LADWP Fuel Cell Demonstration Project

250 kW – Molten Carbonate Fuel Cell Power Plant
Located at
Terminal Island Wastewater Treatment Plant

Final Report

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Disclaimer

Abstract:

The Los Angeles Department of Water and Power (LADWP) has developed one of the most recognized fuel cell demonstration programs in the United States. In addition to their high efficiencies and superior environmental performance, fuel cells and other generating technologies that can be located at or near the load, offers several electric utility benefits. Fuel cells can help further reduce costs by reducing peak electricity demand, thereby deferring or avoiding expenses for additional electric utility infrastructure. By locating generators near the load, higher reliability of service is possible and the losses that occur during delivery of electricity from remote generators are avoided. The potential to use renewable and locally available fuels, such as landfill or sewage treatment waste gases, provides another attractive outlook. In Los Angeles, there are also many oil producing areas where the gas by-product can be utilized.

In June 2000, the LADWP contracted with FCE to install and commission the pre-commercial 250kW MCFC power plant. The plant was delivered, installed, and began power production at the JFB in August 2001. The plant underwent manufacturer's field trials up for 18 months and was replace with a commercial plant in January 2003.

In January 2001, the LADWP contracted with FCE to provide two additional 250kW MCFC power plants. These commercial plants began operations during mid-2003. The locations of these plants are at the Terminal Island Sewage Treatment Plant at the Los Angeles Harbor (for eventual operation on digester gas) and at the LADWP Main Street Service Center east of downtown Los Angeles.

All three carbonate fuel cell plants received partial funding through the Department of Defense's Climate Change Fuel Cell Buydown Program. This report covers the technical evaluation and benefit-cost evaluation of the Terminal Island 250kW MCFC power plant during its first year of operation from June 2003 to July 2004.

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Executive Summary:

The Los Angeles Department of Water and Power (LADWP) was established more than one hundred years ago and today serves more than 1.5 million commercial and residential customers within the city.

In January 2001 LADWP contracted with FuelCell Energy (FCE) for the delivery of two commercial 250kW carbonate fuel cell plants. The value of the contract was $2.4 million of which $500,000 was sought to be funded through the Department of Defense Climate Change Buydown Program.

This report, which is part of the buydown program requirements, describes the operation of the initial plant at the Terminal Island Wastewater Treatment Plant located at the Port of Los Angeles. The plant was delivered on May 21, 2003 and was installed by LADWP in partnership with the Los Angeles Department of Public Works (LADPW) and FCE. The plant began operating on May 30 and reached the criteria for plant acceptance and ownership transfer from FCE to LADWP on June 24, 2003.

The fuel cell fuel cell is designed to deliver 250kW AC net at minimum 47% efficiency while operating on pipeline natural gas. It is connected to a 4.8kV overhead distribution line and is operated at constant output. LADWP is currently working along with LADPW to purchase and install a gas-processing unit to convert operation to locally produced renewable anaerobic digester gas. Currently this operation is scheduled to begin during first quarter of 2005.

During the first year of operation the plant accumulated nearly 6200 hours of operation with an availability of 71%. The total electrical production reached more than 1400 MWh with a capacity factor of 65%. The longest period of continuous operation was over 2300 hours on partial load and over 800 hours at full nameplate rating of 250kW. As expected, the total NOx and SOx emission were virtually zero with NOx being less than 0.1 part per million and SOx being less than 0.01 part per million.

The operation at Terminal Island yielded several important findings concerning the plant's design that resulted in improvements in reliability and performance, as well as operability and maintainability. Improvements included, better stack-manifold seals and improved gas sulfur removal filter. Plant controls were improved and the plant emergency shut down process was redesigned.

The benefit to cost analysis shows that fuel cells are not economical at this point, basically due to the high capital cost in procuring the plant. However, it is anticipated that volume production will drive cost down to competitive level, especially since in resent years the gas prices have nearly tripled.

This fuel cell project has demonstrated that fuel cells continue steady development and since operations began FCE has delivered a number of additional plants that incorporates lessons-learned from Terminal Island Wastewater Treatment Plant.

Introduction:

The Los Angeles Department of Water and Power (LADWP), which recently marked its 100th year anniversary of providing reliable and cost effective electric and water service to the residents of Los Angeles, has developed one of the most recognized fuel cell programs in the United States and Asia. The program is part of an overall strategy concerning Distributed Generation (DG).

DG can take the form of any number of types of electric generators, from large industrial combustion engines, to small residential rooftop photovoltaic panels that are operated alone, clustered, or connected to the electric grid.

DG has already made an impact on the Los Angeles electric system. In the last 15 years, over 125 megawatts (MW) of DG have been installed, representing nearly one quarter of new generating capacity for Los Angeles. In the past, the primary driver for these installations was large customers' demand for co-generation systems that could utilize the waste heat to substantially lower their overall energy costs.

In recent years, clean and efficient DG technologies that are smaller and easy to site and install, have been developed. In addition to utilizing waste heat, DG may offer several potential electric utility benefits. DG can help reduce costs by reducing peak electricity demand, thereby deferring or avoiding expenses for additional electric utility infrastructure. By locating generators near the load, higher reliability of service is possible and the losses that occur during delivery of electricity from remote generators are avoided. The potential to use renewable and locally available fuels, such as landfill or sewage treatment waste gases, provides another attractive outlook for DG. In Los Angeles, there are also many oil producing areas where the gas by-product can be utilized in a local generating plant.

Fuel cells that are intended for utility scale electric generation have been in development for several decades. Compared to mature generating technologies, such as large gas turbines, fuel cells remain very costly and lack the product distribution and service infrastructure, and the general know-how, that are typical for widely deployed technologies. These are perhaps the major challenges fuel cell developers are faced with.

Because of the many potential benefits of deploying fuel cells in Los Angeles, the LADWP has a long history of supporting projects to commercialize stationary fuel cells. In particular, the LADWP actively participated in the engineering and construction of the Santa Clara Demonstration Project, a large-scale demonstration of a 2MW carbonate fuel cell power plant in the city of Santa Clara, California during the early to mid-1990s. High temperature fuel cells such as the MCFC and SOFC have particular benefits that include high electrical efficiency. Its waste-heat, because it is of high temperature, can be utilized in both heating and air-conditioning systems.

In June 2000, the LADWP contracted with FCE to install and commission the pre-commercial 250kW MCFC power plant. The plant was delivered, installed, and began power production at the JFB in August 2001. The plant underwent manufacturer's field trials up for 18 months and was replace with a commercial plant in January 2003.

In January 2001, the LADWP contracted with FCE to provide two additional 250kW MCFC power plants. These commercial plants began operations during mid-2003. The locations of these plants are at the Terminal Island Wastewater Treatment Plant at the Port of Los Angeles (for eventual operation on digester gas) and at the LADWP Main Street Service Center east of downtown Los Angeles.

All three carbonate fuel cell plants received partial funding through the Department of Defense's Climate Change Fuel Cell Buydown Program. This report will covers the technical evaluation and benefit-cost evaluation of the Terminal Island 250kW MCFC power plant during the one year operating period from June 24, 2003 to June 23, 2004.

Results and Discussion

The fuel cell plant was delivered on schedule on May 21st. Installation and commissioning took about one week to complete and the plant start-up began on May 30, 2003. The 100MWhr continuous acceptance test at nameplate rating of 250kW started on June 6, 2003 with anticipated completion by June 23rd. The Acceptance Testing encountered some problems. About mid-way through the test the plant was intentionally shutdown for LADWP scheduled electrical distribution system maintenance work in the area. However, the work took longer than anticipated, causing the plant to "free cool" 90 minutes beyond the permissible three-hour time window. With no apparent damage due to this incident the Acceptance Testing was completed June 24, 2003. Efficiency testing was done and the 47% minimum net efficiency was verified

After the Acceptance Test the plant operated continuously at nameplate rating. The plant experienced a large number of nuisance alarms from the various plant processes, however most originated in the water treatment unit. FCE engaged into major efforts to solve this problem and over the year of operation the alarm problem became largely resolved.

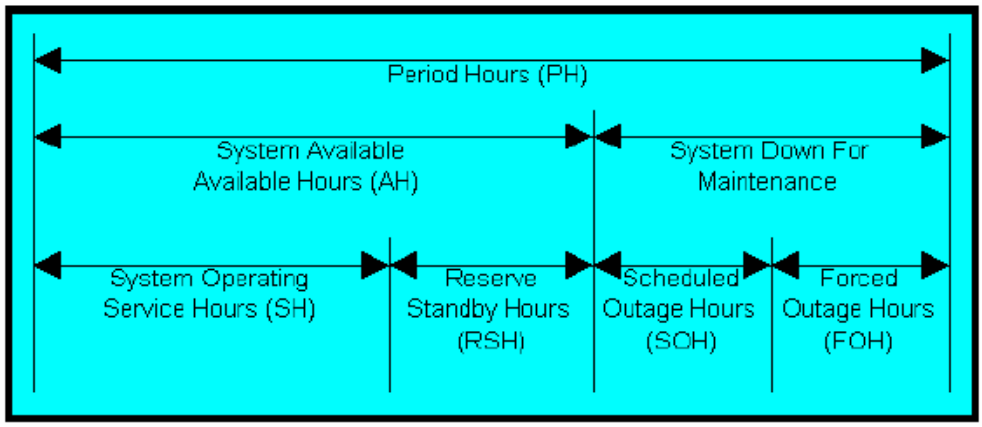
On July 13, 2003 the plant tripped offline due to a water leak in the natural gas reformer equipment. At the same time, the pager system did not work and the plant was left to "free cool" for almost 24 hours. FCE proceeded to inspect the plant and to carry out some plant improvements. When restored to full nameplate operation there was no indication of performance loss due to the "free cooling" incident. After about one week of operation a voltage problem occurred in the fuel cell stack, the output was reduced and after several weeks of testing and software modifications the plant was returned to full rated output and operated with few problems until late in 2003. In December the stack voltage problem reoccurred and FCE eventually decided to return the fuel cell module to the factory for inspections and to ship out a replacement module.

The plant operated at reduced output until January when the plant was shut down while a new type of activated carbon material for the "desulferizer" was procured and installed. The new material is expected to prolong the scheduled routine maintenance interval of the "desulferizer" from six to nine months. The plant was returned to operation during the first week of March. In April the replacement fuel cell module was

installed, along with several important plant modifications. The plant was restored to full operation in early May and has continued to perform steadily in the months afterwards.

Reliability Analysis (MTBF)

To determine the reliability statistics, performance indices are used that are published by the Gas Technology institute (GTI) in Des Plaines, Illionois.



Reliability Performance Indices	***Formula***
Period of Demand (POD): *Measures the time the unit was planned to operate.*	$POD = PH - RSH - SOH$
Availability Factor (AF, %): *Measures, on a percent basis, the unit's "could run" capability. Impacted by planned and unplanned maintenance.*	$AF = \frac{(PH - SOH - FOH) \times 100}{PH}$
Forced Outage Rate (FOR, %): *Measures portion of downtime due to unplanned factors.*	$FOR = \frac{FOH \times 100}{SH + FOH}$
Scheduled Outage Factor (SOF, %): *Measures percent of time set aside for planned maintenance.*	$SOF = \frac{SOH \times 100}{PH}$
Service Factor (SF, %): *Percent of total period hours the unit is on-line – varies due to site-related or economic factors.*	$SF = \frac{SH \times 100}{PH}$
Mean Time Between Forced Outages (MTBFO): *Measures the nominal time between unscheduled forced outages.*	$MTBFO = \frac{SH}{\#\ ForcedOutages}$
Mean Down Time (MDT): *Measures the nominal duration the unit is down during maintenance events.*	$MDT = \frac{SOH + FOH}{\#\ ForcedOutages + \#\ PlannedOutages}$

(Source: http://www.gri.org/pub/solutions/dg/rel_metrics.html)

The following table provides details about the first Year of operation of the fuel cell power plant including data on reliability and performance.

Reliability Performance Indices		
Period Hours, PH	8784	hrs
Scheduled Outage Hours, SOH	1967	hrs
Forced Outage Hours, FOH	630	hrs
Reserve Standby Hours, RSH	0	hrs
System Available – Available Hours, AH	6187	hrs
System Operating Service Hours, SH	6187	hrs
Period of Demand, POD	6817	hrs
Availability Factor, AF	70%	
Forced Outage Rate, FOR	9%	
Scheduled Outage Factor, SOF	22%	
Service Factor, SF	70%	
Mean Down Time, MDT	325	hrs
Mean Time Between Failure (MTBF)	3093	hrs
System Total Use (kWh)	1,426,162	kWh
System Peak Use (kW)	254	kW
Total Fuel Cell Plant Capacity (kW)	250	kW
Heat Rate Ave Yr (BTU/kWh)	7322	BTU/kWh
Capacity Factor (% of Nameplate Rating)	65%	
Thermal Output (Btu/yr), if byproduct used	0	Btu/yr

Shutdown Summary:

During it's first year of operation the fuel cell plant was monitored by FCE in Danbury, Connecticut through a secure data line throughout the one-year of operation. The following table shows a detailed timeline of the shutdowns at the Terminal Island fuel cell.

Description/Event	Date and Time	Loadtime	Run Hours	System Down Hours
First Start Up	6/24/03 0:00			
Emergency Shut Down due to leak in Water Treatment Unit. The plant "free cooled" above time limit.	7/13/03 15:00	471	471	
Return to nameplate rating after completing construction punch-list items. FCE did extensive plant inspections during the period.	8/7/03 22:00	471		607
Intentional shutdown to due to high stack-voltage differential	8/25/03 20:00	901	430	
Return to reduced output of 170kW net AC	8/26/03 19:00	901		23
Plant brought to "hot-standby" to allow work on the pre-ignition oxidizer	9/10/03 15:00	1257	356	
Return to reduced output of 170kW net AC	9/12/03 3:00	1257		36
Return to full power of 250kW net AC	10/10/03 20:00	1946	689	
Shutdown for periodic maintenance and software upgrade	12/16/03 7:00	3541	1595	
Return to reduced output of 220kW net AC	12/17/03 16:00	3541		33
Shutdown to "cold standby" for periodic maintenance and plant inspections. Serious fuel cell module problem detected.	1/26/04 7:00	4492	951	
Return to reduced output of 220kW net AC	3/18/04 15:00	4492		1256
Plant shutdown for carbon filter material replacement	3/27/04 16:00	4709	217	
Return to reduced output of 220kW net AC	3/30/04 13:00	4709		69
Plant shutdown due to grid disturbance	4/18/04 20:00	5172	463	
Return to full power of 250kW net AC	4/19/04 19:00	5172		23
Shutdown plant for fuel cell module replacement.	4/25/04 21:00	5318	146	
Return to near full power of 250kW net AC	5/18/04 19:00	5318		550
End of test period	6/23/04 23:59	6187	869	
Totals			6187	2597

Emissions

The LADWP constantly strives to improve the air quality in the city of Los Angeles. By installing the fuel cell power plant, LADWP is reducing the amount of harmful chemicals in the air such as NOx or CO. From this table, it can be seen that the amount of NOx produced is negligible along with the other harmful chemicals.

Emissions	TI Fuel Cell Emissions (15% O_2)
Nox	0.0004 lb/MWh
Sox	0.003 lb/MWh
VOC	<10 ppmv
CO	<10 ppmv
Particulates	Negligible
Smoke	None

Thermal Output

Fuel cells are very clean forms of producing power and the main byproduct is water and heat. The heat from the fuel cell can be used for heating purposes or for cooling purposes using absorption chillers. The utilization of heat recovery can increase the efficiency of the fuel cell from 35-40% to 80-85%. Currently the fuel cell at the Terminal Island Wastewater Treatment Plant is in phase-1 of its operation where the power generated from this fuel cell unit goes into LADWP's power grid. Phase-2 of the operation is to recover heat from the fuel cell for use in the digester process of the wastewater.

Cost Parameter

The following table provides the economic data from the first year of operation.

Specification	Data
Total Fuel Cell Plant Cost ($)	1,450,000
Fixed Operating Cost	$40,000
Variable Operating Costs (mil/kWh) (Fuel)	$50,000
Local Area Electricity Price (cents/kWh)	5 cents/kWh for generation 9 cents/kWh for delivered
*Fuel Price ($/MBtu)	$4.85/MBTU

Cost-Benefit Evaluation

Activity	Cost
Investment	
Total Fuel Cell Plant Cost	$1,225,000
Installation Cost	$225,000
Total Investment	**$1,450,000**
Funding	
U.S. DOE	$250,000
Total Funding	**$250,000**
Total Costs	
Fuel Cost	$50,000
Operation and Maintenance Cost	$40,000
Total Costs	**$90,000**

Electrical Consumption of Terminal Island Wastewater Treatment Plant

Terminal Island Prior to Installation

Date	Electrical Use (kWh)	Peak Electrical Use (kW)
Jun-02	960,000	1920
Jul-02	1,130,000	1970
Aug-02	920,000	2040
Sep-02	1,150,000	2030
Oct-02	1,400,000	2160
Nov-02	1,150,000	2060
Dec-02	1,330,000	2240
Jan-03	1,290,000	2360
Feb-03	1,240,000	2310
Mar-03	950,000	2030
Apr-03	1,150,000	2040
May-03	1,000,000	1890

Terminal Island During Operation

Date	Electrical Use (kWh)	Peak Electrical Use (kW)
Jun-03	1,000,000	1880
Jul-03	1,090,000	1980
Aug-03	1,110,000	2150
Sep-03	1,310,000	2120
Oct-03	1,450,000	2330
Nov-03	1,190,000	2280
Dec-03	1,410,000	2220
Jan-04	1,310,000	2230
Feb-04	1,470,000	2350
Mar-04	1,120,000	2320
Apr-04	1,170,000	2190
May-04	920,000	2160
Jun-04	1,390,000	2330

The 250kW molten carbonate fuel cell is connected directly to LADWP's power grid system which helps supply an additional 250 kW. Since the fuel cell is connected to the power grid instead of Terminal Island, the electric consumption of the Terminal Island site will not be affected.

Fuel Consumption of Terminal Island Wastewater Treatment Plant

	Terminal Island Less Fuel Cell		Terminal Island Including Fuel Cell	
Date	Gas Use (MMBtu)	Peak Gas Use (MMBtu/dy)	Gas Use (MMBtu)	Peak Gas Use (MMBtu/dy)
Jun-03	5,700	250	6,000	290
Jul-03	3,400	170	3,900	210
Aug-03	1,200	60	2,100	100
Sep-03	2,000	100	3,000	140
Oct-03	1,600	80	3,000	130
Nov-03	2,200	110	3,500	160
Dec-03	3,600	180	4,800	220
Jan-04	3,200	160	4,100	200
Feb-04	2,600	130	2,600	130
Mar-04	2,800	140	3,400	190
Apr-04	4,000	200	4,800	240
May-04	2,800	140	3,300	180
Jun-04	3,000	150	4,000	190

Fuel Cell Electric Output

Date	Electric Output (kWh)	Peak Electric Output (kW)
Jun-03	42,000	254
Jul-03	75,000	253
Aug-03	133,000	252
Sep-03	134,000	240
Oct-03	181,000	252
Nov-03	175,000	253
Dec-03	160,000	223
Jan-04	124,000	220
Feb-04	0	0
Mar-04	77,000	220
Apr-04	111,000	222
May-04	77,000	250
Jun-04	137,000	250
Total	1,426,000	254

The 250kW molten carbonate fuel cell produced a total of 1,426 MWh within its first year of operation. The fuel cell performed well its first year and helped relieve the LADWP power grid. There was no power output during the month of February 2004 due to internal deterioration of the fuel cell. This required the installation of a new fuel cell stack that was installed in May 2004.

Conclusion

Through its successful carbonate fuel cell field demonstrations, LADWP is demonstrating leadership in the advancement of clean and efficient generating technologies that are easy to site near the point of use.

This report covers the initial year of operation of the second carbonate fuel cell in Los Angeles. Compared to the first early production fuel cell plant DFC300, a number of performance achievements were reached. For instance, plant availability increased from 64% to 70% and the total MWhrs produced in the one-year period increased by over 50%.

Several important plant improvements where made. For instance the stack manifold seal was redesigned and the plant was retrofitted with capability to transition to safe standby mode during grid events causing the plant to trip offline. A number of software modifications were made to improve monitoring and operator alarm paging. The plant provided valuable input to FCE in developing a 24-hour remote monitoring center at their factory in Connecticut.

The fuel cell plant is the first installed as a joint venture between LADWP and LADPW and is regarded as a precursor to increase cooperation between the two City departments in order to increase the utilization of renewable fuels such as landfill and digester gases.

The plant has provided great opportunity for the training city personnel and for the integration of fuel cell operations into existing utility routines and protocols.

The funding assistance provided by the US Department of Defense, as managed by the US Department of Energy, was instrumental in allowing this successful fuel cell demonstration program to proceed.

Photo Gallery

	
Site Preparation	**Delivery**

	
In Service	**In Service**

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