Appendix I

The Bloom Box: A Solid Oxide Fuel Cell

In 2010, after a "60 Minutes" segment on the Bloom Box fuel cell aired on CBS, City Light commissioned the Wenatchi Group, Inc. to undertake a brief review of its applicability in City Light's service area.

General Fuel Cell Background

What is a fuel cell? A single fuel cell is made up of an anode and a cathode with an electrolyte in the middle. Fuel such as natural gas, biogas, or hydrogen is passed into the anode side and an oxidant is passed into the cathode side causing a reaction that moves electrons into the fuel cell's circuit, thus producing electricity. There are several types of fuel cells, but the primary focus in this appendix is on solid oxide fuel cells (SOFC) and, more specifically, the Bloom Box produced by Bloom Energy, Inc. in Sunnyvale, California.

Fuel Cell History

- The technical roots of fuel cells began in the 1930s when two Swiss scientists experimented with zirconium and other elements as electrolytes.
- In the 1950s, GE and some other companies started small-scale research projects involving solid oxide fuel cells. Projects were discontinued because cell materials melted, short-circuited, and had high electrical resistance inside of them.
- In 1962, the first federally funded research contract was awarded to Westinghouse to study zirconium oxide and calcium oxide-based fuel cells
- About 10 years ago, a 100 kW tubular solid oxide fuel cell system operated for four years. The record for an individual fuel cell staying operational is 8 years.
- By now, many types of fuel cells have been developed. All of them are extremely expensive, with the more cost-competitive running about 15-20 times the cost of a typical gas turbine generator.
- Currently, the DOE's SECA program is attempting to develop solid-state fuel cell modules that cost no more than $700/kW and large systems that are greater than 100 MW.

Department of Energy's Solid State Energy Conversion Alliance (SECA)

In the fall of 1999, DOE initiated the SECA initiative to bring together government, industry, and the scientific community to promote the development of environmentally friendly solid oxide fuel cells. Most of the technologies, systems, and materials were focused on large-scale (greater than 100 MW), stationary, power generating units that would gasify coal to create a feedstock for the SOFC units.

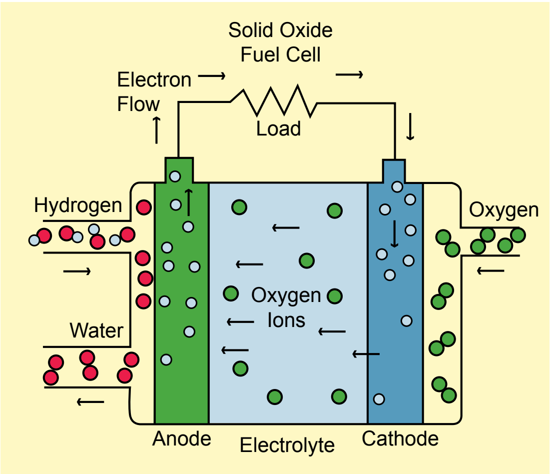
Until 2007, the system cost target was $400/kW so that it would compete favorably with natural gas turbines. Having come nowhere close to the target, a new cost target of $700/kW was established. The original four commercial teams are down to three, with Siemens having dropped out.

DOE now describes SECA as "formed to accelerate the commercial readiness of SOFCs in the 3 kW to 10 kW range for use in stationary, transportation, and military applications." Next year, Delphi (one of the commercial teams), will be commercializing a 3 kW APU that generates electricity for heavy-duty commercial trucks' in-cab electrical accessories.

The Solid Oxide Fuel Cell (SOFC)

Two types of fuel cells, solid oxide and hydrogen, have emerged as the fuel cell types of greatest commercial interest. Both types have been heavily subsidized – hydrogen primarily in automotive applications, and more recently, solid oxide systems as a potential source of distributed power generation. We will examine in depth the solid oxide fuel cell.

The solid oxide fuel cell has gained recent attention for having potential applications in commercial and residential power. The diagram and explanation below showing a solid oxide fuel cell powered by pure hydrogen are from the Smithsonian Institution.



Solid Oxide fuel cells use a hard, ceramic compound of metal (like calcium or zirconium) oxides (chemically, O_2) as electrolyte. Efficiency is about 60 percent, and operating temperatures are about 1000 degrees C (about 1800 degrees F). Cell output is up to 100 kW. At such high temperatures a reformer is not required to extract hydrogen from the fuel, and waste heat can be recycled to make additional electricity. However, the high temperature limits applications of SOFC units, and they tend to be rather large. While solid electrolytes cannot leak, they can crack. If natural gas is used as fuel instead of pure hydrogen, carbon dioxide and other off-gases are also produced.

Bloom Energy's "Bloom Box" Energy Server

Economics of the Bloom Solid Oxide Fuel Cell System

Bloom Energy's "Bloom Box" Energy Server (ES-5000) is a solid oxide fuel cell-based generating system, which is generally powered by natural gas, with rated power output of 100 kW. Recent publicity may have created the impression that the Bloom Box is available for residential power generation and that it will usher in a new era – a paradigm shift – of distributed power generation. However, while the Bloom Box is currently being tested and debugged at several California commercial sites, Bloom Energy specifically states that "at this time" it is not interested in residential applications. Bloom Energy's sales force only talks to companies with facilities in California that spend at least $25,000 per month on electricity, which is the most attractive market given the current subsidy structure.

The Bloom Box ES-5000 Energy Server offered currently is at a quoted price of $800,000 and is a 100 kW unit. According to company sales people, the total purchase cost of the system and related project can be reduced by 80% using Federal and California State taxpayer subsidies and utility ratepayer subsidies and rebates.

The breakdown of these cost offsets and their benefactors are:

- 30% ($240,000) using a federal taxpayer subsidy in the form of a tax credit
- $250,000 using a California ratepayer rebate under the Statewide Self-Generation Incentive Program
- 20% of the project cost (at least $160,000) using a California incentive bonus if the supplier is a "California Supplier"

This $650,000 contribution using Federal and California State taxpayer subsidies and utility ratepayer subsidies and rebates reduces the buyer's net capital cost to $150,000 for a 100 kW system. Accounting for capital costs in a fair financial analysis requires some significant assumptions about a system's longevity. Solid oxide fuel cells have long faced challenges with durability, since they operate at 1800 degrees Fahrenheit. Bloom spokespeople say the company spent many years developing a proprietary seal made from low-cost materials that prevents cracks and leaks. They are estimating the current units will have a 10-year life as long as the fuel-cell stacks are swapped out twice. However, there are currently no operational solid oxide fuel cell systems that have approached this age.

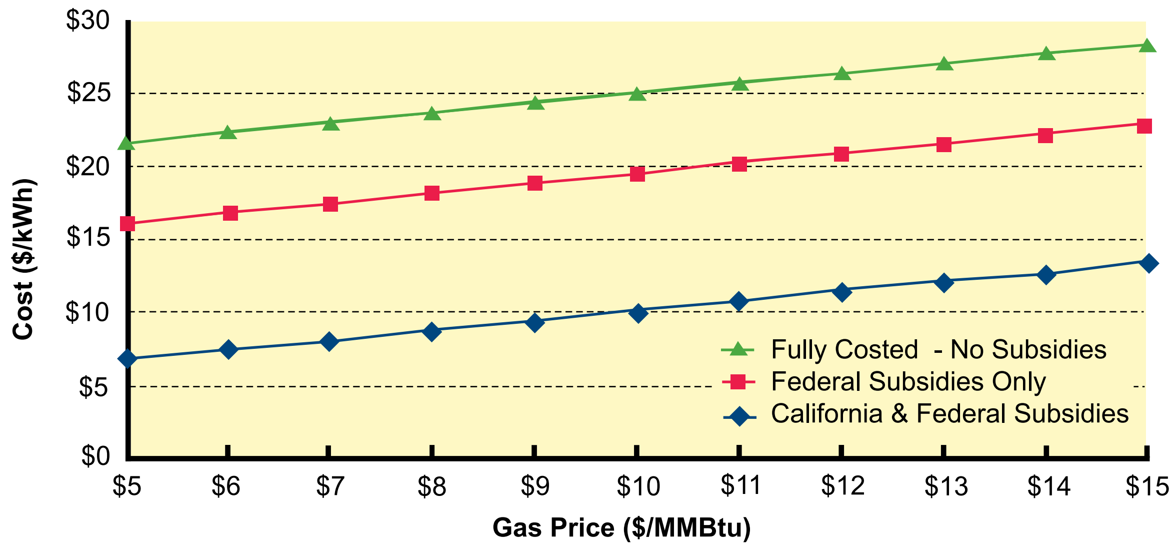
Under the assumption that the subsidized cost of $150,000 could be amortized flat over a five-year life, annual depreciation would be $30,000. With 8,760 hours/year and a 100% capacity factor, the resulting capital amortization is $3.42 per hour or 3.42 cents per kWh.

Natural gas is the largest consumable operating expense for the Bloom Box. Bloom Energy's 100 kW unit consumes 0.661 MMBtu/hr of natural gas. It has an electrical efficiency above 50% (LHV net AC), similar to a combined-cycle natural gas turbine. Taking recent gas prices in the Northwest of $10/MMBtu, the fuel costs would be about 6.6 cents per kWh. This fuel cost is similar to City Light's medium network general service energy charge. Thus accounting for fuel and subsidized capital costs only, the cost per kWh produced is about ten cents. This is close to the California subsidized break-even point of 11 cents/kWh that Bloom Energy sales information states.

Unsubsidized costs of $800,000 result in amortization of about 18 cents/kWh. This would bring the fuel and capital costs to about 24 cents/kWh. If we account for the federal tax credits but not the California credits and incentives, the $800,000 system would cost $560,000, and the amortization would be about 12.75 cents/kWh, making fuel and capital cost of just under 19 cents/kWh. Some simplification goes into this approach to costing out the power produced by the ES-5000 energy server, but given the lack of information provided by the company and the unknowns associated with the system's short operating history, this approach seems reasonable.

Bay Area electric rates for customers of the 100-500 kW size are about twice those found in City Light's service area, so with all the subsidies given in California, the system is closer to making economic sense for them than City Light customers. The table below shows costs as a function of gas prices given different levels of subsidy.

Bloom Box Cost Depends on Gas Price and Subsidies



Environmental Impacts of Bloom Energy's Solid Oxide Fuel Cell System

The Bloom Energy system emits carbon dioxide from the chemical reaction involving natural gas. A natural gas turbine powered by combustion releases about 1,300 lbs of carbon dioxide per MWh. The Bloom Energy system, by comparison, emits about 773 lbs of carbon dioxide per MWh, about 60% of the carbon dioxide that a natural gas combustion turbine emits.

While this is by no means a zero emissions technology, whether it is "clean" relative to the fuel mix of the utility in a service area depends on where you are. The accompanying table shows the average carbon dioxide emissions of City Light for comparison to the ES-5000. The Bloom Server is high in CO_2 emissions compared to City Light's existing portfolio.

Carbon Dioxide Emissions Comparison

Generation Type	Percentage	Carbon Dioxide lbs/MWh*	Contribution to Total lbs/MWh
Seattle City Light (2008)			
Hydro	0.8883	0	0
Nuclear	0.0568	0	0
Natural Gas	0.0058	1,314	7.6
Wind	0.0343	0	0
Coal	0.0138	2,117	29.2
Other	0.0010	0	0
Total			37 lbs/MWh
Bloom Energy ES-5000	1.0	773	773 lbs/MWh

*US average by generation type. Source: EPA

Technical Considerations of Bloom Energy's Solid Oxide Fuel Cell System

Bloom Energy Servers are heavy, and the chemical reactions occur at 1800 degrees. The 100 kW system weighs 20,000 lbs. Given the same energy density for a hypothetical system that could "one day power a house," instead of the little cell stack Dr. Sridhar, CEO of Bloom Energy, holds up in one hand in his public presentations, one would expect a 200 pound device.

Outlook

At this time, there is no compelling reason for City Light to pursue any interests in solid oxide fuel cell systems. Bloom Energy has the only commercially available system, the ES-5000 Energy Server, and it is available only to facilities located in California with very specific energy requirements. This narrow market focus parallels the structure of major subsidies from state and federal taxpayers and utility ratepayers.

No system is available in Washington for either residential or commercial applications. Because this natural gas-based system is vastly more expensive than any alternate source to City Light (or their customers), and because City Light's current power portfolio is very nearly free of carbon dioxide or other greenhouse gas emissions, the possible advantages of a Bloom Box all fail. City Light's electricity sources are cleaner and less expensive. No renewable resource presently under consideration by City Light is as expensive as the Bloom Box, which is not renewable.

The Department of Energy and various companies and researchers have, for over a decade, worked to reduce the cost and improve the reliability of these systems. There appears to be no near-term breakthrough that should substantially change City Light's outlook.