

Residential Fuel Cells: A Field Demonstration

Final Report

Prepared by

Richard H. McClelland
Energy Signature Associates, Inc
220 Dombey Drive
Pittsburgh, Pennsylvania 15237

for

Cooperative Research Network
National Rural Electric Cooperative Association
4301 Wilson Boulevard
Arlington, Virginia 22203-1860

copyright and legal information

THE NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION

The National Rural Electric Cooperative Association (NRECA), founded in 1942, is the national service organization supporting more than 900 electric cooperatives and public power districts in 47 states. Electric cooperatives own and operate more than 44% of the distribution lines in the nation and provide power to 12% of the population.

RESIDENTIAL FUEL CELLS: A FIELD DEMONSTRATION

Copyright © 2007 by National Rural Electric Cooperative Association. Reproduction in whole or in part strictly prohibited without prior written approval of the National Rural Electric Cooperative Association, except that reasonable portions may be reproduced or quoted as part of a review or other story about this publication.

LEGAL NOTICE

This work contains the results of an investigation sponsored by the Cooperative Research Network (CRN) of the National Rural Electrical Cooperative Association (NRECA). As such, its findings are general in nature, and readers are reminded to perform due diligence in applying these findings to their specific needs, as it is not possible for NRECA to have sufficient understanding of any specific situation to ensure applicability of the findings in all cases.

The authors, CRN, and NRECA assume no liability for how readers may use, interpret, or apply the information, analysis, templates, and guidance herein or with respect to the use of, or damages resulting from the use of, any information, apparatus, method, or process contained herein. In addition, the authors, CRN, and NRECA make no warranty or representation that the use of these contents does not infringe on privately held rights.

Contact: Richard H. McClelland
Energy Signature Associates, Inc
220 Dombey Drive
Pittsburgh, Pennsylvania 15237
Phone: 412 635 8042
E-mail: dickmc@telerama.com

contents

EXECUTIVE SUMMARY	viii
1 INTRODUCTION	1
The Demonstration	2
Findings in Brief	2
Milestones in the Demonstration	3
About This Report	5
2 TECHNOLOGY OVERVIEW	6
Types of Fuel Cells	7
PEM Fuel Cell	8
Solid Oxide Fuel Cell	10
Long-Life Mechanical Cell	13
3 DEMONSTRATION RESULTS	17
Efficiency	17
Availability	18
Comparative Consumer Costs	19
Battery Storage	21
Installation Costs	23
Predicting Fuel Cell Prices	24
How Fuel Cells Compare to Other Products: Dollars per Pound	24
How Manufacturers' Catalogs Influence Pricing	25
4 RESIDENTIAL FUEL CELL MARKET	27
Cost to Customers	27
The Markets	31

contents

5 CONNECTING TO THE GRID	37
Grid-Parallel Operation	40
Grid-Independent Operation	40
Dual-Mode Operation	41
Structure of the Electric Distribution Grid	41
Beneficial Effects	42
Adverse Effects	43
Recloser Operation	44
Interconnection Experience in the Demonstration	45
What Co-ops Told Us about Interconnection	47
Grid Import-Export Analysis	49
6 THERMAL RECOVERY	50
Thermal Recovery Constraints	50
Water Heating	52
Combined Space Heating and Water Heating	59
Reducing Thermal Recovery Installation Costs	64
7 CONCLUSIONS	67
What Is the Market for Residential Fuel Cells?	67
Are Residential Fuel Cells Practical?	68
Is There a Future for Residential Distributed Generation?	68

contents

FIGURES

FIGURE A:	A fuel cell converts hydrogen (derived from natural gas or propane fuel) into hydrogen ions (H ⁺) and electrons. The electrons flow to a useful load, such as a residence, as electric current.	vii
FIGURE B:	A Power Plug proton exchange membrane (PEM) fuel cell at a residence in upstate New York.	vii
FIGURE C:	A mechanical fuel cell.	viii
FIGURE 1.1:	Sites of the CRN Residential Fuel Cell Demonstration Program.	2
FIGURE 2.1:	Basic components of a fuel cell are a front-end fuel processor, a cell stack where the electrochemical reaction takes place, and power-conditioning equipment to convert the cell's dc output to alternating current.	6
FIGURE 2.2:	The proton-exchange membrane (PEM) fuel cell.	8
FIGURE 2.3:	How a PEM fuel cell works. A single cell in a 50-cell stack is shown.	9
FIGURE 2.4:	A Plug Power 5-kW PEM fuel cell undergoing service.	10
FIGURE 2.5:	A propane-fueled Plug Power fuel cell operated by Delaware County Electric Cooperative in Tompkins, New York.	10
FIGURE 2.6:	A propane-fueled fuel cell manufactured by IdaTech, operated at Fort A.P. Hill, Virginia, under U.S. Department of Defense auspices.	10
FIGURE 2.7:	The solid oxide fuel cell.	11
FIGURE 2.8:	How a solid oxide fuel cell works.	11
FIGURE 2.9:	Accumentrics 5-kW residential fuel cell.	13
FIGURE 2.10:	Fuel Cell Technologies 4-kW residential fuel cell.	13
FIGURE 2.11:	Propane-fueled solid oxide residential fuel cells at Big Goose Ranger Station, Colorado. (Photo: Accumentrics.)	13
FIGURE 2.12:	The mechanical fuel cell, an engine-generator-inverter combination.	14
FIGURE 2.13:	A Marathon Ecopower 5-kW micro cogen system and its engine-generator assembly.	14
FIGURE 2.14:	A 6-kW mechanical cell by Aisin-ECO Technology Solutions.	15
FIGURE 2.15:	A Marathon mechanical cell at a remote location.	15
FIGURE 3.1:	PEM fuel cell efficiency.	17
FIGURE 3.2:	PEM fuel cell availability.	18

contents

FIGURE 3.3:	Change in spark spread from 1991 to 2005.	19
FIGURE 3.4:	Cost and life expectancy of a battery storage system.	22
FIGURE 3.5:	A cost-versus-weight comparison of various products.	25
FIGURE 3.6:	Effects of adjusting a manufacturer's catalog.	26
FIGURE 4.1:	Effects of residential fuel cell (RFC) cost components on operating cost and electricity cost.	28
FIGURE 4.2:	Customer usage profiles for average kilowatt demand.	29
FIGURE 4.3:	Market types for residential fuel cells.	32
FIGURE 5.1:	Interconnections to the power grid for residential fuel cells.	38
FIGURE 5.2:	Operating pattern for a residential fuel cell in a Western utility on a cooling peak day.	39
FIGURE 5.3:	A typical co-op distribution system with distributed generation. Fuel cell interconnection issues are highlighted in the boxes.	42
FIGURE 5.4:	Typical configuration of connections from a residence to the fuel cell and the grid.	46
FIGURE 5.5:	Co-ops' responses to questions about grid interconnection.	48
FIGURE 6.1:	Direct thermal recovery system. Approximate costs of key components are shown.	53
FIGURE 6.2:	CRN's spreadsheet for estimating installation costs of fuel cells, including thermal recovery costs.	54
FIGURE 6.3:	Cutaway view of an electric water heater.	55
FIGURE 6.4:	An indirect thermal recovery system with an auxiliary tank. Approximate costs of key components are shown.	57
FIGURE 6.5:	An indirect combined water heater and thermal recovery system. Approximate costs of key components are shown.	58
FIGURE 6.6:	Combined hot water heating and space heating thermal recovery system. Approximate costs of key components are shown.	60
FIGURE 6.7:	Guide to using prefabricated components in a thermal recovery system.	65

contents

TABLES

TABLE 2.1:	Types of Fuel Cells	7
TABLE 2.2:	Characteristics of a Plug Power Residential Fuel Cell	10
TABLE 2.3:	Characteristics of Solid Oxide Fuel Cells	12
TABLE 2.4:	Characteristics of Mechanical Cells	14
TABLE 2.5:	A Comparison of Environmental Characteristics	15
TABLE 3.1:	Customer Costs for Site-Based Distributed Generation	20
TABLE 3.2:	Installation Costs for the CRN Demonstration Program	23
TABLE 4.1:	Comparison of Costs for a Residence	31
TABLE 4.2:	Market Economics for On-Grid Distributed Generation, Natural Gas Fuel	32
TABLE 4.3:	Market Economics for Backup Generation, Propane Fuel	33
TABLE 4.4:	Market Economics for Edge-of-Grid Generation, Propane Fuel	34
TABLE 4.5:	Market Economics for Remote Generation, Propane Fuel	35
TABLE 6.1:	Typical Heat Consumption by a Residence	51
TABLE 6.2:	Thermal Recovery Savings from Combined Water and Space Heating	63

executive summary

When small-scale fuel cells, with about 5 kW capacity, first appeared in the late 1990s, they seemed made to order for electric cooperatives' needs (see Figure A). Small, quiet, efficient, and clean, they held out a lot of promise not just as backup power sources, but also as primary power sources of electricity for residential customers near the ends of fast-growing, overburdened routes and in sparsely populated remote areas where extending the grid would be a costly endeavor.

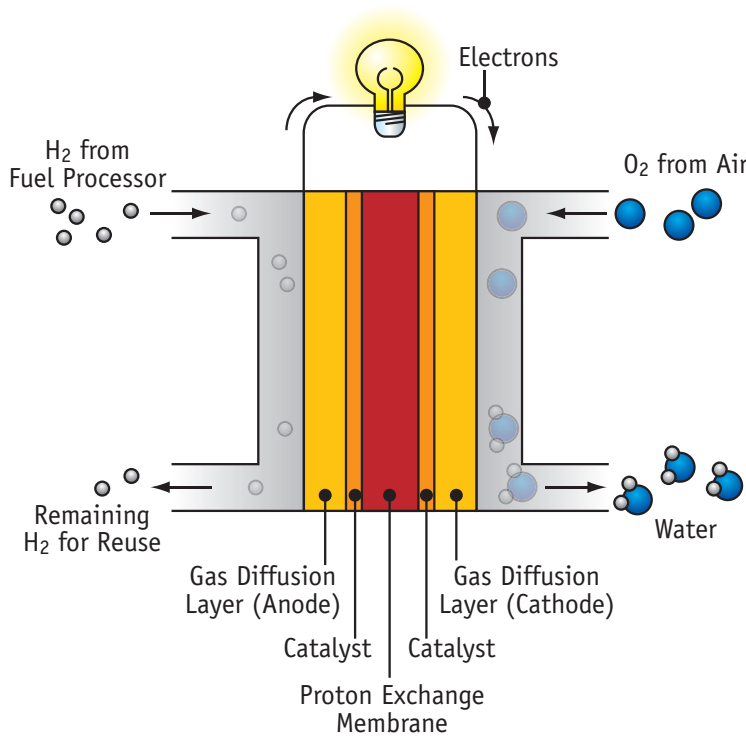


FIGURE A: A fuel cell converts hydrogen (derived from natural gas or propane fuel) into hydrogen ions (H+) and electrons. The electrons flow to a useful load, such as a residence, as electric current. The hydrogen ions flow through the cell to combine with a oxygen from the air, forming by-product water that discharges from the cell.

Participants in the Residential Fuel Cell Demonstration

- 1st Rochdale Cooperative, New York City
- Delaware County Electric Cooperative, Delhi, New York
- Delta-Montrose Electric Association, Montrose, Colorado
- Flint Energies, Reynolds, Georgia
- DOD CERL, Chery Point, North Carolina
- DOD CERL, Fort Jackson, South Carolina
- DOD CERL, Yosemite, California

DOD CERL is the U.S. Department of Defense, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory.

The CRN Residential Fuel Cell Demonstration Program aimed to explore that potential. It operated prototype fuel cells, in residential settings (Figure B), in collaboration with electric cooperatives and with the U.S. Department of Defense, which was conducting a similar demonstration program at military bases and shared its information with CRN. The CRN program had these goals:

1. Evaluate the performance, durability, reliability, and maintainability of residential fuel cells.
2. Investigate the interaction of the fuel cells with the electric distribution grid and with the dispatch of electric energy.
3. Determine the suitability of key materials, designs, and components for utility and customer service.
4. Define and assess the related interface requirements for fuel, electricity, thermal recovery, and water and the associated installation costs.
5. Identify and refine promising applications for residential fuel cells, including planning for early-entry and mature markets.

The results of the program are documented in this report.

For more information about the demonstration program, see Section 1, Introduction.

For a discussion of the principles, characteristics, and operation of fuel cells, see Section 2, Technology Overview.

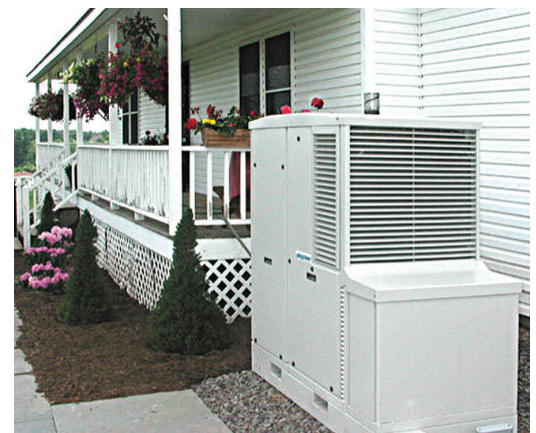


FIGURE B: A Power Plug proton exchange membrane (PEM) fuel cell at a residence in upstate New York. The propane-fueled unit is operated by Delaware County Electric Cooperative in Tompkins, New York.

executive summary

A GOOD TECHNOLOGY, BUT AN EXPENSIVE ONE

The demonstration clearly showed that fuel cells can function reliably and efficiently, and do not adversely affect the distribution grid. But the cost of the electricity they produce is very high: about 85¢/kWh at best for a future propane-fueled unit, versus about 9¢/kWh, on average, for grid-supplied electricity.

A major reason for this high cost is the high purchase price of fuel cells, which are highly complex systems comprising a fuel processor, electrochemical cell stack, dc to ac inverter, and storage batteries. A 5-kW unit today costs about \$80,000. With design and manufacturing improvements, the price might drop to \$30,000 by 2015.

To compound the cost problem, the price of fuel—natural gas or propane—is soaring. It is much higher today than it was when residential fuel cells first appeared, and it is rising at a faster rate than grid electricity.

The combination of high purchase price, high fuel prices, and high maintenance costs make residential fuel cells an unattractive supplement or replacement for grid electricity.

For more information about the demonstration’s findings, see Section 3, Demonstration Results, and Section 5, Connecting to the Grid.

AN ALTERNATIVE TO FUEL CELLS

But, although the outlook for residential fuel cells is bleak, a promising new contender for residential distributed generation appeared on the scene during the course of the demonstration. It is the micro cogeneration system,



FIGURE C: A mechanical fuel cell.
(Photo: Marathon Engine Systems.)

often called a mechanical fuel cell or simply mechanical cell (Figure C). It is not a fuel cell but rather a small internal combustion engine designed for long life, infrequent maintenance, low emissions, and ultraquiet operation. Like a fuel cell, it delivers high-quality ac power by means of an inverter.

Mechanical cells were not demonstrated in the CRN program, but they were analyzed on the basis of performance and economics. Because they cost much less to buy and maintain than fuel cells, even though they consume about the same amount of fuel, mechanical cells can produce residential electricity at about half the cost of fuel cells—about 44¢/kWh. This is still a high price to pay for electricity, but nevertheless may be acceptable for remote sites where building a connection to the grid would carry a prohibitive cost.

For more about mechanical cells, see Section 2, Technology Overview.

POTENTIAL MARKETS

The CRN demonstration evaluated four key co-op markets for residential fuel cells, and assessed their economic viability:

- On-grid natural gas distributed generation
- Backup propane-fueled generation
- Edge-of-the-grid propane-fueled generation
- Remote propane-fueled generation

Of these potential markets, the largest is the on-grid natural-gas-fueled residential distributed generation market. However, this market is not economic now and will not be in the next decade, if ever, because of the declining differential between natural gas cost and residential grid electric prices—that is, the shrinking spark spread.

executive summary

Surprisingly, the remaining three markets are largely owned by rural electric co-ops. They are principally propane fueled. None of the three, however, looks particularly attractive for even a future mature residential electrochemical fuel cell, because of high equipment costs.

However, the edge-of-the-grid market and the remote generation market do look attrac-

tive for today's mechanical cell. Although these markets are not large, they clearly merit attention by rural electric co-ops since they can be supplied by today's equipment with modest effort.

For more about potential markets, see Section 4, Residential Fuel Cell Market.

UTILIZING WASTE HEAT

In generating electricity for a residence, a fuel cell creates a fair amount of by-product heat—heat that can be put to use in heating water and interior space for the home, instead of just flowing into the atmosphere. Utilizing that heat requires an investment in thermal recovery equipment, but the savings in fuel costs for heat can pay for the equipment in 10 years or less, depending on application.

The savings can be applied against the cost of producing electricity from the fuel cell. The cost of electricity will still remain high,

however. In fact, the 85¢/kWh cost mentioned above already includes a credit for water heating by thermal recovery.

The new mechanical cells produce about the same amount of heat as electrochemical fuel cells. So thermal recovery savings apply equally well to mechanical cells. In fact, the electricity cost of 44¢/kWh quoted above for mechanical cells already includes an allowance for thermal recovery for water heating.

For more information, see Section 6, Thermal Recovery.

OUTLOOK FOR THE FUTURE

The viability of residential fuel cells is not really a technical issue, but rather an economic one. The high cost of the units, both now and in the predictable future, makes it unlikely that they will be used for normal residential distributed generation. A further barrier is the run-up in propane cost relative to grid electricity rates.

At the same time, mechanical cells offer a useful option for co-ops. Many such units, with

price tags under \$15,000, are already in service in Europe. Mechanical cells appear ready to satisfy specialized co-op customer needs, principally for edge-of-the grid or remote power generation.

For more information, see Section 7, Conclusions.