ELECTRIC POWER RESEARCH INSTITUTE'S ROLE IN DEVELOPING FUEL CELL SYSTEMS

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Introduction

The Electric Power Research Institute (EPRI) manages a collaborative research and development (R&D) program on behalf of the U.S. electric utility industry and its customers. Founded in 1972, the Institute is the nation's oldest major research consortium. Funded through voluntary contributions by over 600 member utilities, EPRI's technical staff directs research in a broad range of technologies related to the generation, delivery, storage and use of electricity. EPRI's staff provides member utilities with objective and current technical information on products and services ranging from complex systems such as coal gasification technology, state of the art electric vehicles, to software computer codes for improving plant productivity and efficiency. Special attention is given to developing products which are cost-effective and environmentally acceptable. Research and development expenditures in 1989 will be approximately $280 million (Fig. 1).

Since its inception, EPRI's role in developing new technologies for its customers has changed dramatically. Fifteen years ago, it was assumed that newly developed technologies would be wholeheartedly implemented by the utility industry and quickly adopted into their systems. A substantial effort has been made in developing and demonstrating new and improved power generation technologies, including the fuel cell, under the assumption that commercialization would happen without the need for EPRI support. However, during the past seven years, the electric utility business in the U.S. has changed significantly and this has impacted commercialization of new technology. Reduced load growth, an unpredictable fuel supply, high interest rates, and a difficult regulatory climate have contributed to the reluctance of utilities to pioneer new technology, especially if that requires accepting extraordinary costs and risk. Equipment suppliers, for similar reasons, have not been bullish on the electric utility industry as a business opportunity. Yet by the mid to late 1990s, the utility industry will need new technology options to meet the demand for electricity in a cost-effective, reliable and environmentally acceptable manner. To bring these new technologies to commercial fruition, EPRI's role has gone beyond focusing solely on technical and developmental issues; a better understanding of the industries' market-driven needs and customer requirements is now essential.

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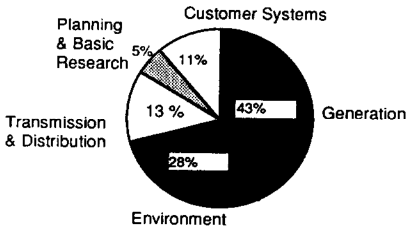

Fig. 1. Research funded by EPRI. Total 1989 research and development budget: $280 million.

EPRI's role in developing fuel cell power systems provides an excellent case study illustrating the challenges of bringing a new technology to a commercial reality. EPRI's role in development of this novel power generation option has involved exploratory and applied research; component engineering development and full-scale demonstration projects; definition of market opportunities and identifying fuel cell products which satisfy those opportunities. The Institute is also playing an important role in bridging the barriers of commercialization by bringing together suppliers and buyers. EPRI is also enhancing the technical awareness of fuel cells internationally. Collaboration with foreign developers, information exchange and monitoring worldwide development efforts is becoming a more important element in the Institute's R&D planning. EPRI's past and current activities in developing and commercializing fuel cell power systems for electric utility applications are reviewed here.

Near-commercial — low temperature fuel cell systems

EPRI's fuel cell program has been in place since the Institute was founded; cumulative R&D expenditures to date have been approximately $70 million dollars. Because low temperature fuel cells of the phosphoric acid type (PAFC) were closest to commercial reality, emphasis during the past 10 years has been placed on developing a commercially viable phosphoric acid fuel cell power module; suitable for dispersed siting applications in large urban or municipal regions.

Research efforts in the early 1970s focused on fundamental work in understanding electrochemical reactions, improving the performance of electrocatalysts and identifying new electrolytes for use in PAFCs. Since the preferred fuel for early market power cells will be natural gas and possibly liquid fuels ranging from naphtha to heavier fuel oils, early research also focused on steam-reforming catalysts, fuel processing system development and steam-reformer reactor design so that fuel cells could effectively use the feedstocks.

After a successful verification of a 1 MW pilot plant in 1977 by United Technologies Corporation (UTC) and nine electric utilities, it became clear that further verification of the fuel cells operational, environmental and siting claims would be required before the industry would implement this

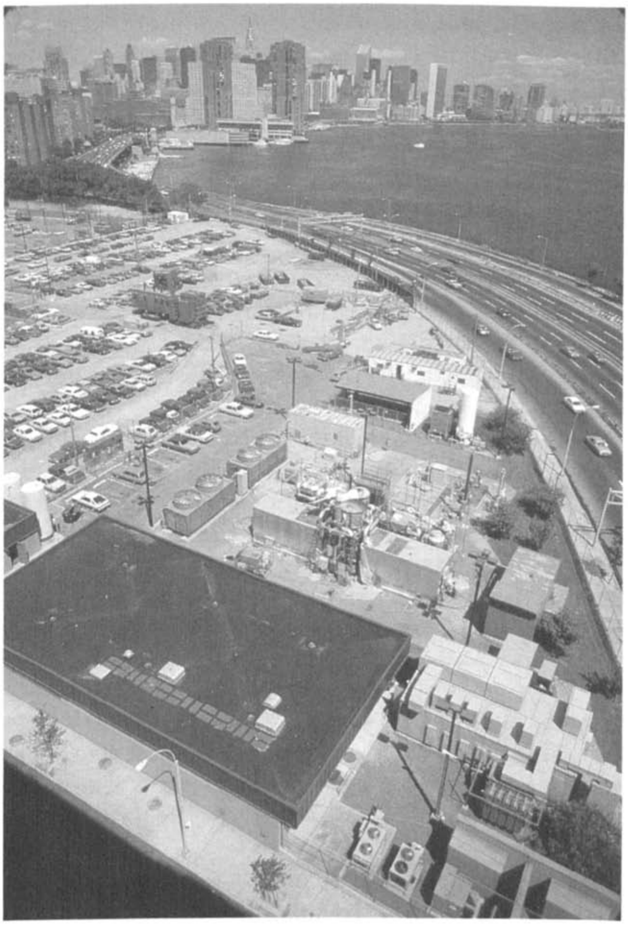

Fig. 2. 4.5 MW demonstrator at New York City site.

new type of power generation option in their systems. EPRI, together with ERDA [now the U.S. Dept. of Energy (DOE)], funded a multi-million dollar program with UTC to design, manufacture and test a 4.5 MW fuel cell power plant demonstrator in downtown New York City, Fig. 2. EPRI believed it was critical that this demonstrator be connected to the utility grid and operated by utility personnel. The demonstrator was also to provide a check on the fuel cell's operational features, including heat rate, power quality, transient response and start-up and shutdown characteristics — all necessary prerequisites for electric utility acceptance.

In 1980, Japan's Tokyo Electric Power Co. (TEPCO) also announced that it would install and test its own fuel cell demonstrator — a twin of the New York unit. This began a collaborative relationship between TEPCO and EPRI that continues today. Results from both the New York and the TPECO demonstration units were published [1, 2] and EPRI was able to identify many of the lessons learned and design deficiencies in the demonstration units and address these issues in ongoing development projects at UTC, where development of a market entry PAFC unit was proceeding in parallel to the pilot-plant demonstration projects.

During the 4.5 MW demonstration time period, EPRI recognized that the cost and complexity issues of PAFC systems and durability issues of fuel cell stacks would have to be addressed for market acceptance. EPRI, together with DOE, sponsored development of an improved fuel cell stack design and power plant system. EPRI focused on improving and simplifying the overall system design and ensuring that a fuel cell power plant, designed to utility standards, would meet performance, durability and operational needs the electric utility industry required. DOE focused on stack scale-up, manufacturing and cost reduction.

Results from EPRI sponsored work in the mid-1980s included: definition and preliminary design of a much improved 11 MW power plant system (Table 1, Fig. 3); technology development of key components in the system (reformer, inverter, controller) and verification of performance and durability of those components. PAFC stack manufacturing cost assessments and power plant capital cost estimates for near-commercial and advanced PAFC power plants were also developed. These activities contributed to the first pre-commercial offering of fuel cell power modules to the electric utility industry in 1986 [3 - 7]. TEPCO is currently constructing an 11 MW PAFC power plant of this design which is expected to be operational by 1991.

In the early 1980s, EPRI also sponsored Westinghouse Electric Corporation in the development of an air-cooled fuel cell system design. Emphasis again was placed on cost, performance and durability. A 7.5 MW PAFC

TABLE 1

Characteristics of improved pre-commercial fuel cell *vs.* 4.5 MW demonstrator design

	Demonstrator	11 MW pre-commercial configuration
Module size (MW)	4.5	11
Heat rate (Btu/kW h) HHV	9300	8300
Power range (%)	25 - 100	30 - 100
Plant operating pressure (psia)	50	120
Fuel cell active area (ft^2)	3.7	10
Plant foot print (acres)	0.8	0.8 - 1.0
Startup time (h)	4	6
Emissions (lb/million Btu)		
NOx	0.02	0.006
SOx	0.00003	0.0004
Relative installed cost ($/kW) (1987 $)		
(a) custom built, first-of-a-kind	5500	
(b) based on 3 units produced		3600
(c) 100 - 300 MW/year production		1550

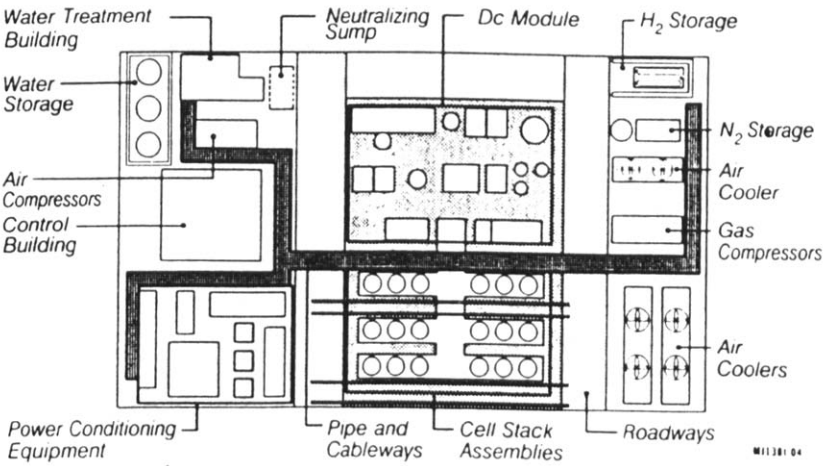

Fig. 3. Standard physical arrangement of 11 MW pre-commercial unit.

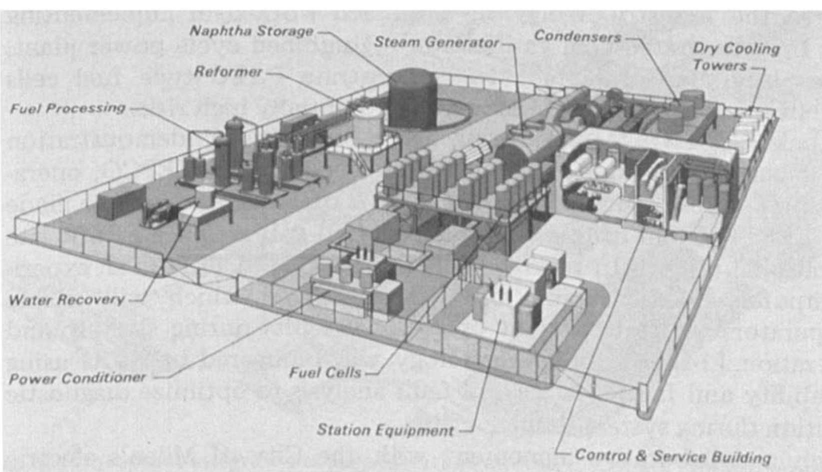

Fig. 4. Conceptual design of a Westinghouse PAFC 7.5 MW plant.

reference system was defined (Fig. 4), including a 1.5 MW pilot-plant demonstrator. Through an EPRI sponsored project at Westinghouse, a modular, high-efficient steam reformer was also developed and demonstrated at the 1.25 MW scale [8, 9]. This reformer technology is now available on a commercial basis from Haldor Topsoe, Inc. and is being applied to PAFC designs as small as 200 kW to 1000 kW.

As the phosphoric acid fuel cells became technically ready for the utility market in the mid 1980s, EPRI's role turned to commercialization. The Fuel Cell Users Group of The Electric Utility Industry (FCUG) was organized under EPRI leadership. Composed of over 55 utilities, the FCUG represented both potential early purchasers and technology advocates and was the first organized utility group to begin interacting with fuel cell developers. Through the vehicle of the FCUG, EPRI conducted several fuel cell market studies and application guides to assist developers in understanding market needs and to aid utility system planners in conducting accurate technology assessments and system expansion planning [10 - 13]. These studies identified the potential initial market opportunities for fuel cells and the necessary 'market entry' capital costs for electric utility deployment.

A study titled "EPRI Roles in Commercialization of Fuel Cells" showed that the most effective use of EPRI's R&D funds for PAFC commercialization was to assist in underwriting the initial high cost of the demonstration unit. And today, regardless of the type of fuel cell technology, underwriting a portion of the initial plant cost, or minimizing utility risk in other ways, continues to be an important role for EPRI in implementing fuel cell technology on utility systems.

Through EPRI leadership, the idea of forming utility consortiums to share the risks and rewards in commercializing fuel cells was also first introduced to the industry. While this approach worked in implementing the world's first integrated coal gasification — combined cycle power plant, U.S. utilities have been reluctant to demonstrate PAFC type fuel cells because of current market conditions and the potentially high risks.

Nevertheless, EPRI is monitoring large scale PAFC demonstration projects in Japan and Europe. Through an agreement with TEPCO, operational data and key results from TEPCO's 11 MW fuel cell plant will be made available to EPRI member utilities as well as limited access to the 11 MW site during operational testing. In return, EPRI is providing to TEPCO an experimental computer aided training and diagnostic aid which will enable TEPCO's operators to trouble-shoot operational faults during start-up and routine operation [14, 15]. This technology was pioneered by EPRI using system testability and failure mode and fault analysis to optimize diagnostic instrumentation during system design.

Through a collaborative agreement with the City of Milan's electric utility, Azienda energetica municipale, EPRI is also monitoring a 1 MW PAFC pilot-plant demonstration which will be sited on the municipal system.

Developmental — high temperature fuel cell systems

High temperature molten carbonate and solid oxide fuel cell systems offer the highest conceivable efficiency and lowest emission coal-based power generation technology known (Table 2). EPRI's long term goals are to couple advanced high temperature fuel cells with coal gasification technology (Fig. 5). However, before advanced fuel cells can be accepted by utilities to operate on coal gas, they must first be accepted using natural gas. Hence, EPRI's near term role in developing both advanced molten carbonate and solid oxide systems is focused on high value market entry products which are attractive and economical using natural gas.

TABLE 2

Design targets for integrated coal gasification/molten carbonate fuel cell systems

Characteristic	Design target
Application	Electric utility, baseload
Unit rating (MW)	200 - 250 module
Heat rate (Btu/kW h) HHV	6800
Fuel flexibility	all coals and natural gas
Emissions (lbs/MW h)	
NOx	0.1
SOx	0.005
particulates	trace
Installed cost ($/kW)	1200

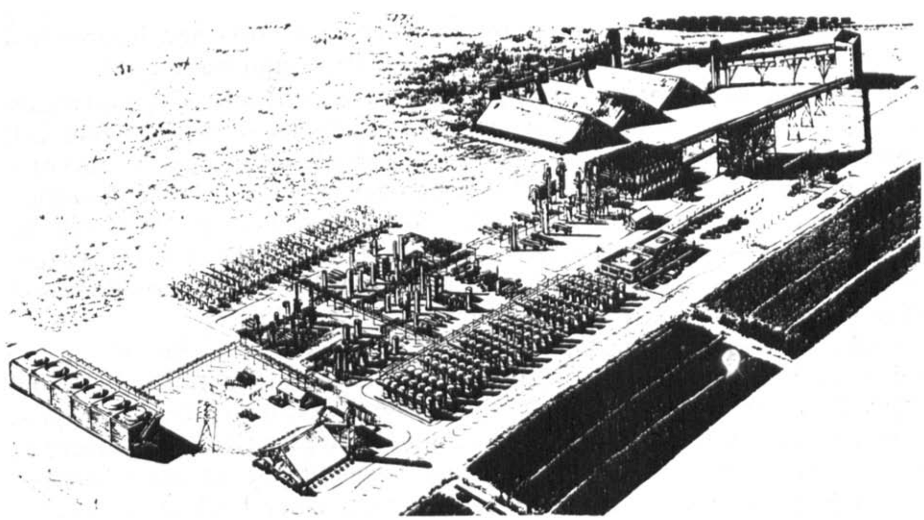

Fig. 5. Conceptual integrated coal gasification/molten carbonate fuel cell power plant.

In the early 1980s, research sponsored by EPRI pioneered the development of the 'direct fuel cell'. In this concept, natural gas fuel (or methanol) is converted to a hydrogen rich gas on the anode surface of a molten carbonate fuel cell; the hydrogen produced is rapidly consumed electrochemically and converted into d.c. power. A fuel cell power system based on this concept is extremely efficient (60%+), simple in design since no external fuel processor is needed, and has attractive installed capital cost (Fig. 6).

Our approach here has included defining a commercially attractive system and using the system results to establish performance, scale and cost requirements of fuel cell stacks [16, 17]. In developing fuel cell stacks, the key thrust is to impose design-to-cost requirements consistent with commercial requirements. In this approach, fuel cell designs are analyzed/

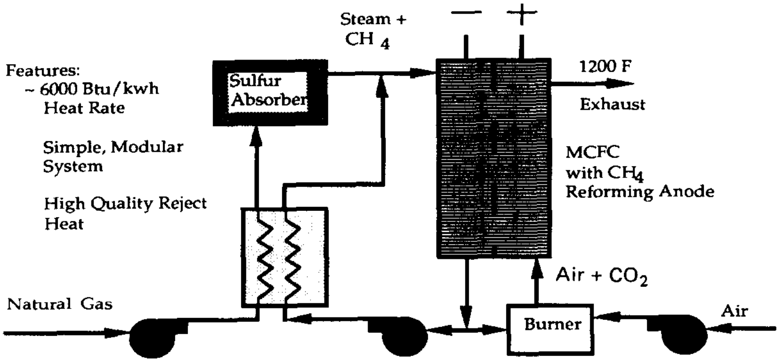

Fig. 6. Internal reforming molten carbonate system.

optimized to cost requirements before rigorous fabrication and testing programs are initiated. This minimizes development costs and insures fuel cell stacks will be technically acceptable as well as economically viable.

The development of the 'direct fuel cell' concept into a commercially acceptable dispersed generator is the current focus of EPRI's fuel cell research program. A completely integrated 100 kW pilot-plant is currently under construction. This unit will be installed at Pacific Gas & Electric's R&D facility near San Francisco, CA. Integrated system tests will be conducted by PG & E by the fall of 1990. This project is an important milestone in moving towards a 2 MW, 6500 Btu/kW h heat rate dispersed generator and smaller market entry products, Table 3, Fig. 7.

EPRI's strategy in developing advanced fuel cells relies heavily on the overall U.S. National Fuel Cell Program. In that program, EPRI, DOE and the Gas Research Institute (GRI) collaborate to prioritize research issues and coordinate areas of research to eliminate duplication. For example, EPRI and GRI are currently sponsoring development of early market, advanced fuel cell systems, and DOE is supporting research which will enable advanced fuel cells to operate on a coal gas. This year's coordinated EPRI and DOE efforts involve assessing MCFC and SOFC system integration,

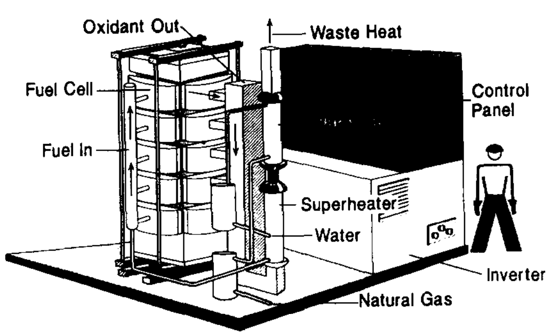

Fig. 7. Conceptual layout of a 100 kW MCFC market entry unit.

TABLE 3

Market entry MCFC system characteristics

Design parameter	Applications	
	Commercial on-site	Dispersed generator
Size, net power output (kW)	200 - 500	2000 - 5000
Electrical efficiency (%) HHV	50	55 - 57
Fuel	natural gas	natural gas
Site area (ft^2)	500 - 700	4000
Water supply make-up	0	0
Modularity	pallet assembled	pallet assembled
Emissions (lb/MW h)		
NOx	< 0.01	0
SOx	trace	< 0.01
CO	0	0
CO_2	820	820
hydrocarbons	0	0
particulates	0	0
Design life		
plant (years)	20	20
fuel cell stacks (h)	25000	25000
Availability (%)	85	85
Installed cost target ($/kW)	< 1500	< 1500

performance and capital cost requirements. Results will aid in guiding research programs.

Development and evaluation of solid oxide fuel cell (SOFC) components and system concepts has only recently been sponsored. Development and evaluation of a new planar SOFC concept was performed, and currently EPRI is funding research examining alternative SOFC design concepts. Over the next few years, EPRI will assess the feasibility of tubular SOFC systems using coal and/or natural gas. Through a collaborative agreement with the New Energy and Industrial Development Organization (NEDO) in Japan, EPRI is directing research on their behalf which will assess the technical and economic merits of large-scale (300 MW) and small (15 - 30 MW) SOFC system concepts.

Challenges of commercialization

To expedite the commercialization of fuel cells, EPRI has had to focus more on quantifying the market for fuel cells and understanding current 'market driven' utility needs. The efforts in this area have increased recently through working closely with the American Public Power Association (APPA). A recent market assessment, funded together by EPRI and APPA, identified the magnitude of the early market potential for fuel cells on public power systems, capital cost thresholds, and optimal unit size considerations. The 'likely early market' for fuel cells in public power is ~12 000 to 14 000 MW over the 1996 to 2010 time period; unit sizes ranging from 3 MW to 10 MW would be attractive; and installed capital costs near or below $1000/kW (1986 $) will be necessary to achieve a sizable mature market in public power [18].

The public power market is a potentially attractive early market 'niche' for near-commercial fuel cells. APPA's 'Notice of Market Opportunity' generated considerable interest from fuel cell developers in this market [19]. Currently, EPRI is assisting APPA utilities by providing technical expertise in reviewing vendor product offerings, business plans and overall approach to commercialization. The goal is to identify one or more commercialization approaches for a broad range of U.S. utilities by early next year.

Collaborative research

While certain U.S. utilities are developing fuel cell commercialization strategies with vendors, the majority of the industry (for numerous economic or market reasons) are waiting for the fuel cell to become commercial in the late 1990s.

Utilities in Japan and Europe are moving much faster in deploying precommercial fuel cell generators in their systems. In that regard, EPRI has established collaborative information exchange agreements with these utilities and foreign government funding organizations. The lessons learned and information exchanged from collaborative projects is valuable in establishing R&D needs; operating and maintenance data from early units can quantify risk and assist other utilities in evaluating the technology. International collaboration can shorten development time, minimize R&D investments and increase business opportunities worldwide.

EPRI has recognized that a U.S. research and development program cannot ignore worldwide technological developments. This is particularly true in the fuel cell area. International collaboration can truly make this promising technology a reality.

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