Los Angeles Department of Water and Power
Fuel Cell Demonstration Project

250 kW - Molten Carbonate Fuel Cell Power Plant
Located at
LADWP Main Street Service Center

FINAL REPORT

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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 Main Street 250kW MCFC power plant during its first year of operation from September 2003 to August 2004. The data for the month of September 2004 was not available at the time this report was prepared. An addendum to this report will be prepared and transmitted to the Department of Energy once this data becomes available.

This fuel cell power plant was originally intended to be installed at an American Airlines facility located at Los Angeles International Airport, however, due to difficulties in obtaining a site, the plant was ultimately installed at the LADWP's Distributed Generation Test Facility at it's Main Street Service Center.

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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 Main Street Service Center located on the outskirts of downtown Los Angeles. The plant was delivered on July 18, 2003 and was installed by LADWP in partnership with FCE. The plant began operating on September 8, 2003 and reached full load on September 18, 2003.

The fuel cell plant is designed to deliver 250kW AC net at minimum 47% efficiency while operating on pipeline natural gas. It is connected to a 4.8 kV overhead distribution line and is operated at constant output.

During the first year of operation the plant accumulated over 7000 hours of operation with an availability of 86%. The total electrical production reached more than 1700 MWh with a capacity factor of 83%. The longest period of continuous operation was over 1300 hours on partial load and over 700 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 Main Street 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 costs down to competitive levels, especially since in recent years 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 incorporate lessons-learned from Main Street 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 demonstration programs in the United States. The program is part of an overall Distributed Generation (DG) strategy for the LADWP.

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 northeast 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 Main Street 250kW MCFC power plant during the nearly one year operating period from September 18, 2003 to August 24, 2004.

Results and Discussion

The fuel cell plant was delivered on July 18, 2003. Installation and commissioning took about two months to complete and the plant start-up began on September 8, 2003. The plant was ramped up to full load over the next several days and the twelve months of operation for this demonstration started on September 18, 2003 with anticipated completion by September 17, 2004.

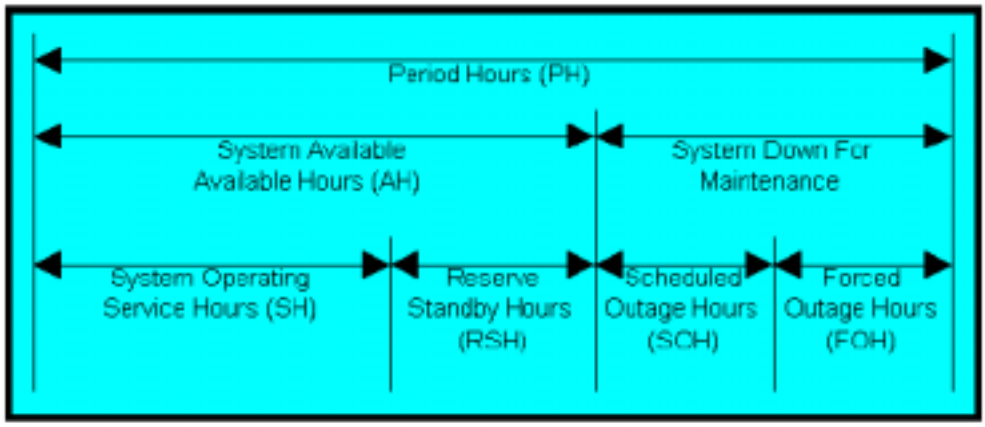
Prior to turnover of ownership to LADWP FCE would have to successfully perform two performance test and one safety test.

A Load Rejection Test was performed successfully on December 4 when the feeder disconnect was intentionally pulled open during load condition. The plant immediately shut down, demonstrating that the plant does not operate in an islanded condition and cause danger to working linemen.

Few problems occurred during the initial period of operations. The carbonate fuel cell plant is the third operated by LADWP and several improvements resulting from past experience had been implemented to the plant design and to operations and maintenance protocols. One surprising incident occurred in early October when the gas supply pressure dropped below minimum. The gas distribution infrastructure is weak in the area and the colder weather caused increased gas consumption and lower gas pressure in the distribution system. A new pressure regulator and some changes to the supply line resolved the problem. At two emergency trip conditions the plant was left unattended for several hours beyond the three hour limit, but it caused no apparent damage to the fuel cell module. In early June 2004 FCE decided to replace the fuel cell module with one that had a newer manifold seal design. The plant began shutdown operations for the module replacement on June 28, 2004. The module was replaced along with the cathode outlet blower's gas seal and bearing and the plant was back on line on July 19, 2004. The plant has basically operated stable since it was restarted. Due to timing, this report will not include the last month of operation and in order to complete the one year reporting requirement the last month of operation will be submitted as an addendum as was requested by Department of Energy staff.

Reliability Analysis (MTBF)

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



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	8184	hrs
Scheduled Outage Hours, SOH	810	hrs
Forced Outage Hours, FOH	325	hrs
Reserve Standby Hours, RSH	0	hrs
System Available – Available Hours, AH	7049	hrs
System Operating Service Hours, SH	7049	hrs
Period of Demand, POD	7374	hrs
Availability Factor, AF	86%	
Forced Outage Rate, FOR	4%	
Scheduled Outage Factor, SOF	10%	
Service Factor, SF	86%	
Mean Down Time, MDT	71	hrs
Mean Time Between Failure (MTBF)	1007	hrs
System Total Use (kWh)	1,701,244	kWh
System Peak Use (kW)	259	kW
Total Fuel Cell Plant Capacity (kW)	250	kW
Heat Rate Ave Yr (BTU/kWh)	7301	BTU/kWh
Capacity Factor (% of Nameplate Rating)	83%	
Thermal Output (Btu/yr), if byproduct used	0	Btu/yr
# of forced outages	7	
# of planned outages	9	

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. The following table shows a detailed timeline of the shutdowns at the Main Street plant.

Description/Event	Date and Time	Loadtime	Run Hours	System Down Hours
First Start Up	18-Sep-03 00:00:00			
Emergency Shut Down (ESD) due to low natural gas pressure	23-Sep-03 17:00:00	137	137	
Return to grid oparations	24-Sep-03 13:00:00	137		20
Hot Standby (HSBY) while replacing gas regulator	06-Oct-03 01:00:00	413	276	
Return to grid oparations	07-Oct-03 18:00:00	413		41
HSBY while taking gas samples	20-Oct-03 19:00:00	726	313	
Return to grid oparations	22-Oct-03 22:00:00	726		51
Emergency Shut Down (ESD) due to momentary loss of grid	31-Oct-03 22:00:00	942	216	
Return to grid oparations	01-Nov-03 15:00:00	942		17
ESD due to erroneous control setpoints	09-Nov-03 15:00:00	1134	192	
Return to grid oparations	17-Nov-03 11:00:00	1134		188
ESD due to momentary loss of grid	07-Dec-03 04:00:00	1607	473	
Return to grid oparations	09-Dec-03 13:00:00	1607		57
Hot Standby (HSBY) for planned maintenance	23-Dec-03 11:00:00	1941	334	
Return to grid oparations	23-Dec-03 20:00:00	1941		9
HSBY for stack inspections	24-Feb-04 02:00:00	3435	1494	
Return to grid oparations	25-Feb-04 13:00:00	3435		35
ESD due to operator error	02-Mar-04 13:00:00	3579	144	
Return to grid oparations	02-Mar-04 20:00:00	3579		7
HSBY for planned maintenance	03-Mar-04 20:00:00	3603	24	
Return to grid oparations	06-Mar-04 08:00:00	3603		60
HSBY for planned maintenance	08-Apr-04 19:00:00	4406	803	
Return to grid oparations	11-Apr-04 12:00:00	4406		65
ESD due to grid disturbance	03-May-04 01:00:00	4923	517	

Description/Event	Date and Time	Loadtime	Run Hours	System Down Hours
Return to grid oparations	03-May-04 11:00:00	4923		10
HSBY for stack inspections	01-Jun-04 10:00:00	5618	695	
Return to grid oparations	01-Jun-04 20:00:00	5618		10
HSBY for stack inspections and module replacement	28-Jun-04 11:00:00	6257	639	
Fuel Cell Module replacement complete. Back to grid operations.	19-Jul-04 15:00:00	6257		508
HSBY on 7/20/04 due to a failed ambient temperature sensor in the inverter	20-Jul-04 16:00:00	6282	25	
Sensor was replaced. Plant returned to grid operations	21-Jul-04 18:00:00	6282		26
HSBY for software modifications	10-Aug-04 02:00:00	6746	464	
Return to grid operations	11-Aug-04 09:00:00	6746		31
End of test period	24-Aug-04 00:00:00	7049	303	
Totals		7049	7049	1135

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	Main Street 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%.

Cost Parameters

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

Specification	Data
Total Fuel Cell Plant Cost ($)	1,460,000
Fixed Operating Cost	$40,000
Variable Operating Costs (Fuel)	$60,000
Local Area Electricity Price (cents/kWh)	5 cents/kWh for generation 9 cents/kWh for delivered
Fuel Price ($/mmBtu)	$4.85/mmBTU

Cost-Benefit Evaluation

Activity	Cost
Investment	
Total Fuel Cell Plant Cost	$1,225,000
Installation Cost	$235,000
Total Investment	**$1,460,000**
Funding	
U.S. DOE	$250,000
Total Funding	**$250,000**
Total Costs	
Fuel Cost	$60,000
Operation and Maintenance Cost	$40,000
Total Costs	**$100,000**

Electrical Consumption of Main Street Service Center

Main Street Prior to Installation

Date	Electrical Use (kWh)	Peak Electrical Use (kW)
Sep-02	281,600	1,152.00
Oct-02	230,400	1,152.00
Nov-02	364,800	1,152.00
Dec-02	364,800	1,152.00
Jan-03	281,600	1,152.00
Feb-03	262,400	960
Mar-03	320,000	960
Apr-03	422,400	1,024.00
May-03	377,600	1,024.00
Jun-03	384,000	1,024.00
Jul-03	428,800	1,024.00
Aug-03	403,200	1,024.00

Main Street During Operation

Date	Electrical Use (kWh)	Peak Electrical Use (kW)
Sep-03	428,800	1,024.00
Oct-03	307,200	1,024.00
Nov-03	313,600	1,024.00
Dec-03	300,800	1,024.00
Jan-04	294,400	1,024.00
Feb-04	230,400	1,024.00
Mar-04	236,800	1,024.00
Apr-04	224,000	960
May-04	249,600	960
Jun-04	204,800	960
Jul-04	377,600	960
Aug-04	224,000	960

The 250kW molten carbonate fuel cell power plant is connected directly to LADWP's power grid system. Since the plant is connected to the power grid instead of the Main Street Service Center, the electric consumption of the Main Street Service Center site will not be affected.

Fuel Consumption of Main Street Service Center Fuel Cell Plant

Date	Gas Use (MMBtu)	Peak Gas Use (MMBtu/dy)
Sep-03	470	44
Oct-03	1115	44
Nov-03	910	43
Dec-03	1122	42
Jan-04	1289	42
Feb-04	1176	43
Mar-04	1200	43
Apr-04	1165	44
May-04	1337	44
Jun-04	1209	45
Jul-04	478	45
Aug-04	948	45

The Main Street Service Center uses very little natural gas itself, as it is an electrical repair and warehouse facility, therefore the data shown above is only the natural gas consumed by the fuel cell plant.

Fuel Cell Electric Output

Date	Electric Output (kWh)	Peak Electric Output (kW)
Sep-03	62,500	243
Oct-03	154,500	257
Nov-03	125,600	259
Dec-03	161,000	258
Jan-04	185,500	253
Feb-04	164,500	252
Mar-04	164,900	250
Apr-04	158,600	251
May-04	180,600	249
Jun-04	159,000	248
Jul-04	60,800	250
Aug-04	123,900	249
Total	1,701,200	259

The 250kW molten carbonate fuel cell produced a total of 1,701 MWh within its first year of operation. The fuel cell performed well its first year and helped relieve the LADWP power grid. A new fuel cell stack module was installed in July 2004 to incorporate new manifold seal design.

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 86% and the total MWhrs produced in the one-year period increased by over 85%.

Several plant improvements were made. For instance the improved stack manifold seal was implemented in the replacement fuel cell module; so were the improved gas seal in the cathode outlet blower. 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 plant has provided a great opportunity for the training of LADWP 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**

Contact & Addresses

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