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The 2 MW Santa Clara Project

Paul H. Eichenberger

Energy Research Corporation, 3080 Olcott St. Su. 201-d, Santa Clara, CA 95054, USA

Abstract

The City of Santa Clara, CA, USA, has hosted the world's first field demonstration of a molten carbonate fuel cell power plant. This US$46 million, 2 MW generator was a joint effort of five US utilities, the federal government, and two US research organizations. The demonstration used sixteen 125 kW stacks placed in four modules. The balance of plant (BOP) is the equipment that prepares and supplies the fuel to the stacks and converts the d.c. current to a.c. BOP construction started in April 1994, and was completed in June 1995. The BOP configuration allowed testing and development before installation of the four modules. The final full-temperature test was completed in February 1996. The four fuel cell modules were installed and cured, and power delivery began in April 1996. The plant operated for approximately 720 h at design output before electrical anomalies occurred and the plant was shut down for repairs. The plant restarted in August, but it soon became obvious that other problems had been caused by the electrical anomalies. The plant shut down and was reconfigured to a 1 MW plant. The restarted plant was ramped to 1 MW, but additional problems began to occur and the plant demonstration ended. The plant produced 2500 MWh, and operated at 1000°F, or higher, for over 5290 h. The plant set operational records, and demonstrated multistack, automatic control, and stable-field operation. Power quality met all standards with no measurable NO_x or SO_x output. The plant isolated itself from the grid during two major California, USA grid outages. The plant also experienced a shutdown of the automatic control system, and placed itself on hot standby using the mechanical field systems. The plant then restarted without incident. © 1998 Elsevier Science S.A.

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1. Introduction

It is a pleasure to be able to share with you the experiences and results from, and reasons for, the City of Santa Clara, CA, USA hosting the world's first field demonstration of a carbonate fuel cell project. In sharing these events, I will cover points that explain the purpose, the process, the participation, and the pain. These points are: (a) Why did the City of Santa Clara Electric Department host a Fuel Cell Demonstration Project? (b) Why were there so many participants? (c) How was the project funded? (d) What was the project philosophy or purpose? (e) What did we accomplish? (f) What did we learn?

2. The prior initiative

The City of Santa Clara was a participant in a prior fuel cell commercialization initiative. That initiative was not successful, but the City, and other municipal utilities, wanted the attributes of the fuel cell power plant available for their use.

The fuel cell power plant siting attributes most desired by the municipal utilities were: small scale, skid mounted, low noise, and no measurable nitrogen oxide and sulfur oxide emissions. The fuel cell attributes were: efficiency of over 50%, use of any liquid or gaseous fuel such as natural gas, sewer plant, landfill, coal gas, biomass feed stocks and petroleum liquids. The planning attributes consisted of: short delivery time, small capacity, less project risk, re-locatable, and ultimately, sized to meet the requirement.

3. The commercialization initiative

The promise of this technology was the reason the City of Santa Clara participated in an American Public Power Association (APPA)/Electric Power Research Institute (EPRI) initiative seeking fuel cell power plant vendors, interested in partnering, to commercialize their technology. This solicitation was initiated in November 1988, and resulted in the selection of Energy Research Corporation (ERC) of Danbury, CT, USA.

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4. Commercialization plan

After selecting ERC, a group was formed to support the commercialization effort known as the Fuel Cell Commercialization Group (FCCG). The group jointly developed a commercialization plan with ERC's commercial plant subsidiary, Fuel Cell Engineering Corporation (FCE), prime contractor for the Santa Clara project. The plan is comprised of a series of linked steps, with success triggering the next step, with the goal of having ERC's fuel cell power plants commercially available by the turn of the century. These linked steps were:

- the organization of an industry funded group (the FCCG) to provide customer support for the technology, and purchase initial units at a premium
- development of a royalty incentive program to return to purchasers premiums paid for early units
- demonstration of the technology at megawatt scale

The demonstration required the following steps:

- ERC's funding the development of preliminary estimate for the demonstration project
- the utilities organizing a group of participants to provide funding for a 2 MW demonstration project (Project)
- the Project participants accepting FCE's preliminary project estimate
- ERC successfully demonstrating a full-height fuel cell stack in the laboratory

5. The demonstration

The first field demonstration of sixteen full-height fuel cell stacks required additional incentives to attract participants. The primary incentive for the participants to fund the demonstration was a royalty amount of two-times the participant's Project funds. In addition, these royalties, based on a percentage of future sales, were to be paid before any other royalties. Other incentives were also provided, such as ownership of data and intellectual property rights, field of use restrictions, favored nations clause, and others. To provide additional risk mitigation for the Project participants, the following had to occur before the demonstration was constructed.

- A successful laboratory test of a full-height 125 kW fuel cell stack, operating on pipeline natural gas and meeting the design parameters for the demonstration's fuel cell stacks to be used in the demonstration, had to be performed. The first test article failed as a result of a utility power line failure. However, the tests of a subsequent stack met the participant's requirements.
- A detailed design estimate for the demonstration project had to be prepared and accepted by the participants.
- An estimate, using the Project design as a basis, had to be prepared, to verify that a commercial product could be priced at the 1990 commercial target price of US$1000/kW, plus 10%.

When these contract conditions were met, the participants were willing to proceed with the demonstration. The participants did not insist on performance guarantees, but did establish specific target criteria.

6. Why a field demonstration?

Without a field demonstration, the promise of fuel cell technology remains just a promise. A major element in transferring technology to the commercial market is availability of the necessary labor skills in the field, and the ability to operate in a field environment. Successful demonstrations confirm this ability.

7. Why so many participants?

The primary reasons for multi-participants are to reduce the risk and costs to the individual participants. An additional benefit is a larger audience of motivated and involved individuals and organizations. The larger audience provides for improved technology transfer through group interaction and experience. Obviously, there is a limit to the number of participants, since they add complexity and required more time to negotiate with the participants who have differing experiences and goals.

8. How was the project funded?

The project funding responsibility was shared among all the participants. The fuel cell modules were funded through a cooperative agreement between FCE and the US Department of Energy Federal Energy Technology Center, Morgantown, West Virginia, USA. This funding was originally estimated at US$16 million. The rest of the Project was funded by the utilities, Electric Power Research Institute (EPRI), ERC, and Fluor-Daniel, as shown below.

- City of Santa Clara, Electric Department: $6.3 million, partially offset by funding from the California Energy Commission of $650 000, and two consortium members, Northern California Power Agency and Salt River Project of Tempe, AZ, USA
- City of Los Angeles Dept. of Water and Power, CA: $3.15 million
- City of Vernon, CA: $3.15 million
- Sacramento Municipal Utility District, CA: $3.15 million

- National Rural Electric Cooperative Association, represented by United Power Association of Elk River, MN: $3.15 million
- Southern California Edison (Edison Source), CA: $3.15 million
- Electric Power Research Institute: $5.4 million
- Energy Research Corporation: $3 million
- Fluor Daniel: Reduced fee

Consequently, the Project had funding participation from all types of electric utilities in the US: Investor (stockholders), Municipal (local government), and Rural (utilities serving primarily remote regions in the USA). The one type of utility that was not a participant was a utility providing both gas and electricity. The participation by the vendor and the A and E indicated an organizational commitment to the technology, and this served to reduce the participants' perceived Project risk.

9. What was the Project philosophy or purpose?

The purpose of the Project was to construct and operate a carbonate fuel cell power plant with labor and material available in the field. This demonstration would represent the first time the technology would be operated in a multiple stack configuration using a Project developed digital control system producing 2000 kW. In order to minimize the risk to the fuel cells, the equipment which integrates the fuel cells into a power plant and connects them to the electric utility grid (BOP) would be designed to operate without the fuel cell modules to the maximum extent possible. As a result, the BOP was tested for almost one year before the modules arrived. This testing began with individual BOP component tests, followed by eight full system BOP tests at operating temperature. During the BOP testing phase, the operating procedures, manuals, and parameters were developed to be used with the fuel cell plant. As a result of the extensive testing, the BOP operated almost perfectly throughout the full power plant operation.

10. What did we accomplish?

10.1. Operationally

The fuel cell modules were cured on site and brought up to full power. During this period of approximately 720 h, the plant operation was excellent, at power levels up to 1.93 MW, and it appeared we would be able to reach all our goals. However, we began to see voltage anomalies and, upon shutting down the plant and entering the modules, it was discovered that glue used during the manufacturing process to hold thermal insulation in place had compromised the dielectric isolation between the fuel cell stacks and the BOP piping, resulting in ground faults. Field repairs were made and the plant was subsequently restarted. However, it soon became apparent that the plant had sustained more damage than was repaired. The plant was shut down on March 3, 1997, after approximately 5200 h of operation at temperatures above 1000°F, 4100 grid connected hours and delivering 1710 MWh to Santa Clara's system. We operated above the 1.8 MW design, 1.93 MW, at 43.6% efficiency (below the 49.8% target due to operation of the standby burner), generating 2500 MWh on pipeline natural gas without external hydrogen production. Load ramping was demonstrated, as was operation at low NO_x, SO_x, and noise levels.

10.2. Control system

The project demonstrated a digital control system, which allows sixteen stacks to be operated automatically. All operations were through the control system that operated exceptionally, even during two major California, USA power grid outages. During both outages, the plant was separated from the grid and placed in hot standby on the diesel generator by the control system. In addition, the digital control system was taken offline by an office power supply failure, and the field mechanical devices placed the system in a safe mode. After all of these events, the plant was returned to its set point prior to the event, without detectable change in operating parameters, i.e. no damage to the stacks or system.

11. What was learned?

11.1. Construction and operation

The most obvious lesson learned was that a 16-stack/4-module carbonate fuel cell plant could be transported 2500 road miles, assembled, cured and operated in a field environment. The plant output was controlled and set points changed with the control system. We successfully separated from the utility grid during grid disturbances, and then returned to normal operation. In addition, the performance and reliability of the Balance of Plant, including the inverters, was excellent, producing power with $<2\%$ voltage harmonics and all 16 stack voltage levels at full load within 1%. Load following and VAR production was also demonstrated.

11.2. Demonstration process

In organizing the demonstration project, several improvements were identified. One of the most challenging tasks was developing the Project Agreements. These Agreements provided the relationship between the participants and with the contractor so that the Project could be directed and the liabilities identified and minimized. The Agreement between the participants took longer to develop than the

Agreements to support the Project. This was a direct result of the different levels of experience and size of the participant organizations. Some of the participants had never taken part in an R&D project, or in a joint project where individual rights and obligations must be compromised in order to arrive at a common understanding. One possible solution to these problems would be to have model agreements to provide a framework for discussions. It is hoped that these Project Agreements could provide such a model.

11.3. Awards

The City received two national awards. On June 18, 1997, the American Public Power Association (APPA), a US organization of approximately 2000 city government-owned electric utilities, presented its 'Energy Innovator Award' in recognition of the Project's contribution to energy efficiency. In addition, the City was awarded a 'Technical Achievement Award' from the Electric Power Research Institute for hosting and managing the first commercial-scale demonstration of a carbonate fuel cell power plant on a utility system.

12. Conclusions

We made a decision to demonstrate a multi-stack full-scale carbonate fuel cell plant in the field. Along the way, we developed a set of unique Agreements which allows many participants of various levels of experience and knowledge to support a demonstration effort. We developed a digital control system to control the sixteen stacks and met most of our demonstration goals. One objective which we did not meet was the 10 000 h operation period. However, the demonstration was a success, and set many records in fuel cell technology. The experience gained in the demonstration provided valuable input for commercialization of direct fuel cell technology.

Appendix 1 Lessons learned

Recently the project has released a summary document, which provides a complete description of all the project's accomplishments compared to the project's objectives. Shown here is a table of accomplishments from this document (Table 1).

Appendix 2 Suggestions for organizing future projects

A major challenge in developing the Project was dealing with multiple participants. Clearly having multiple participants in any venture adds the requirement of compromise,

Table 1

Power plant performance vs. key Santa Clara demonstration project criteria

Power output	1.93 MW rated power exceeded target by 0.13 MW
Heat rate	Stack performance level for heat rate target achieved, 7920 Btu/kWh (43.6% efficiency) achieved, target of less than 7000 Btu/kWh achieved after supplemental fuel to burners was removed; 6821 Btu/kWh (note that burners were left on to provide soft landing during the early stages of demonstration testing)
Power quality	Voltage harmonics less than half IEEE 519.5% distortion level Overall current harmonics below IEEE 519 except for four higher level harmonics correctable with inverter tuning
Ramp rate	4.8% per min achieved exceeding target by 1.5%
Emissions	SO_x emissions level undetectable NO_x emissions level undetectable from fuel cells, 2 ppm with startup burner
Noise	Met project and City requirements of <60 dB(A) 100 ft from equipment and <70 dB(A) at property line
Permitting	Ease of permitting demonstrated, no air permit required
Power plant start up	Multiple stack start-up demonstrated Automatic control of multiple modules and staks demonstrated
Stack operation	Uniform performance above voltage target achieved, less than 0.5% open circuit and less than 1.0% on load
BOP Operation	Automatic control of BOP with Project developed third party vendor digital control system 0.99% BOP availability Staffed by field forces No nuisance trips, responded to major and minor grid outages by islanding as designed using on site diesel gen. set Identified design issues to be addressed
d.c. Power module	Stacks had uniform performance above design projections Established requirements for future design efforts addressing electrical configurations and thermal issues
Operational experience	Gained operating experience Provided dynamic operating and insight into load and transient response
Skid mounted construction	BOP supplied by third party vendors on skids d.c. Power block truck transported

liabilities and communication to the list of Project activities. These elements are reflected in the Participation Agreement, which is not required in a single participant project. The Participation Agreement describes the rights and responsibilities to and between the members including coordination and the establishment of committees and their meeting requirements, voting, and timely sharing of information among other things. Ownership of property has to be established in the Participation Agreement both for the equipment and for the data and intellectual property including patents and licence rights. The simplest project method is to not have participants. This solution, while simplifying the process, does not maximize the value of the demonstration, which includes transferring knowledge about the technology. Taking participation to its extreme would be to raise funds from many donors. However, a large group of inconsequential donations does not provide the type of technology transfer that a small group of participants with significant funding shares provides. ‘Significant’ means contributions that are large enough so that the organization has an interest in the demonstration.

If one accepts the premise that multiple participants are necessary, then it is suggested that it would be ideal if the various participants share similar demonstration experience and characteristics. However, the reality is that one makes use of the participants as they are, as it is more important to have the organizational interest than to be similarly experienced.

A more important question is would the organization undertake another demonstration? The City of Santa Clara demonstrated new technology once before when it constructed the world’s first aero-derivative gas turbine co-generation plant. This 17-year 6 MW plant is still running today. The answer for the City is that it has led other demonstrations and would be inclined to do so again.

Would there be another demonstration? Actually, we are still working on the goal, which was not to demonstrate but to commercialize. The demonstration was but a step in this process. This author has been fortunate enough to have been provided an opportunity to join the Energy Research Corporation to continue the process. We have approached the City of Santa Clara about reusing the BOP by placing the world’s first commercial type 1 MW carbonate fuel cell module at this site. After testing of the module, we plan to replace this module with two next-generation modules and begin operating the world’s first demonstration of a 2 MW carbonate fuel cell power plant with commercial modules. The penalty will be a BOP with a 10% higher heat loss than the commercial BOP. However, to answer the question directly, if the commercialization is successful than we would undertake another commercialization programme as the pain was worth the gain.