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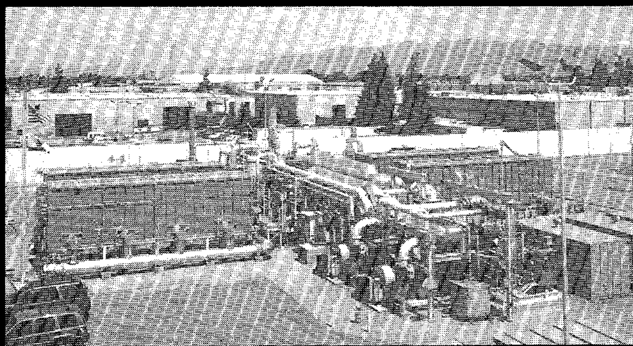

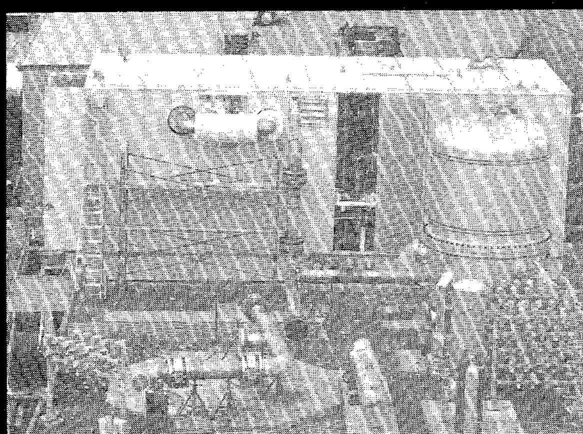

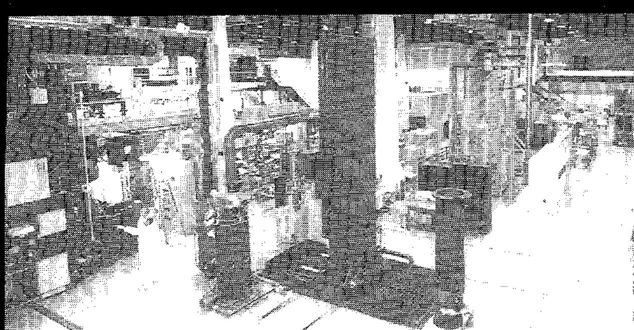

Fuel Cell Systems Program for Stationary Power

1996

U.S. Department of Energy
Assistant Secretary for Fossil Energy
Deputy Assistant Secretary for Advanced Research and Special Technologies

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Cover Photos

Top: 2 megawatt Molten Carbonate Fuel Cell Field Test at Santa Clara, California (Courtesy Energy Research Corporation)

Second: 250 kilowatt Molten Carbonate Fuel Cell Field Test Under Construction at San Diego, California (Courtesy M-C Power Corporation)

Third: Solid Oxide Fuel Cell Pilot Manufacturing Facility (Courtesy Westinghouse Electric Company)

Bottom: 200 kilowatt (PC-25™) Phosphoric Acid Fuel Cell Power Plant Assembly Facility (Courtesy ONSI Corporation)

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Washington, D.C. 20585

TABLE OF CONTENTS

List of Exhibits

FORWARD

This document is intended to foster improved communications among those with an interest in the development and application of fuel cells. The document provides a short overview of the fuel cell program being conducted by the Department of Energy, Office of Fossil Energy in partnership with the private sector and other government agencies.

SUMMARY

The mission of the fuel cell systems program of the Department of Energy, Office of Fossil Energy, in partnership with its customers and stakeholders, is to foster the creation of a new domestic fuel cell industry. This industry should be capable of commercialization of new, improved fuel cell power generation systems and thereby provide significant economic and environmental benefits. This program is aligned with the Department of Energy's core mission (business line) of energy resources.

Consistent with the concept of sustainable energy resources development, the fuel cell program supports the Department's natural gas program overall mission and strategic plan. These encourage economic growth and job creation, make the most effective use of domestic resources, promote economic and energy efficiency, protect human health and the environment, and enhance energy security. The program is conducted within the guidance of the Energy Policy Act (EPACT), the National Environmental Policy Act (NEPA), and the Clean Air Act Amendments (CAAA), and Federal and DOE energy acquisition regulations.

The Energy Policy Act lays the foundation for a more efficient, less vulnerable and environmentally sustainable energy future. Several advanced energy conversion technologies under development by the Department of Energy can help achieve these objectives. Fuel cell systems are among those technologies having the potential for highly efficient energy conversion, enhancement of environmental quality and stimulating creation of a major new manufacturing industry.

The Department of Energy (DOE), Office of Fossil Energy, is participating with the private sector in sponsoring the development of molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC) technologies for application in the utility, commercial and industrial sectors. Phosphoric acid fuel cell (PAFC) development was

sponsored by the Office of Fossil Energy in previous years and is now being commercialized by the private sector.

Private sector participants with the Department of Energy include the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), electric and gas utilities, universities, manufacturing companies and their suppliers. The Department of Energy program is also coordinated with fuel cell development, demonstration and application efforts by the Department of Defense (DOD), and the National Aeronautics and Space Administration (NASA).

Also within the Department of Energy, the Office of Energy Efficiency and Renewable Energy is participating in sponsoring development of fuel cells for transportation propulsion systems. The program for transportation applications is focused primarily on the development of polymer electrolyte or proton exchange membrane fuel cells, and also included a demonstration program for three phosphoric acid fuel cell buses. DOE fuel cell research, development and demonstration efforts are part of the national fuel cell development and commercialization efforts which also involve private sector participation and funding. This document describes the fuel cell activities of the DOE Office of Fossil Energy.

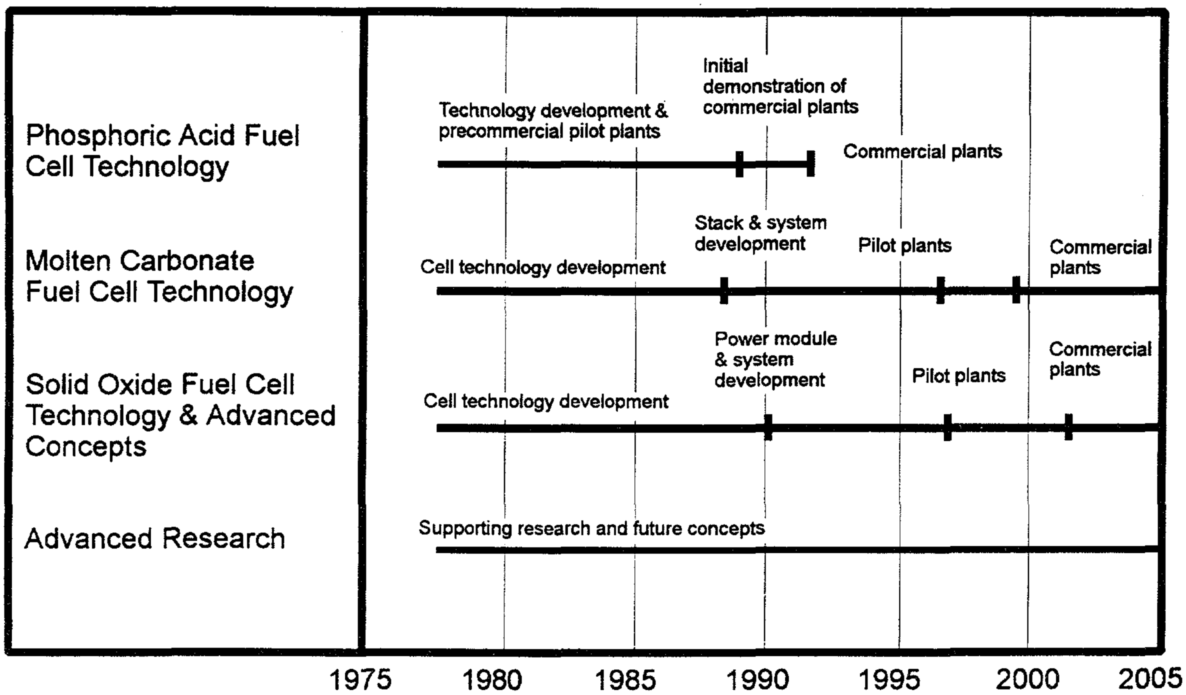
Through continued government and private sector support, fuel cell systems are emerging power generation technologies which are expected to have significant worldwide impacts. An industry with annual sales of over a billion dollars is envisioned early in the 21st century. PAFC power plants have begun to enter the marketplace and MCFC and SOFC power plants are expected to enter the marketplace around the year 2000.

In support of the efficient and effective use of our natural resources, the fuel cell program seeks to increase energy efficiency and economic effectiveness of power generation. This is to be accomplished through the development and commercialization of cost-effective, efficient and environmentally desirable fuel cell systems which will operate on fossil fuels in multiple end use sectors.

The program objectives are to develop and demonstrate cost effective fuel cell power generation which can be successfully commercialized by the year 2000.

The overall schedule of the fuel cell program is shown in Exhibit 1.

EXHIBIT 1
OVERALL FUEL CELL PLAN



The activities shown in Exhibit 1 include basic and applied research and development, proof-of-concept activities, precommercial demonstrations, and associated private sector commercial scale activity. Some of the key elements of the program include:

- Development and demonstration, in 1996 and 1997, of commercial size MCFC and SOFC integrated system units meeting functional requirements for utility scale, distributed power and on-site generation applications;

- Demonstration of cost reduction, performance and durability improvements which would enable private sector production of competitive market entry power plants by the year 2000;

- Evaluation and identification, by 1999 of advanced fuel cell concepts and configurations which would enable efficiencies over 60% (on higher heating value basis; 70% on lower heating value basis) and installed costs below 1000 dollars per kilowatt for utility scale, distributed power and on-site generation;

- Support of advanced research which would ensure availability of the critical materials and processes required for commercial market entry units by 2000 and advanced units by 2005;

- Cooperation with private sector commercialization activities to facilitate rapid cost reductions and rapid market penetration enabling industry growth to annual sales over $1 billion early in the 21st century.

- Coordination with fuel cell development and testing activities of the Department of Defense, DOE's Office of Energy Efficiency and Renewable Energy, the Electric Power Research Institute, the Gas Research Institute, the National Aeronautics and Space Administration, electric and gas utilities and manufacturing companies in order to leverage the available resources, avoid duplication, and maximize taxpayer return on investment.

The program strategy is to assist the private sector in developing molten carbonate and solid oxide fuel cell technologies and to participate in those field tests which would greatly improve prospects for commercialization by the private sector. The strategy also includes supporting advanced research to provide solutions in critical areas and to identify concepts which offer opportunities for significant reductions in cost and improvements in performance.

This strategy has been selected in order to leverage and focus the available resources of the government and private sectors. The intent is to accomplish important advancements in these technologies through research and development and foster the translation of these advancements into actual economic and environmental benefits.

Commercialization plans have been formulated by the private sector for market entry of these power plants fueled by natural gas by 2000. Introduction of larger power plants with integrated coal gasifiers is anticipated prior to 2010.

Congressional appropriations for this program in fiscal year 1996 are $52.5 million. This is comparable to the appropriation levels in fiscal years 1994 and 1995 of $51.1 million and $46.9 million respectively. Private sector resources being devoted to fuel cell development in the United States have also been estimated to be approximately $50 million per year.

I

INTRODUCTION

Fuel cell power systems are emerging power generation technologies for the efficient, economical and environmentally acceptable production of electricity. In some applications the by-product heat can also be efficiently used in cogeneration. Fuel cells produce electricity through the electrochemical oxidation of a fuel. They can be operated on a variety of fuels, including natural gas, coal gas, land fill gas and renewable fuels. First market entry units are fueled by natural gas. Fuel cells offer the opportunity for a major new manufacturing industry.

System studies have shown that fuel cell power plants can be designed with overall system efficiencies in the 50 to 60 percent range (higher heating value basis) (55 to 65 percent on lower heating value basis). Fuel cell power plants are unique in that they offer high efficiency and low emissions even at part-load and in small sizes. Because of their efficiency, fuel cells will help in reducing CO_2 emissions.

Additional benefits are the environmentally desirable operating characteristics offered by fuel cells. Because electricity is produced through an electrochemical reaction rather than by combustion, fuel cells generate very little NO_X and are extremely quiet. This combination of operating characteristics and high efficiency make fuel cells attractive for future electric utility applications. On-site industrial and commercial applications where the by-product heat can be utilized are also attractive. Fuel cells can be sited in environmentally sensitive and populated areas and early commercial units have been installed in hotels, office buildings and similar locations. The overall program goal is to develop and commercialize cost-effective fuel cell systems which utilize these advantages.

Development of fuel cell technologies has been underway in the United States with funding support provided by both public and private sectors. The DOE Office of Fossil Energy, the Gas Research Institute (GRI), and the Electric Power Research Institute (EPRI) are cooperatively sponsoring the development of fuel cell systems for applications in the utility, commercial and industrial sectors. Funding of development and demonstration is also provided by fuel cell developers and potential users.

This document describes the fuel cell program of the DOE Office of Fossil Energy and its coordination with other fuel cell activities.

II

GOALS AND STRATEGIES

In support of achieving the power generation vision for natural gas, the strategic goal of the fuel cell program is to expand the clean, efficient and economic use of natural gas in the utility-scale, distributed, and on-site power market sectors through: (1) the successful development, demonstration and commercialization of advanced fuel cell power generation systems; and (2) the reduction of market hurdles and removal of regulatory barriers to the deployment of new, advanced gas-based fuel cell power generation technologies. The strategic approach to overcome the issues / barriers associated with increased fuel cell use in the power generation area is guided by the natural gas commercialization strategy in the Power Generation section of the natural gas strategic plan and program crosscut plans.

To achieve this strategic goal, DOE has identified supporting goals for (1) developing technology, (2) fostering market pull for technology, (3) removing policy impediments, and (4) ensuring the maximization of the environmental benefits of advanced gas-based fuel cell power generation, while recognizing the changing market forces in the electric generation area.

TECHNOLOGY

Goal

The program technology goal is to complete the development and demonstration which responds to domestic industry needs leading to the commercialization of high efficiency, environmentally benign molten carbonate and solid oxide fuel cell power plants for stationary applications in utility-scale, distributed, and on-site power markets (domestic and export). Efficiency targets are 55 to 60 percent on the basis of higher heating value (HHV) (60 to 65 percent on basis of lower heating value, LHV) for molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC) systems, with both technologies cost competitive with other power technologies. *(Near-Term)*

Development targets for system efficiency and capital cost for MCFC and SOFC (based on volume production and the 2010 time frame) are shown in Exhibit 2.

EXHIBIT 2
DEVELOPMENT TARGETS FOR FUEL CELL SYSTEMS

	TYPES OF FUEL CELL SYSTEMS BEING DEVELOPED	
	Molten Carbonate	Solid Oxide
Capital Cost		
Natural Gas-Fueled Plant:		
• Electric Utility	$800/KW	$600/KW
• On-Site	$1000/KW	$800/KW
Coal-Fueled Plant:		
• Electric Utility	$1200/KW	$1000/KW
Efficiencies (HHV)		
Natural Gas-Fueled Plant:		
• Electric Utility	60%	60%
• On-Site	55%	55%
Coal-Fueled Plant:		
• Electric Utility	50%	50%

Strategy

- Foster the development, scaleup and system integration of molten carbonate and solid oxide fuel cell power plants through the demonstration plant stage (with increasing levels of private sector cost sharing). *(Near-Term)*

MARKET/COMMERCIALIZATION

Goal

- The market and commercialization goal is the private sector realization of significant market penetration with molten carbonate and solid oxide fuel cell power plants for on-site cogeneration and distributed power generation as well as new and repowering central power plant applications in domestic and export utility and nonutility generator markets. *(Mid-Term)*

Strategies

- Foster the realization of expanded fuel cell market penetration in partnership with industry.

  While each developer has its own specific commercialization strategy, common elements exist such as the need to offer a product meeting the needs of specific customers, competitive costs, and a need to lower the perceived risks associated with this new type of power plant. The government role complements the private sector commercialization strategies by assisting in demonstrating the capabilities and level of development of these emerging technologies. *(Mid-Term)*

- Coordinate with the Department of Defense on fostering application of near-term power plants ready for commercial offering. *(Near-Term)*

- Cultivate opportunities for commercialization activities which target market entry of advanced fuel cells by 2000. *(Mid-Term)*

POLICY/REGULATORY

Goal

- The policy and regulatory goal is to foster market opportunities by overcoming market and regulatory hurdles for commercialization of advanced gas-based fuel cell power generation technologies both domestically and globally. *(Near-Term)*

Strategies

- Increase DOE interaction with States and other stakeholders, including participation in meetings with the National Association of Regulated Utility Commissioners, on matters such as increased competition, industry restructuring, rate making, environmental regulations, and integrated resource planning. Participate as an interested party in the state rule making process to encourage the enactment of state regulations which allow for introduction of new technologies into the power generation market. Institute regional strategies for changes to rate making and dispatching on basis of integrated resource planning including environmental and externality considerations. *(Near-Term)*

- Participate in forums to improve networking of users, suppliers, and manufacturers and provide opportunities conducive to constructive interaction with key local, state and federal regulators. *(Near-Term)*

- Analyze domestic and export markets to improve understanding of customer needs and concerns. Utilize optimization analyses to provide input useful to government or private sector decision-making processes with regards to investments, regulations, and market response to changes in the power industry. *(Near-Term)*

ENVIRONMENTAL

Goal

- The program environmental goal is to realize consistent and rational standards set by states and EPA to allow gas-based fuel cell power generation systems to compete in the power generation market.

Strategies

- Spotlight fuel cell technology as a means for power generation systems to meet environmental standards.
- Examine environmental incentives as a means of increasing use of fuel cell power plants.
- Encourage states and the EPA to adopt scientifically based emissions standards that allow economically and realistically achievable emissions for specific applications, areas and regions.

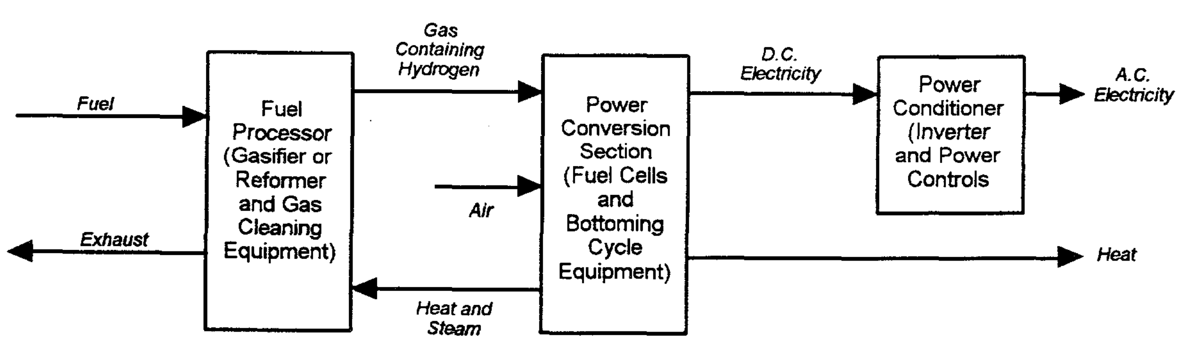
The program being implemented and progress toward achieving these goals are described in the following sections of this report.

III

TECHNOLOGY DESCRIPTION

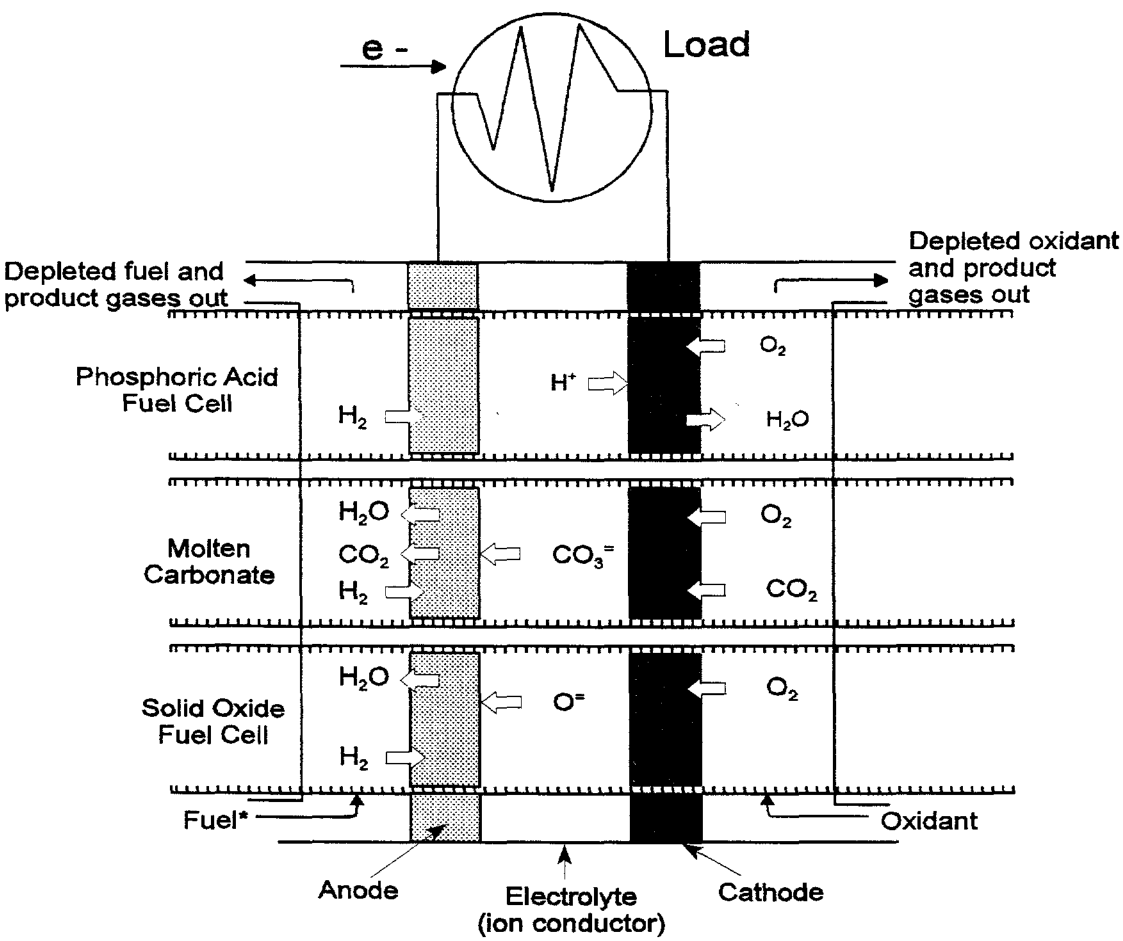
A basic fuel cell consists of two electrodes, the anode and cathode, separated by an electrolyte. Fuel cell types are typically characterized by their electrolyte. For example, phosphoric acid fuel cells utilize a phosphoric acid electrolyte in a matrix between anode and cathode electrodes. A fuel cell power plant as shown schematically in Exhibit 3 has three main components: the power conversion section which contains the series of fuel cells (often referred to as the fuel cell stacks), the fuel processor, and the power conditioner. The fuel processor converts a hydrocarbon fuel (e.g., natural gas or coal) to a hydrogen-rich gas that is fed to the fuel cell stacks. The fuel cell stacks combine oxygen from the air with the hydrogen from the fuel processor to generate direct current electricity and heat. The heat may either be used directly as a co-product or applied in a bottoming cycle to produce additional electricity. The power conditioning section changes the direct current from the fuel cells to alternating current.

EXHIBIT 3
FUEL CELL POWER PLANT



Fuel cell technologies under development in the U.S. include phosphoric acid, molten carbonate, solid oxide, polymer, and alkaline. A schematic representation of the three fuel cell technologies addressed by DOE's Office of Fossil Energy is shown in Exhibit 4. The figure shows the hydrogen and oxygen reacting with the electric charge carrying ion of the electrolyte. These reactions produce an electric current which powers the external load. Water and heat are also produced by these reactions and must be controlled by the overall system. In the case of molten carbonate systems carbon dioxide is also used at the air electrode and formed at the fuel electrode, requiring a CO_2 supply or recycle in these systems. In the solid oxide and molten carbonate fuel cells, carbon monoxide in the fuel stream is also typically utilized as fuel.

EXHIBIT 4
REPRESENTATIONS OF THREE TYPES OF FUEL CELLS



* In the solid oxide and molten carbonate fuel cells, carbon monoxide in the fuel stream is also typically utilized as fuel

Phosphoric Acid Fuel Cells

Phosphoric acid fuel cells use an electrolyte of phosphoric acid in a matrix and operate at approximately 200 °C (400 °F). Development since the late 1960s has brought the technology to market introduction in the electric utility and commercial on-site sectors with natural gas as the fuel. Commercial deliveries of 200 kW on-site units began in 1992 and an electric utility 11 MW power plant has been demonstrated in the private sector.

Molten Carbonate Fuel Cells

Molten carbonate fuel cells use an electrolyte composed of alkali metal carbonates and operate at approximately 650 °C (1200 °F). The high operating temperature is needed to achieve sufficient conductivity of the electrolyte. An effect associated with this higher temperature is that noble metal catalysts are not required for the cell electrochemical oxidation and reduction processes. Molten carbonate fuel cells are being developed for natural gas and coal based power plants for the industrial and electric utility sectors.

Solid Oxide Fuel Cells

Solid oxide fuel cells are being developed which use a ceramic electrolyte of yttria stabilized zirconia and operate at about 1000 °C (1800 °F). The attractiveness of this cell relates to its solid state nature, its potential to reform gaseous fuel within the cells, demonstrated long cell life and its high operating temperature which can provide high quality heat for additional power production or other uses. The solid electrolyte eliminates problems of electrolyte containment and allows designs which utilize the electrolyte as part of the structural members of cells.

Polymer Fuel Cells

Polymer fuel cells use a class of fluorinated sulfonic acid polymer electrolytes. The electrolyte is a solid membrane which is currently operated between 40 °C and 90 °C (100 °F and 200 °F). Polymer fuel cells are being considered for applications where high specific power together with high efficiency are important. Examples are space power and transportation system applications. Polymer fuel cells currently being developed are also sometimes referred to as proton exchange membrane (PEM) fuel cells. Polymer fuel cells development is not being funded by the DOE Office of Fossil Energy but is being funded by the DOE Office of Energy Efficiency and Renewable Energy for transportation applications.

Alkaline Fuel Cells

Alkaline fuel cells have been used since the mid 1960s in the U.S. space program. Future space system applications are expected. Alkaline fuel cells are not economically attractive for commercial terrestrial applications at present because they require the use of reactants free of carbon dioxide. The carbon dioxide contained in reformed fuels and air forms insoluble carbonates in the alkaline electrolyte. These carbonates hinder operation of the cell. Removal of the carbon dioxide from the fuel and air has not been economical. Alkaline fuel cell development is not being funded by the Department of Energy.

IV

TECHNICAL STATUS

PHOSPHORIC ACID FUEL CELL STATUS

PAFC systems were developed for megawatt-scale applications in the electric utility sector and kilowatt-scale applications in the commercial and industrial sectors. International Fuel Cells (IFC) is marketing a 200 kW system for on-site cogeneration use in the commercial sector.

Approximately 85 of the 200 kW on-site power plants have been produced. Worldwide fleet availability averages 95%. More than one-million hours of operating time have been accumulated. The 200 kW power plant is a first-of-a-kind cogeneration system. The cost of these units is expected to decrease from the initial market entry levels with increased production and with continued technology improvement by industry.

The Department of Defense implemented a program funded in FY 1993 and 1994 for fuel cell demonstration and use. Under this program the Army, Navy and Air Force are purchasing and installing commercially manufactured, 200 kilowatt fuel cell units. The DOE is cooperating in these activities to provide information and to obtain maximum benefits from these demonstrations. A subsequent program funded in FY 1995 in the Department of Defense provides partial rebates (up to 1000 $/kW or 1/3 of purchase cost) to buyers of market entry fuel cell units. The Department of Energy is also cooperating in the implementation of this later DOD program.

MOLTEN CARBONATE FUEL CELL STATUS

The MCFC developers have integrated commercial size stacks with the balance of plant and are installing field test units. Developers have pilot plant manufacturing facilities with capacities of 3- to 17-megawatts (MW) per year. Stack testing also continues with emphasis on testing that directly supports the pilot manufacturing and commercial-scale demonstration efforts. Private sector (i.e., utilities and manufacturing industries) and regional (state and local) interest and funding support remain strong and industry is proceeding to implement commercialization plans. Domestic MCFC developers are Energy Research Corporation (ERC), M-C Power Corporation, and International Fuel Cells (IFC).

ERC has constructed a pilot manufacturing facility in Torrington, Connecticut which is manufacturing full size 125 kW internally reformed test stacks with cell areas of 0.56 square meters each (6 square feet). Manufacturing capacity of this plant is 17 MW/year. Three full size stacks were tested in 1993 and 1994. Full size stacks have been assembled for a 2 MW field test described below.

An ERC subsidiary, Fuel Cell Engineering Corp. (FCE), signed an agreement with DOE in 1992 for a 2-megawatt field test demonstration. The 2 MW unit includes 16 of the 125 kW stacks. The cost-shared power plant is installed at a municipal utility site in Santa Clara, California. Operation began in April 1996. ERC plans a second 2-megawatt class field test in 1998, and the stacks required will be reduced from 16 to 8. Cell size will be increased to 0.8 square meters (8.6 square feet).

The second developer, M-C Power, is developing an internally manifolded MCFC design and has assembled their first full scale stack containing approximately 250 cells with an electrical output rating of approximately 250 kW plus cogeneration heat. This stack was installed at a test site in Brea, California, and testing was completed during FY 1995.

M-C Power produces full size stack components in their pilot manufacturing facility in Burr Ridge, Illinois. Manufacturing capacity is estimated at 3 to 4 MW/year.

M-C Power signed an agreement with DOE in 1992 for a 250-kilowatt field test demonstration of a cogeneration unit. The cost-shared power plant is being installed at a site at the Miramar Naval Air Station in San Diego, California. Completion of installation and start of operation is scheduled for FY 1996.

In addition to the two continuing efforts described above, another developer, International Fuel Cells Corporation has concluded DOE funded research contracts to improve MCFC stack performance. Further development is planned under private sector sponsorship. This private sector effort is being assisted through a Cooperative Research and Development Agreement between DOE and IFC which makes certain development equipment available to IFC and keeps DOE informed on program progress.

Although significant progress has been made in the development of MCFC, further cell and stack technology advances aimed at product improvement will be required to achieve the targets for cost, performance and durability necessary for prototype MCFC power plants. Cooperative agreements for product design and development were awarded to ERC and M-C Power in FY 1995 to reach these targets. The efforts are scheduled over a 5 year period.

Designs have been prepared by the developers for 250 to 3000 kW plants. Design studies predict 50-60 percent efficiency (HHV basis) with small scale units on natural gas and for plants integrated with coal gasifiers. Manufacturing cost estimates indicate that stack selling prices of less than $300/kW may be feasible at modest production rates (200 MW per year). These results increase confidence that overall development targets (shown in Exhibit 2) are achievable.

In cooperation with an initiative by the American Public Power Association, ERC has developed a commercialization plan that aims to have, by 1998, orders for over 100 MW of early production units. A group of electric and gas utilities, known as the Fuel Cell Commercialization Group, (presently approximately 26 members) has endorsed this plan and is helping to secure the orders for 50 (or more) of their early commercial power plants.

M-C Power has also developed plans for commercial market entry around 1998. M-C Power has formed a commercialization team including Bechtel Corporation and Stewart and Stevenson which plans to package and market M-C Power fuel cells. A number of gas and electric utilities and other companies have formed a group known as the Alliance to Commercialize Carbonate Technology (with approximately 20 members) to facilitate commercialization of the M-C Power technology.

SOLID OXIDE FUEL CELL STATUS

Several SOFC geometric configurations are now under development or are being evaluated in the United States. These have been characterized as tubular and various planar approaches. The tubular configuration is much farther along the development cycle than the other SOFC approaches. The planar approaches may offer advantages in power density, efficiency and fabrication costs, but are at a very early development stage and projections have not yet been proven.

Westinghouse Electric Corporation has been the major developer of the tubular configuration. The Westinghouse design packages tubular cells in bundles containing eighteen cells. Groups of bundles are then mounted in a thermally integrated system which make up a module. Westinghouse has built and tested systems ranging in size from 500 W to 25 kW (40 kW peak). Six 20 to 25 kW generators have been built and are being tested by gas and electric utilities. Westinghouse has a pre-pilot manufacturing facility in operation which is capable of producing approximately 6 MW of cells per year on two shifts.

Testing at Westinghouse has progressed to the point where groups of cells have been operated for over 62,000 hours (over seven years). Self-supported cells are now used in generators, which improve performance and reduce cost by eliminating the porous support tube. Cell lengths of up to 200 centimeters have been produced and tested. Conceptual design of a 300 MW integrated gasifier/fuel cell power plant has been completed. Several 100 kW tests are planned. A 100 kW module is designed to be the fundamental repeatable element in larger power plants. The first 100 kW generator is scheduled for completion of fabrication in FY 1996 and start of testing at a utility site in FY 1997.

Planar cells have not yet been operated above the small module, laboratory test scale. Expanded development efforts focused on material selection and stack fabrication would be required to realize the potential of these alternative SOFC concepts. Under prior DOE sponsorship, Allied Signal teamed with Argonne National Laboratory and fabricated stacks of several cells by techniques which roll thin uniform layers of the materials used to form the ceramic structure. Planar cell stacks of up to several kW output have been reported from private sector programs.

V

PROGRAM DESCRIPTION AND IMPLEMENTATION

PROGRAM DESCRIPTION AND IMPLEMENTATION

The Fuel Cell Program Office is in the Office of Special Technologies within the Office of Fossil Energy. Program contracts with industry are implemented through the Department's Morgantown Energy Technology Center.

The program of the Department of Energy and the private sector seeks to develop and deploy fuel cell power plant technology for use in electric utility-scale, distributed, and on-site power generation applications with 55 to 60 percent efficiencies and producing economic and environmental benefits. The following issues are being addressed.

Issues

- Although advanced fuel cell systems achieve high efficiencies of 55 to 60 percent in development testing with gaseous fuels, they must be scaled up to commercial size complete power plants and operated in user environments. Commercialization of these power plants will require building market place confidence through verifying performance, durability, reliability, applicability, and cost-effectiveness of the market entry products.

- Commercialization of fuel cell power plants will require raising capital in the private sector for expansion of manufacturing facilities. Raising this investment capital in a timely manner may be a challenge.

- Integration of pilot demonstration plants of up to 11 MW on natural gas has been accomplished with a PAFC power plant. However, no large scale integrated system tests (above 125 kW) have been performed with more advanced molten carbonate or solid oxide fuel cell technologies.

- For many on-site and distributed power applications, the costs of these new power plants may not be competitive during the market entry phase which involves low production volumes. Means are sought which aid in achieving lower costs of the early units as well as means to stimulate market pull to accelerate the market penetration rate and realize the cost reductions associated with higher production volumes.

- Notwithstanding the environmental and efficiency benefits of fuel cells and their potential for becoming economically competitive, the historical position for many state public utility commissions (PUCs) has been to pursue only the least cost of electricity to the consumer, thereby making the introduction of these new technologies into the utility market difficult. Further, utilities have generally been discouraged from taking risks with these newer, advanced technologies by PUC rulings which 1) do not allow passing on costs of power systems demonstrations into the rate base; and 2) do not provide any return for investments in successful demonstrations by ruling that any savings garnered must be passed to the consumer.

Program Outputs

In support of the Energy Policy Act, the DOE program, with the private sector participation, (1) supports technology base development of fuel cell systems to provide highly efficient, environmentally superior technology for the generation of electrical and thermal energy for utility, distributed, and on-site applications; and (2) seeks to strengthen the national economy by providing technologies that improve U.S. international competitiveness in this new manufacturing industry, and by generating export sales for technology and products. Specific projected outputs are:

- Near-term (to year 2000) - demonstration and commercial introduction of high efficiency, gas-fueled, multi-kilowatt, on-site power plants and low MW electric utility power plants at competitive costs;

- Mid-term (to year 2010) - significant penetration of all markets for high efficiency gas-based systems, and commercial introduction of fuel flexible, multi-MW power plants at competitive costs; and

- Long-term (to year 2030) - commercial availability of advanced, ultra-high efficiency, integrated fuel cell systems.

The DOE program is providing support toward the development, integration, scaleup, and commercial scale demonstration of molten carbonate and solid oxide fuel cell power plants with increasing levels of private sector cost sharing. In addition, the program facilitates technology transfer to the private sector by stimulating interactions between manufacturers and potential users. Activities also continue involving basic and applied research on materials, processes, and components applicable to fuel cell systems in order to achieve steady progress in improving these technologies.

DOE also conducts analyses of domestic and global markets to identify hurdles to commercializing fuel cells and generate strategies to overcome those hurdles. Specific focus areas of the domestic analyses include prediction of market responses to the introduction of fuel cells, inclusion of environmental attributes and other externalities in integrated resource planning, and the effect of electric utility restructuring on fuel cell commercialization. Analyses of global markets lead to better understanding of markets and market timing for specific fuel cell systems. Results are presented in workshops and forums with the participation of industry as well as regional, state, and federal government representatives. These interactions foster more informed deliberations regarding environmental and other regulatory decisions as well as private sector decisions regarding commercialization activities.

FY 1995 Accomplishments

- Completed field test of first 250 kW molten carbonate fuel cell stack

- Completed fabrication tests of 125 kW molten carbonate stacks for installation and operation in a 2 MW molten carbonate power plant field test in FY 1996

- Demonstrated continuing operation of 25 kW solid oxide fuel cell generators and demonstrated solid oxide laboratory cell life over 62,000 hours (150% of life goal)

- Initiated market analyses and participated in forums, public hearings, workshops and other meetings to accelerate commercialization of fuel cells and encourage policy and regulatory decisions with sound scientific basis and desirable economic results

Planned Activities

- Field test demonstration of a 2 MW molten carbonate fuel cell power plant fueled by natural gas on a municipal utility grid (installation in FY 1995, begin operation in FY 1996)

- Field test demonstration of a 250 kW molten carbonate co-generation integrated power plant (complete installation and begin operation in FY 1996)

- Implementation of rebate program (funded through Defense Department) for stimulating application of fuel cells

- Field test demonstration of a 100 kW solid oxide fuel cell power plant fueled by natural gas (install in FY 1996 and begin operation in FY 1997)

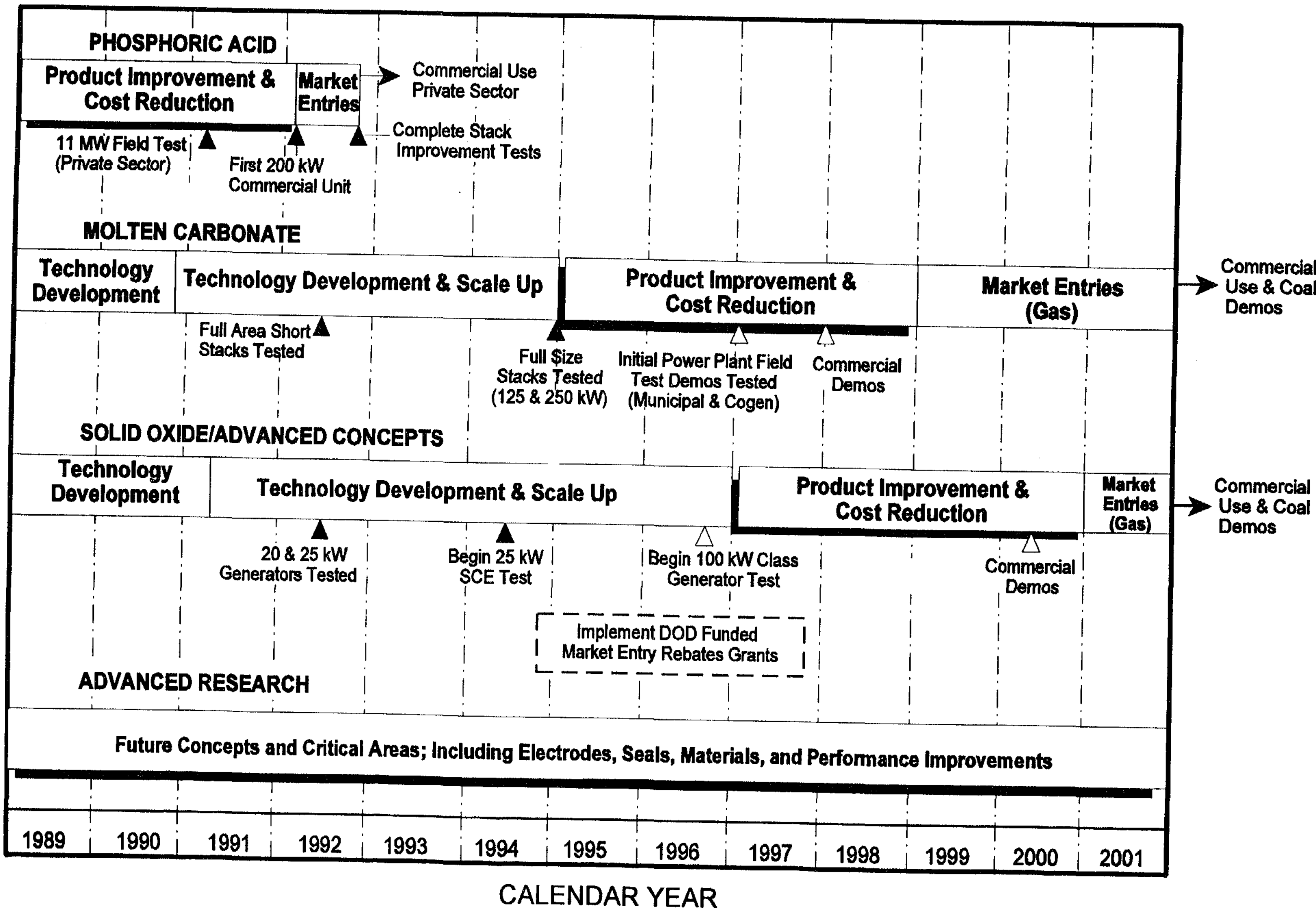
- Initial commercial production of natural gas-fueled molten carbonate fuel cell power plants (FY 1999)

- Phase I study on commercialization opportunities and hurdles for advanced fuel cells (end of FY 1996)

- Regional forums on development and commercialization opportunities involving fuel cell power plants (several during FY 1996)

Major planned program activities are shown in Exhibit 5. These activities are, of course, subject to the availability of resources and the degree of technical progress realized.

EXHIBIT 5
FUEL CELL PROGRAM ACTIVITIES



Program Funding

Program funding is shown in the following table ($ in millions).

Projects	*FY 1994*	*FY 1995*	*FY 1996*
Solid Oxide Fuel Cell	17.8	18.1	13.1
Molten Carbonate Fuel Cell	31.9	30.0	38.1
Advanced Research	1.4	1.5	1.3
Total DOE, Office of Fossil Energy, Fuel Cell Program	**51.1**	**49.6**	**52.5**

Most of the funded activities involve cost-shared contracts with private industry interested in commercializing these power plants. Cost sharing sources include the fuel cell developers, gas utility companies, the Gas Research Institute, electric utility companies, and the Electric Power Research Institute. Some supporting research is also performed by the DOE National Laboratories.

Cost-Sharing

Cost-sharing in major activities ranged from approximately 30 percent to over 50 percent in FY 1995.

The DOE Fossil Energy program is coordinated with GRI, EPRI and the Department of Defense fuel cell programs through a joint fuel cell steering committee, a memorandum of understanding and periodic meetings and frequent informal communication. The GRI and EPRI programs emphasize application to gas and electric utility industries and provide synergistic support of the DOE program. Considerable synergism also exists with the Department of Defense fuel cell program which focuses on operation on liquid fuels compatible with the Defense mission.

VI

COORDINATED FUEL CELL PROGRAM INTERACTIONS

The natural gas fuel cell power generation program interacts with other programs within the Department of Energy's Office of Fossil Energy, Office of Energy Efficiency, Office of Energy Research, and Office of Policy. Coordination and significant cost sharing on development efforts is conducted on projects involving the Department of Defense, the Gas Research Institute, the Electric Power Research Institute, and gas and electric utilities as well as the companies developing the fuel cell technologies and other private, state and local interests. The following paragraphs provide brief summaries of some of these activities.

- The Office of Fossil Energy manages R&D programs to develop, scaleup, and demonstrate fuel cell technologies applicable to stationary, on-site, and distributed power plants and cogeneration in industrial, commercial, and residential applications. The primary focus of the work is to develop advanced high efficiency, low pollution fuel cell power generation technologies for increased effective use of natural gas and to overcome technical, market, and regulatory obstacles to private sector adoption and deployment.

  Different fuel cell types are being considered for a range of power generation applications. Phosphoric Acid Fuel Cells (PAFCs) are being commercialized by industry primarily for on-site (including cogeneration) power applications.

Advanced natural gas-based fuel cells (molten carbonate and solid oxide) are being developed for on-site, industrial and distributed power applications by the year 2000. For the longer term, development of larger systems to serve central power plant applications is planned for completion by 2010.

- Fuel Cells in Transportation (Office of Energy Efficiency and Renewable Energy): These programs are focused on systems with considerably different performance and cost targets but provide information applicable to some aspects of fuel cells operating on natural gas for stationary uses. This effort has been focused on development of proton exchange membrane fuel cell technology for automotive use and adapting phosphoric acid fuel cell technology to bus applications.

- Gas Stream Cleanup Program (Office of Fossil Energy/Coal): This program is primarily targeted at cleaning hot gas streams in coal-fired gasification and combustion systems. Some results of the program may have application to natural gas systems as well as to operation with gasified coal.

- The Department of Defense initiated a program in FY 1993 (continued in FY 1994) for the purchase and use of market entry fuel cell power plants at sites located on defense bases. This effort was followed in FY 1995 with a Department of Defense funded, Department of Energy implemented initiative to provide rebates to purchasers for up to one-third of the purchase costs of market entry units with use in defense applications to have preference. Interest by potential purchasers from the private sector has been strong. The first and second phases of rebates are scheduled to be completed by the end of FY 1996 and end of FY 1997 respectively. The Department of Defense is also funding modification of fuel cell power plant technology for defense applications emphasizing durability and operation on logistic diesel and jet fuels. This development activity is being conducted by the Defense Advanced Research Project Agency of the Department of Defense. The Department of Energy maintains close coordination with these activities and is providing support in implementing the rebate grant initiative as well as sharing some fuel cell test hardware involved in the technology modification activities. Total funding of $18.7 million was appropriated in FY 1996 for these Defense Department programs.

- The Gas Research Institute fuel cell program is directed toward on-site cogeneration and electric utility distributed power generation equipment fueled with natural gas. With the introduction of a 200 kW phosphoric acid fuel cell power plant in 1992, GRI's program emphasis has shifted from the development of phosphoric acid fuel cells to supporting the development of more advanced molten carbonate and solid oxide fuel cell technologies while maintaining some monitoring activity in the performance of phosphoric acid fuel cell units. GRI's interest in fuel cell technology spans the marketplace from small commercial (30 kW to 100 kW) to industrial (500 kW to 40 MW) to electric utility applications (1 MW to 20 MW). The GRI budget for fuel cells in FY 1995 was approximately $3.6 million and FY 1996 funding of $2.7 million is planned. The objectives of the GRI program over the next 5 years are to: demonstrate the operation of a 250 kW packaged molten carbonate fuel cell system; identify and assess alternate materials and processing techniques for solid oxide fuel cell components with emphasis on reducing solid oxide fuel cell operating temperatures; and assist with phosphoric acid fuel cell system deployment efforts.

- The Electric Power Research Institute fuel cell program is focused to develop and commercialize electric power plants with the highest possible efficiency and least environmental intrusion. With regard to natural gas fed fuel cells, small modular distributed generators in the 1 MW to 10 MW size range are being developed with the expectation that as capital costs are reduced, these fuel cell systems can be adapted to central power generation applications. Towards these goals, the near-term EPRI projects are aimed at assisting utilities which are considering the deployment of fuel cells by documenting fuel cell demonstrations in collaboration with utility companies, and where necessary, by developing lower-cost components and resolving systems integration problems in collaboration with DOE or GRI sponsored R&D. The EPRI budget for fuel cells in FY 1995 was approximately $7.7 million and $4.9M in FY 1996 is planned involving co-funding by EPRI and member utilities. The major objectives of the next five year period are to: complete technical and economic evaluation of the 1 MW and 11 MW phosphoric acid fuel cell power plants being demonstrated overseas; initiate utility demonstrations of 250 kW and 2 MW molten carbonate fuel cell power plants in distributed power generation applications, stimulate fuel cell commercialization programs with member utilities; define approaches and risks to the development of yet more efficient fuel cell power plants; and develop molten carbonate and solid oxide fuel cell technology applicable for central station utility power plants in the late 1990s.

VII

FUEL CELL ACTIVITIES OUTSIDE THE UNITED STATES

Fuel Cell development activities are being actively pursued in a large number of countries. Some of the major programs are being conducted in Canada, European countries and Japan. A sense of some of these activities is given below.

Canada

The Canadian government is providing significant R&D support focused on polymer fuel cell technology and system development at Ballard Power Systems. This technology is generally considered the leading polymer fuel cell technology in the world today. Intended applications include transportation, submarine and other defense uses, portable and stationary domestic applications.

European Countries

A number of very significant efforts are being focused on development of molten carbonate, solid oxide, and polymer electrolyte fuel cells within the European Commission and within individual countries in Europe. Several countries are also participating in demonstrations and marketing activities involving phosphoric acid fuel cell systems. Research funded by the European Commission is conducted through contracts with industry within its member countries. Funding by the European Commission does not normally exceed 50 percent of the cost of an individual project. Some particular areas of activity are noted below.

- Molten carbonate fuel cell development has been emphasized in the program of the Netherlands. A number of efforts on developing balance of plant for molten carbonate systems are proceeding in other countries with plans to utilize cell technology being developed elsewhere. Developers in Germany, Italy, and Denmark are among those active in these systems engineering activities.

- Solid oxide fuel cell technology development is being pursued vigorously in many of the European countries. Some of the more active developers are located in Germany, Denmark, Switzerland, Norway and the United Kingdom.

- Polymer electrolyte fuel cells are being developed for transportation as well as other applications in European countries. Some of the major programs reported at the cell and system levels are by developers in the United Kingdom, Germany, Italy and the Netherlands. Laboratory evaluation programs are also being conducted in a number of other countries. Research on direct methanol fueled systems is also being conducted.

Japan

In Japan, there are large and well organized fuel cell development programs with funding by the government and private sector. A large number of firms are actively pursuing the development of each major type of fuel cell. Government funding has been provided under the New Sunshine Program through the Ministry of International Trade and Industry's (MITI's) Agency of Industrial Science and Technology (AIST), with the majority of this funding going to industry through MITI's New Energy and Industrial Technology Development Organization (NEDO) with the remaining funds going directly to government research institutes. The Japanese government is also actively supporting fuel cell commercialization, in large part to lower manufacturing costs for fuel cells and lay a foundation for future fuel cell use according to articles in the Japanese press. The Ministry of International Trade and Industry (MITI) projects that Japan will have an installed fuel cell capacity of 200 MW by the year 2000 and 2200 MW by the year 2010.

Russia

The Russian effort slowed with the end of the Soviet Union. However, interest in fuel cell development is being renewed with a view to building fuel cell systems that could utilize Russia's large natural gas resources.

South Korea

Following prior efforts aimed at developing fuel reformers and coupling them with imported fuel cell stacks, South Korea is proceeding to establish a national program with a goal of developing a 40 kW phosphoric acid fuel cell unit.

MAJOR 1995 EVENTS REPORTED AND PLANNED 1996 EVENTS

Phosphoric Acid Systems:

Operational experience with phosphoric acid fuel cells is continuing throughout Asia and Europe with the early market entry 50 and 200 kilowatt units from manufacturers in Japan and the United States.

Installed operating capacity in Europe is reported to be approximately 4 MW. Countries in Europe with the most installed capacity are Italy and Germany, however eleven countries are reported to have demonstration units. Most of these units are 50 and 200 kW cogeneration units, but a 1.3 MW power plant containing cell stacks from IFC is installed in Italy. Some of the test units involve reformers and other system components which have been supplied by companies in Europe.

Commercialization activities have also increased in Japan. The gas industry has over 60 units (including 25 units with partial funding by MITI) in operation. These are atmospheric pressure units ranging in size from 50 kW to 1 MW. The installed capacity of these units in 1995 was 9.7 MW. Electric power companies had an installed capacity of 18.75 MW in 1995 with over 20 units operating in the size range of 50 kW to 11 MW.

An earlier field test project in Japan continues to acquire operation and maintenance records on a group of phosphoric acid fuel cell systems installed between 1992 and 1994. Twenty seven units are being monitored in the project with sizes ranging from 50 to 500 kW and a total capacity of 4.05 MW.

Two new phosphoric acid fuel cell demonstrations (a 1 MW and 5 MW unit) started operation in Japan in 1995. These are described further below.

A 1 MW phosphoric acid unpressurized plant began operating in May of 1995 at Tokyo Gas Company Fundamental Technology Research Institute. This unit was built by Toshiba Corporation and is intended for on-site cogeneration installations within buildings. Design targets include an electrical generating efficiency above 36% (HHV) and co-generation efficiency above 72%. The unit provides steam at 170 C for adsorption chiller air conditioning.

A 5 MW phosphoric acid pressurized plant began operating in April of 1995 at Amagasaki Technoland of Kansai Electric Power Company. The unit was built by Fuji Electric Co. and is intended for application to urban energy centers. Design targets include: electrical generating efficiency above 42% (HHV); steam at 170 C and hot water at 80 C; high temperature off gas at approximately 6 atmospheres pressure for a gas turbine.

Molten Carbonate Systems:

In Europe, the most ambitious carbonate fuel cell programs are in The Netherlands, Germany and Italy. These programs have been developing cell and system technology and are now scaling up for 50 kW to 250 kW system demonstrations. A major focus of these programs has been to develop cell technologies capable of adequate operating lifetime of 40,000 hours. Field trials of complete systems have been scheduled as early as 1998.

Of the 2000 MW of fuel cells projected by MITI to be installed in Japan by 2010, about 50% are projected to be MCFC. After 2010, MCFC is projected to be the main utility fuel cell power generation system in Japan.

Fabrication of a 1 MW molten carbonate pilot plant has begun in Japan with operation tests scheduled for completion by fiscal 1997 at the Chuba Electric Power Company's Kawajoe Thermal Power Station, Saitama Prefecture. The pilot plant contains 4 fuel cell units utilizing external reformation and rated at 250 kW each. Two units are cross flow design and 2 utilize parallel flow design in the stacks. IHI and Hitachi are each supplying two of the stacks. Plant design is a joint endeavor of the MCFC Research Association, IHI and Hitachi. Design of the reformer subsystem is being done by Hitachi. Target electrical generating efficiency is 45%. This pilot plant follows earlier tests of 100 kW class stacks built by Hitachi Ltd., and Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI), as well as tests of a 30 kW internal reforming stack (for 13,434 hours, producing 315,035 kWh) built by Mitsubishi Electric Corporation. Test of a Mitsubishi 200 kW unit with internal reforming and cell area of 1 square meter is scheduled for 1997.

Solid Oxide Systems:

Continued development of solid oxide technology for applicability to large and small scale power plants has been continuing and accelerating in Europe and Japan.

In Europe, there are ambitious solid oxide development programs reported in Germany, Switzerland and Norway. A number of other countries also have significant solid oxide research programs and are participating in supplying balance of plant components for solid oxide systems.

In Japan, the NEDO program completed the current phase of development of two types of solid oxide cell stacks with testing at the 500 Watt to 1 kW levels in 1995. Beginning in 1996, several 10 kW planar types are to be developed for demonstration in fiscal 1997. Prior basic research activities tested four planar cell types and one tubular cell configuration.

Polymer Electrolyte Systems:

Developed of polymer electrolyte fuel cell systems is being pursued aggressively in Canada, Japan and a number or European countries for transportation and other applications. These programs have been aimed at enabling low emission vehicles with range capabilities exceeding those available with battery powered vehicles. Some full scale stacks of approximately 50 kW (for automobiles) have been operated. Major challenges remain at the system level in satisfying the fuel reforming and transient operation requirements. The cost targets for an automotive application remain a formidable hurdle.

Canada has focused their fuel cell program almost exclusively on polymer electrolyte system development with Ballard Power Systems. Ballard is reported to have a number of collaboration agreements in place with companies in other countries.

Major European development programs are continuing in the United Kingdom, Germany, and Italy and development programs are reportedly being started in other countries. Research on polymer electrolyte technologies is also being conducted at some level in a number of other countries. Progress is also reported in developing direct methanol fueled cells which would eliminate the need for a fuel reformer in the system. These systems are in early stages of development but are considered of particular interest for small size units and for some vehicle applications.

Three types of polymer cell stacks in the 500 Watt to 1000 Watt class have been developed in Japan under a four year program with NEDO (1992 through 1995). The next phase of the program would be development of a 10 kW class stack. It is reported that polymer cell and system technology is also being developed in entirely private sector programs involving the automotive companies with the results proprietary to those companies.

Areas of emphasis for further development cited in literature include understanding life limiting mechanisms and extending life; cost reduction; reducing land area required for power plants; reformers and system integration.

References:

Japan 21st, November, 1995 (several articles)

European Fuel Cells R&D Review, ANL-94/96, Argonne National Laboratories, September 1994