BACKGROUND

Working with the U.S. Environmental Protection Agency and FuelCell Energy, Inc., King County sponsored the world’s largest demonstration project of a single-unit fuel cell power plant. Using digester gas from the county’s South Wastewater Treatment Plant in Renton, WA, the fuel cell was operated during a two-year demonstration project. The fuel cell power plant was sized to produce 1 megawatt (MW) of electricity and designed to capture additional waste heat for recycle to the treatment plant hot water system.

King County began its investigation of fuel cells for electrical power generation in 1997. FuelCell Energy, Inc. was selected in 2000 to design and construct a molten carbonate fuel cell power plant. Two project goals were established to measure fuel cell performance during the demonstration period – (1) demonstrate that the molten carbonate fuel cell technology can be adapted to use anaerobic digester gas as a fuel source and (2) achieve a nominal plant power output target of 1 MW (net AC) using either digester gas (DG) or natural gas (NG).

Project Timeline

<table>
<thead>
<tr>
<th>September</th>
<th>FuelCell Energy selected for the project</th>
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<tbody>
<tr>
<td>October</td>
<td>Fabrication of fuel cell stack initiated</td>
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<tr>
<td>April</td>
<td>Startup</td>
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Two-year demonstration period

Operation – Year 1
- 1-MW operation on NG and DG
- Emission and noise testing
- Incorporation of auto fuel switchover
- One month waste heat recovery
- DG condensation problems

Operation – Year 2
- Stack failure and replacement
- Stack replaced within 30 days
- 850-kW capacity (derated from 1-MW)
- Off-line due to non-related construction
- Continued problems with DG condensate
- NG operation for remainder of project
How Does a Fuel Cell Work?

Fuel cells are electrochemical devices that convert chemical energy from fuels containing hydrogen directly to electricity and heat. Combustion is not needed.

Similar to a battery, a fuel cell has hundreds of individual cells. Cells are grouped to form a stack. Each fuel cell contains an anode, cathode, and electrolyte. A hydrogen-rich fuel, such as digester gas, enters each stack and reacts with oxygen in the air to produce electricity in each cell.

A typical battery has a fixed supply of energy. But fuel cells are like large continuously operating batteries that generate electricity as long as they get a fuel, such as methane, which is a large component of digester gas.

Fuel Cell Advantages:
High Efficiency, Low Emissions

Electricity is typically generated in a two-step process: fuel is combusted to produce mechanical energy (or heat), which then turns a generator to produce electricity. Fuel cells convert fuel directly to electricity. By dropping the mechanical energy step, fuel cells are more efficient than traditional methods of generating electricity and produce very low emissions.

Molten Carbonate Fuel Cells

Fuel cells are defined by their electrolyte, or the material inside them. There are five types of commercial fuel cells: solid oxide, phosphoric acid, alkaline, proton exchange membrane and molten carbonate. King County’s South Treatment Plant used the molten carbonate fuel cell (MCFC) which operates at 1,100 °F and is designed with reforming (conversion of methane to hydrogen) incorporated into the fuel cell stack. The fuel cell power plant components included fuel scrubbing, fuel processing, power production, power inverter, and heat recovery (reference fuel cell process flow diagram).

Molten Carbonate Fuel Cell Chemistry

\[
\begin{align*}
\text{(Digester Gas)} & \quad \text{(Purified Water)} \\
\text{CH}_4 + 2\text{H}_2\text{O} & \quad \text{CO}_2 + 4\text{H}_2 \\
\quad & \quad \text{(Reformer)} \\
+ \\
\text{H}_2 + \frac{1}{2}\text{O}_2 & \quad \text{H}_2\text{O} \\
\quad & \quad \text{(Fuel Cell)} \\
\text{CH}_4 + 2\text{O}_2 & \quad \text{CO}_2 + 2\text{H}_2\text{O} \\
\text{Stack Exhaust} & \quad \text{(Overall)}
\end{align*}
\]
Fuel Cell Module (4-stack assembly)

Air Blower & Oxidizer
Air is heated and fed to the fuel cell module.

Fuel Scrubbing
Methane from the wastewater treatment plant passes through iron and carbon filters.

Heat Recovery & Stack
Excess heat is recycled within the fuel cell facility and the wastewater treatment plant. The exhaust gas, consisting of carbon dioxide and water, discharges through the stack.

Electrical Enclosure
DC power from fuel cell is converted to AC power and returned to the wastewater treatment plant.

Fuel Cell Module
Conditioned methane, steam and air are converted to DC electricity and exhaust gas.

Power Plant Configuration
(1/4-acre site at South Plant)

Process Flow Diagram

Demonstration Power Plant
Operating Conditions at 1MW Net Output

<table>
<thead>
<tr>
<th></th>
<th>Digester Gas</th>
<th>Natural Gas</th>
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<tbody>
<tr>
<td>Gas Flow</td>
<td>225 scfm</td>
<td>140 scfm</td>
</tr>
<tr>
<td>Lower Heating Value</td>
<td>550 Btu/ft³</td>
<td>900 Btu/ft³</td>
</tr>
<tr>
<td>Methane Content</td>
<td>60 %</td>
<td>98 %</td>
</tr>
<tr>
<td>Carbon Dioxide Content</td>
<td>38 %</td>
<td>0 %</td>
</tr>
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Water

| Water Flow                     | 2.5 gpm                     |

Source: Brown and Caldwell
DEMONSTRATION PROJECT OBSERVATIONS AND CONCLUSIONS

Based on the two-year operating period, project operation and maintenance observations include:

- The project represented a successful research and development effort.
- The power plant control system was modified to provide automated fuel source switching and to respond to process transients.
- The power plant subsystem configurations are being modified in future fuel cell designs based on the demonstration operating experience.
- Appropriate selection of a stable methane source in the wastewater treatment plant digester gas system is critical to reliable operation of the fuel cell power plant.
- The power plant had numerous components requiring frequent maintenance and high replacement cost (fuel cell stack life of < 3 years).
- The operation of the power plant was highly automated.

Project Partners

FuelCell Energy of Danbury, CT ($9.4M), the U.S. Environmental Protection Agency ($8.6M), and King County ($2.3M) provided financial support for the South Treatment Plant Fuel Cell Demonstration Project. The U.S. Environmental Protection Agency provided the federal funds to King County through annual cooperative agreements. The total value of the project was $20.3 million.

CH2M HILL of Bellevue, WA, and Brown & Caldwell of Seattle, WA, provided engineering services to King County for the fuel cell project. Hawk Mechanical Contractors, Inc. of Redmond, WA, installed the fuel cell.

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