Fuel Cell Combined Heat and Power Commercial Demonstration

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U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project ID# MT006

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Overview

- Timeline
  - Start: Aug. 2010
  - Project End: Mar. 2015
    - Pending additional funding
  - Percent complete: 55%
- Budget
  - $3.0M Total (PNNL) Program
    - Includes $1.36M for subcontracts
    - Contractor cost share $1.32M
  - FY10: $3M
  - FY11: $0k
  - FY12: $0k
- 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
  - Fuel cell supplier
  - Fuel cell users

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ClearEdge POWER
Power Your Independence.™

Portland Community College

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Relevance

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

DOE Barriers	Project Goals
F. Inadequate user experience	• Educating users about benefits of fuel cells • Overcoming inherent resistance to new technologies • Provide information to help replicate successful deployments
H. Stakeholder lack of awareness of applications	Perform business case to identify FCS applications
I. Lack of information on combined energy efficiency and renewable technologies	Provide end-users with independent assessment of technology • Engineering (reliability and durability) • Economics • Environmental Impact

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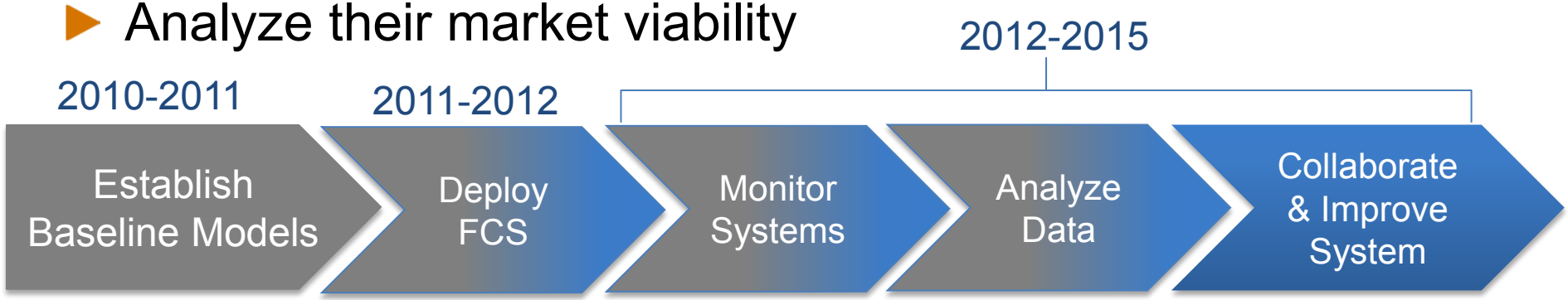
CHP FCS Value Proposition

- Demonstrate CHP fuel cells as:
  - An environmentally-friendly technology
  - Moving toward cost competitive with conventional technologies
  - Reduces risk of electric grid disruptions and enhances energy reliability
  - Provides stability in the face of uncertain electricity prices
  - With benefits of high availability
  - For applications such as base-load backup power, or a foundation for other renewable alternatives
  - Reduces the need for new transmission and distribution (T&D) infrastructure and enhances power grid security

Approach

- Demonstrate Fuel Cells in Commercial Application
- Assess their performance
- Analyze their market viability



Establish baseline model to evaluate cost and technical performance of FCSs.

Acquire FCSs for demonstration.

- Acquisitions through open competition
- Both United States (U.S.) and foreign companies solicited
- Team of Manufacturers and end-users

Monitoring and analysis of data remotely.

- Engineering Performance including heat recovery and building site specifics
- Financial Performance including IRR, payback, cost
- Environmental Performance including GHG and end of life
- Develop a business case demonstrating the commercial viability of the FCS

Interactions

- Discuss results with trade groups, potential customers and industry
- Identify ways to improve the FCS and implement if possible

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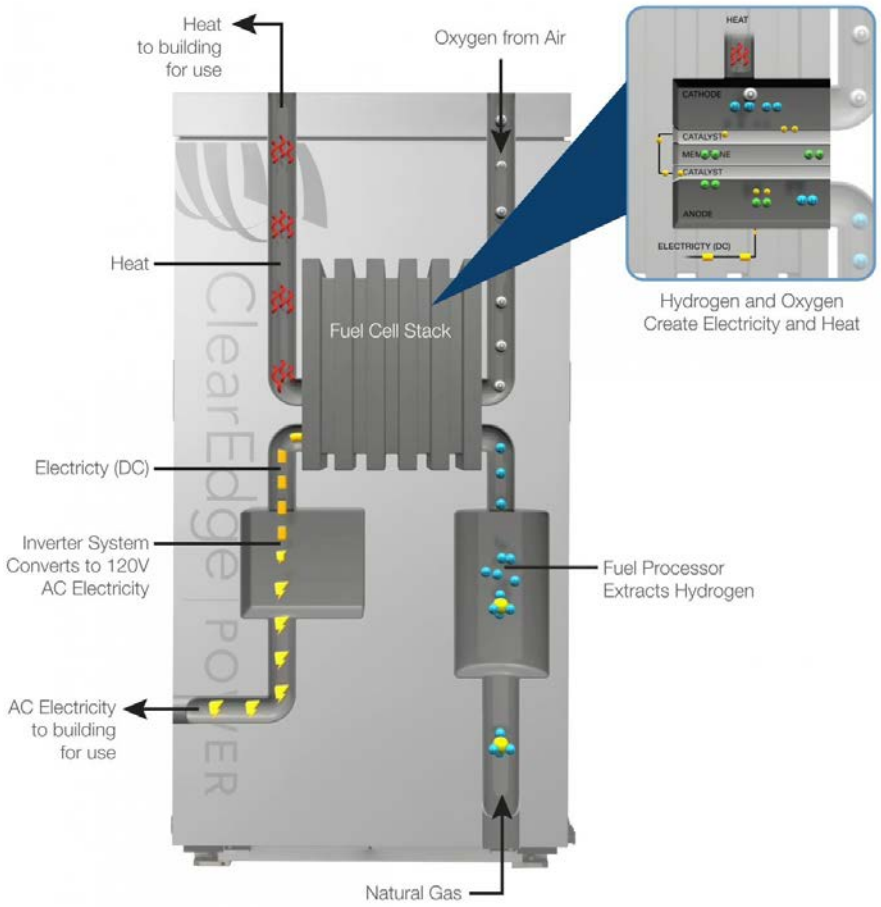
Establish Baseline Models

- PNNL finalized Technical Requirements and Evaluation Criteria documents
- PNNL refined existing baseline cost models
- PNNL developed a building simulation model with output of space heating demand and demand seen by FCS
  - DOE Commercial Reference Buildings: Large Office New Construction
  - DOE Commercial Reference Buildings: Small Office New Construction
- Completed in FY11 and FY12

Deploy Fuel Cell CHP

Fuel Cell Description

- 5 kWe high temperature PBI fuel cell
- Hydrogen from reformed natural gas
- 5.5 kWt hot water at 50-60°C



Monitor Systems/Analyze Data: Installation Sites

Partner	Number of FCSs	Unit #	Data Collection Start Date	DOE Cost Share [%]
College (Portland Community College – Hillsboro, OR)	**2**	129 & 130	9/21/11	44%
Plant Nursery (Roger's Gardens – Corona Del Mar, CA)	**3**	131, 132 & 133	11/26/11	36%
Recreation (Oakland Hills Country Club – Oakland, CA)	**5**	137, 139, 140, 141 & 142	12/15/11	37%
Grocery Store (Fresh & Easy – San Francisco, CA)	**5**	147, 153, 161, 162 & 163	3/1/12	37%
Total	**15**			**38%**

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: < 5 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

Recently Completed and Future Milestones

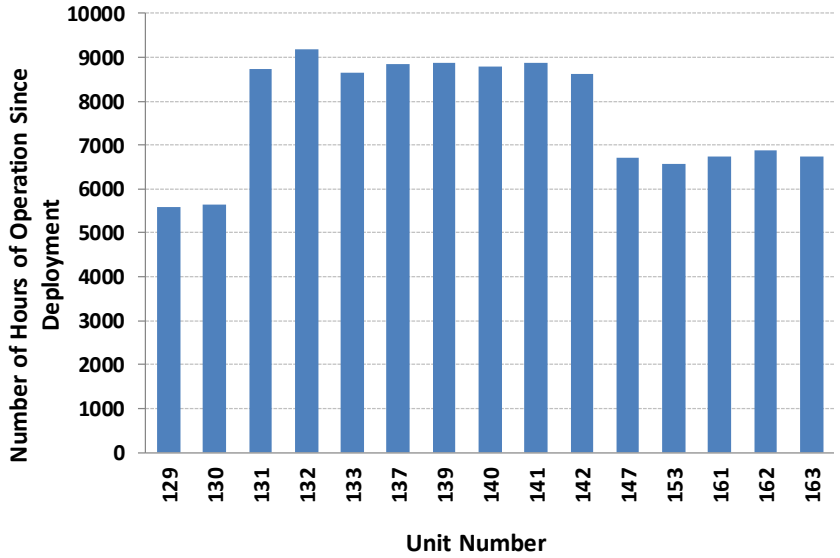
Milestone	Completion Date	Status
Updated BOP for all monitored CHP FCS	May 2013	8 Units Completed, 7 Units Remaining
Finalize Micro-CHP FCS Business Case	June 2013	Draft completed
Quarterly Data Analysis Updates	Various	Ongoing
Issue Final Report on Micro-CHP Demonstration	March 2015	Could be extended to September 2016 with additional funding

Summary of Accomplishments in Previous Years

- Established Baseline Models
  - Finalized Technical Requirements and Evaluation Criteria documents
  - Developed building simulation models for large and small offices
- Deployed CHP FSC
  - Contracted ClearEdge Power
  - Deployed all of the planned 15 CHP FCS
- Monitored System
  - Initiated remote monitoring of units
  - Collected 10 parameters at 1 second intervals
- Analyzed Data
  - Observed decline in electric power output over time

Summary of Accomplishments This Year

- Average operation hours 7688 ± 1306 hours
  - Analyzed **12.5 billion** data points as of 01/01/2013
  - Increased the parameters collected
- Recommended improvements resulting in fuel cell stability
- Evaluated GHG reduction
- Performed economic analysis compared to conventional technologies
- Developed a fuel cell micro-CHP business case

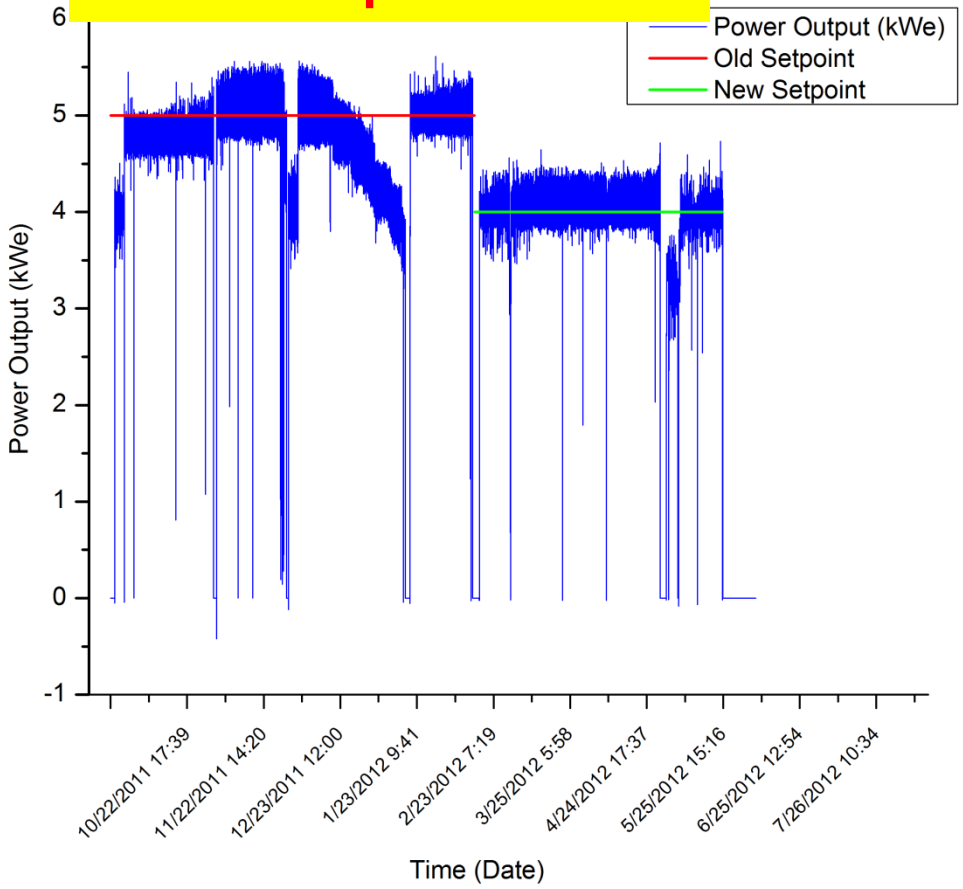


Key Parameters Analyzed

- Overall Efficiency = 71.6% (HHV basis)
  - Average electrical efficiency = 33.5%
  - Average thermal efficiency = 38.1%
- Average Net Electrical Power = 4.09 kWe
- Average Net Heat Produced
  - Average net heat recovery = 4.64 kWt
  - Water temperature to site = 50.4C
- Overall Availability = 93.4%

Identify Set-Point Change (09/21/11 – 02/29/2012)

Note difficulty in maintaining 5 kWe setpoint



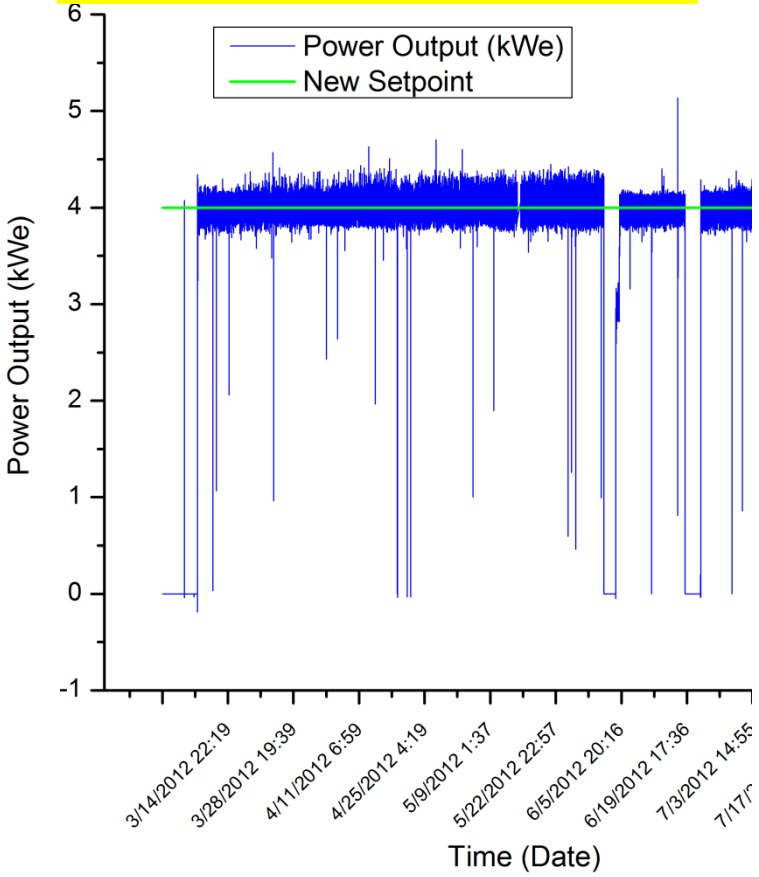
Unit 129 PCC

- Initial Engineering Analysis
- Problem
  - Units initially programmed to 5 kWe set-point
  - Analysis determined set-point at the limit of operation
  - Power output was decreasing over time!
- Solution
  - PNNL recommended 4 kWe set-point.

Note: Data analysis is based on HHV.

After PNNL Recommended Set-point Change (03/01/12 – 06/30/2012)

PNNL recommended set point change addressed problem



Unit 163 PCC

Note: Data analysis is based on HHV.

- Result
  - All units programmed to a new set-point of 4 kWe.
  - New set-point provided more stable power output.
  - ClearEdge Power Inc. is working to address the set-point problem with upgrades in their next generation units.

Improved Availability (07/01/12 – 01/01/13)

- ClearEdge made balance of plant improvements recovered high availability
  - Primarily required proper selection of more robust minor components (water filter, flowmeter, etc.)

Dates	Availability	Description
9/11 – 3/12	96%*	Initial Operation
3/12 - 7/12	89%	After Set-Point Changes
7/12 - 1/13	**94%**	**After ½ Systems BOP Upgraded**

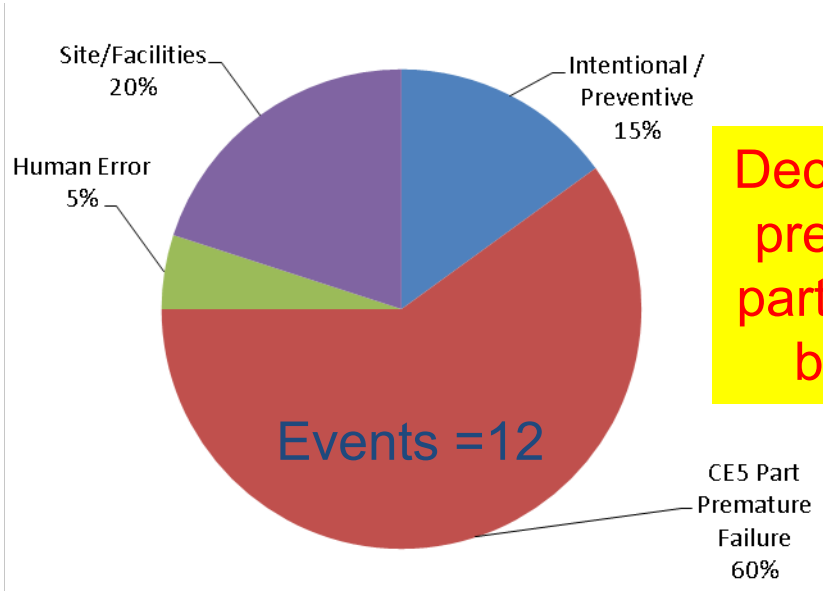
* Initial availability is high but there were lot of degradation issues

Replacement of select BOP components resulted in higher availability

Maintenance Events Before & After System Upgrades

BEFORE UPGRADES

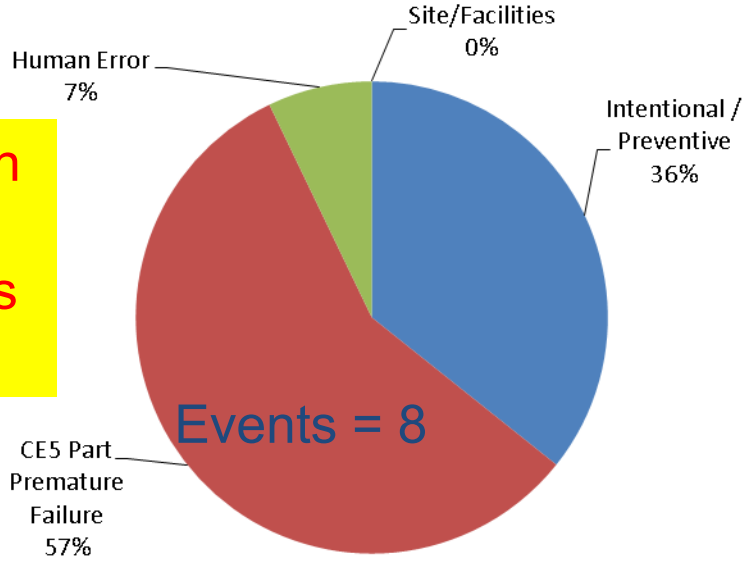
Total Events = 20



Decrease in premature part failures by 33%

AFTER UPGRADES

Total Events = 14



Data compiled from 5 units (unit #s147, 153, 161, 162 & 163) before and after upgrades over 6 month period

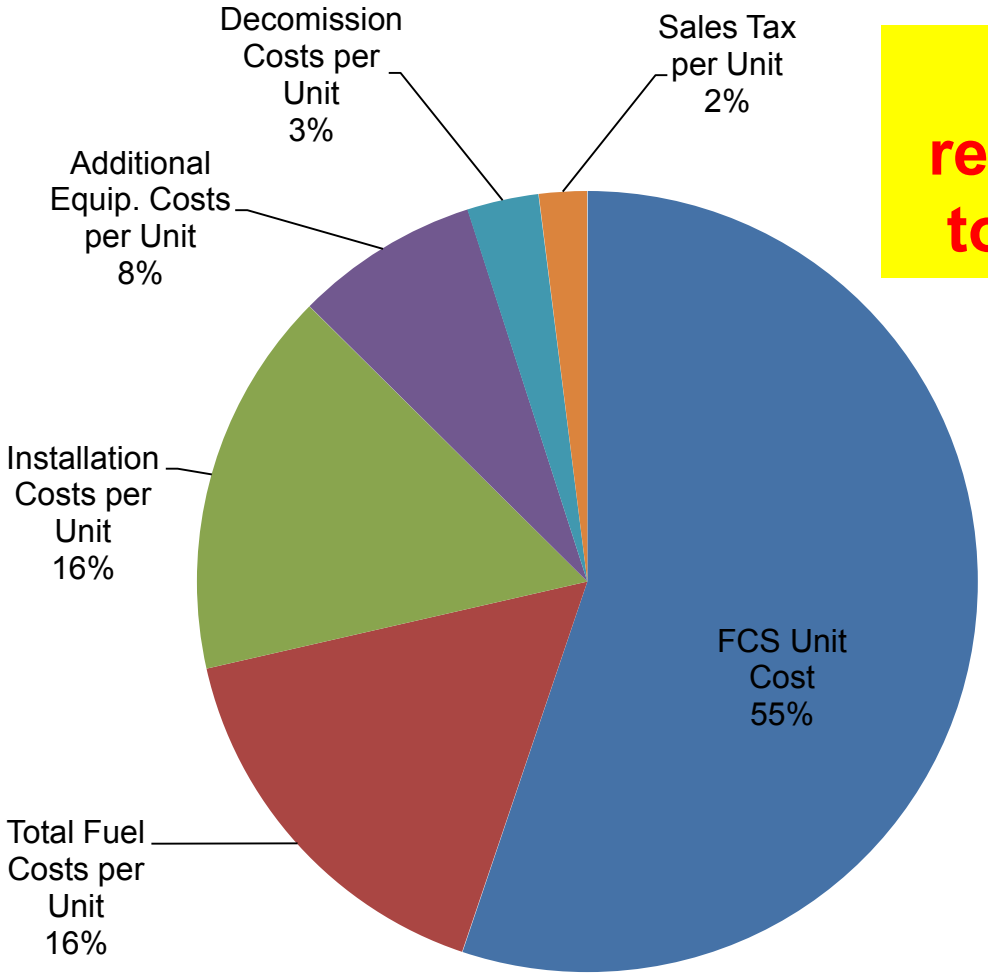
Environmental Analysis of micro-CHP FCSs

- Environmental analysis of CHP FCSs
  - Green House Gas (GHG) mitigation cost.
  - Air pollution emissions - human health cost from United Nations Intergovernmental Panel.
- Preliminary environmental analyses
  - GHG emissions = 1/3 conventional coal fired plant
  - Does not include transmission and distribution losses
- Human Health Effects decreased by a factor of 1000

Energy Generators	CO2 Equivalent for Total Energy (tonnes/kWhr)	Human Health Cost (Billion $)
Conventional Coal Power Plant	6.49	505
Conventional Gas Plant	4.54	485
Cogenerative Gas Plant	2.52	146
CHP Fuel Cell	2.05	0.57

Economic Analysis of CHP FCSs

- Distribution of Total Project Cost



Fuel cell cost represents 55% of total project cost

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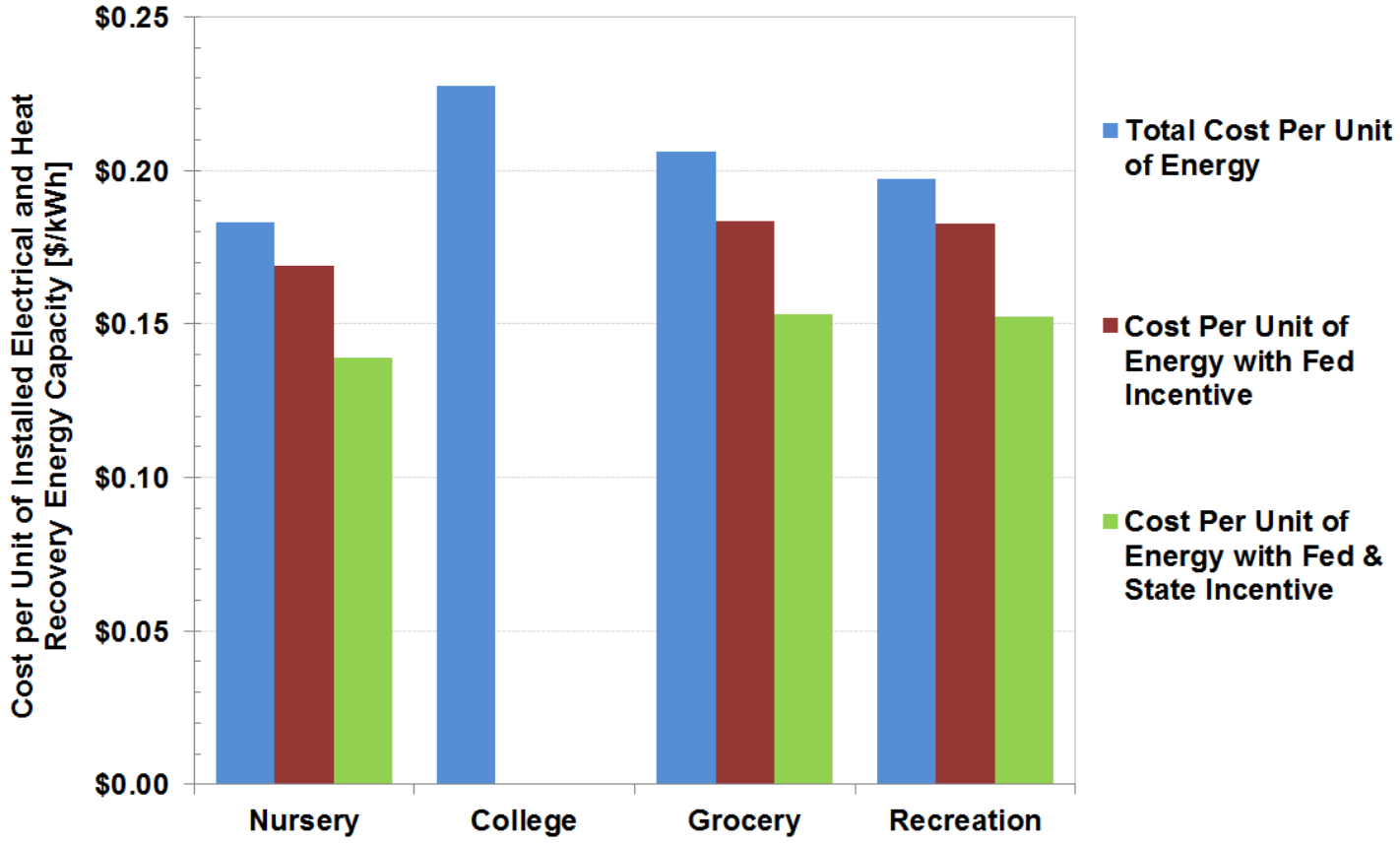
Breakdown Cost per Unit of Energy (Energy = Electrical + Heat)

Cost per Unit Energy: $\frac{\$}{kWhr} = \frac{FCS\ Cost}{kWhr_{thermal} + kWhr_{electrical}}$

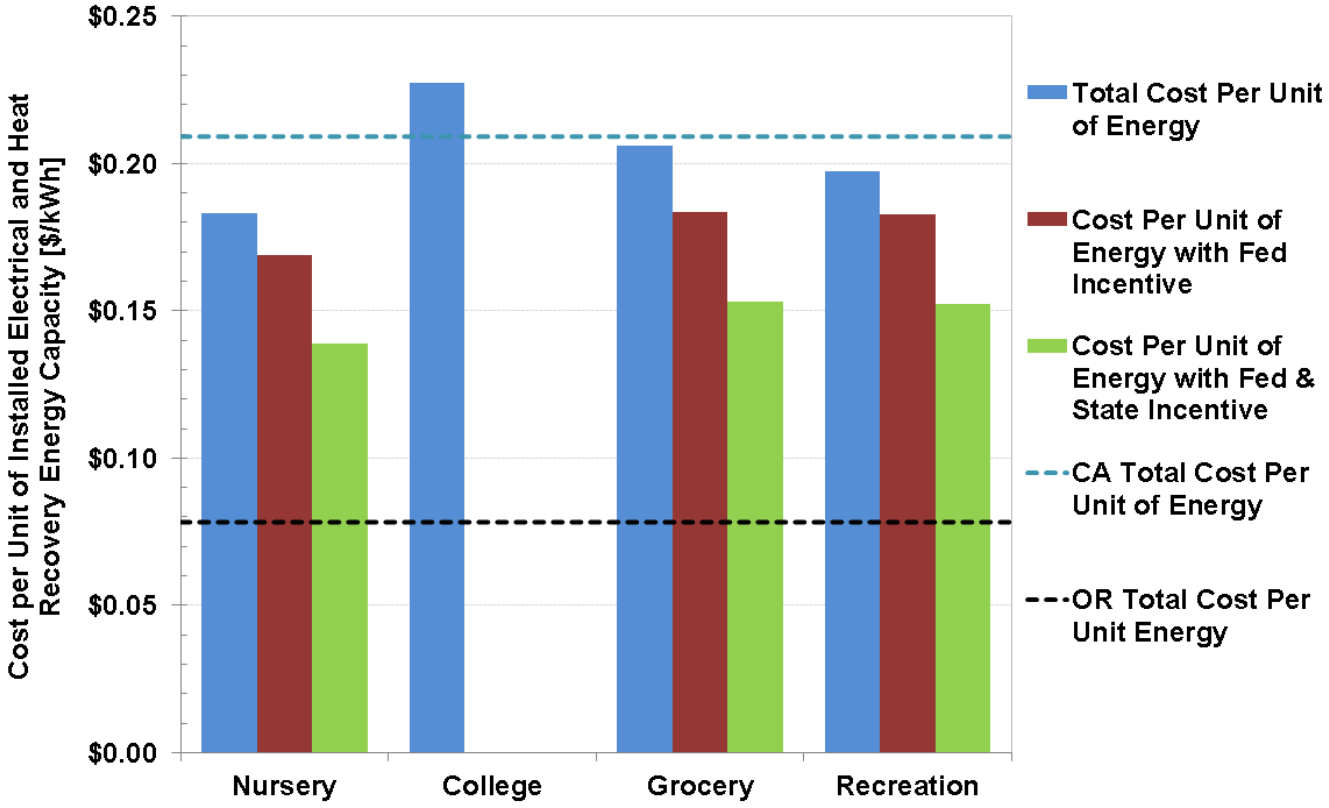
Unit energy = 48% electrical. 52% thermal



Note: College is not eligible for federal and state incentives due to location and nature of the business

Breakdown Cost per Unit of Energy (Energy = Electrical + Heat)

- California (CA) and Oregon (OR) heat from **electricity only**.
- One unit of energy includes 48% electrical and 52% heat.

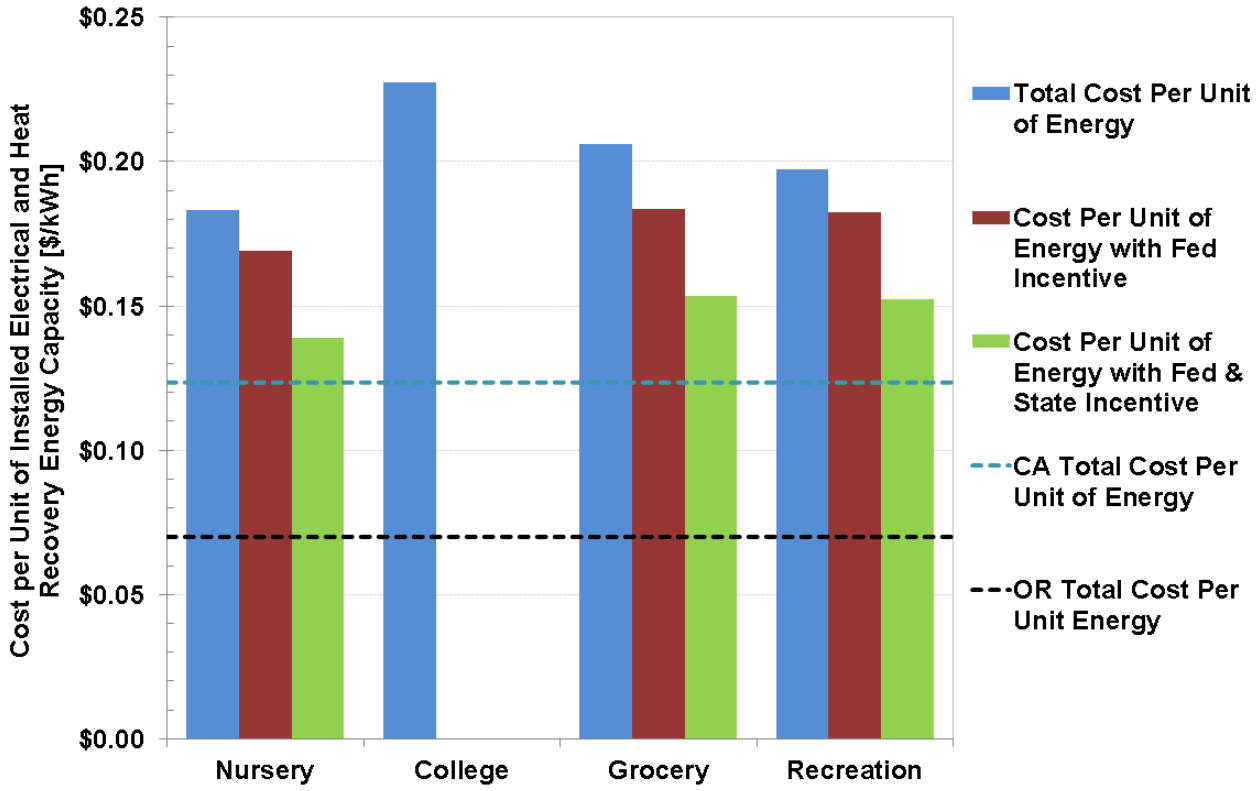


Fuel Cell energy is cost competitive with California electricity prices even without Government Incentives

Note: College is not eligible for federal and state incentives due to location and nature of the business

Breakdown Cost per Unit of Energy (Energy = Electrical + Heat)

- California (CA) and Oregon (OR) heat from **natural gas only**.
- One unit of energy includes 48% electrical and 52% heat.



Fuel Cell energy is nearly cost competitive with average California electricity prices with Government Incentives

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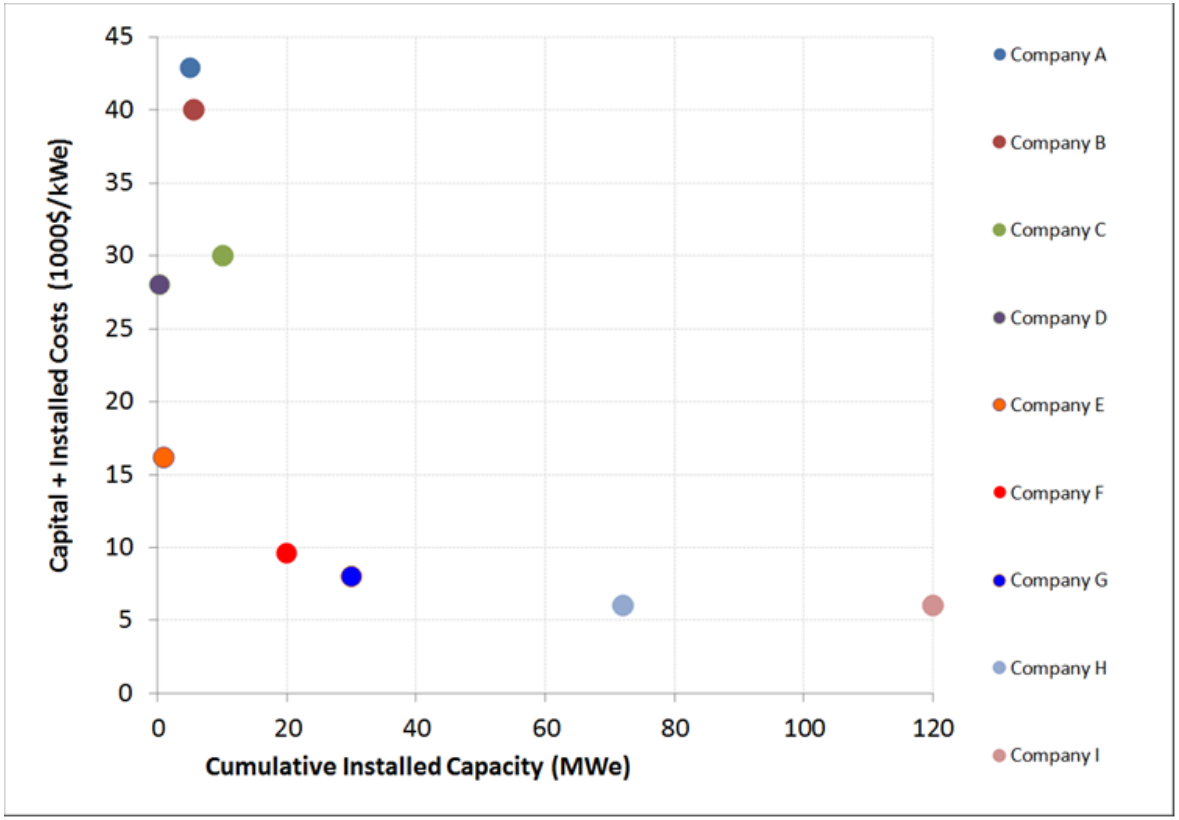
Note: College is not eligible for federal and state incentives due to location and nature of the business

Consider How to Reduce FCS Cost

- ClearEdge Power's CHP FCSs compared with other FCSs
  - Not apples-to-apples comparison
  - Shows relative system price
- Higher installed capacity → lower capital costs.
  - Projected ClearEdge Power's cost show a similar trend.



Increased capacity should result in reduced cost

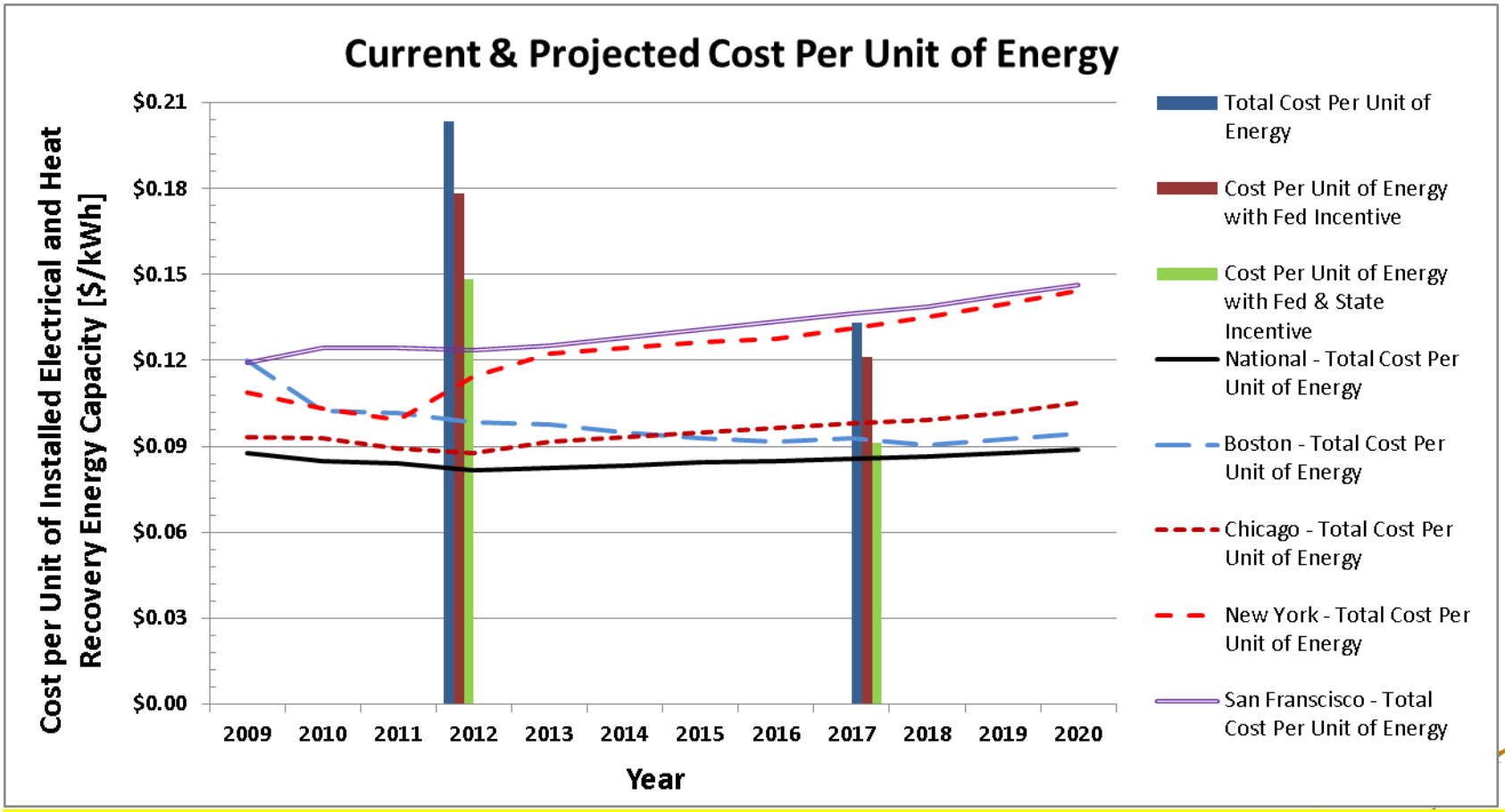
Note: Costs shown here uses the electricity portion of the output! This is used to enable comparison with all types of FCSs because some of the FCSs do not provide heat.

References: (1) International Energy Agency (IEA) 2010 Report, Stationary Fuel Cells Annex 25. (2) ASME Fuel Cell Conference 2011, Keynote Presentation by ToHo Gas Company. (3) Katrina Fritz-Intwala, UTC Power, IEA Advanced Fuel Cells Annex 25 Meeting No. 5, Orlando, FL, Oct. 31, 2011. (4) Christian Lorenz, E.ON Ruhrgas AG, Essen, Germany.

Markets Identified in Business Case

- Applications that can utilize the heat
  - Identifying cold climate zones where electricity and fuel oil prices are high
  - Identifying businesses with a high ratio of hot water to power usage: hotels, hospitals, food service
  - Businesses with long operating hours
- Remote and Back-up power needs
  - Identifying applications off the grid
  - Identifying industries with high cost of power outage
  - Identifying where transmission/distribution losses are high
- Benefits of Green Power
  - Quantifying advertising and sales benefits for using FCS
  - Combining consistency of fuel cells with other less consistent renewable power sources

Identify and Perform Sensitivity Analysis on Conditions to Improve Commercial Viability



In 5 years, fuel cell energy may be cost competitive with national average with government incentives and some states without

Collaborations

- Partners
  - ClearEdge Power
    - Fuel Cell Supplier
    - Maintenance and Data Acquisition
  - Fuel Cell Users
    - 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," said Dieterich Steinmetz, dean of Sylvania's Science and Engineering Division*
    - 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*
    - Oakland Country Club
    - Fresh & Easy
  - Special Thanks
    - Pete Devlin, DOE-EERE Fuel Cells Technology Office

Future Work

- Micro-CHP Demonstration
  - Complete development of business case (June 2013)
  - Continue data acquisition and analysis (FY13 to FY15)
    - Characterize and quantify contributors to down time
    - Quantify availability improvements with recently completed system upgrades
    - Identify additional opportunities for improvements
  - Continue publications and presentation (FY13 to FY15)
- Refrigerated Truck APU
    - 400 hour demonstration of 15 kWe fuel cell powering the refrigeration unit on a Class 8 truck
  - Assist in the development of a business case (FY13)
  - Manage recently awarded contract (FY13- FY15)
  - Perform data acquisition and analysis during demonstration (FY15)

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	• 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	• Significant improvements have been made fuel cell stability and availability • Conditions where fuel cells are economically attractive have been identified • Target markets have been identified
Collaborations	• ClearEdge Power and their fuel cell users
Proposed Future Research	• Finalize business case and continue data analysis • Initiate refrigerated truck APU demonstration contract

Project ID# MT006

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Technical Backup Slides

Engineering Analysis of CHP FCSs
First Ten Systems installed (09/21/11 – 02/29/2012)

- Average electrical output = ~4.5 kWe
- Average net system electrical efficiency = ~33.0% (based on HHV)
- Overall system efficiency = ~ 70%
- Averages looked good but lot of performance/degradation issues

Unit #	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
Stated value →	**5.0**	**5.5**	**up to 65**	**36**	**40**	**76**	**%**
129	4.71 ± 0.40	5.33 ± 0.45	47.00 ± 2.54	33.18 ± 2.37	37.61 ± 2.68	70.79 ± 5.05	95.60
130	4.65 ± 0.40	5.27 ± 0.45	46.50 ± 1.91	32.47 ± 1.91	36.81 ± 2.16	69.28 ± 4.06	96.29
131	4.77 ± 0.25	5.40 ± 0.29	53.54 ± 5.52	33.29 ± 1.83	37.74 ± 2.07	71.03 ± 3.90	98.96
132	4.76 ± 0.25	5.40 ± 0.29	51.49 ± 5.71	33.67 ± 1.58	38.16 ± 1.79	71.83 ± 3.37	96.99
133	4.68 ± 0.36	5.30 ± 0.40	51.13 ± 6.04	34.16 ± 1.97	38.72 ± 2.23	72.88 ± 4.20	96.47
137	4.46 ± 0.36	5.06 ± 0.40	58.80 ± 2.81	32.29 ± 1.63	36.60 ± 1.85	68.89 ± 3.47	95.46
139	4.11 ± 0.21	4.66 ± 0.24	63.84 ± 3.29	32.09 ± 3.05	36.37 ± 3.46	68.46 ± 6.51	98.00
140	4.04 ± 0.39	4.57 ± 0.44	63.53 ± 3.77	31.51 ± 2.67	35.71 ± 3.02	67.22 ± 5.68	93.94
141	4.38 ± 0.47	4.96 ± 0.53	64.16 ± 3.13	33.36 ± 1.71	37.81 ± 1.93	71.16 ± 3.64	88.99
142	4.07 ± 0.35	4.61 ± 0.40	63.36 ± 3.77	33.93 ± 1.83	38.45 ± 2.06	72.38 ± 3.88	96.78
147	-	-	-	-	-	-	-
153	-	-	-	-	-	-	-
161	-	-	-	-	-	-	-
162	-	-	-	-	-	-	-
163	-	-	-	-	-	-	-
Average →	**4.46 ± 0.34**	**5.06 ± 0.39**	**56.34 ± 3.85**	**33.00 ± 2.05**	**37.40 ± 2.32**	**70.39 ± 4.38**	**95.70**

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.
Units147, 153, 161, 162 and 163 were installed in March 2012.

Engineering Analysis of CHP FCSs After Set-point Changes (03/01/12 – 06/30/2012)

- Average electrical output = ~4.0 kWe
- Average net system electrical efficiency = ~33.5% (based on HHV)
- Overall system efficiency = ~71.6%

Unit #	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
Stated value →	**4.0**	**4.5**	**up to 65**	**36**	**40**	**76**	**%**
129	3.92 0.25	4.44 0.28	43.81 3.40	32.73 4.37	37.10 4.95	69.84 9.32	-
130	4.00 0.10	4.53 0.11	43.21 2.60	33.97 2.57	38.50 2.90	72.47 5.47	-
131	3.91 0.24	4.44 0.27	48.78 3.64	32.39 3.24	36.72 3.66	69.11 6.90	84.05
132	4.42 0.39	5.01 0.45	48.89 3.75	32.70 1.11	37.06 1.25	69.76 2.37	88.57
133	4.19 0.43	4.75 0.48	47.10 3.97	33.78 1.74	38.29 1.96	72.07 3.70	75.15
137	3.96 0.18	4.49 0.21	50.32 3.52	33.55 2.94	38.03 3.32	71.59 6.26	95.67
139	3.99 0.16	4.52 0.18	56.48 3.20	33.74 2.60	38.25 2.94	71.99 5.54	98.81
140	4.00 0.10	4.53 0.11	55.71 2.81	33.68 1.23	38.18 1.38	71.86 2.60	98.02
141	3.98 0.16	4.51 0.18	57.14 3.01	32.53 3.22	36.87 3.65	69.41 6.87	92.79
142	4.00 0.15	4.53 0.17	55.30 2.94	34.59 1.99	39.20 2.25	73.78 4.24	96.46
147	3.94 0.22	4.46 0.25	47.27 5.16	32.95 1.50	37.34 1.69	70.29 3.18	82.16
153	4.13 0.55	4.68 0.63	47.54 5.00	33.28 2.99	37.72 3.39	71.00 6.38	79.15
161	4.01 0.11	4.54 0.12	47.83 5.41	34.54 2.57	39.15 2.91	73.69 5.47	88.34
162	3.98 0.22	4.51 0.25	47.63 4.92	34.41 2.90	39.00 3.28	73.41 6.17	86.91
163	3.99 0.13	4.53 0.14	47.59 5.35	34.31 2.85	38.88 3.23	73.19 6.08	89.11
Average →	**4.03 0.23**	**4.56 0.25**	**49.64 3.91**	**33.54 2.52**	**38.02 2.85**	**71.56 5.37**	**88.86**

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.
Availability of units 129 and 130 is not shown here as they were shutdown during the last week of May, 2012 per customer request which is due to site maintenance, unrelated to the fuel cell systems.

Engineering Analysis of CHP FCSs After BOP Upgrades (07/01/12 – 01/01/2013)

- Average electrical output = ~4.0 kWe
- Average net system electrical efficiency = ~33.5% (based on HHV)
- Overall system efficiency = ~71.6%

Unit #	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
Stated value →	**4.0**	**4.5**	**up to 65**	**36**	**40**	**76**	**%**
129	-	-	-	-	-	-	-
130	-	-	-	-	-	-	-
131	3.99 0.11	4.53 0.13	48.83 4.08	33.73 1.92	38.23 2.17	71.97 4.10	89.05
132	3.98 0.15	4.51 0.17	49.23 4.43	32.95 1.99	37.34 2.26	70.29 4.25	98.08
133	3.98 0.14	4.51 0.16	47.72 4.46	34.09 2.04	38.64 2.31	72.73 4.35	90.90
137	-	-	-	-	-	-	-
139	-	-	-	-	-	-	-
140	-	-	-	-	-	-	-
141	-	-	-	-	-	-	-
142	-	-	-	-	-	-	-
147	3.96 0.19	4.48 0.21	48.92 5.94	33.04 2.58	37.45 2.92	70.48 5.50	97.46
153	3.97 0.15	4.50 0.17	48.80 5.48	33.71 1.39	38.20 1.57	71.91 2.95	96.16
161	3.99 0.11	4.53 0.12	48.60 5.57	34.32 1.78	38.9 2.02	73.22 3.80	93.98
162	3.96 0.18	4.49 0.20	49.22 5.74	34.12 2.54	38.68 2.87	72.80 5.41	96.25
163	3.94 0.22	4.47 0.25	49.55 5.72	34.80 2.02	39.45 2.28	74.25 4.29	93.37
Average →	**3.97 0.16**	**4.50 0.18**	**48.86 5.18**	**33.85 2.03**	**38.36 2.3**	**72.21 4.33**	**94.41**

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.
Units 129 , 130, 137, 139, 140, 141, 142 are scheduled to have the BOP upgrades in the next few weeks.

Engineering Analysis of CHP FCSs Summary of All Systems (09/21/11 – 01/01/2013)

- Average electrical output = ~4.1 kWe
- Average net system electrical efficiency = ~33.5% (based on HHV)
- Overall system efficiency = 71%

Unit #	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
Stated value →	**Set-point**	**Set-point Adj.**	**up to 65**	**36**	**40**	**76**	**%**
129	4.43 0.50	5.02 0.57	45.63 3.23	33.32 2.94	37.77 3.33	71.09 6.27	-
130	4.41 0.46	5.00 0.52	45.14 2.79	33.10 2.37	37.52 2.68	70.62 5.05	-
131	4.17 0.40	4.72 0.45	49.67 4.91	33.54 2.31	38.02 2.62	71.56 4.93	90.83
132	4.28 0.42	4.85 0.47	49.61 4.74	32.90 1.78	37.30 2.01	70.20 3.79	95.50
133	4.20 0.40	4.76 0.45	47.96 5.22	34.34 1.96	38.93 2.22	73.27 4.18	89.72
137	4.03 0.34	4.56 0.39	51.72 5.05	33.06 2.61	37.47 2.96	70.53 5.57	96.11
139	3.99 0.22	4.52 0.25	56.44 6.10	33.24 2.77	37.68 3.14	70.92 5.91	96.57
140	3.96 0.24	4.49 0.27	55.50 6.20	32.78 2.86	37.16 3.24	69.94 6.09	95.48
141	4.02 0.30	4.55 0.34	56.78 6.25	32.46 2.42	36.79 2.74	69.26 5.16	96.46
142	3.98 0.23	4.51 0.26	55.73 6.30	33.84 2.78	38.36 3.15	72.20 5.93	97.59
147	3.95 0.20	4.48 0.23	48.33 5.73	33.01 2.25	37.41 2.55	70.41 4.80	91.35
153	4.03 0.36	4.57 0.41	48.35 5.35	33.56 2.11	38.03 2.39	71.59 4.50	89.37
161	4.00 0.11	4.53 0.12	48.30 5.52	34.41 2.12	39.00 2.40	73.40 4.52	91.73
162	3.97 0.19	4.49 0.22	48.62 5.50	34.23 2.68	38.80 3.03	73.03 5.71	92.52
163	3.96 0.19	4.49 0.22	48.79 5.66	34.61 2.39	39.23 2.70	73.84 5.09	91.67
Average →	**4.09 0.30**	**4.64 0.34**	**50.44 5.24**	**33.49 2.42**	**37.96 2.74**	**71.46 5.17**	**93.45**

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.
Availability of units 129 and 130 is not shown here as they were shutdown during the last week of May, 2012 per customer request which is due to site maintenance, unrelated to the fuel cell systems.

Questions?

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