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Navy Fuel Cell Demonstration Project

Abbas Akhil and Bill Black

Prepared by
Sandia National Laboratories
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Abbas Akhil
Energy Infrastructure and DER Department

Bill Black
NWS Technical Operations

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-1033

Abstract

This is the final report on a field evaluation by the Department of the Navy of twenty 5-kW PEM fuel cells carried out during 2004 and 2005 at five Navy sites located in New York, California, and Hawaii. The key objective of the effort was to obtain an engineering assessment of their military applications. Particular issues of interest were fuel cell cost, performance, reliability, and the readiness of commercial fuel cells for use as a standalone (grid-independent) power option. Two corollary objectives of the demonstration were to promote technological advances and to improve fuel performance and reliability. From a cost perspective, the capital cost of PEM fuel cells at this stage of their development is high compared to other power generation technologies. Sandia National Laboratories' technical recommendation to the Navy is to remain involved in evaluating successive generations of this technology, particularly in locations with greater environmental extremes, and it encourages their increased use by the Navy.

ACKNOWLEDGMENTS

Several people lent considerable time and expertise to complete this project. Without their efforts and patience, it could not have been accomplished. We want to recognize their contributions and express our thanks for their efforts:

- Eugene Crank, Energy Engineering Branch Head, NAVFAC, Port Hueneme, California, for his guidance and continual support through all phases of the project;
- Dave Menicucci (SNL), for his guidance and advice in developing the project;
- Vinny Cassala (Plug Power, Inc., Project Manager), and his technical team at Plug Power;
- Aaron Murray and Ben Schenkman (SNL), for their outstanding performances at collecting, archiving, and analyzing the data;
- George Collard (LOGAN Energy) for dedication and responsiveness in servicing and maintaining the San Diego fuel cells;
- Dale Foster (POC San Diego), who facilitated the fuel cell installation and operations; and
- Kevin Saito (POC Hawaii) and John Grobel, who facilitated the fuel cell installation and operations at Pearl Harbor.

Abbas Akhil and Bill Black
Co-Leads of the Sandia Project Management Team

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1. SUMMARY AND CONCLUSIONS

This is the final report on a field evaluation by the Navy of twenty 5-kW proton exchange membrane (PEM) fuel cells that was carried out during 2004 and 2005.[1] The key objective of the effort was to obtain an engineering assessment of the "viability of applying PEM technology to improve military readiness [1]." Particular issues of interest were fuel cell cost, performance, reliability, and the readiness of commercial fuel cells for use as a standalone (grid-independent) power option. Two corollary objectives of the demonstration were to promote technological advances and to improve fuel performance and reliability, leading to reductions in energy use and cost.

To make the assessment, 20 commercial PEM fuel cells were installed and operated for about a year at five Navy sites located in New York, California, and Hawaii [2]. Instantaneous performance parameters were recorded and used to characterize the fuel cells individually and as a group.

The 20 PEM fuel cells collectively operated for over 140,000 hours and had an availability of greater than 95%. The fuel cells provided electric power and heat to their various loads. From a cost perspective, the capital cost of PEM fuel cells at this stage of their development is high compared to other power generation technologies. Based on the costs for this project, the cost per kW capacity for the fuel cell only is $10,050/kW. Total cost per kW including installation maintenance, reporting, and decommissioning is $21,330/kW.

By comparison, other small distributed generation systems, such as microturbines, are in the $1,200 to $1,500/kW range.

Further cost analysis for this project's installations was not possible with the collected data because the natural gas consumed by each fuel cell was not metered and recorded.

The project also successfully completed the task of creating a website (Navy Fuel Cell Demonstration Project[2]) as a tool to report on the project outcomes. The website helps to serve the Navy's goal of informing, promoting, and educating stakeholders in the Navy and elsewhere regarding PEM fuel cell technology and its potential as a power and heat source.

Sandia National Laboratories' technical recommendation to the Navy is that it continue to remain involved in evaluating successive generations of this technology and in encouraging their increased use by the Navy.

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[1] The Navy received funding for this work in the amount of $4.5M by an allocation of Congress' Defense Appropriation Committee for FY03.

[2] Website can be found at http://fuelcell.sandia.gov.

2. PROJECT OVERVIEW

The PEM industry is manufacturing fuel cells with improved thermal energy recovery and load-following capability, and the military's expectations are that these and other features will enable operation in a wide variety of applications. This demonstration was intended to evaluate and report on the performance of PEM fuel cells and provide recommendations as to steps needed to improve the suitability of the technology to meet the requirements of the Department of the Navy.

2.1 Team Members and Task Distribution

The project team members are listed in Table 1 along with the task breakdown structure and the deliverables for the project. In accordance with this distribution of responsibilities, the Navy specified the PEM fuel cell technology to be employed, selected the sites for the demonstration, and obtained the site hosts' consent and support for placement of the fuel cells at their respective locations. Sandia was given the overall technical lead role in the project and placed a sole-source contract with Plug Power to supply and install the project's 20 fuel cells; Plug Power subcontracted with LOGAN Energy for the installation and maintenance of the fuel cell systems. The performance evaluation task, which was Sandia's, was facilitated by the fact that the GenSys 5C system is equipped with instruments and sensors that measure ~90 distinct operational and performance parameters. These measured values were captured by the unit's data logger. Plug Power provided to Sandia, on a monthly basis, a data set comprising the prior month's readings from the fuel cell data loggers and a narrative of significant events and outages recorded by each fuel cell during that period.

2.2 Technology Specification and Equipment Selection

In the first stage of the work, the Navy specified that the fuel cells were to be in the small, 5-kW size range. Sandia determined that the only domestic source of commercially available fuel cells that met this requirement were those manufactured by Plug Power.[3] Fuel cells offered by other domestic sources were not as commercially mature and were either advanced prototypes or in a pre-commercial state of readiness. The fuel cells available from Plug Power were deemed commercially ready as evidenced by their well-established manufacturing facility in Latham, New York, an established supply chain of parts and components that supports this manufacturing facility and a network of qualified maintenance personnel to service the installed units. In addition, Plug Power offers a certified training program for prospective buyers to train their personnel on the installation and maintenance of the units.

These considerations led to the selection of Plug Power's SU1 GenSys^{TM} 5-kW Fuel Cell, Model5C,[4] as the preferred PEM fuel cell for the project. Figure 1 illustrates a typical unit used in this demonstration project.

[3] Plug Power, 968 Albany-Shaker Road, Latham, New York 12110.
[4] Hereafter to be referred to as the GenSys 5C.

Table 1. PEM Fuel Cell Demonstration Team and Task Breakdown Structure.

Organization	Role/Task	Deliverable
Navy	a. Specify the requirements for the PEM fuel cells to be employed b. Define the site requirements c. Select the actual sites where PEM fuel were to be installed and operated d. Obtain site host cooperation	1. Specifications for PEM fuel cells 2. Site list 3. Agreement of site hosts to participate
Sandia National Laboratories	a. Overall technical lead role b. Select and procure the PEM fuel cells c. Develop website for communication, education, and technology promotion d. Monitor PEM fuel cells in operation e. Analyze data and determine performance metrics f. Report operating results to the Navy and provide interim and final reports	1. Interim report and presentation (to Navy) 2. Contract placement with equipment provider 3. Website 4. Final report to Navy
Plug Power (equipment supplier)	a. Supply GenSys 5C fuel cells b. Provide monthly data to Sandia c. Decommission and remove fuel cells at end of project	Same as task itself
LOGAN Energy	a. Install PEM fuel cells b. Provide on-site operations and maintenance	Same as task itself

Figure 1. Plug Power GenSys 5C – 5-kW PEM Fuel Cell.

2.3 Site Requirements

The dimensions of the Plug Power GenSys 5C are approximately 84 inches L × 32 inches W × 68 inches H.

A minimum clearance of 6 ft is required on all sides to allow access for maintenance.

The installation of the GenSys does not require any special foundation and the units were skid mounted at all the 20 sites and placed directly on the ground with minimal site preparation.

All the systems, except the Pearl Harbor, Hawaii, installation, operated on natural gas, which was available at the sites at a nominal pressure of 15 psi. The Pearl Harbor unit operated on propane, which was supplied by a local vendor and stored on site in a 500-gallon storage tank.

The GenSys 5C also requires a supply of de-ionized water. This is provided by an auxiliary subsystem that processes the domestic water at the site to meet the fuel cell needs. Water consumption is proportional to the power/energy output of the fuel cell and depends on site-specific operational requirements. In the case of the GenSys 5C, most of the sites used an average of 10 gallons/day.

2.4 Site Selection and Systems Installations

Twenty fuel cells were sited at US Navy facilities across America: eight were installed in Saratoga Springs, New York; eleven units in California (San Diego, China Lake, and Point Mugu); and one in Pearl Harbor, Hawaii. The various fuel cell sites offered an assortment of combined heat and power (CHP) utilization schemes such as swimming pools, residential domestic hot water, and a laundromat. These sites were carefully chosen for their CHP utilization. A schematic for each site installation is shown in Appendix A.

The site locations, fuel cell unit serial numbers, and system commissioning dates are shown in Appendix B. Seventeen of the 20 GenSys 5Cs were installed and commissioned by the end of September 2004. Two of the remaining three were commissioned by mid-January 2005, and the last was commissioned in Pearl Harbor in mid-February 2005.

2.4.1 Field Test Period

The original project plan envisioned a field evaluation period of 12 months for each of the 20 fuel cells, but 11 of the 20 units had shorter field operating times due to site-specific reasons.

Commissioning of the two units at Naval Base Ventura County, Pt. Mugu, was delayed because of delays in obtaining an interconnection permit from Southern California Edison, the local electric utility company. These two units commenced operation on January 18, 2005, almost five months after project start.

Commissioning of the single unit at Pearl Harbor was delayed until propane meeting the higher purity requirements of the fuel cell could be finalized. This unit commenced operation on

February 16, 2005, following satisfactory resolution of the propane fuel supply from the local vendor.

The remaining eight fuel cells at NSU Saratoga Springs were installed and commissioned on August 10, 2004, as planned. However, these eight units did not complete their planned 12-month field operation because the Saratoga Springs Naval Housing was privatized about the same time as the fuel cell project started. The new management of the privatized housing did not wish to support the fuel cells because the homes with the fuel cells were incurring higher natural gas costs than the other housing units. The additional expense of the natural gas was not offset by any credit from the local electric utility for the electricity that was fed back on the local grid by the fuel cells. Further, the contract for the privatized housing did not include specific clauses that required the new management to support the continued operation of the eight fuel cells. Negotiations were undertaken with the housing management in an attempt to continue operating the fuel cells. However, these negotiations were inconclusive and the fuel cells were eventually removed from the site on March 22, 2005, after approximately seven months of operation.

2.4.2 Project Costs

The 20 fuel cell systems were purchased from Plug Power under a single contract that included the cost of the systems, maintenance, installation and decommissioning, and data acquisition and monitoring. Note that these costs do not include the cost of natural gas (or propane for Pearl Harbor unit) as these were borne by each host site.

The detailed breakdown of the costs by each site is shown in Appendix C. A summary of these costs on a per unit basis calculated from the 20 fuel cell cluster is presented in this section.

The average cost of the Plug Power GenSys 5C fuel cell system is $50,250 or $10,050/kW based on the 5 kW nameplate capacity rating.

The average total cost for each system including the installation, maintenance, decommissioning, and reporting is $106,650.

3. TESTING AND EVALUATION

Six performance metrics were applied to characterize the PEM fuel cells: system availability, average output power, capacity factor, estimated electrical efficiency, total cumulative hours of operation, and cumulative hours of outage.

These performance measures were calculated using data from the GenSys 5C's on-board data logger, which obtains readings from the unit's instruments and sensors.

The parameters were calculated as follows:

- Availability (%) = [RunTime (hr)/TimeInMonths(hr)] × 100
- Avg. output power (kW) = Energy Produced (kWh)/RunTime (hr)
- Capacity factor (%) = {EnergyProduced (kWh)/[RatedPower(5 kW) × TimeInPeriod (hr)]} × 100
- Electrical efficiency (%) = [EnergyProduced (kWh)/LifetimeFuelConsumed (kWh)] × 100
- Total cumulative hours of operation: a measured value
- Cumulative hours of outage: a measured value

The measures obtained for the performance of the PEM fuel cells were derived using data recorded directly from the GenSys 5C's data logger at 1-minute intervals. The Sandia team received from Plug Power and archived on a monthly basis data sets that represented 10-minute averages of these same readings. A comparison of the 1-minute and the 10-minute data made using results from the first four months showed a difference of 2% or less in the calculated performance of the systems. Consequently the final results presented here are based on Sandia's analysis of the 10-minute average data.

4. PERFORMANCE SUMMARY

A summary of the performance metrics for the group of PEM fuel cells is given in Table 2. This group of 5-kW PEM fuel cells demonstrated a system availability above 95%.[5] The average output power was 2.46 kW, which was calculated by dividing the energy produced by the run time. The capacity factor was 47.12%, and was calculated by dividing the average output power by the output setting.[6] The overall electrical efficiency was 25.43%, and was calculated by dividing the total energy produced in Btus (1 kWh = 3,414 Btus) by total fuel usage. In calculating hours of outage, the total scheduled and unscheduled shutdowns were combined. The total hours of outage for all the systems were 6,650 hours.

Table 2. Performance Summary.

System Availability	95.76%
Average Output Power for each fuel cell	2.46 kW
Total kWh produced by 20 fuel cells	344,623 kWh
Capacity Factor	47.12%
Electrical Efficiency	25.43%
Cumulative Hours of Operation – 20 fuel cells	140,492 hr
Cumulative Down Time – 20 fuel cells	6,650 hr

While Table 2 presents the results of the full set of 20 fuel cells, the eight fuel cells at Saratoga Springs had a considerably shorter field operating period from August 10, 2004, to March 22, 2005. A separate performance summary was prepared to determine if the performance statistics changed if the eight Saratoga Springs fuel cells were excluded. This analysis showed a slight drop in the overall system availability and capacity factor to 93.95% and 45.96%, respectively. Table 3 shows the complete performance statistics excluding the Saratoga Springs units.

[5] System availability was defined as the system run time divided by the time in the period.

[6] Technically, capacity factor is the ratio of the energy generated by an electricity generator during a given time period to the energy that could have been generated had the unit run at its full rating over the same time period. The method used here mimicked a methodology set by Plug Power but yields a result that is numerically equivalent.

Table 3. Performance Summary, Excluding Saratoga Springs.

System Availability	93.95%
Average Output Power for each fuel cell	2.45 kW
Total kWh produced, less Saratoga Springs	239,434 kWh
Capacity Factor	45.96%
Electrical Efficiency	25.28%
Cumulative Hours of Operation	98,108 hr
Cumulative Down Time – 20 fuel cells	6,026 hr

5. CONCLUSION AND RECOMMENDATIONS

The 20 fuel cells demonstrated an availability in excess of 95% over a cumulative operating period of 140,000 hours.

The present high cost of PEM fuel cells is a disadvantage. This cost is presently driven by two factors: low production volumes and the use of precious metals, such as platinum and other proprietary catalysts. It is expected that wider adoption of fuel cells will increase the production volumes, which subsequently lead to lower costs. Further, ongoing research in fuel cells seeks to introduce less expensive materials to lower their cost and extend system life.

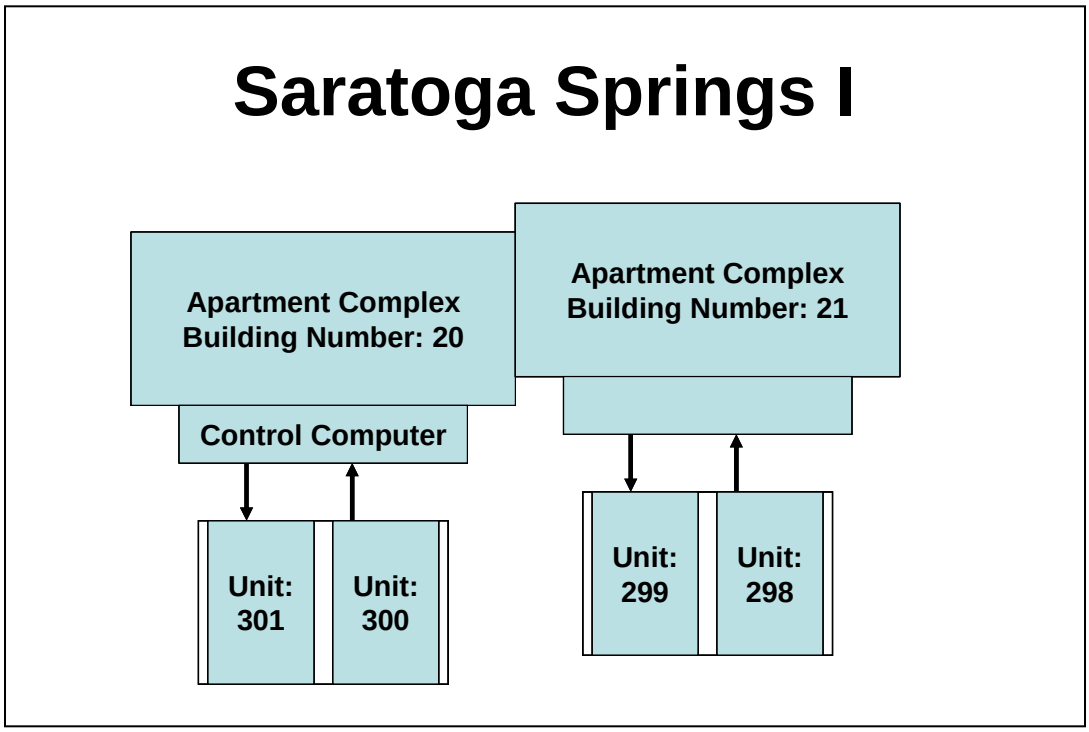
It is recommended that future field testing of fuel cells by the Navy be conducted in locations where there are greater environmental extremes such as temperature, humidity, and elevation. Budget constraints for this project favored the selection of demonstration sites with more benign environmental conditions and where access and technical support was readily available.

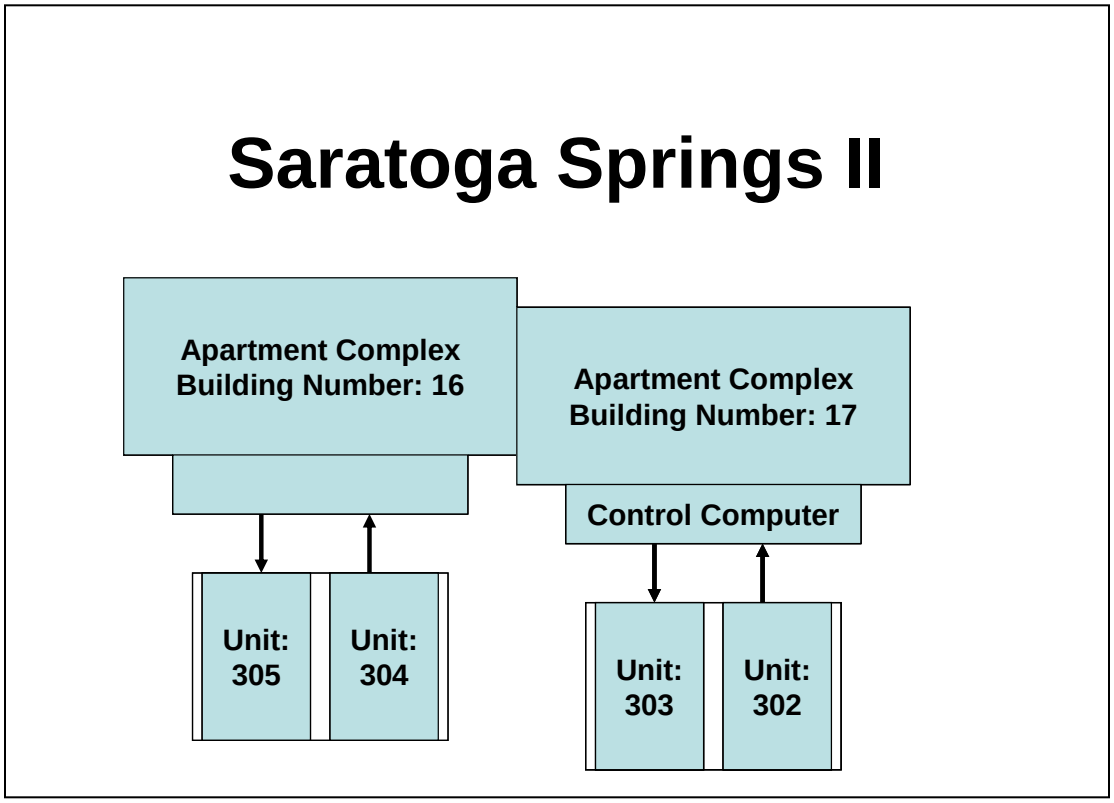
6. REFERENCES

1. *FY03 Proton Exchange Membrane (PEM) Fuel Cell Demonstrations*, Gene Crank, Project Facilitator, April 2004.

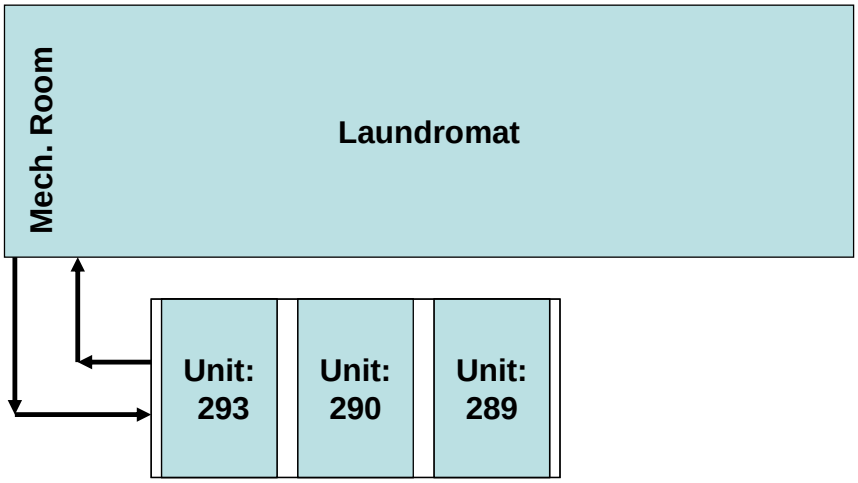
2. *Navy Fuel Cell Demonstration Project, Interim Progress Report*, Sandia National Laboratories, February 23, 2005.

APPENDIX A: Schematic of Site Installations

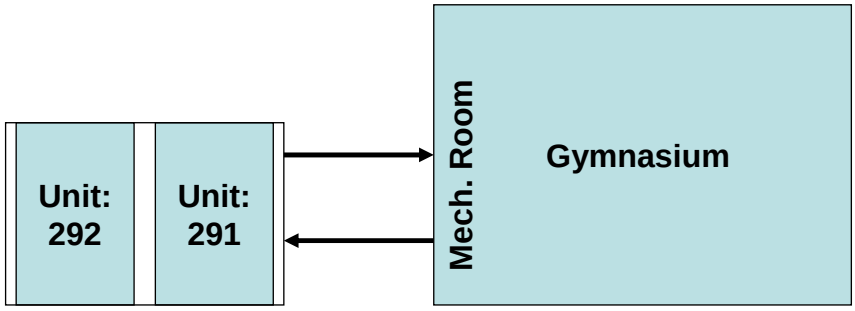




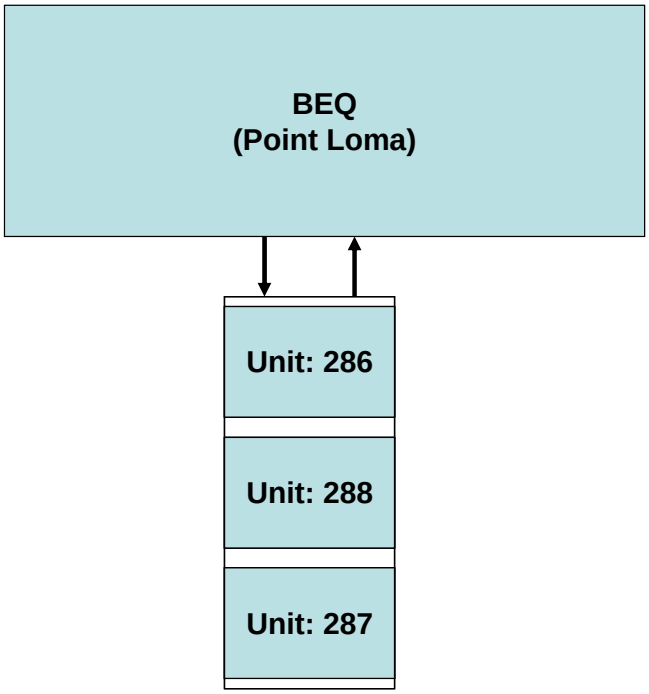
San Diego (Laundromat)



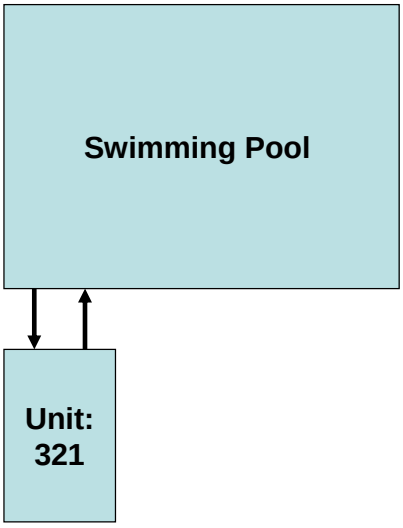
San Diego (Gymnasium)



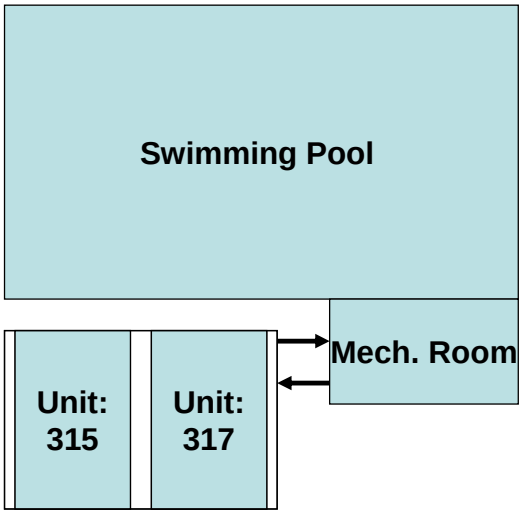
San Diego (Housing)



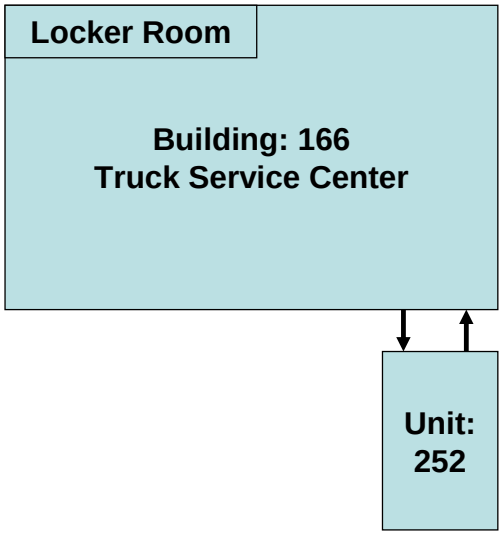
China Lake



Point Mugu



Pearl Harbor



APPENDIX B: Site Names, Unit Serial Numbers, and Commissioning Dates

Site Name	Unit Serial Number	Commissioning Date
NAS North Island Laundromat, San Diego, CA – 3 Units	SU01B000000289 SU01B000000290 SU01B000000293	08/17/2004 08/17/2004 08/17/2004
NAS North Island Fitness Center, San Diego, CA – 2 Units	SU01B000000291 SU01B000000292	08/13/2004 08/13/2004
Point Loma Sub Base San Diego, CA – 3 Units	SU01B000000286 SU01B000000287 SU01B000000288	08/17/2004 08/17/2004 08/17/2004
Saratoga NSU – Bldg. 16 Saratoga Springs, NY – 2 Units	SU01B000000304 SU01B000000305	08/10/2004 08/10/2004
Saratoga NSU – Bldg. 17 Saratoga Springs, NY – 2 Units	SU01B000000302 SU01B000000303	08/10/2004 08/10/2004
Saratoga NSU – Bldg. 20 Saratoga Springs, NY – 2 Units	SU01B000000300 SU01B000000301	08/10/2004 08/10/2004
Saratoga NSU – Bldg. 21 Saratoga Springs, NY – 2 Units	SU01B000000298 SU01B000000299	08/10/2004 08/10/2004
China Lake, CA – 1 Unit	SU01B000000321	09/30/2004
Naval Base Ventura County Pt. Mugu, CA – 2 Units	SU01B000000315 SU01B000000317	1/18/2005 1/18/2005
Pearl Harbor, HI – 1 Unit (Propane fueled)	SU01B00000252	2/16/2005

APPENDIX C: Project Costs (Excluding Fuel Costs)

The complete breakdown of project costs, including fuel cell systems, site preparation, operations and maintenance, and decommissioning costs for all the demonstration sites are listed below.

NAS North Island and Point Loma Sub Base – Total 8 fuel cells:

Fuel Cell System Cost	$400,000
Shipping and Handling	$8,600
Site Preparation Costs	$134,530
Maintenance Costs	$262,240
Reporting by TetraTech	$32,000
Contractor Travel & Living Expense	$52,679
Program Management & Reporting	$7,546
Decommissioning Costs	$18,880
Total Cost for 8 systems	**$916,475**

Saratoga Springs NSU – Total 8 fuel cells:

(The Saratoga Springs demonstration site is located very close to the Plug Power corporate headquarters and manufacturing facility in Latham, New York; hence, there was no shipping and handling charge for these units. The data logging and monitoring was also performed by Plug Power at no cost to the project.)

Fuel Cell System Cost	$400,000
Shipping and Handling	$0
Site Preparation Costs	$32,445
Maintenance Costs	$190,112
Reporting	$0
Contractor Travel & Living Expense	$4,840
Program Management & Reporting	$10,062
Decommissioning Costs	$17,564
Total Cost for 8 systems	**$655,022**

China Lake, CA – 1 fuel cell:

Fuel Cell System Cost	$50,000
Shipping and Handling	$1,040
Site Preparation Costs	$24,295
Maintenance Costs	$35,444
Contractor Travel & Living Expense	$7,942
Program Management & Reporting	$1,006
Decommissioning Costs	$2,697
Total Cost for 1 system	**$122,424**

Naval Base Ventura County, Pt. Mugu, CA – 2 fuel cells:

Fuel Cell System Cost	$100,000
Shipping and Handling	$2,080
Site Preparation Costs	$79,128
Maintenance Costs	$60,452
Reporting to TetraTech	$0
Contractor Travel & Living Expense	$6,026
Program Management & Reporting	$1,006
Decommissioning Costs	$4,720
Total Cost for 2 systems	**$253,412**

Pearl Harbor, HI – 1 fuel cell:

Fuel Cell System Cost	$55,000
Shipping and Handling	$2,165
Site Preparation Costs	$55,326
Maintenance Costs	$52,717
Reporting to TetraTech	$0
Contractor Travel & Living Expense	$17,595
Program Management & Reporting	$1,006
Decommissioning Costs	$1,860
Total Cost for 1 system	**$185,669**

APPENDIX D: Site Installation Photos

Ribbon Cutting for the Propane-fueled Fuel Cell,
Number 252, Installed at the Truck Service Center, Pearl Harbor

Fuel Cell Unit Numbers 315 and 317, Installed at Swimming Pool, Pt. Mugu.

Fuel Cell Unit Number 288. One of three fuel cells at Pt. Loma BEQ, San Diego.

Two Fuel Cells Numbers 292 and 291, Installed at the Fitness Center/Gymnasium, San Diego.

Fuel Cell Units, Number 300 and 301, Installed at Bldg. 20, Saratoga, Springs, NSU.

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External Recipients (distributed electronically unless otherwise noted):

1 Naval Facilities Engineering Service Center
Attn: Gene Crank, eugene.crank@navy.mil

2 Plug Power *(paper)*
Attn: Mr. Andrew Marsh, President/CEO
968 Albany Shaker Road
Latham, NY 12110

1 LOGAN Energy
Attn: George Collard, gcollard@loganenergy.com

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