OEMS, developers, state and federal agencies; better understand project deployments, costs, and incentives and the changes over time; compare performance to DOE targets for the technology; and provide other value-added analysis for stationary OEMs, developers, and other key stake-holders.
- **Can data be segmented by power and application more?**
  - We have developed several new CDPs which start to segment the capacity ranges and therefore stationary applications. In some cases we have data that we do not show due to data sensitivity. We also have some cross-app CDPs which compare across applications, ie. vehicle, material handling, lab-scale, etc.
- **Can missing data be included through literature or benchmark data points?**
  - We typically do not include literature data in CDPs because by definition we work with real data sets and may not have enough confidence in literature data sources though some of this could be included as text or footnote references.

Collaborations

- **Partners for data delivered at the end of 2014**
  - National Fuel Cell Research Center
  - California Stationary Fuel Cell Collaborative
  - Five fuel cell OEMs
- **Communicating with several organizations to establish agreements for sharing data with NREL**
  - Connecticut Department of Transportation (through TIGGER - separately funded project)
  - NJ Clean Energy Fund/NJ Economic Development Authority (public data, deployment and incentives only)
  - California Public Utilities Commission
  - Verizon
  - State and regional fuel cell organizations
  - Fuel cell developers

Proposed Future Work

- **Q3 2015 milestone: Update all CDPs with current data and publish technical report**
- **Remainder of FY2015:**
  - Continue to analyze current California SGIP deployment data
  - Collect additional operations data
  - Expand analysis
    - Further segmentation of the data (CHP/non-CHP, competing technologies, load following/base load, fuel sources) and trends over time
    - New operations CDPs for availability/capacity factor
  - Continue to develop 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
- CA SGIP
  - Deployment of fuel cells is increasing steadily, 25% increase since 2013.
  - Incentive spending ($/kW) for fuel cells has been steadily decreasing
  - There has been a resurgence of digester gas projects in 2014
  - Average fuel cell CHP costs ($/kW) are close to that of gas turbines and below with incentives.
  - Some larger fuel cell projects are meeting the DOE target of $1,500/kW with incentives
  - Digester gas projects have the lowest average and median costs ($/kW), but also the largest range
- Operations Data
  - Units >100 kW: The mean fuel cell efficiency exceeds the DOE target of 43% LHV
  - Stationary fuel cells being used for both base load and load following applications
  - Units <100 kW: The mean availability is 92% with ~60% over 90% availability.
  - Units <100 kW: The mean time between stoppages is 2407 hours with >80% less than 3000 hours

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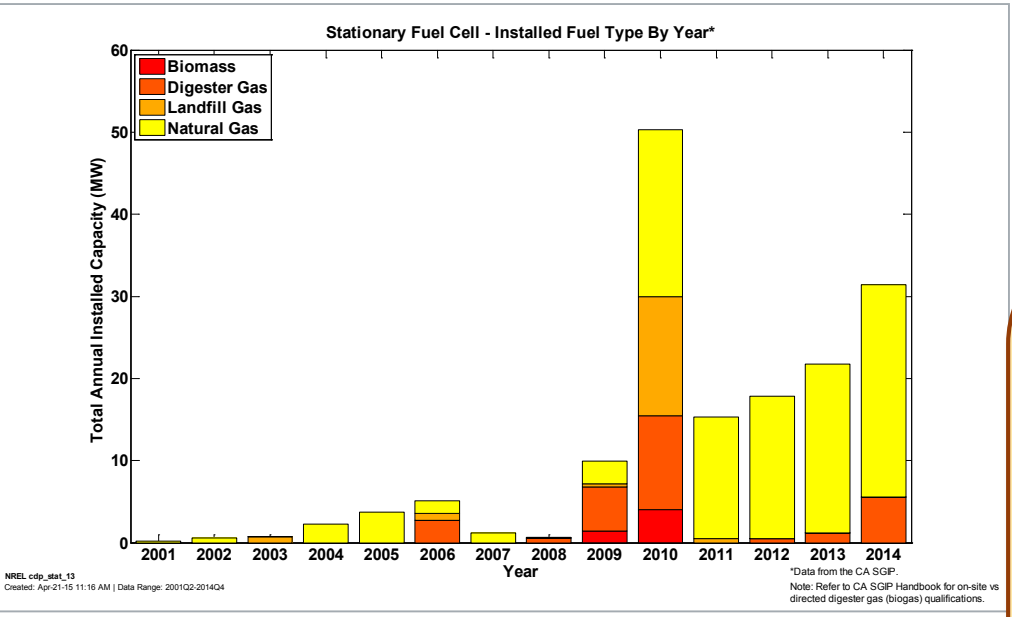
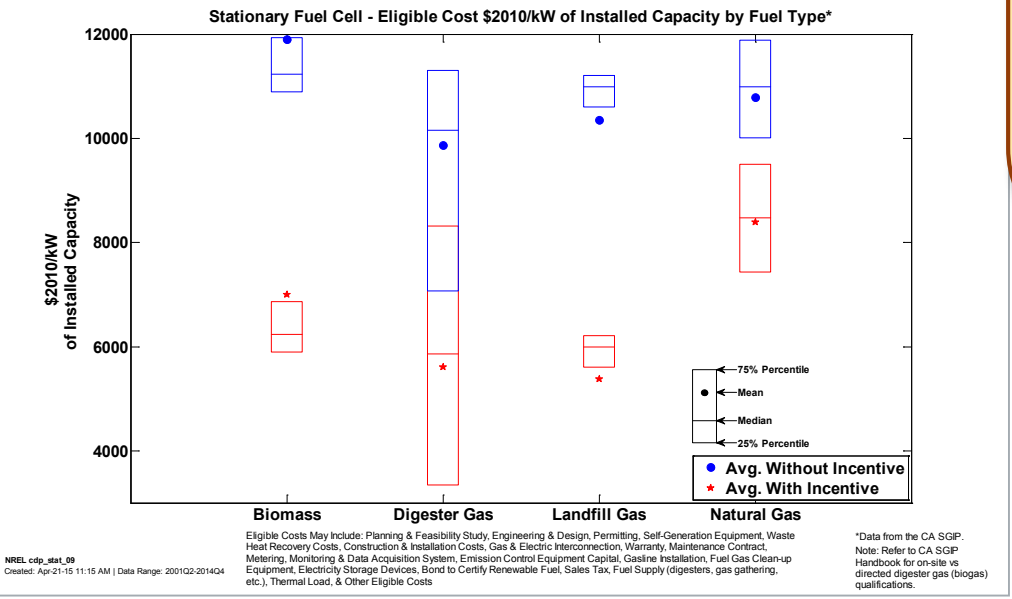
Technical Back-Up Slides

Accomplishments: CA SGIP – Fuel Types

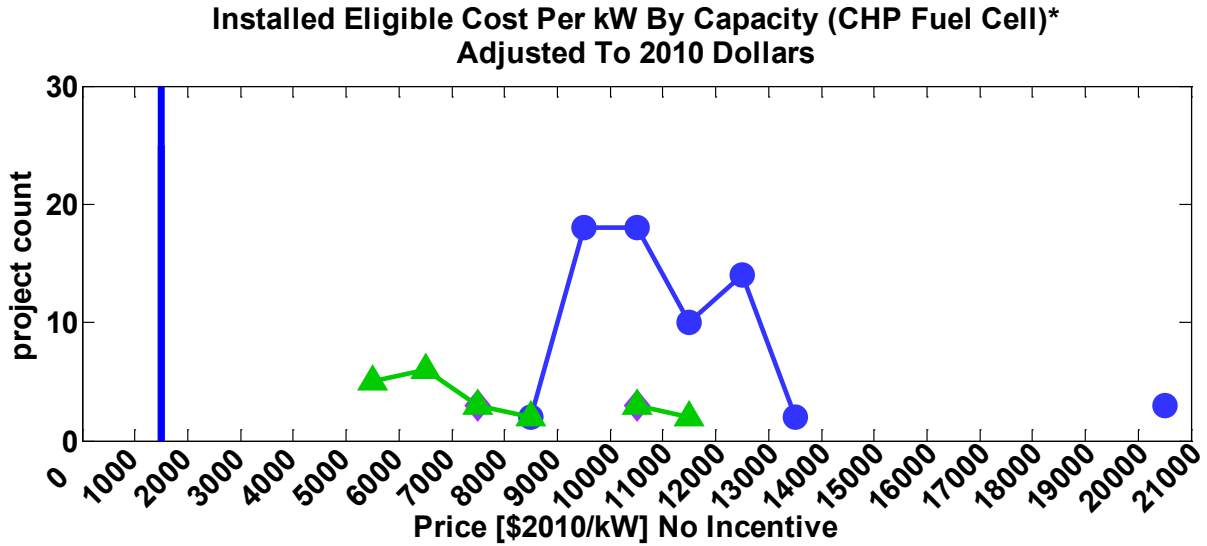


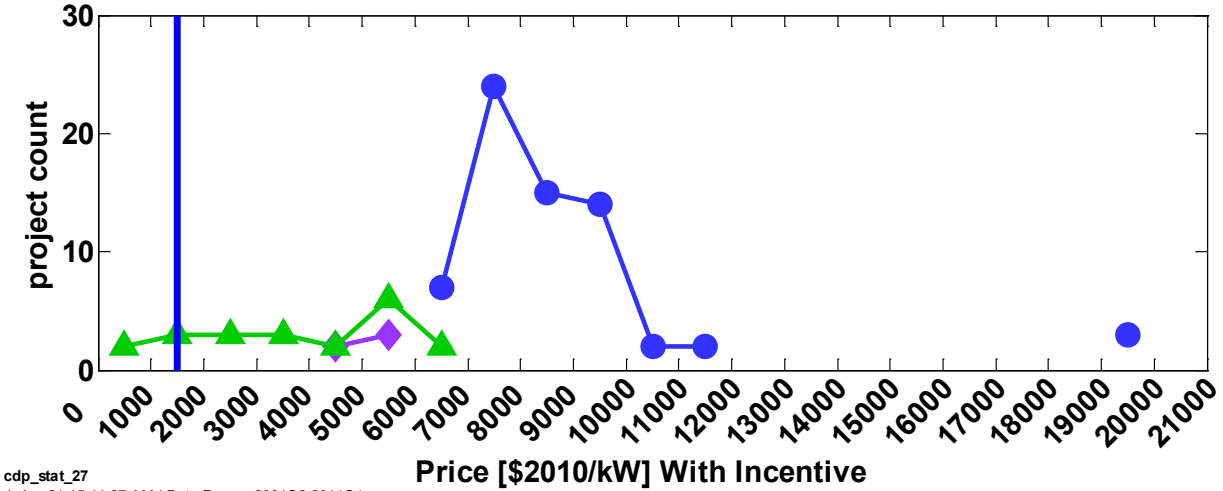


California SGIP – Fuel Types

- Annual installed capacity has been steadily climbing since recession dip
- Digester gas projects have made a comeback in 2014, but still lag natural gas in total capacity
- Digester gas projects have the lowest average and median costs ($/kW), but also the largest range

CDP-STAT-27
Installed Eligible Cost per kW By Capacity (CHP Fuel Cell)





Average Prices No Incentive, Incentive
0-50 kW = $11,303/kW, $8,809/kW
51-200 kW = $NaN/kW, $NaN/kW
201-400 kW = $9,165/kW, $5,316/kW
401+ kW = $7,608/kW, $3,706/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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†installed cost for the year 2020, operating on natural gas. May not include all costs reported in CA SGIP.

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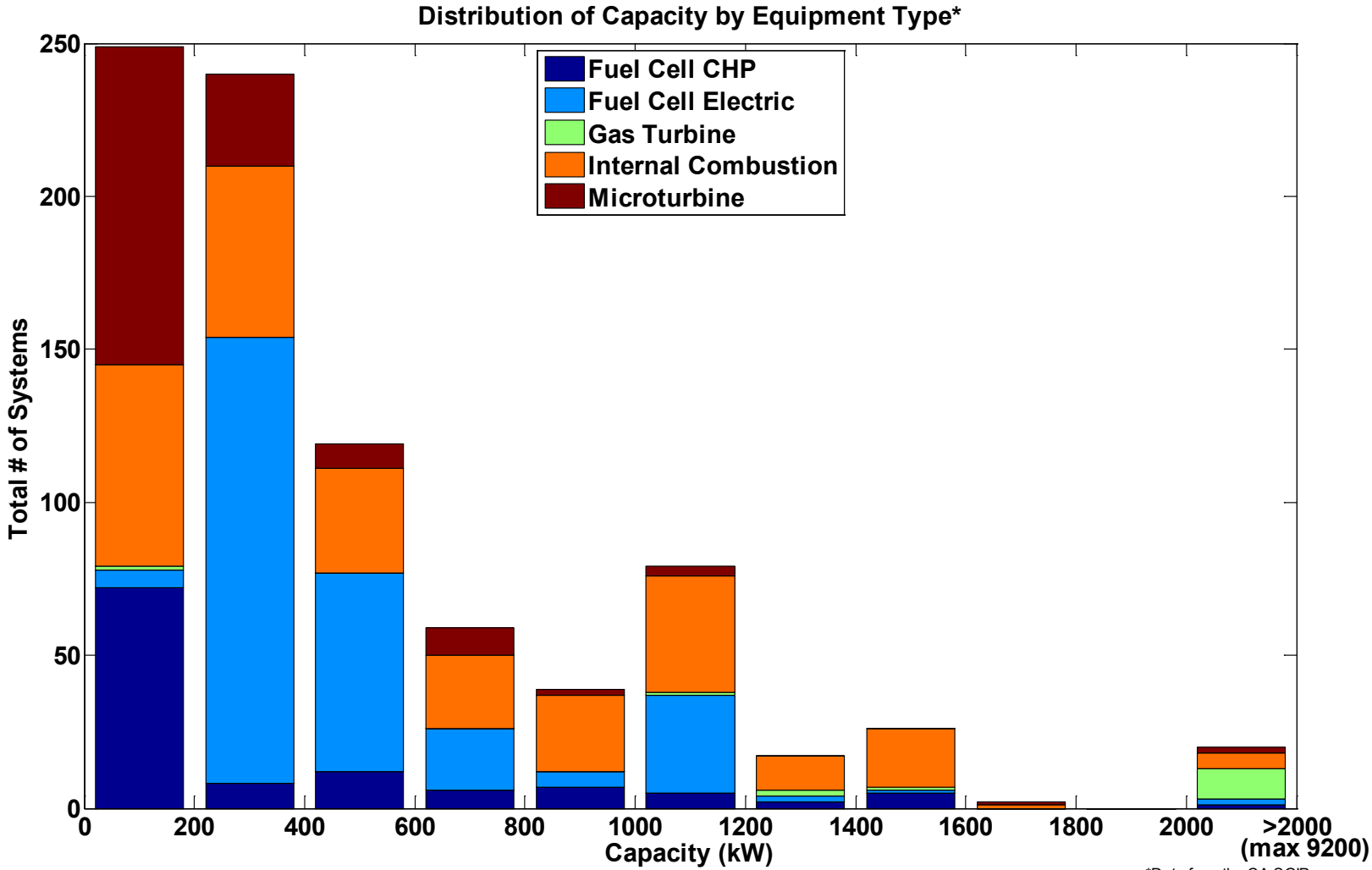
CDP-STAT-14
Distribution of Capacity by Equipment Type



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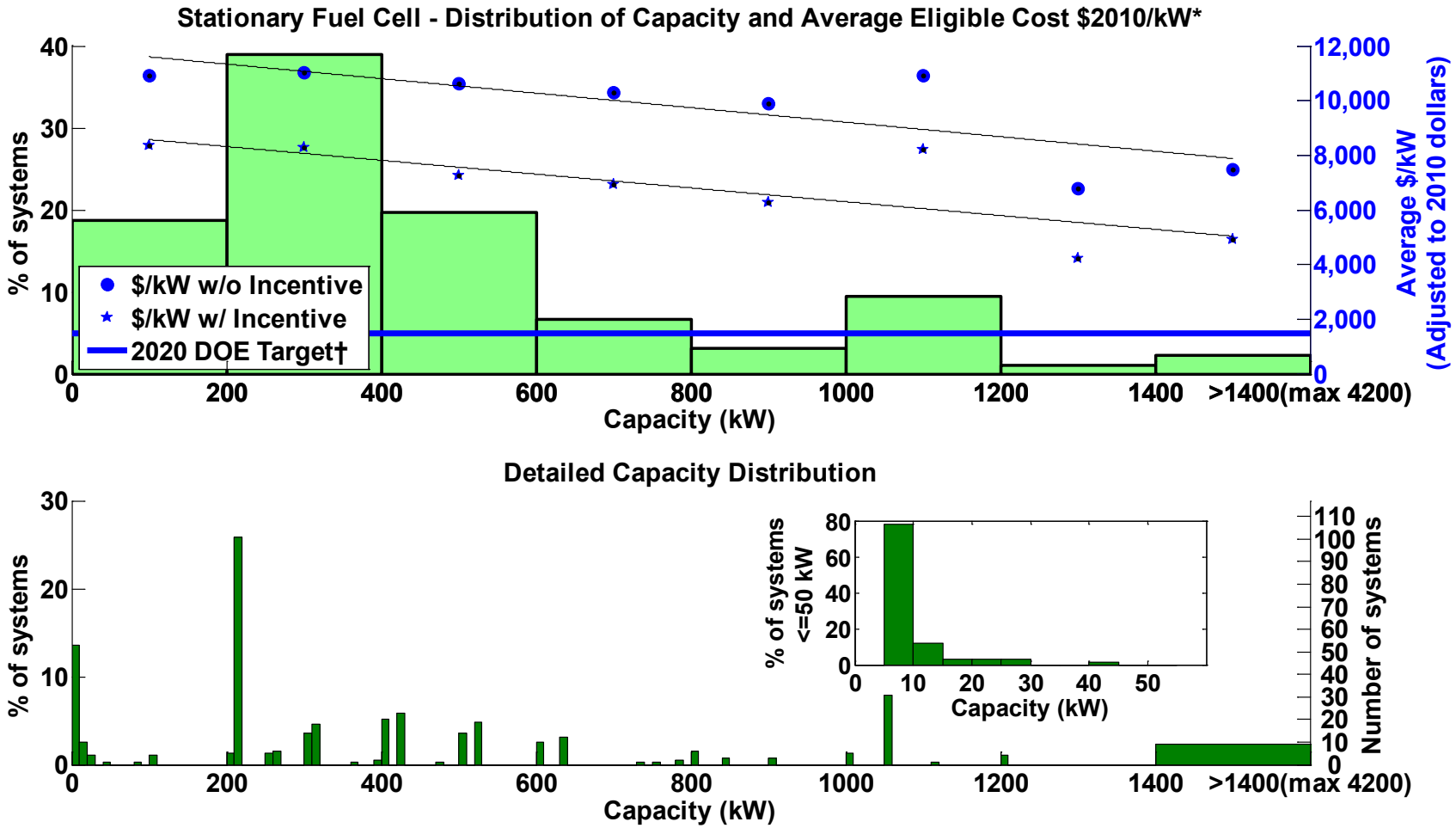
*Data from the CA SGIP.

CDP-STAT-06
Fuel Cell Stationary Capacity and Average Prices



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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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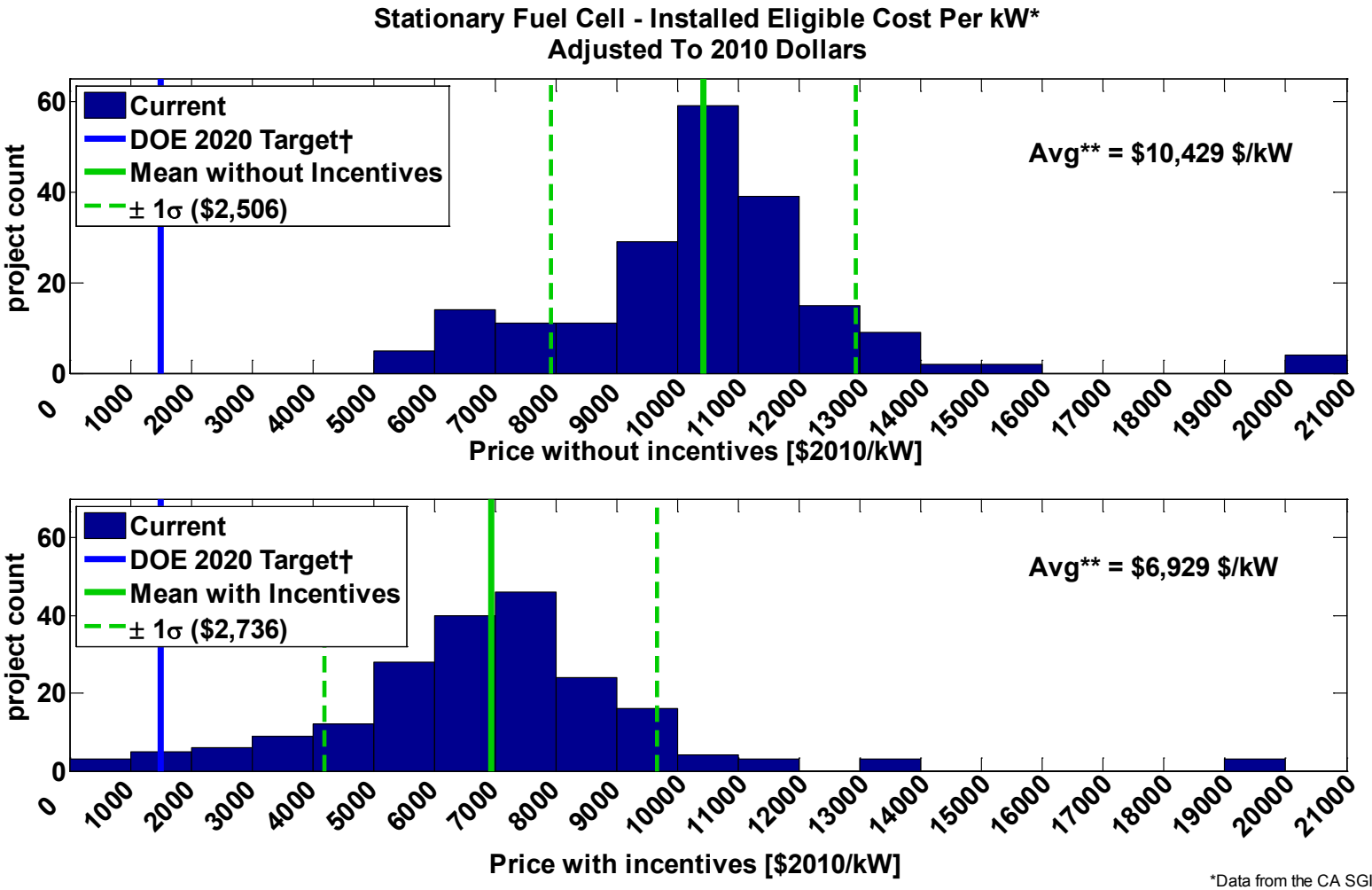
CDP-STAT-07

Distribution of Stationary Fuel Cell Install Price with and without Incentives



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NREL cdp_stat_07
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