Fuel Cell Combined Heat and Power Commercial Demonstration

Kriston Brooks

Pacific Northwest National Laboratory

June 19, 2014

Project ID# MT006

Overview

Timeline

- Start: Aug. 2010
- Project End: Oct. 2014*
- Percent complete: 80%

Budget

- FY13 DOE Funding: $0K
- Planned FY14 DOE Funding: $200K
- Total DOE Project Value: $2400k
  - Includes $473k for subcontracts
  - Contractor cost share $684k

Barriers

F. Inadequate user experience

H. Stakeholder lack of awareness of applications

I. Lack of information on combined energy efficiency and renewable technologies

Partners

- Project Lead — Pacific Northwest NATIONAL LABORATORY
- Fuel cell supplier — ClearEdge POWER, Power Your Independence.™
- Fuel cell users
  - Portland Community College
  - Roger's Gardens
  - Oakland Hills Tennis Club
  - Fresh & Easy

*Project continuation and direction determined annually by DOE

Relevance

Overall Objective: To demonstrate combined heat and power FCSs, objectively assess their performance, and analyze their market viability in commercial buildings.

Barriers Addressed This Reporting Period

F. Inadequate user experience

- Complete collection of data on original systems (CE5)
- Begin collection of data on upgraded systems (M5)

I. Lack of information on combined energy efficiency and renewable technologies

- Evaluate efficiency, performance and reliability (Engineering)
- Evaluate system life cycle cost (Economics)

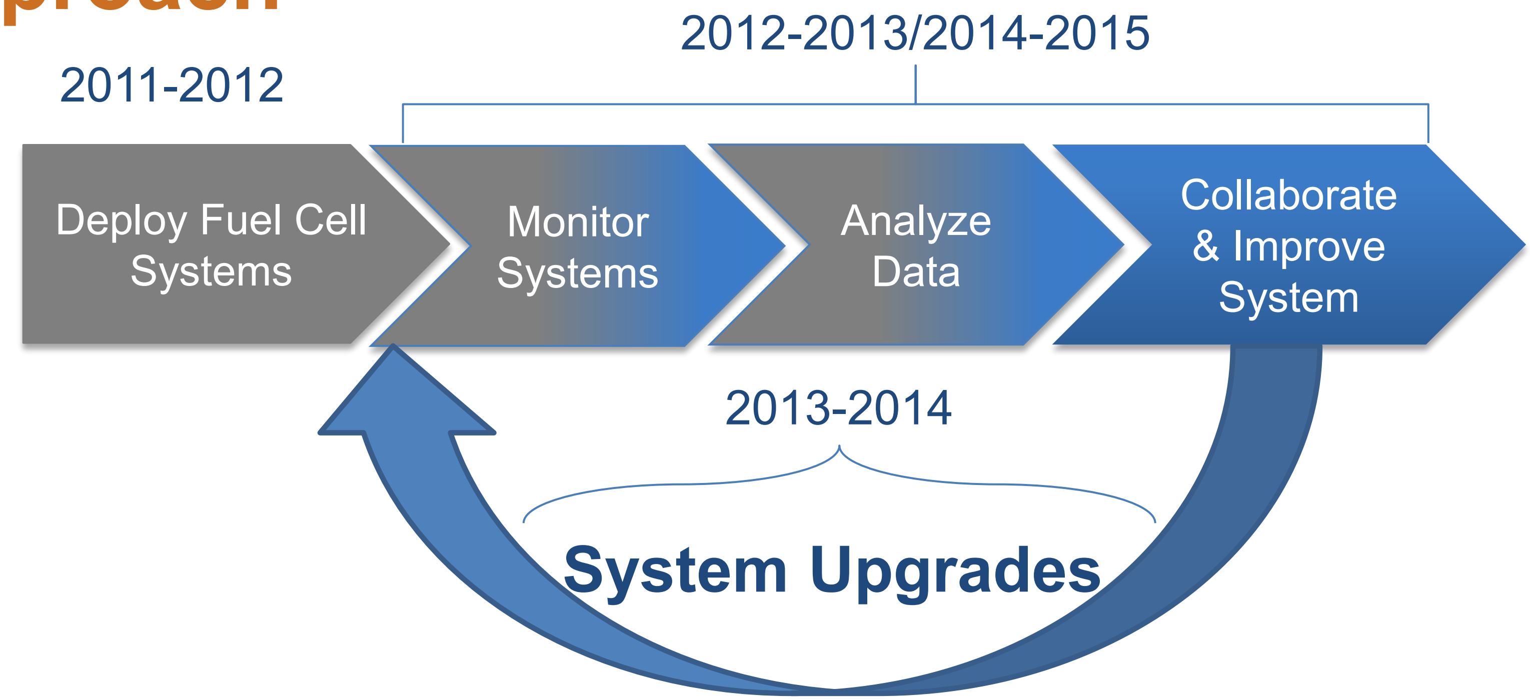
H. Stakeholder lack of awareness of applications

- Prepared and published a business case
- Published and presented results of economic/engineering analysis

CHP FCS Value Proposition

- Demonstrate CHP fuel cells as:
  - An environmentally-friendly technology
  - Moving toward cost competitive with conventional technologies
  - Reducing risk of electric grid disruptions and enhancing energy reliability
  - Providing stability in the face of uncertain electricity prices
  - Supporting applications such as base-load backup power, or a foundation for renewable power
  - Reducing the need for new transmission and distribution (T&D) infrastructure and enhanced power grid security

Approach

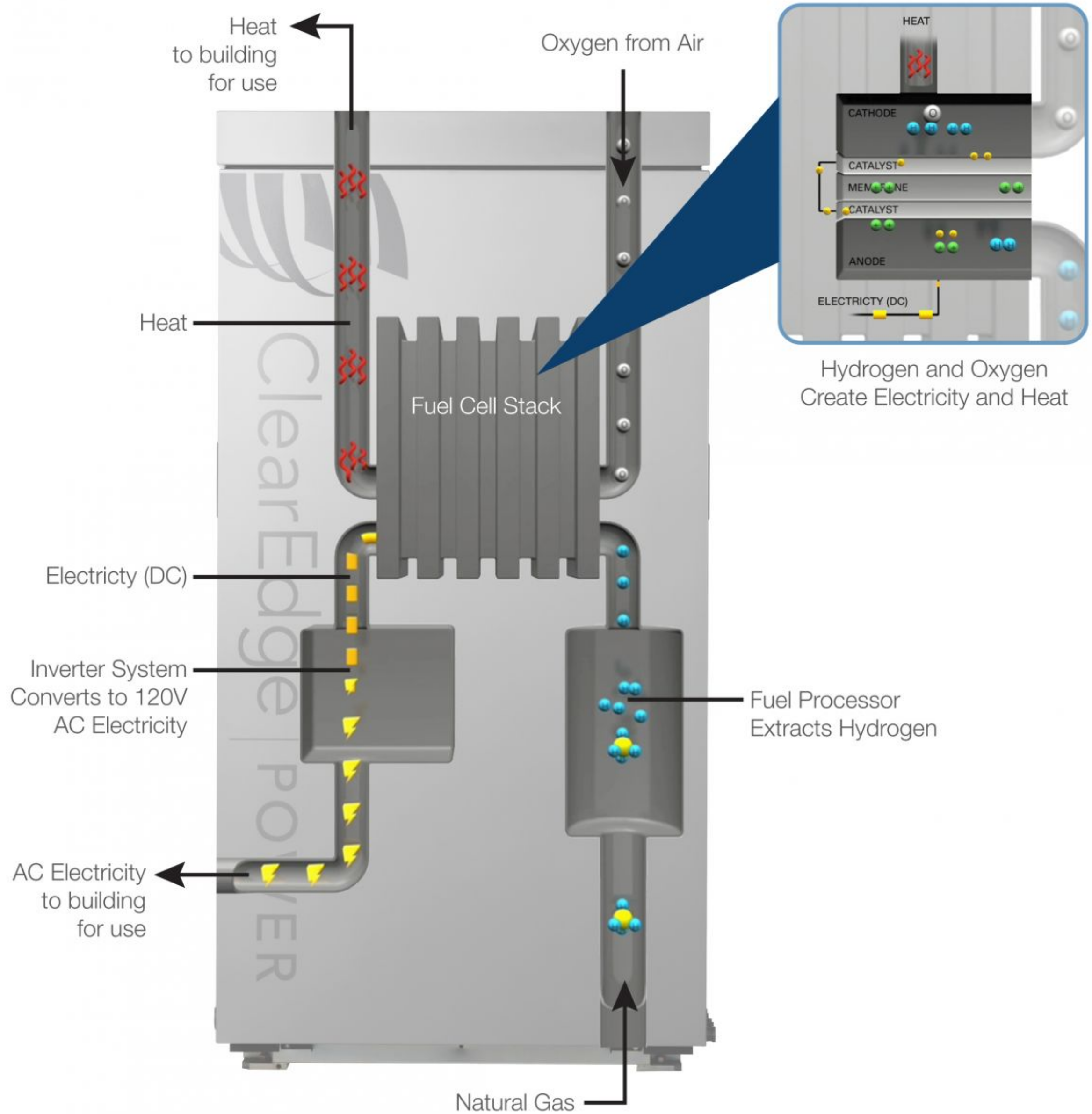


- Demonstrate fuel cells in a range of commercial applications
  - Assist in funding the demonstrations
- Independently assess their performance
- Analyze the market viability
- Share the results with national laboratories, trade groups, potential customers and industry
- Improve the systems and implement improvements
- Repeat process with upgraded system

Approach
Deploy Fuel Cell CHP

ClearEdge Power

- 5 kWe fuel cell
- 5.5 kWt hot water at 40-50°C
- Hydrogen from reformed natural gas



Approach

Monitor Systems/Analyze Data: Installation Sites

Partner	Sector	Heat Usage	Number of FCSs	Data Collection Start Date	# of Days of Operation as of 3/1/14	Date of M5 Upgrade
Portland Community College – Sylvania, OR	College	Pool	**2**	9/21/11	680	2/2014
Roger's Gardens – Corona Del Mar, CA	Plant Nursery	Space Heating	**3**	11/26/11	830, 640, 640	7/2013 2/2014
Oakland Hills Tennis Club – Oakland, CA	Recreation	Pool and Spa	**5**	12/15/11	658, 651, 651, 641, 783	8/2013 1/2014
Fresh & Easy – San Francisco, CA	Grocery Store	Space Heating in Freezer Section	**5**	3/1/12	487 (Not currently operating)	Not upgraded
Total			**15**			

Comparison to Other Studies

- Scale
  - Micro-CHP is a unique range: 5-50 kWe
  - Other FCS/CHP manufactures focus on:
    - Large-scale industrial/ commercial applications: >100 kWe
    - Residential Market: < 7 kWe
- Application
  - Small commercial buildings
- Duration
  - Longer term evaluation than has been done previously
  - 5 year evaluation period as compared to 3-6 months typically done previously
  - Allows us to track system degradation and system development

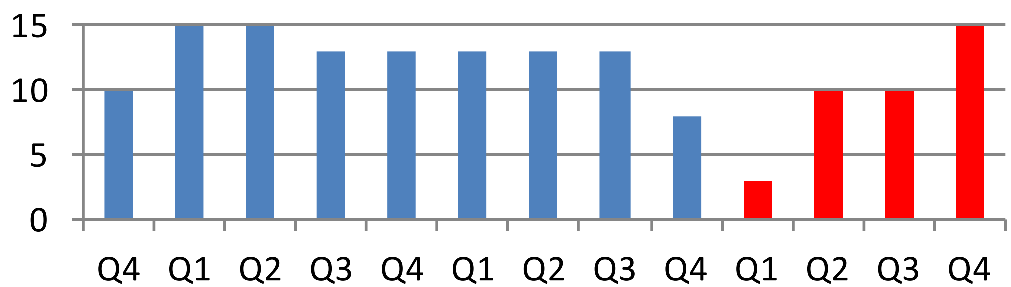
Data Monitoring and System Analysis

- Cost Information
  - System Cost, Federal Incentives
- Data Collection Rate = 1 sec/30 sec
- Electricity and Heat Produced
  - Natural Gas Usage (slpm)
  - Electricity Produced (kWe)
  - Estimated Heat Produced (kWt)
  - Water Temperature to Site (°C)
  - Calculate electrical and thermal efficiency (HHV)
- Two sites have additional monitoring
  - Heat/Electricity utilized by the facility
- Overall Availability (> 1 kWe)
- Reasons for systems being unavailable
  - Premature part failure, human error, preventive maintenance, facility downtime

Project History

Changes	Number of Units Involved in the Change												
		FY12				FY13				FY14			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Initial Deployment (CE5)	10	5											
Set Point Change (5 kWe--> 4 kWe)		15									Now		
BOP Upgrades (CE5)				8									
CE5 Shutdown for Site Maintenance				2									
CE5 Shutdowns for New M5 Upgrade									7	6			
New System Upgrade (M5)									2	1	7		5

Number of Units Collecting Data



- Initial Deployment
  - **CE5:** High Temperature PEM (PBI), 5 kWe setpoint
- New System Upgrade
  - **M5:** Phosphoric Acid Fuel Cell, 5 kWe setpoint, continuous power capable

System Upgrade from CE5 to M5

- New generation prototype units, PureCellÈ System Model 5 (M5), installed at no cost to DOE
  - Two units in July/Aug. 2013
  - Eight units in Jan./Feb. 2014
  - Five remaining units not yet installed. May installation
- Phosphoric Acid (UTC Power Technology)
  - Stability: 10 year life rather than 5 year
  - BOP Improvements:
    - Upgrades from CE5
    - Front access
    - Glycol cooling
  - Grid independent, load following
- Total hours of operation M5 as of March 31, 2014: 27,768 hrs

Roger's Gardens:
New unit - M5 on the left
Old unit - CE5 on the right

Recently Completed and Future Milestones

Milestone	Completion Date	Status
Finalize Micro-CHP FCS Business Case	October 2013	Complete and published as PNNL technical report
Journal Article of FCS Business Case	March 2014	Submitted to JFCST
Outreach Materials	June 2014	Submitted to ACEEE
Quarterly Data Analysis Updates	Various	Ongoing
Issue Final Report on Micro-CHP Demonstration	July 2015	Could be extended to September 2017 with additional funding

Summary of Accomplishments in Previous Years

- Deployed CHP FSC
  - Contracted ClearEdge Power
  - Deployed all of the planned 15 CHP FCS
- Monitored System
  - Initiated remote monitoring of units
  - Collected 26 parameters at 1 second intervals
- Average operation 14,684±2563 hours
  - Analyzed **21 billion** points of recorded data as of 03/31/2014
  - Increased the parameters collected
- Recommended improvements resulting in fuel cell stability
- Evaluated GHG reduction
- Performed economic analysis compared to conventional technologies

Summary of Accomplishments This Year

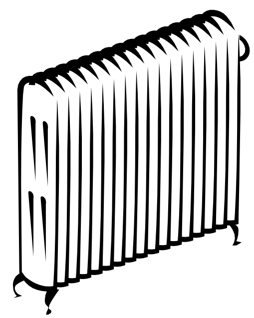
- Completed "Business Case for a Micro-Combined Heat and Power Fuel Cell System in Commercial Applications" (PNNL-22831)
- Completed evaluation of the CE5 data
- Comparison of CE5 and M5 data
- Determined heat utilization for augmented instrumentation
- Presented work in various forums

Engineering Results (CE5 Units)

Electrical Power

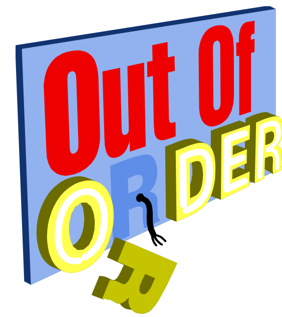
4.1 kWe

Heat Produced



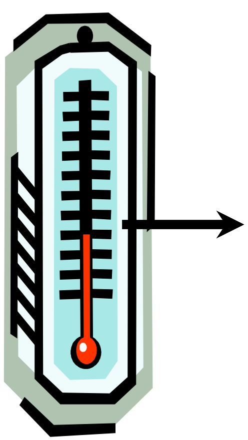
4.6 kWt

Availability



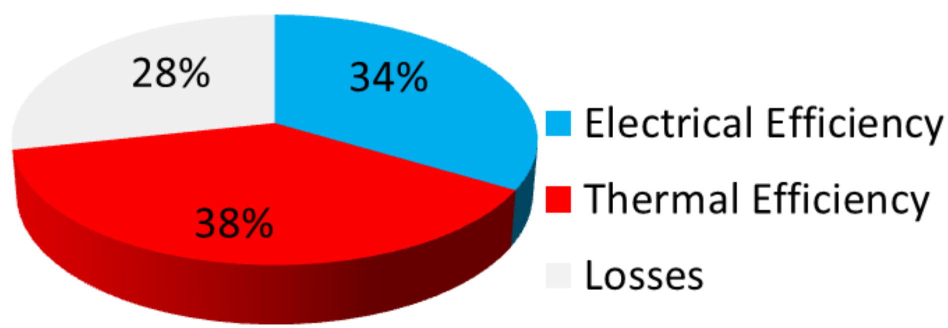
93.4%

Water Temperature



123°F

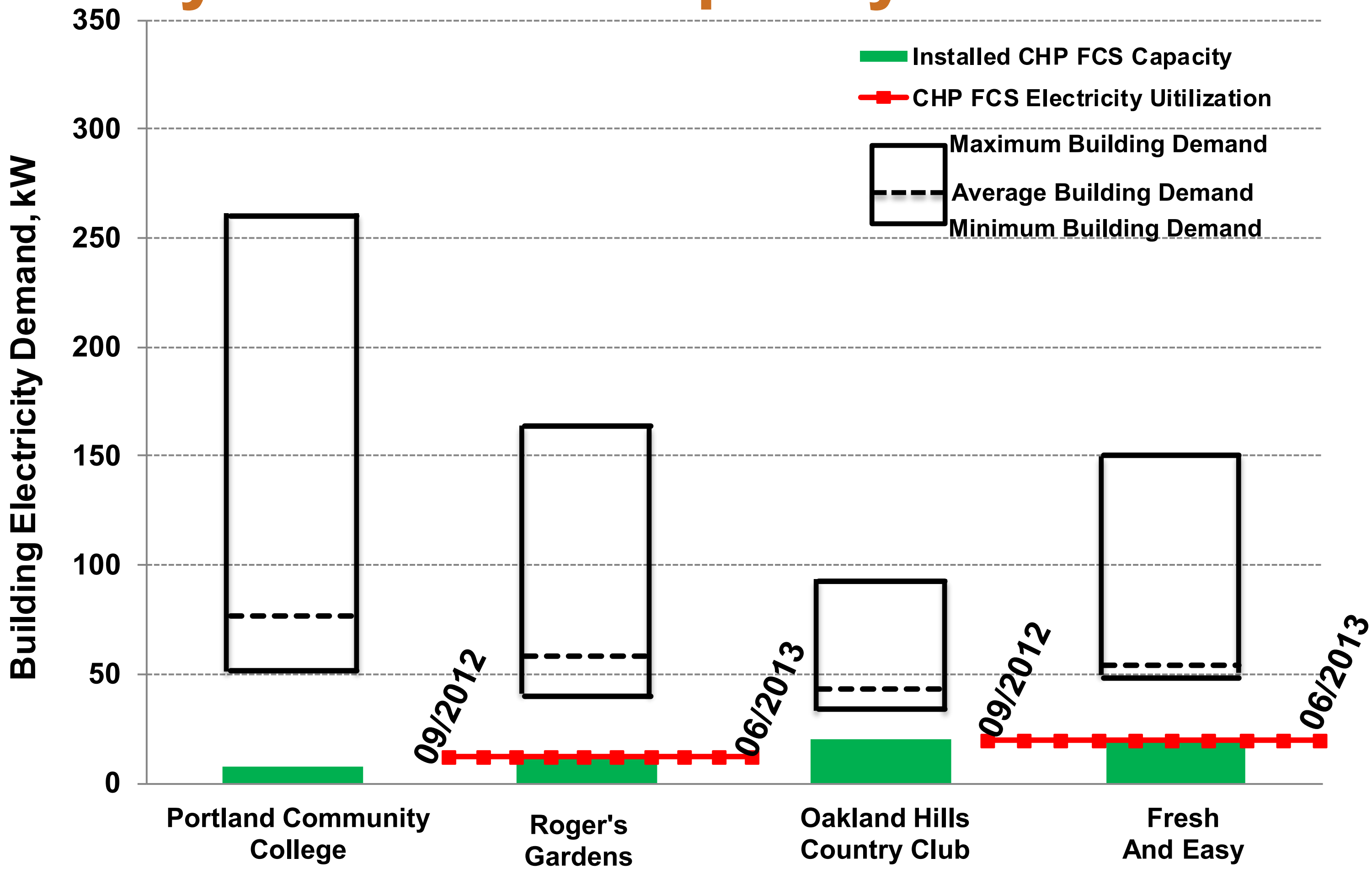
System Efficiency (HHV)



Total Efficiency = 71.6%

Based on 109,946 hours of run time

Electricity: Installed Capacity vs. Utilization

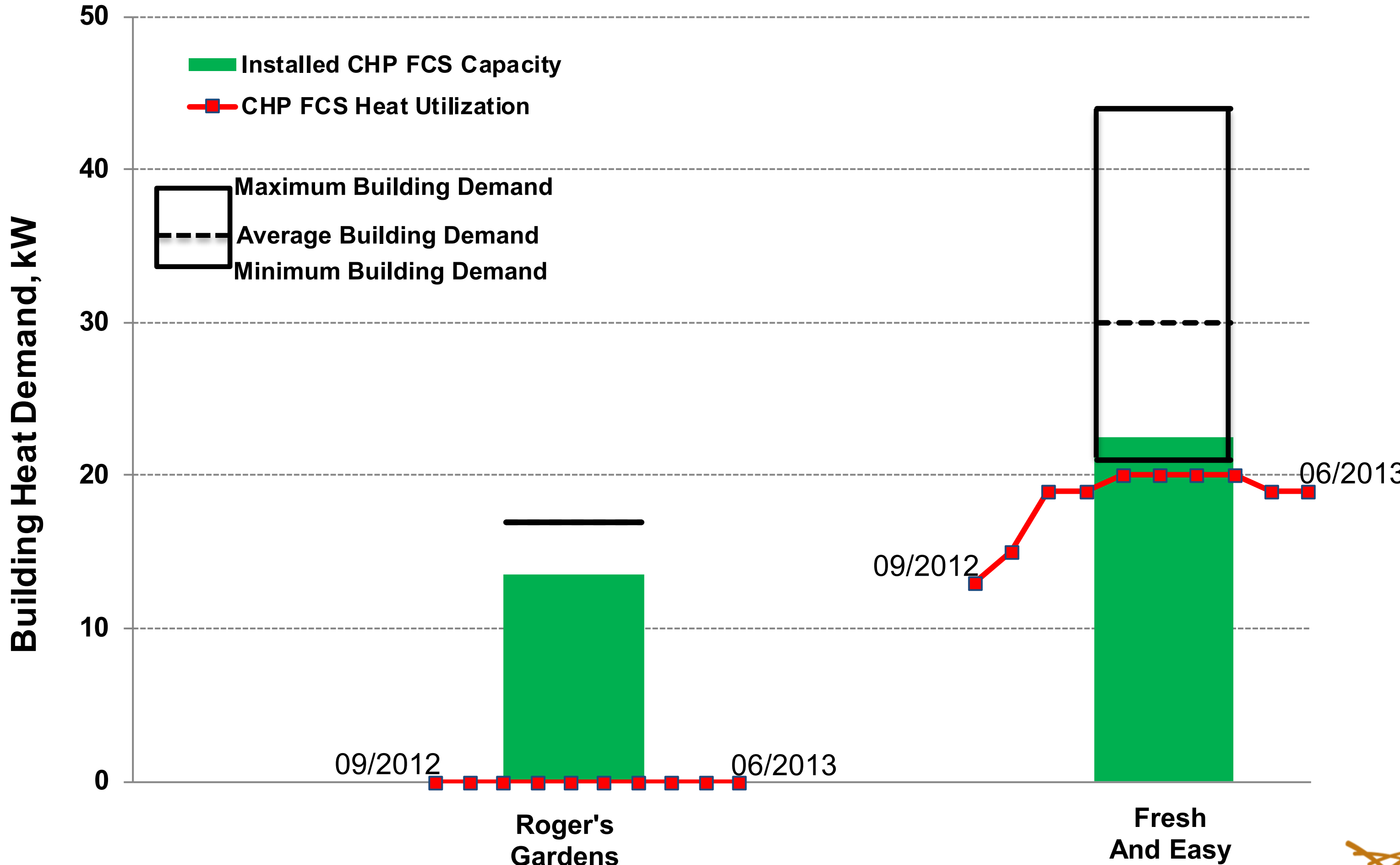


Electricity usage data is collected for Roger's Garden and Fresh & Easy

- **100% of the CHP FCS electricity is utilized**
- **Note: CHP FCS power less than minimum building demand by design**

Pacific Northwest
NATIONAL LABORATORY
…rated by Battelle *Since 1965*

Heat: Installed Capacity vs. Utilization

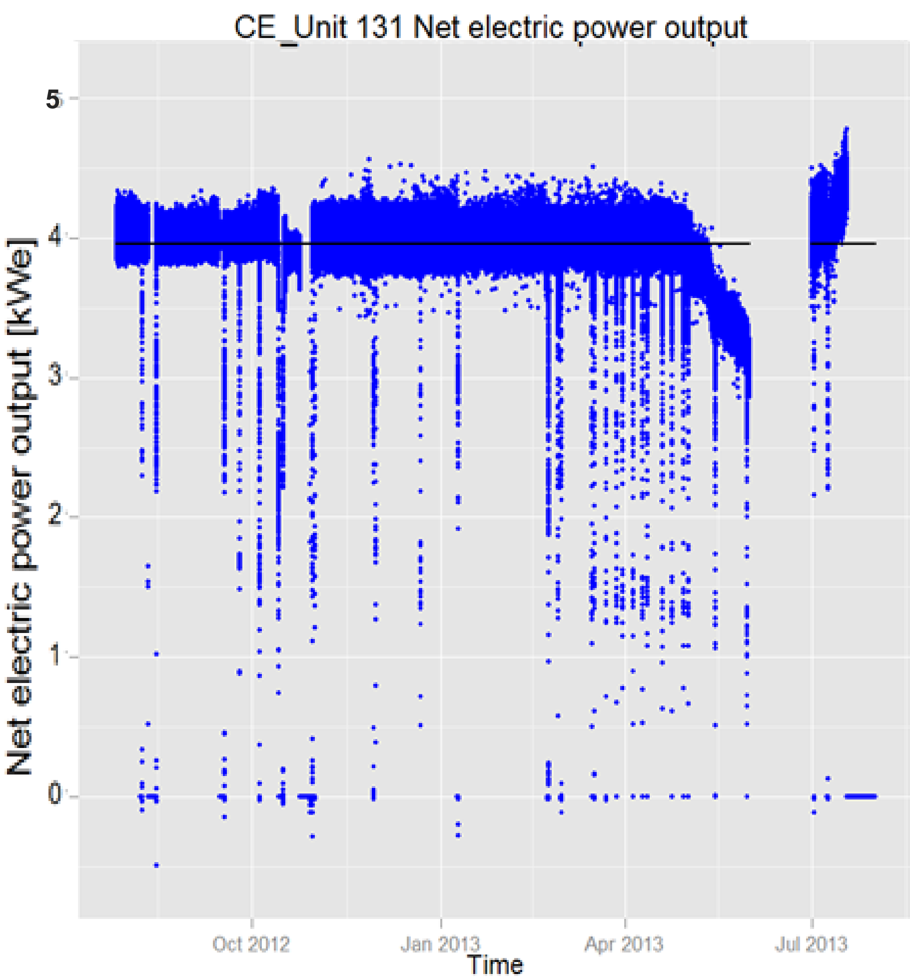


Roger’s Garden was found not to be using the heat being generated

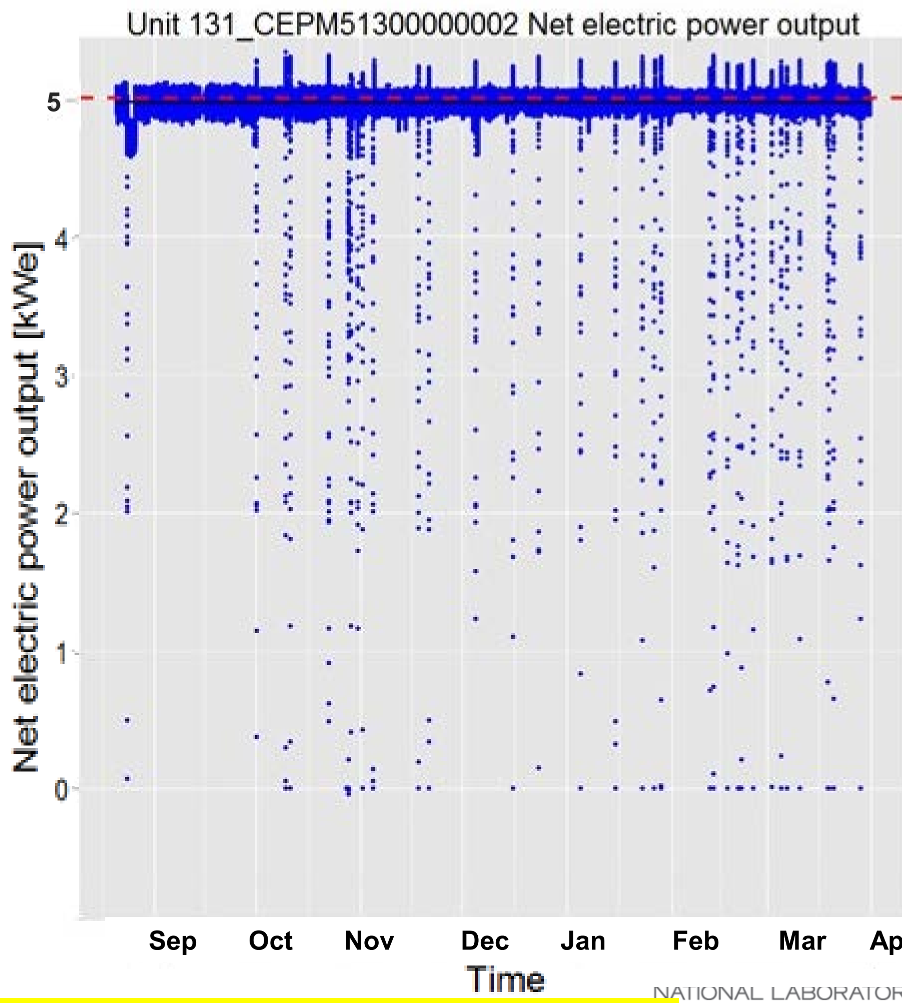
Accomplishments

CE5 vs. M5: Comparison of Power Output

CE5 (August 2012 – January 2013)



M5 Unit (August 2013– March 2014)

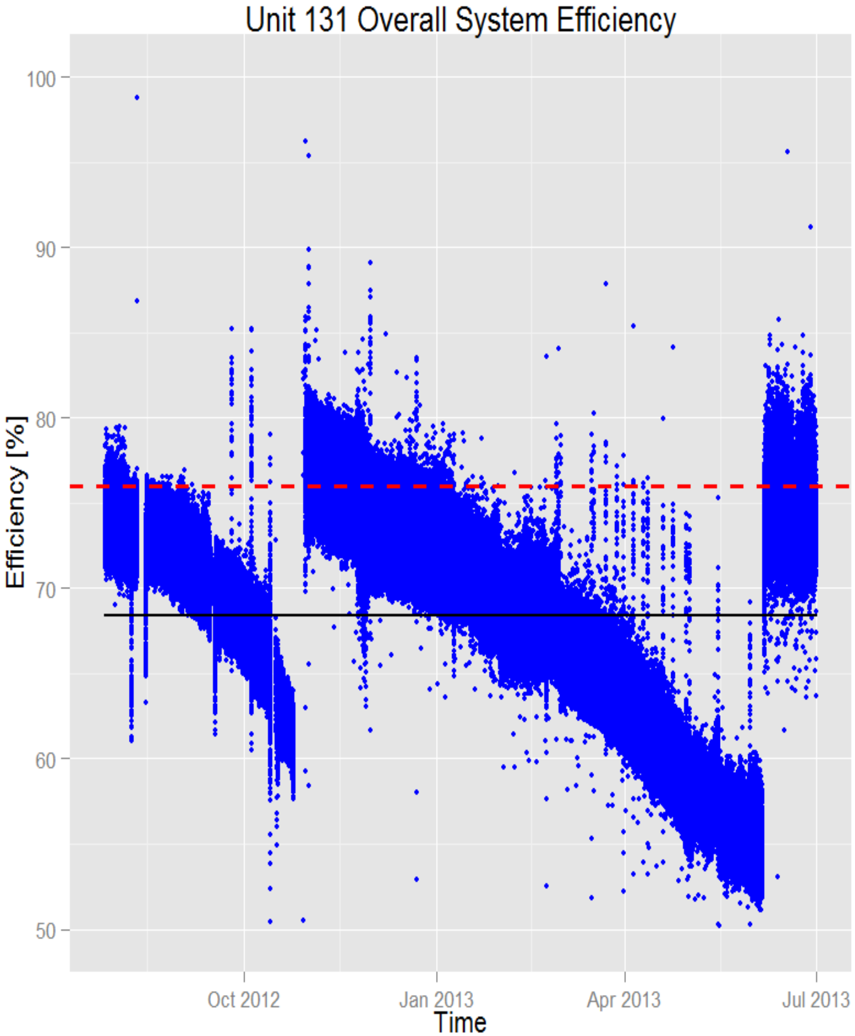


M5 capable of maintaining 5 kWe, CE5 not

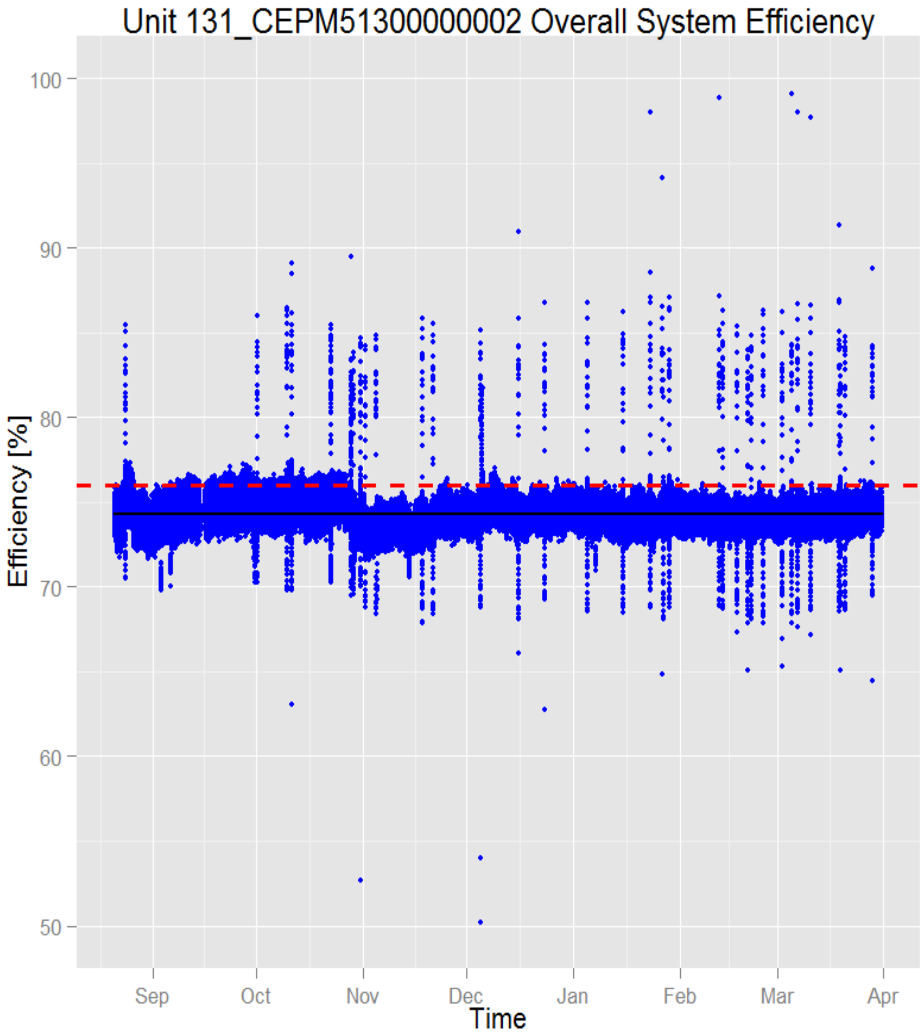
Accomplishments

CE5 vs. M5: Comparison of Efficiency

CE5 (August 2012 – January 2013)



M5 Unit (August 2013– March 2014)



M5 Stability Significantly Improved

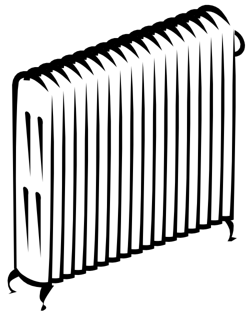
Accomplishments

Engineering Analysis of New "M5" Compared to to "CE5" CHP FCS

Electrical Power

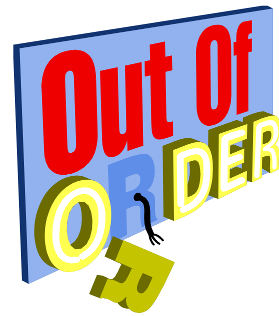
4.1 → 4.9 kWe

Heat Produced



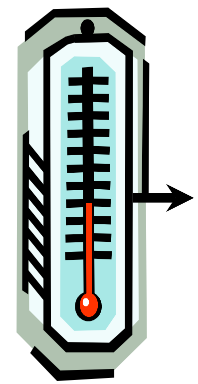
4.6 → 5.6 kWt

Availability



93% → 98%

Water Temperature

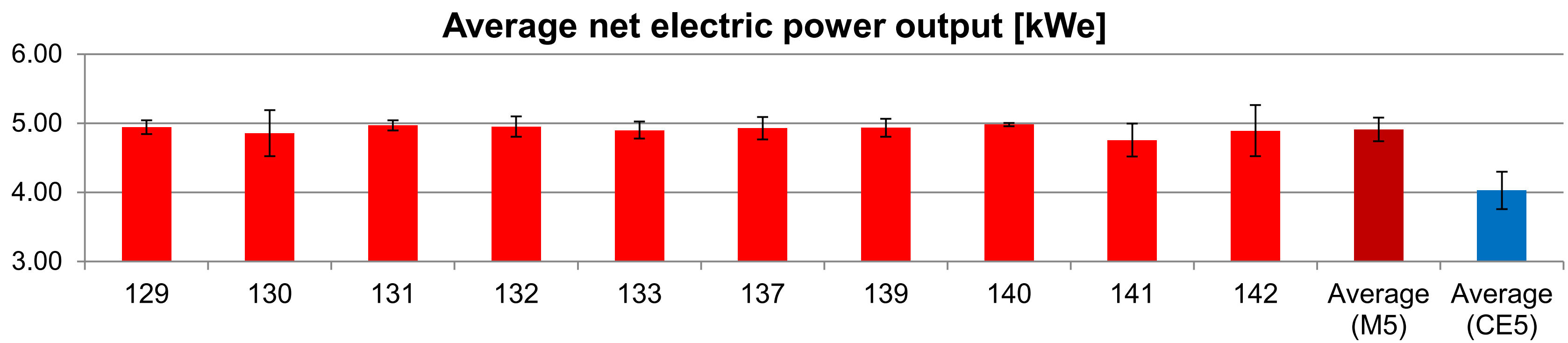


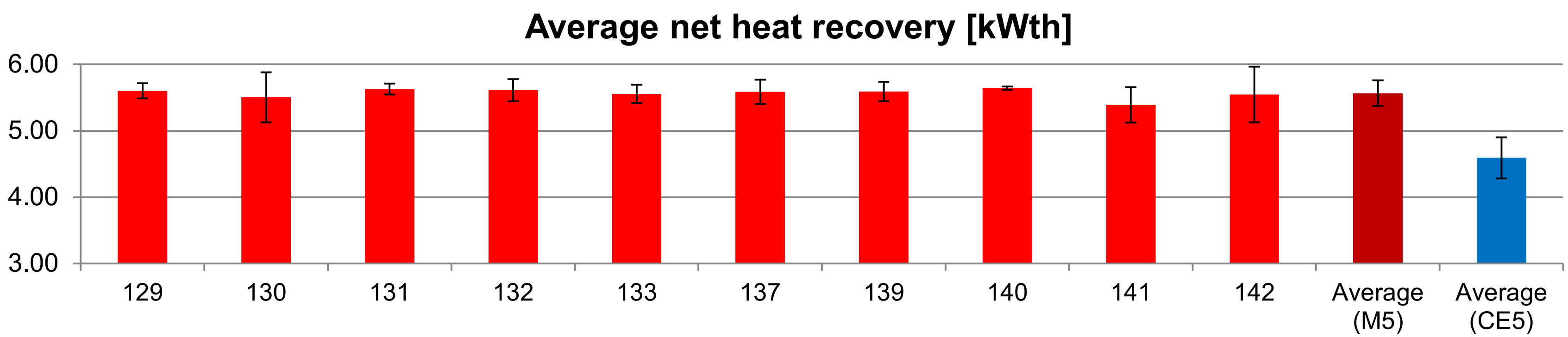
123°F → 106°F

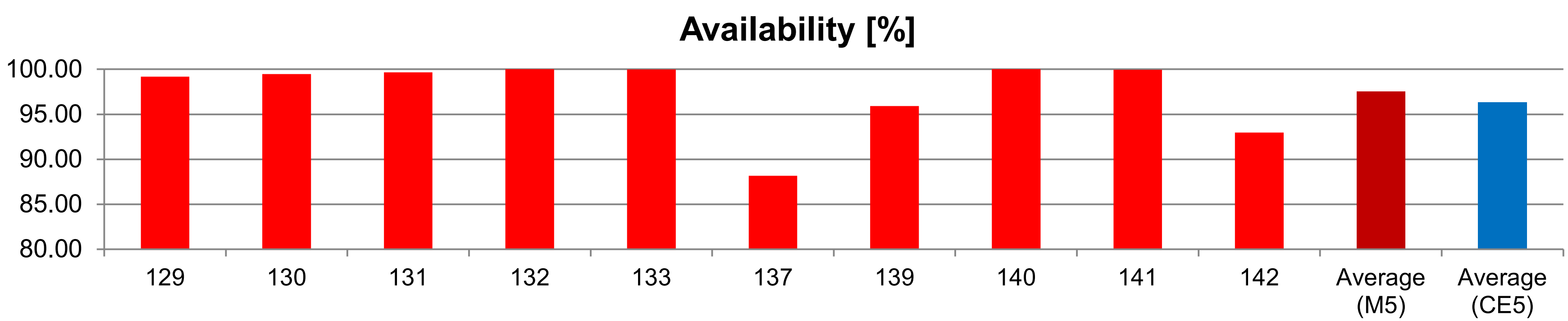
Unit #	Days of Operation	Average net electric power output [kWe]	Average net heat recovery [kWth]*	Temperature to site [°C]	Average net system electric efficiency [%]	Average net heat recovery efficiency* [%]	Overall net system efficiency [%]	Availability A_o
129 (PCC)	32	4.94 ± 0.1	5.6 ± 0.11	49.18 ± 1.18	36.51 ± 0.73	41.38 ± 0.82	77.89 ± 1.55	99.18
130 (PCC)	32	4.86 ± 0.33	5.51 ± 0.38	45.22 ± 1.31	36.47 ± 0.79	41.33 ± 0.89	77.8 ± 1.67	99.48
131 (RG)	248	4.97 ± 0.07	5.63 ± 0.08	46.54 ± 5.86	34.81 ± 0.35	39.45 ± 0.39	74.26 ± 0.72	99.68
132 (RG)	58	4.95 ± 0.15	5.61 ± 0.17	44.02 ± 4.43	34.69 ± 1.99	39.32 ± 2.26	74.01 ± 4.25	100.00
133 (RG)	58	4.9 ± 0.12	5.55 ± 0.14	56.07 ± 2.47	35.81 ± 1.11	40.59 ± 1.25	76.4 ± 2.35	99.97
137 (OHTC)	94	4.93 ± 0.16	5.59 ± 0.18	54.53 ± 2.99	34.05 ± 0.67	38.59 ± 0.76	72.64 ± 1.42	88.16
139 (OHTC)	87	4.93 ± 0.13	5.59 ± 0.15	53.84 ± 3.25	35.56 ± 0.49	40.3 ± 0.55	75.87 ± 1.03	95.92
140 (OHTC)	87	4.98 ± 0.02	5.64 ± 0.02	53.72 ± 2.79	35.71 ± 0.33	40.46 ± 0.38	76.17 ± 0.7	100.00
141 (OHTC)	77	4.76 ± 0.24	5.39 ± 0.27	52.73 ± 3.15	36.2 ± 0.61	41.03 ± 0.69	77.24 ± 1.3	99.95
142 (OHTC)	234	4.89 ± 0.37	5.55 ± 0.42	39.19 ± 5.44	35.46 ± 1.49	40.18 ± 1.68	75.64 ± 3.17	92.97
Average		**4.91 ± 0.17**	**5.57 ± 0.19**	**42.87 ± 3.29**	**35.53 ± 0.86**	**40.26 ± 0.97**	**75.79 ± 1.82**	**97.53**

Notes: Data Analysis (net system electric efficiency) is based on HHV.
* Net heat recovery data are calculated values, derived from real-time measured values.
Availability (A_o) quantifies the system operating (at or above 1 kW) time when compared to the total time since commissioning..

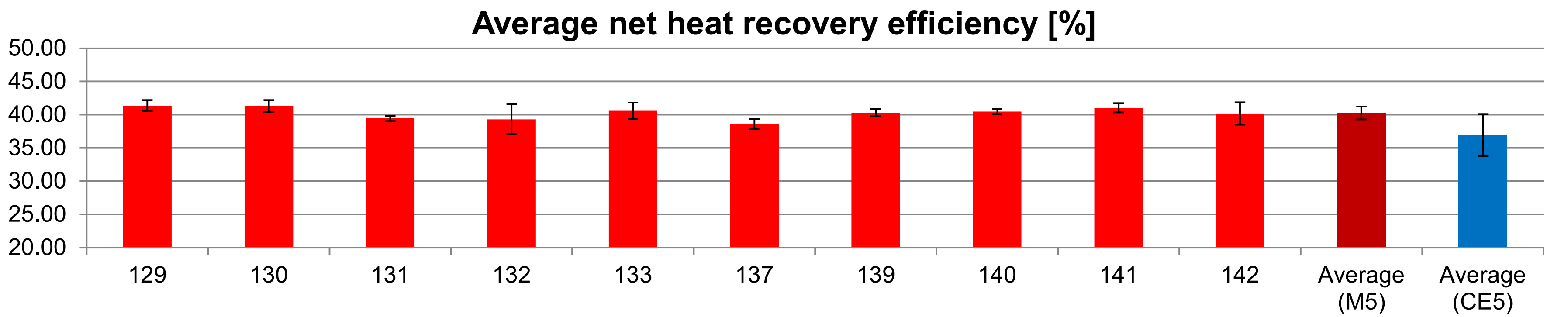
Engineering Analysis of Ten New "M5" Compared to "CE5" CHP FCS

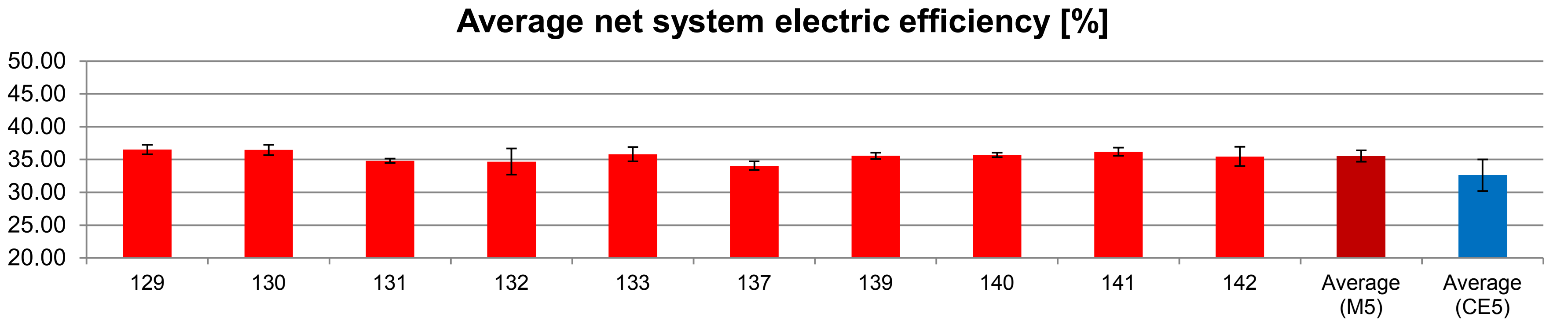


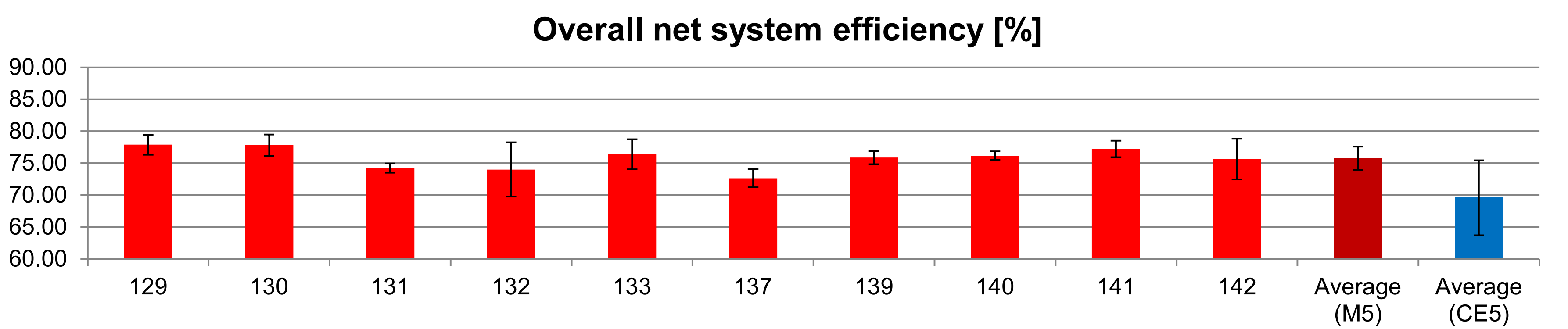




Engineering Analysis of Ten New "M5" Compared to "CE5" CHP FCS





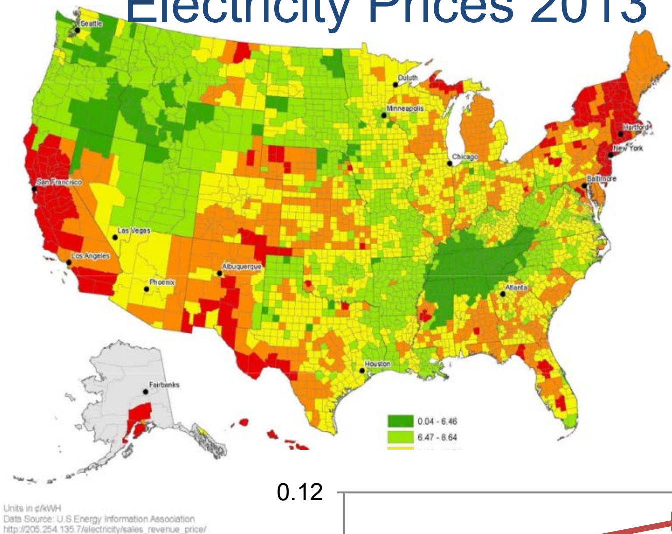


Accomplishments

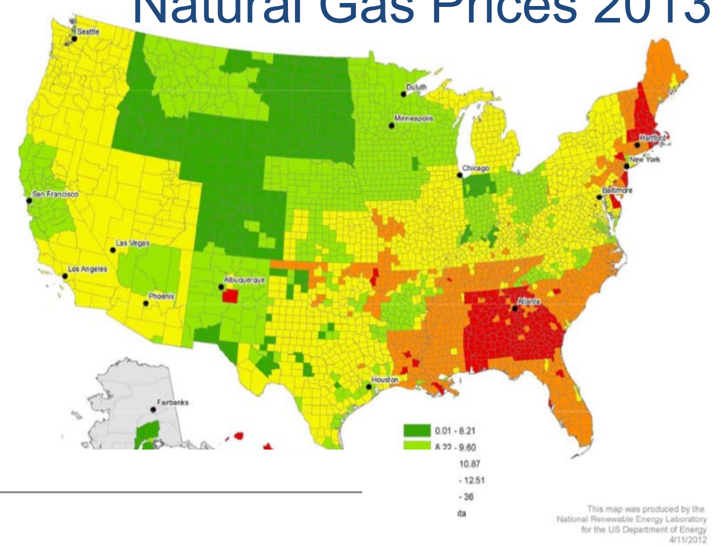
Business Case Drivers: High Spark Spread

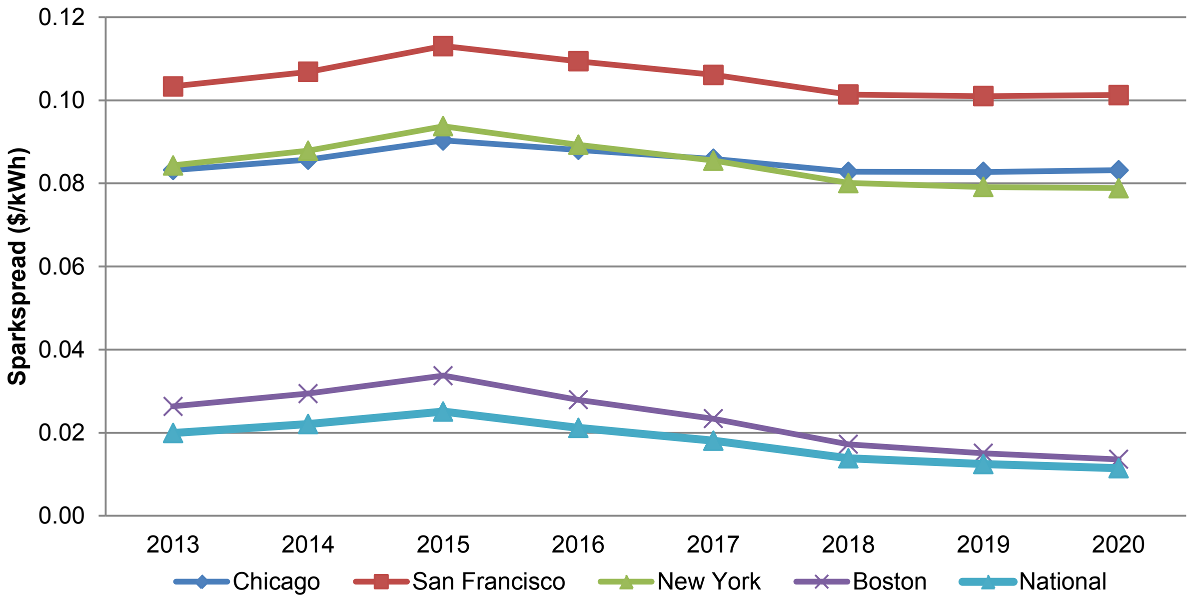
Spark Spread = power price – {natural gas price/(efficiency)}

Electricity Prices 2013



Natural Gas Prices 2013

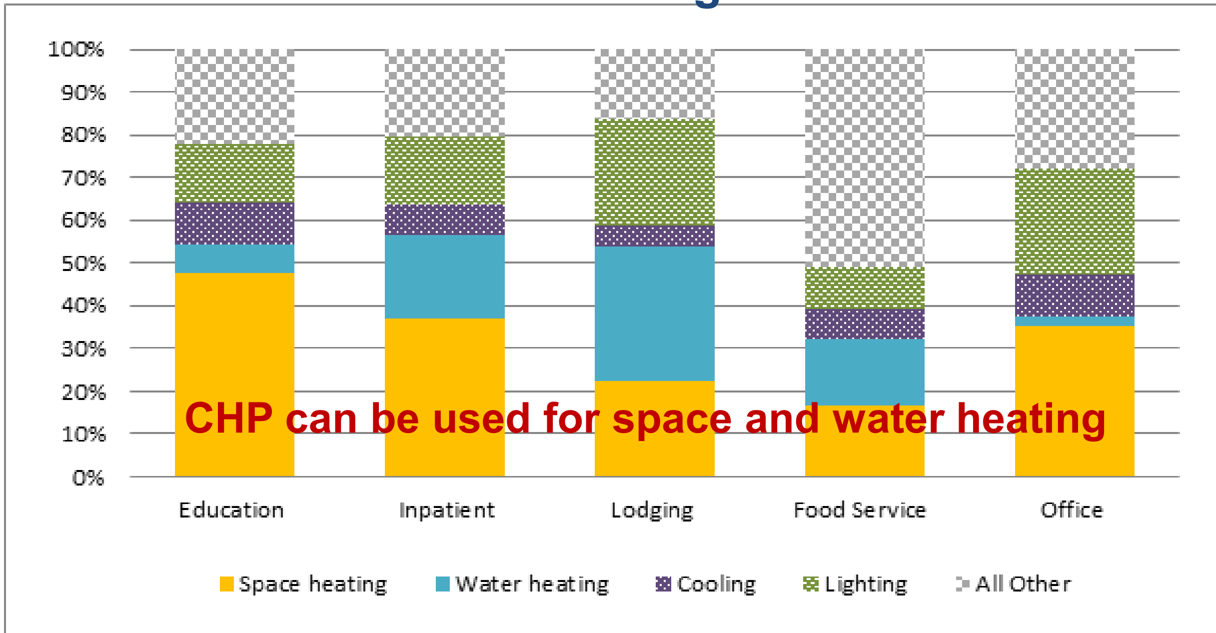




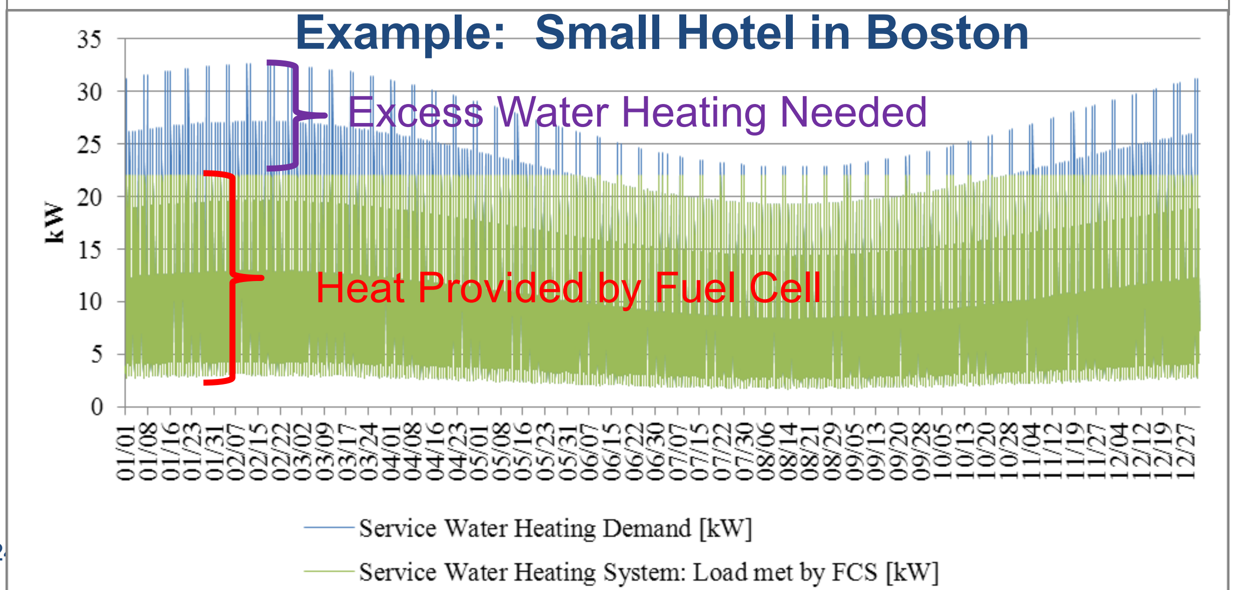
fic Northwest
NATIONAL LABORATORY
by Battelle Since 1965

Business Case Drivers: High Heat Utilization

Market Sectors with High Heat Utilization



Example: Small Hotel in Boston



Sample of Businesses Evaluated with Energy Plus Software

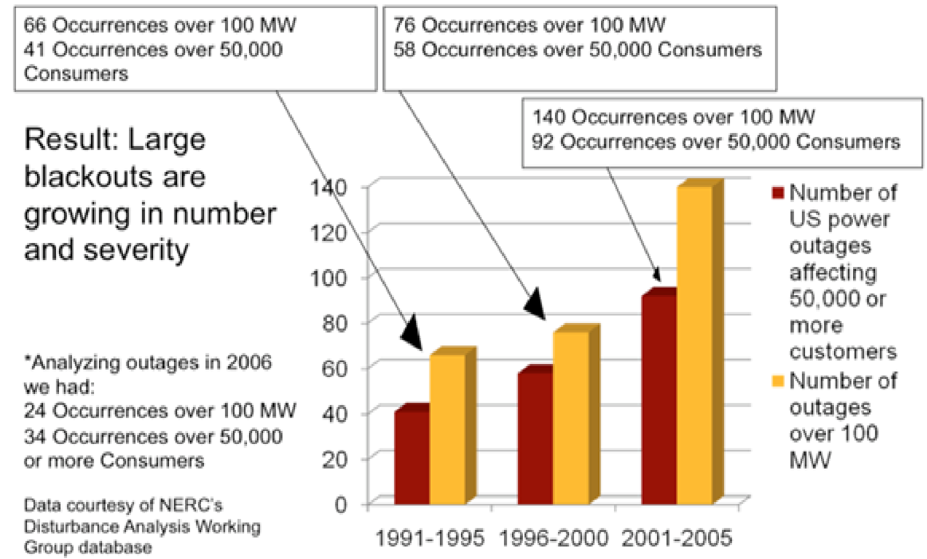
- High Heat Utilization
  - Small hotel in Boston 69%
  - School in Chicago 61%
  - Small hospital in Boston 62%
- Low Heat Utilization
  - Quick Service Restaurant in NYC 40.5%
  - Small Office in San Francisco 2.6%

Based on DOE's Commercial Reference Building Models

Accomplishments

Business Case Drivers: Grid Independence

- Yearly Cost of Power Interruptions in U.S. $30-130 Billion (LBNL 2005)
- **Single facility with modest power outages results in $12K in annual losses**
- IT Power losses can be much higher > $100K/hr



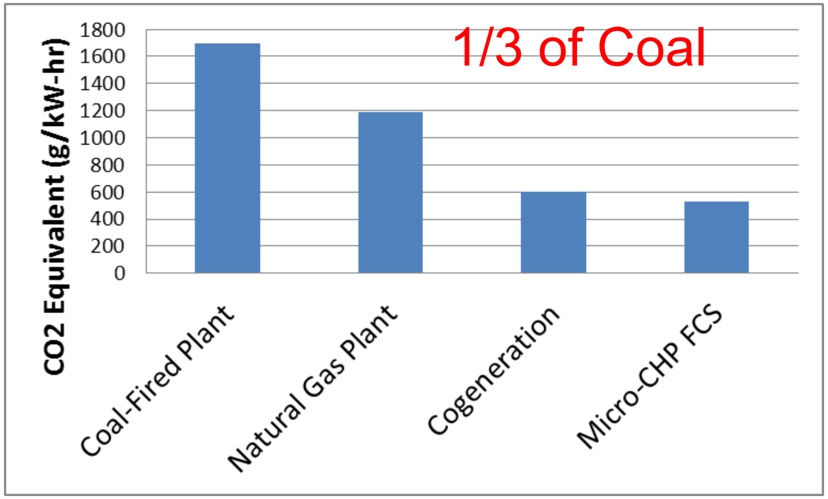
Outage Type	Outage Duration	Facility Disruption per Outage	No. of Outages per Year	Total Annual Facility Disruption	Outage Cost per Hour	Total Annual Costs
Momentary Interruptions	5.3 Seconds	15 Minutes	4	1 Hour	$4,000	$4,000
Long-Duration Interruptions	1 Hour	2 Hours	1	2 Hours	$4,000	$8,000
Total			**5**	**3 Hours**		**$12,000**

Assumptions:
- Commercial Outage Value of Service $40.60-68.20/kWh power not supplied (SAIC 2010)
- Assuming a 100 kW commercial building
- Facility disruption based on EPA estimates

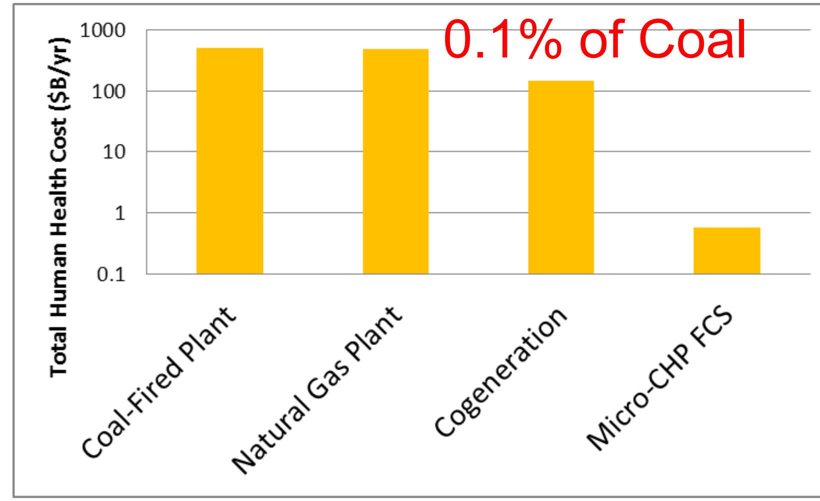
Accomplishments

Ancillary Benefits

Reduced GHG

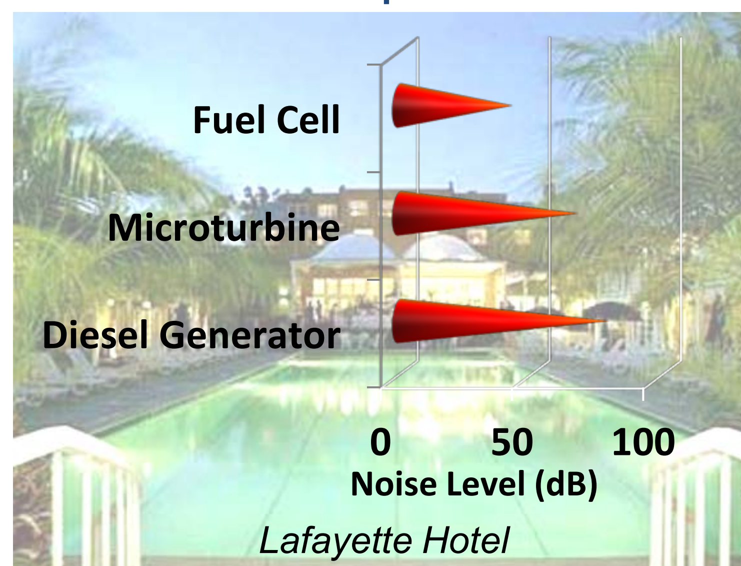


Reduced Human Health Cost*



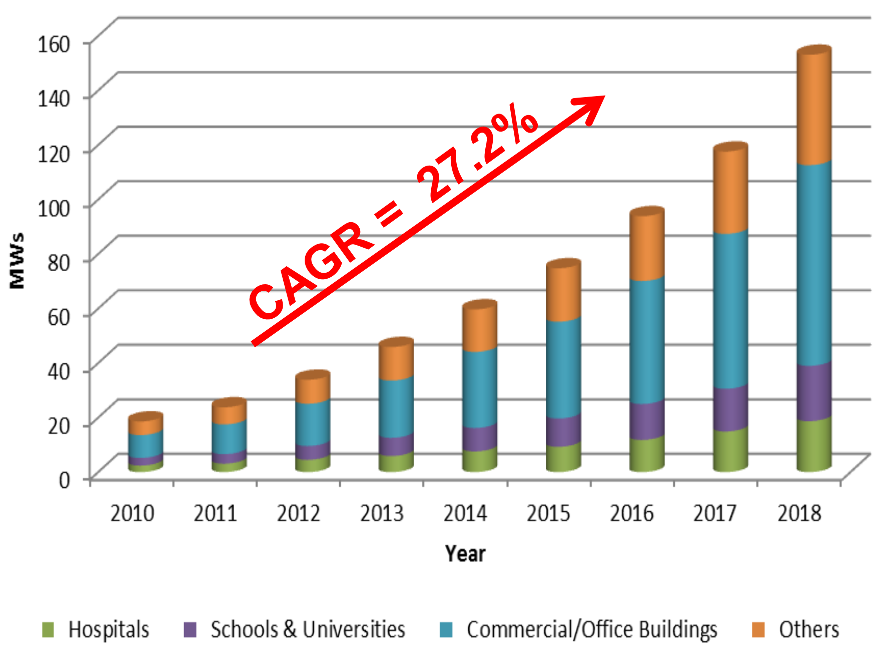
Couple with Renewables

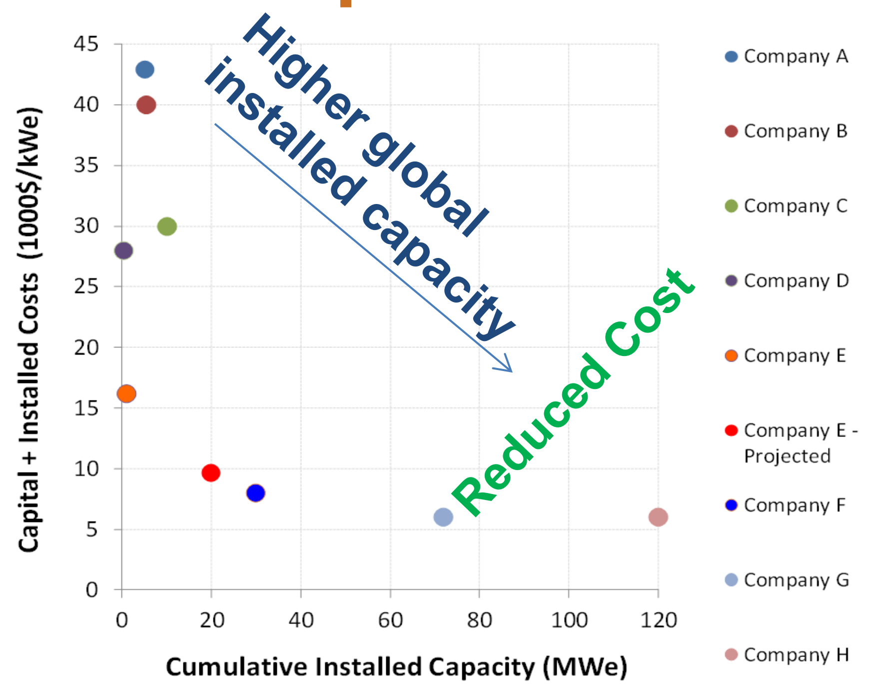
Silent Operation



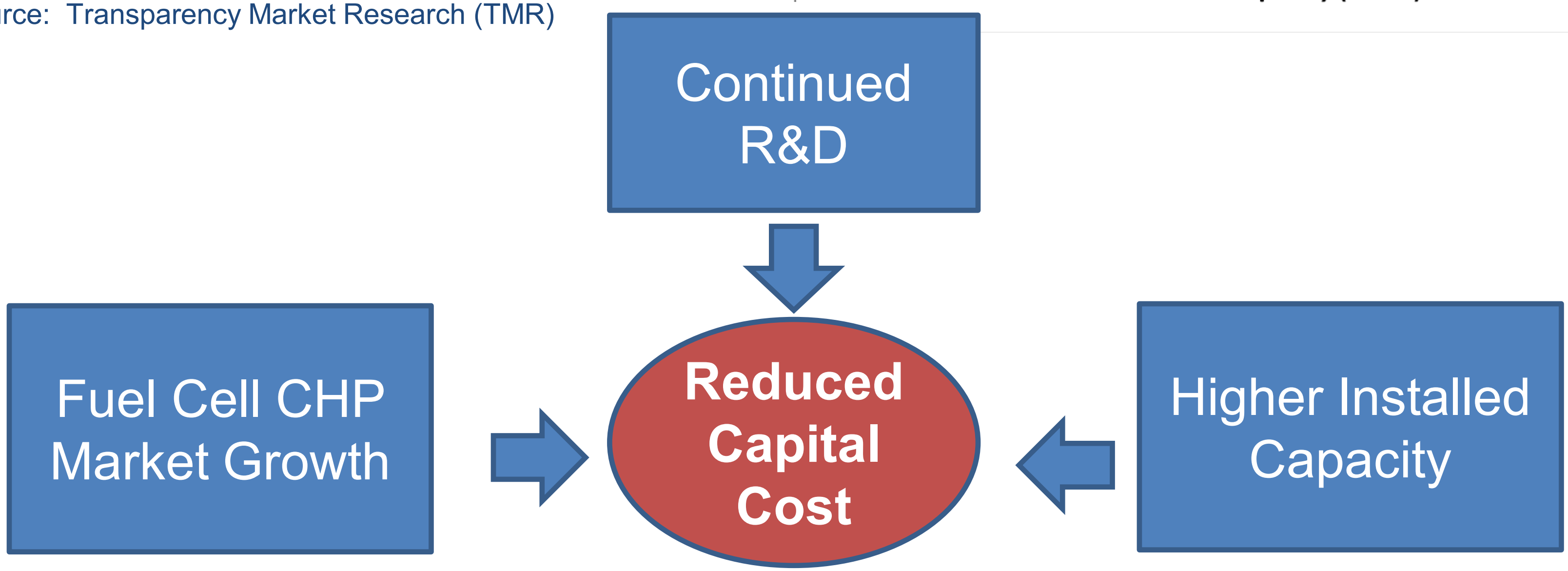
*Based on Colella WG. 2010. "Designing Energy Supply Chains Based on Hydrogen." Chapter 45 in Climate Change Science and Policy , 2nd edition, SH Schneider, A Rosencranz, and MD Mastrandrea (eds.), Island Press, Washington, D.C., pp. 456–466.

Current and Future Fuel Cell Capital Cost





Source: Transparency Market Research (TMR)



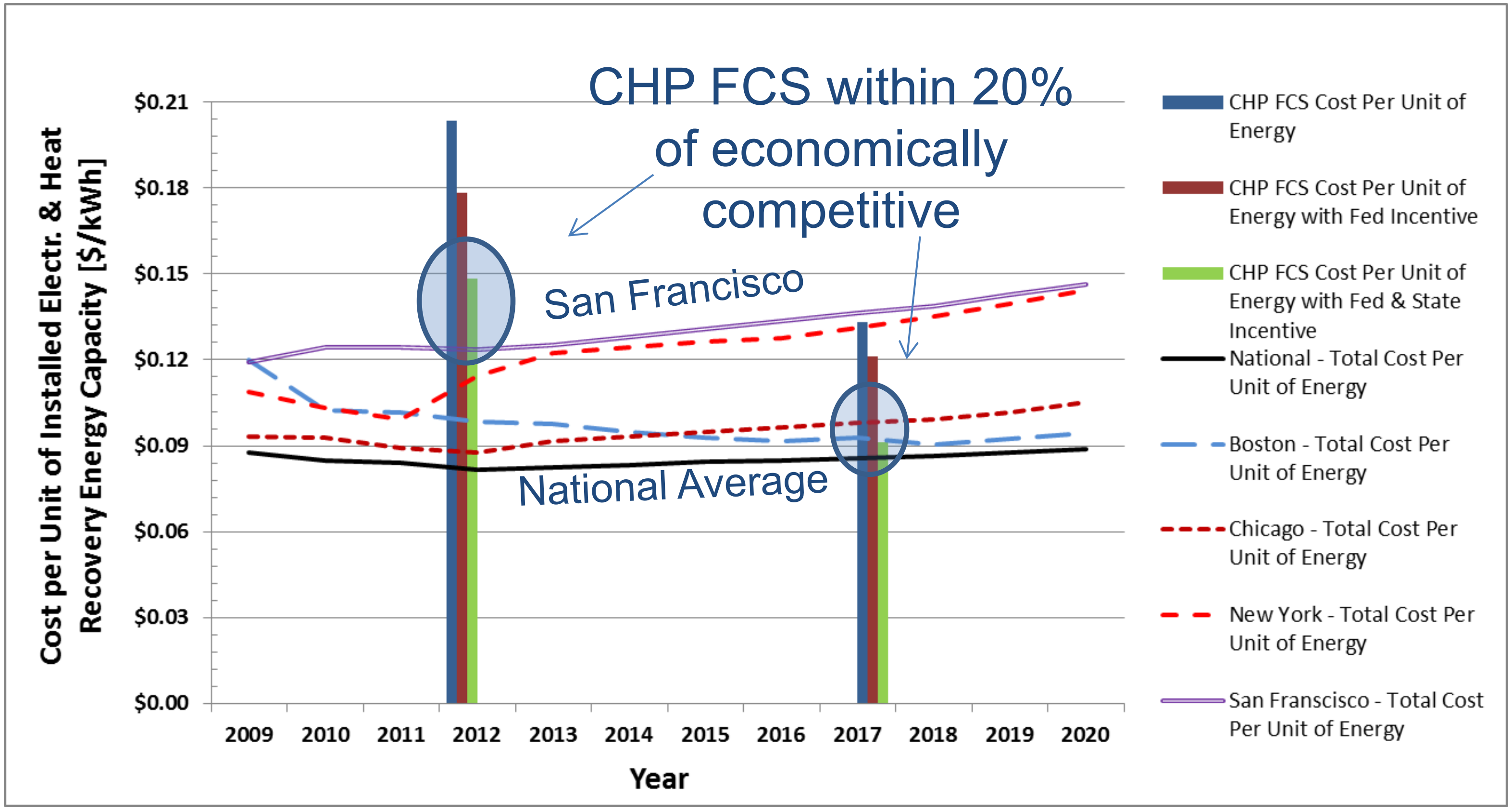
Life Cycle Cost of Ownership

Site	Array Size (units)	LCC Cost ($/5kW unit)	Payback (Without Incentives), Yrs	Payback, (With Incentives) Yrs
College	2	$94K	8.7	N/A
Nursery	3	$76K	4.9	3.7
Recreation	5	$82K	5.3	4.1
Grocery	5	$85K	5.4	4.0
Average		$84K	6.1	3.9

- Includes O&M, fuel, and decommissioning for a 5 year life
  - Will be updated for 10 year life of new M5 units
- College not eligible for incentives
- Savings includes grid electricity and natural gas heating costs and straight-line depreciation at a tax rate of 33%

Accomplishments

Projected Future Business Case



- Assumptions
  - Projected prices of electricity and natural gas and anticipated decline of fuel cell costs
  - Heat is generated by natural gas rather than electricity
  - Current government subsidies remain

Responses to Previous Year Reviewer's Comments

- Comment: "This project lacks information on areas needing technical improvement (research and development)"
  - This analysis identified degradation issues with the PBI fuel cell stack that have been addressed with the new phosphoric acid fuel cell system.
  - Phosphoric acid fuel cell demonstration too early to identify improvements—no significant failures have occurred.
- Comment: "Only one manufacturer is included; however, there are limited manufacturers in this range of CHP systems."
  - A RFP was sent out requesting proposals from fuel cell vendors for 5-50 kWe CHP fuel cells. Efforts were made to publicize with webinars, advertisements and press releases. In the end, only one company proposed.
- Comment: "This project should track the cost of ownership and then project it for the life cycle."
  - As part of the business case we developed the life cycle cost of ownership of a micro-CHP FCS that includes installation, depreciation, fuel cost, and warranty.
- Comment: "It appears all installations were in relatively moderate climates. Perhaps the study and demonstration would benefit from at least one 'cold' weather installation."
  - Although funding was not available for an additional installation, modeling was performed demonstrating heat utilization with a range of building types in a variety of climates.

Collaborations

- Partners
  - ClearEdge Power
    - Fuel Cell Supplier
    - Maintenance and Data Acquisition
  - Fuel Cell Users
    - Roger's Gardens
      - *The ClearEdge system delivers cost-effective clean energy that helps us increase efficiencies and reduce our environmental footprint," said Gavin Herbert, co-owner of Roger's Gardens*
    - Portland Community College
      - *"The HT building fuel cell project and having ClearEdge as a partner naturally led to the creation of curriculum to support students interested in learning fuel cell technology and sustainability science in general."* from Dieterich Steinmetz (*dean of Sylvania's Science and Engineering Division)*
    - Oakland Country Club
    - Fresh & Easy
  - Special Thanks
    - Pete Devlin, DOE-EERE Fuel Cells Technology Office

Remaining Challenges and Barriers

- Obtain similar data set for the new M5 upgrades as developed for the CE5
  - Data demonstrating continued system improvement
- Assist ClearEdge and DOE in identifying system improvements
  - To further improve system performance
  - To reach a larger market

Future Work

- Micro-CHP demonstration
  - Continue data acquisition and analysis
  - Demonstrate long term performance of M5 systems
    - Characterize and quantify contributors to down time
    - Identify additional opportunities for improvements
- Identify other value propositions for micro-CHP
  - Assist in evaluating trade-off between higher water temperature and reduced efficiency
  - Evaluate business case for more building types
  - Update life cycle costs for new M5 systems
- Continue publications and presentations

Project Summary

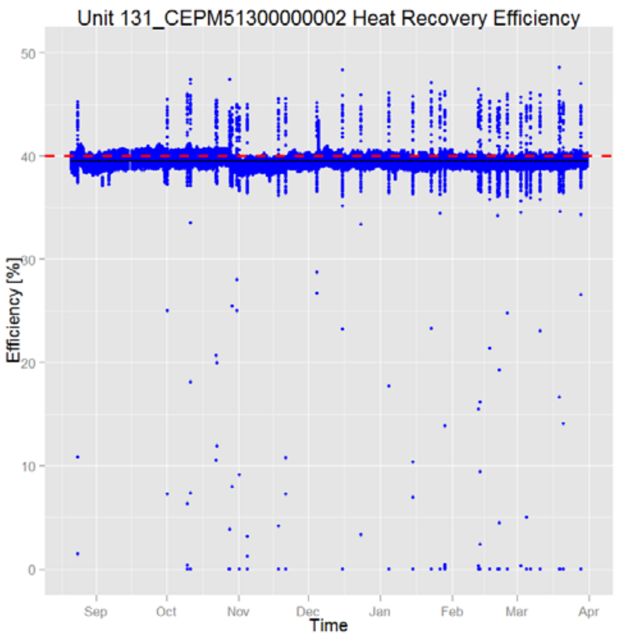
Relevance	Address the DOE barriers of inadequate user experience and the lack of operational and application information for micro-CHP fuel cells.
Approach	• Through long term data collection identify possible system improvements. • Provide independent assessment of operations, economics and environmental impact. • Develop a business case for their continued use.
Technical Accomplishments and Progress	• Develop and publish business case • Demonstrate continued system improvement in stability and availability. • Data analysis to compare initial power, efficiency and failure results of M5 with CE5.
Collaborations	• ClearEdge Power and their fuel cell users
Proposed Future Research	• Demonstrate long-term performance of M5 systems • Expanded business case for new M5 system • Publish results of performance analysis

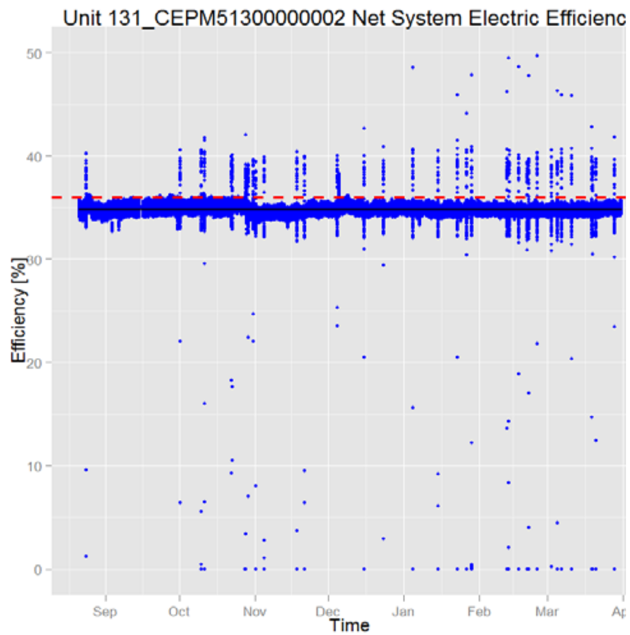
Project ID# MT006

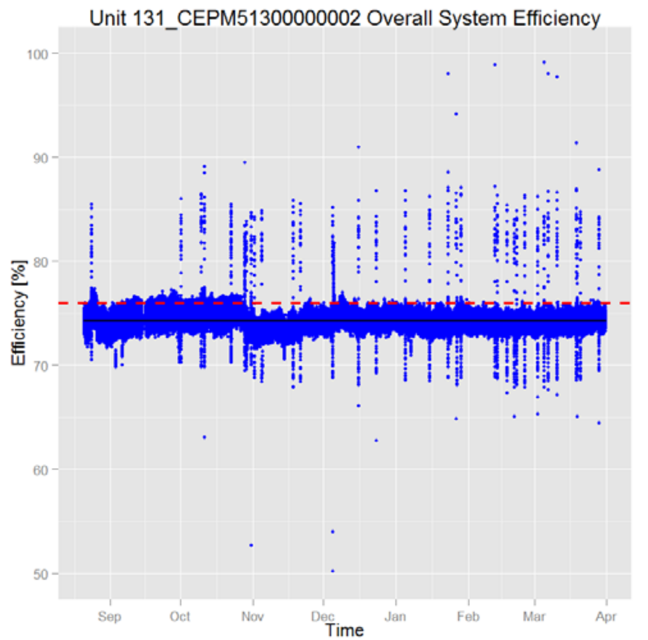
Kriston Brooks
(509) 372-4343
kriston.brooks@pnnl.gov

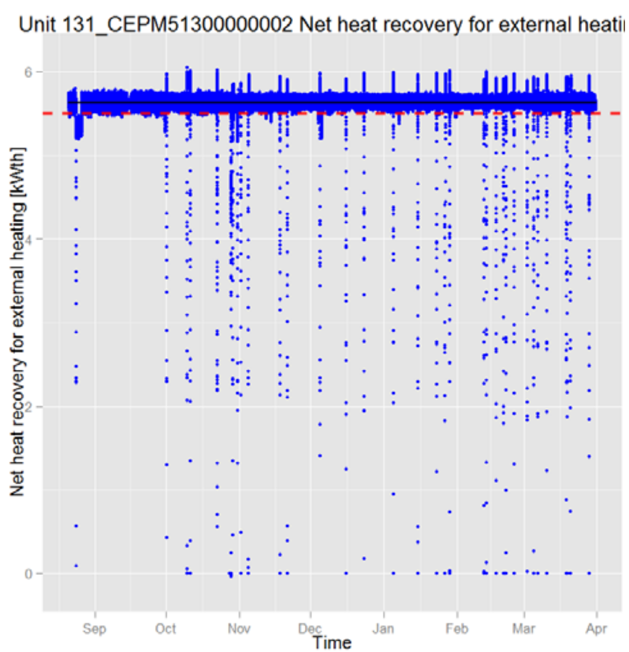
Technical Backup Slides

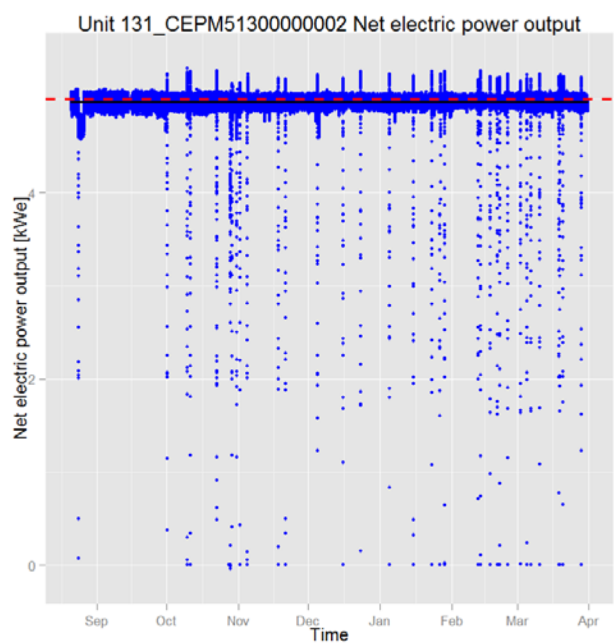
Unit 002 (131) – Roger’s Garden – Aug 2013 to March 2014

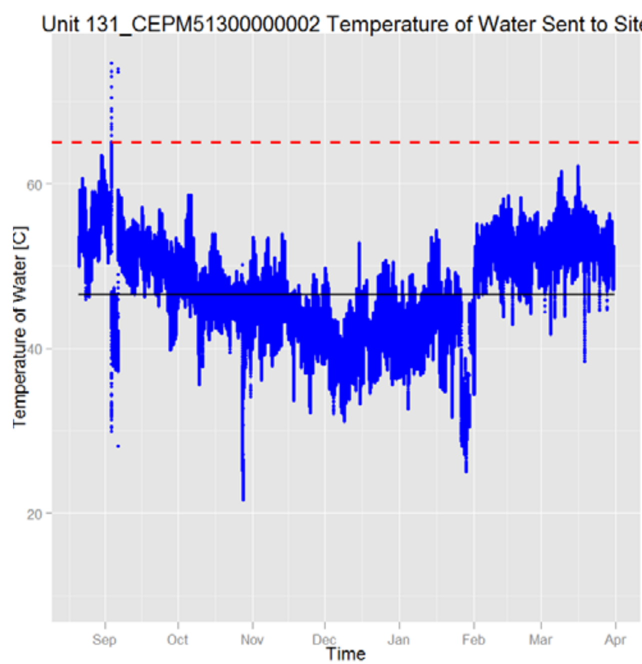




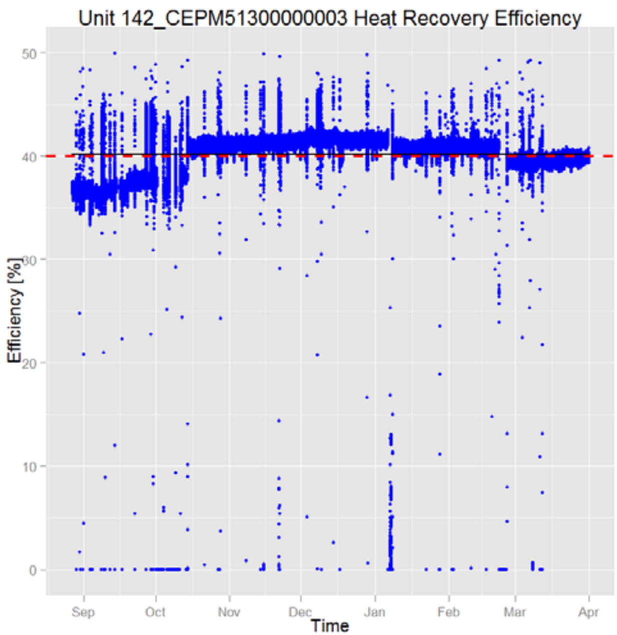


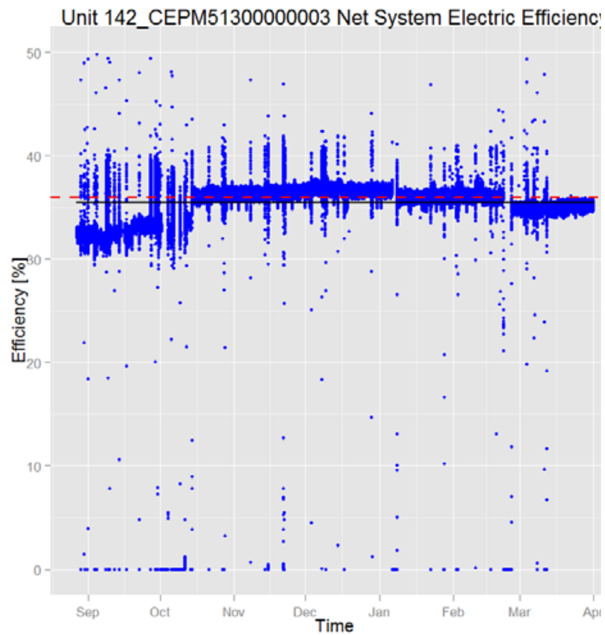


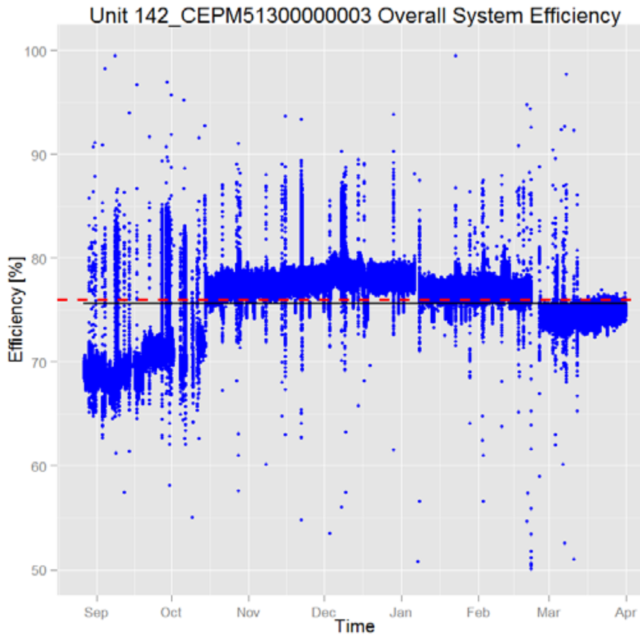


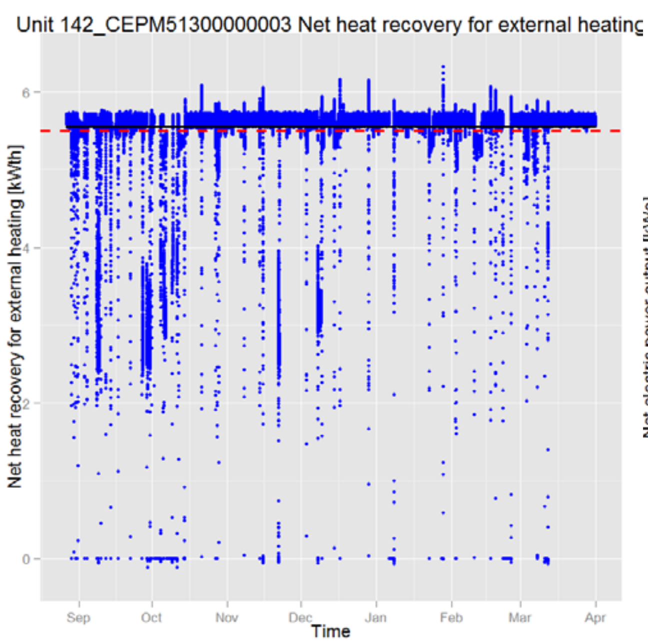


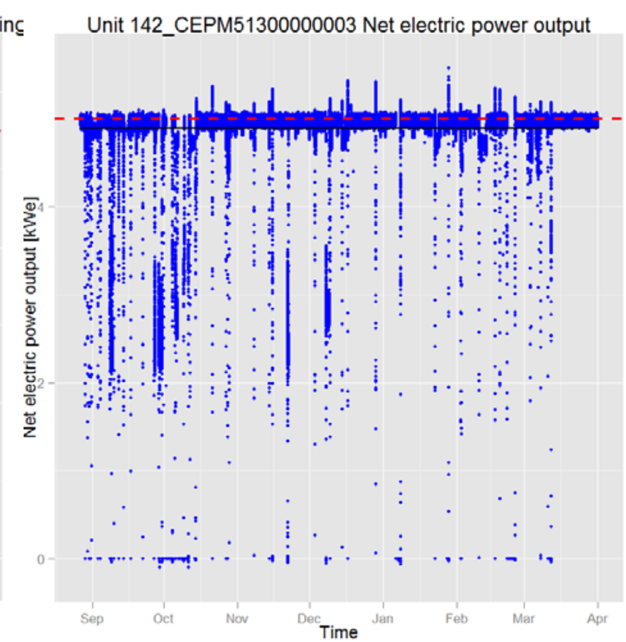
Unit 003 (142) – Oakland Hills – Aug 2013 to March 2014

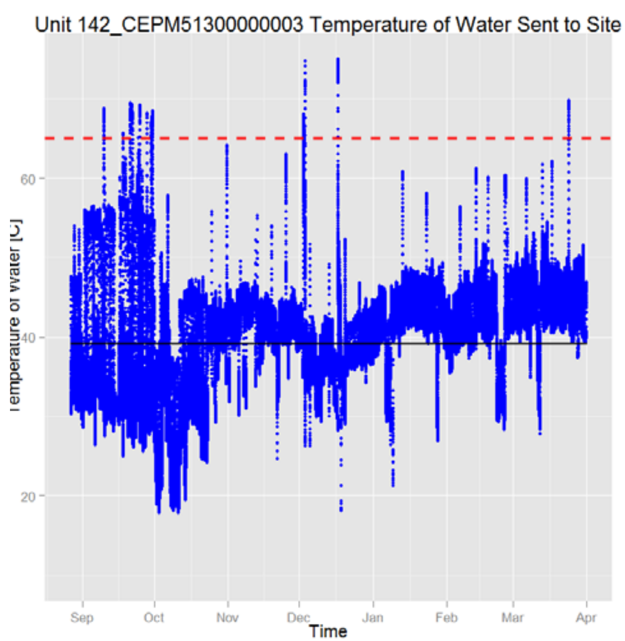












Unit WD00001 (137) – Oakland Hills – February and March 2014