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# Assessment of the Environmental Aspects of the DOE Phosphoric Acid Fuel Cell Program



Herbert L. Lundblad and Ronald R. Cavagrotti  
Government Support Operations  
The Aerospace Corporation

May 1983

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Morgantown Energy Technology Center  
Morgantown, WV 26505  
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## FOREWORD

This report was prepared by The Aerospace Corporation under the direction and sponsorship of the National Aeronautics and Space Administration - Lewis Research Center (NASA-LeRC). The NASA-LeRC effort was funded by the Department of Energy, as a part of the Phosphoric Acid Fuel Cell Program, in accordance with Interagency Agreement No. DE-AI01-80-ET-17081 dated June 30, 1980. Aerospace funding was supplied under NASA Defense Purchase Request No. C-42701 to the Air Force Space Division and processed through the Space Division (AFSC) Contract No. F04701-82-C-0083 under an interagency agreement.

This document was prepared to provide guidance to the Fuel Cell Program Office on environmental aspects of the commercial production and widespread deployment of phosphoric acid fuel cell powerplants. This report is a program document - not a formal environmental assessment. However, the format follows closely that of an environmental assessment document.

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## SUMMARY

The Department of Energy is supporting the private development of phosphoric acid fuel cell (PAFC) power plant systems through its National Fuel Cell Program. This study presents an assessment of the environmental and energy impacts expected to result from the nationwide commercialization of PAFC power plants. These impacts will occur through a wide range of direct and peripheral activities involving the production, installation, and operation of the power plants, and the extraction and processing of various fuel and material resources. Eleven specific commercialization activities are addressed by this study.

Three levels of PAFC penetration into the electric power production market provide the basis for quantifying overall commercialization impacts. It is assumed that PAFC power plant commercialization will not significantly affect the total national demand for electric power, but will rather replace some existing and planned conventional generating capacity. Consequently, the environmental and energy impacts of PAFC manufacture and operation will, in general, replace the manufacturing and operational impacts of other energy technologies and should therefore cause only incremental changes in affected environmental parameters.

Operation of PAFC power plants should produce major national environmental benefits in terms of improved air quality, increased energy conservation, and reduced water consumption and wastewater discharge. Benefits may also accrue from reductions in exposure to high noise levels and reduced land requirements for long distance transmission lines. Solid waste generation will probably be only minimally affected by PAFC commercialization. The production of large numbers of PAFC power plants should not create any large or unusual impacts. Similarly, power plant transportation and installation activities are typical operations and should have no noticeable national impacts. The transportation and distribution of PAFC fuels within urban and suburban areas may increase public exposure to the safety risks of a variety of fuel types.

Based on current and reasonably foreseeable PAFC characteristics and the assumptions made within this study, no environmental or energy impact factor has been identified that would significantly inhibit commercialization of PAFC power plant technology. Overall, the incremental environmental improvements outnumber and outweigh the incremental environmental degradations.



## 1. INTRODUCTION

Phosphoric acid fuel cell (PAFC) power plants are a developing technology for the efficient generation of electric power from hydrocarbon and alcohol fuels. These power plants offer several advantages vis-a-vis other energy conversion systems which make them attractive to both the public and private sectors. These advantages include:

- High energy efficiency;
- Low atmospheric emissions;
- Little or no water usage;
- Low noise and vibration;
- Modular construction with short lead time; and
- Siting flexibility.

Fuel cell technology has now reached a level of maturity where testing under actual field conditions is underway with more field testing planned for the next several years. These field tests are expected to advance fuel cell technology to a development stage suitable for commercial mass production and deployment. The widespread commercialization of PAFC power plants will require the construction and operation of numerous PAFC power plants and major power plant production and fuel delivery infrastructures. These commercialization activities will alter the type and magnitude of environmental impacts caused by the production and operation of conventional generating equipment. Based on current and foreseeable fuel cell technology, this document describes the likely facets of a national PAFC commercial system and assesses the beneficial and adverse environmental impacts produced by the system.

### 1.1 The National Fuel Cell Program

The Department of Energy (DOE) is supporting the development of PAFC power plant systems through its National Fuel Cell Program. A goal of this program is to realize the potential that PAFC technology holds for reducing oil and natural gas use in the United States. This reduction of primary fuel use can be achieved in the near term by PAFC high energy efficiency and over the long term by the increased use of coal, coal-derived fuels, unconventional hydrocarbons, and alcohols in fuel cell systems capable of providing clean and efficient energy conversion and cogenerated heat at reasonable costs. The rationale underlying DOE interest in and support of PAFC technology is based upon this long term fuel use flexibility and the potential fuel cells offer as environmentally benign and efficient conversion systems.

The National Fuel Cell Program supports development of PAFC power plants for a variety of applications. Multi-megawatt power systems are under development for electric utility and large industrial applications while multi-kilowatt power systems are being developed for residential, commercial, and small industrial applications.

Program objectives are to develop reliable prototype PAFC power plant systems in both multi-megawatt and multi-kilowatt power sizes that will meet national goals to conserve energy, reduce energy costs, and preserve the environment. The program seeks to achieve these objectives through support of competitive fuel cell technology development in the private sector.

Fuel cell development support is also being provided by nongovernment sources. The Electric Power Research Institute and the Gas Research Institute have programs promoting the development and demonstration of fuel cell technology. Gas and electric utilities have banded together to form fuel cell users groups that provide consultation, funding, and demonstration opportunities. These nongovernment support activities are coordinated with those of DOE to maximize development progress.

## 1.2 PAFC Technology

A fuel cell is an electrochemical energy conversion device that can continuously transform the chemical energy of a fuel and oxidant directly into electrical energy. It produces useful heat as a byproduct. Unlike a battery, a fuel cell does not run down or require recharging; it will operate as long as both fuel and oxidant are supplied to the electrodes and an adequate level of electrolyte is maintained. The electrodes act as catalytic reaction sites where the electrochemical transformation of fuel and oxidant occurs producing direct current electricity. Because the fuel cell is able to achieve a direct conversion of the fuel's chemical energy into electrical energy, the Carnot cycle efficiency limitation based on the difference in temperature does not apply. The fuel cell can therefore yield a higher fuel to electrical energy conversion efficiency than conventional energy conversion devices operating at comparable temperatures.

A fuel cell consists of a positive electrode (cathode) and a negative electrode (anode) separated by an electrolyte which transmits ions but not electrons. Phosphoric acid is used as the electrolyte in PAFC power plants. Hydrogen is supplied to the anode and oxygen is supplied to the cathode. In fuel cell power plants for terrestrial use, the hydrogen is derived from hydrogen-containing fuels and air is used as the oxygen source. A catalyst on the porous anode facilitates the hydrogen molecules in the fuel to dissociate into hydrogen ions and electrons. In the acidic electrolyte, the hydrogen ions migrate through the electrolyte to the cathode and the electrons flow from the anode to the cathode through an external circuit when the electrodes are connected by an electrical conductor. Hydrogen ions, electrons, and oxygen react at the cathode to form water. Heat is a byproduct of this process. A single cell produces 0.5-1.0 volts direct current (dc) at a current that is proportional to the cell area. Individual cells are connected in series so that a fuel cell stack can be constructed with an output voltage compatible with the application.

If a fuel cell power plant is to be a useful generator of electricity, it must be able to use the types of fuels that are economically available and it must produce an alternating current compatible with customer needs. Therefore, a fuel cell power plant must include not only the fuel cells that produce direct current electricity, but also a fuel processor and a power conditioner. The fuel processor converts a

hydrocarbon or alcohol fuel into a hydrogen-rich gas usable by the fuel cells. The fuel processor also removes impurities in fuel that are damaging to the catalysts in the fuel cells. Because fuels have considerable variability in their chemical and heat content, the fuel processor must be tailored to the particular fuel that the power plant will be using. The power conditioner converts the direct current electricity produced by the fuel cells into alternating current electricity compatible with the utility grid and usable by utility customers. The power conditioner also regulates voltage, harmonic distortion, and other power output variables.

A fourth basic power plant subsystem is thermal management. This subsystem controls the temperature of the fuel cell stack by removing waste heat produced during the fuel cell chemical reactions. This waste heat is in the form of steam and hot water and can be made available for heating, cooling, and other uses.

All PAFC power plant designs include these four basic subsystems (fuel cell stack, fuel processor, power conditioner, and thermal management); however, considerable variation exists in subsystem design between DOE-supported fuel cell developers. These competitive design variations are encouraged by DOE since they test design options and advance fuel cell technology. Primary differences exist in all power plant subsystems including the fuel cell, the fuel processor, the power conditioner, and the thermal and acid management subsystems.

### 1.3 Background of Fuel Cell Development

The fuel cell concept was invented in 1839 by Sir William Grove. It was not until the early 1960s, however, that fuel cell application development began with their use as power suppliers for the Gemini and Apollo spacecrafts. These spacecraft fuel cells were developed for unique applications. The fuel cells under current development for terrestrial use will be available in assemblies thousands of times larger than the ones carried by spacecrafts.

Fuel cell development activity increased following the early spacecraft applications as private companies attempted to adapt the fuel cell to such terrestrial applications as automobiles and central power stations. More than 50 American companies were investigating fuel cells by the mid-1960s. Activity slowed as it became apparent that a substantial amount of research and development work would be required to perfect fuel cells for terrestrial applications. Fuel cell development efforts had dwindled by 1968, and from then until the mid-1970s, development funds came primarily from electric and gas utilities, fuel cell manufacturers, and the U.S. Army.

During the 1970s, the federal government increasingly recognized the fuel cell as an attractive energy technology for mitigating the nation's energy and environmental problems. DOE support was provided to three competing fuel cell developers to ensure continued advancement and to spur competition and innovation. While government funding supported a large share of the private development work, government research activities paralleled private efforts in order to speed development. Substantial funding was also provided by gas and electric utilities and their research organizations. The three government-supported fuel cell developers have preprototype power plants that are either currently available for field testing or will be available in the future as indicated by Table 2-3.

Although DOE is not funding the commercialization of PAFC power plants for nationwide deployment, it is funding fuel cell development to a point where the energy efficiency and environmental impact traits can be fairly and accurately evaluated. DOE recognizes, however, that its fuel cell research and support actions are vital to continued private fuel cell development and that the commercialization of fuel cell power plants may be an outgrowth of these actions.

Consequently, DOE has requested preparation of this document to evaluate the possible environmental impacts that may arise as a result of the commercial production and widespread deployment of PAFC power plants. In accordance with DOE responsibility under the National Environmental Policy Act, separate environmental assessments have already been prepared for two DOE-sponsored fuel cell power plant field tests. The first of these field tests is currently operating a 4.8 megawatt PAFC power plant in New York City (Ref. 1.1)\* and the second will site up to fifty-one 40 kilowatt PAFC power plants at a variety of residential, commercial, and small industrial locations nationwide (Ref. 1.2).

This environmental assessment addresses the environmental impacts that can be reasonably foreseen from the commercialization of phosphoric acid fuel cell power plants. Its scope is limited to phosphoric acid fuel cell technology. The impact analyses and conclusions presented by this environmental assessment are based on current knowledge and projections of commercialization factors. Uncertainty surrounding the future direction of such factors as technology development, economics, market penetration, and fuel availability limits the validity of assessment assumptions and hence the accuracy of its analyses and conclusions.

Section 2 of this environmental assessment is a detailed description of DOE's National Fuel Cell Program including organization, participants, project status, and schedules. Section 3 is a review of fuel cell technology and highlights the technical progress and innovations of the various development efforts. The national energy and environmental setting in which PAFC power plants will be operating is explained in Section 4. Section 5 describes the components of a national PAFC deployment system and evaluates their environmental impacts. Environmental impacts are further evaluated in Section 6 which discusses the effects of altering PAFC technology and deployment variables. Section 7 relates program consistency and compliance with applicable federal, state, and local policies and regulations. Section 8 is a summary and conclusion of expected environmental impacts and provides recommendations for impact mitigating actions. Energy technology alternatives to PAFC development and commercialization are described in the Appendix and their environmental and energy attributes are compared to those of PAFC power plants.

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\* In this document applicable reference lists are placed at the end of each section.

## SECTION 1 REFERENCES

- 1.1 Department of Energy, Environmental Assessment - 4.8 MWe Fuel Cell Demonstration Plant, DOE/EA-0009, January 1978.
- 1.2 Department of Energy, Environmental Assessment of the 40 Kilowatt Fuel Cell System Field Test Operation, (draft document) December 1981.

## 2. DOE PHOSPHORIC ACID FUEL CELL PROGRAM

A major goal of the Department of Energy Fossil Energy (DOE/FE) Program is to displace oil and natural gas (premium fuels) with alternate fuel sources, particularly coal. A key element in the DOE strategy for achieving this goal is its Coal Technology Strategy Objective to conduct research, technology, and verification of systems which when commercialized by industry will use coal in a more economic, efficient, and environmentally acceptable manner in the 1990s and beyond. The DOE/FE National Fuel Cell Program is consistent with this strategy since fuel cell systems are projected to be capable of operating on synthetic fuels and a variety of other hydrogen-yielding fuel feedstocks. The National Fuel Cell Program is composed of three subset programs: (1) the Phosphoric Acid Fuel Cell Program, (2) the Molten Carbonate Fuel Cell Program, and (3) the Advanced Fuel Cell Program.

The rationale underlying DOE/FE interest in and support of fuel cell technology is based upon its long term fuel use flexibility and the potential fuel cells offered as environmentally benign and efficient energy conversion systems. Accordingly, fuel cells will be capable of being sited in numerous and highly variant locales, including populous areas, with minimal difficulty. Additionally, fuel cells hold the potential for high energy conversion efficiency that exceeds the efficiencies of combustion based technologies, and have other attractive features that are of interest to gas and electric utilities.

### 2.1 Program Goal and Objectives

The overall goal of the Phosphoric Acid Fuel Cell Program is to realize the potential of phosphoric acid fuel cell (PAFC) technology for reducing oil and natural gas use in the United States in an environmentally acceptable manner. The major program objective is to establish, in concert with the activities of other funding organizations and fuel cell manufacturers, a verified technology base upon which the private sector can, at lower risk, develop and commercialize PAFC systems for early entry into U.S. markets. This will support the DOE/FE objective to displace oil and natural gas with alternative fuel sources by supporting development of systems which will: (1) efficiently and cleanly utilize oil and natural gas during the near-term fuel switching transition period; and (2) function in an economic, efficient, and environmentally acceptable manner on synthetic fuels, particularly coal-derived fuels, in the 1990s and beyond.

A second program objective is the establishment of the verified technology base for two distinct size systems. Multi-megawatt size system development will be supported for electric utility and large industrial applications while development of multi-kilowatt size systems, particularly on-site, integrated energy systems (OS/IES), is supported for residential, commercial, and small industrial applications (Ref. 2.1). Accordingly, the Phosphoric Acid Fuel Cell Program is comprised of two subprograms: (1) the Multi-Megawatt Electric Utility Applications Program, and (2) the Multi-Kilowatt OS/IES Program. In summary, the objectives of these programs are to:

- Develop reliable prototype PAFC power plant systems that will meet national goals to conserve energy, reduce costs, and preserve the environment through efficient use of fuels from the most available sources,
- Develop multi-megawatt PAFC power plant systems for electric utility and industrial applications including cogeneration systems,
- Support the technology development of multi-kilowatt PAFC on-site integrated energy systems for residential, commercial, and industrial applications, and
- Foster serious technology development competition among fuel cell manufacturers.

Gas and electric utilities and research organizations that are participating in the Phosphoric Acid Fuel Cell Program have the goal of advancing PAFC technology development toward commercialization. Their program objectives are focused on the commercial aspects of PAFC development and include (Ref. 2.2):

- Technology advancement toward initial large scale production of PAFC power plants;
- Identification and evaluation of possible markets for PAFC power plants;
- Establishment that PAFC operating characteristics are compatible with the needs of these markets; and
- Determination that PAFC power plant costs are competitive with alternative types of electrical generators.

## 2.2 Program History

Although DOE support of fuel cell development began in 1976, the roots of government-supported fuel cell research and development activities extend back to the early days of the space program. During the 1950s and 1960s, the National Aeronautics and Space Administration (NASA) funded development of fuel cell power plants for use in spacecrafts. The U.S. Army recognized fuel cell potential for use as portable generators and began to fund its own development program during the mid-1960s. The NASA fuel cell program was terminated during the late 1960s; however, Army funding continued throughout the 1970s to the present day. The power plants under development for the Army are small, portable units designed to operate on a liquid fuel such as methanol.

Many companies conducted fuel cell research during attempts to adapt fuel cell technology to specific terrestrial applications. Most of these activities ended by 1970 because of technical and financial problems. An exception, however, was a development project sponsored jointly by United Technologies Corporation (UTC) and a consortium of gas and gas-electric utilities without government support.

Starting in 1967, the group supported the development of PAFC power plants for on-site residential and commercial applications. The field testing in 1972 and 1973 of more than 60 of these 12.5 kilowatt power plants led to the development and demonstration of a 40 kilowatt power plant in 1975.

A second nongovernment-funded fuel cell project originated with the electric utility industry in 1971 when a group of utility companies joined the Edison Electric Institute and UTC in an assessment of the potential benefit of fuel cells to the industry. The venture led to an effort sponsored by UTC and nine utility companies to develop a 26 megawatt PAFC power plant for electric utility operation. The project demonstrated a one megawatt pilot plant during 1976 and 1977.

The advent of the energy crisis during the mid-1970s spawned increased government interest in efficient energy technologies. Seeking to expedite the development and application of fuel cell technology, DOE began funding support for various fuel cell projects in 1976. DOE and the Electric Power Research Institute (EPRI) became involved in the UTC-electric utility project and funded the design, construction, and testing of a 4.3 megawatt PAFC power plant. This power plant is scheduled to begin operation on the Consolidated Edison system at the end of 1982. DOE also joined the Gas Research Institute (GRI) in supporting an extension of the UTC 40 kilowatt power plant project. In early 1982, this project began field testing the first of 51 power plants at locations across the country.

In 1977, DOE contracted with the Energy Research Corporation (ERC) for development of a PAFC on-site, integrated energy system (OS/IES). ERC had seven years of PAFC developmental experience with the Army. Westinghouse Electric Corporation (W) joined ERC in 1978 to add system analysis, system design, and marketing capability to ERC's electrochemical technology/engineering background. Since then, DOE has joined EPRI in supporting a W/ERC project to develop a 7.5 megawatt PAFC power plant for electric utility application. Government funding continues for this W/ERC multi-megawatt project; however, government funding has been terminated for the W/ERC OS/IES project.

DOE has also contracted with the Engelhard Minerals and Chemical Corporation to study PAFC applications and to develop fuel cell stack technology. This contract began in 1976. The Engelhard plan is to develop a totally integrated OS/IES which includes the PAFC power plant, the heating, ventilating, and air conditioning subsystem, and energy storage. Engelhard's previous PAFC experience included building fuel cells for an Army lift truck development program and building and marketing laboratory-size demonstration fuel cells.

DOE PAFC technology development funding for the 1982 calendar year will amount to \$11.9 million. This sum includes funding for project contracts and inhouse DOE/NASA project support (Ref. 2.1). The DOE PAFC funding history by fiscal year is as follows: 1977 (\$18.1 million), 1978 (\$29.5 million), 1979 (\$21.1 million), 1980 (\$23.5 million), and 1981 (\$11.0 million). These totals include funding of the UTC 4.8 MW demonstration power plant and the UTC 40 kW power plant field test (Ref. 2.2).



## 2.3 Current Program Status

As previously discussed, the development efforts of three major contractors or contractor teams are being supported by the Phosphoric Acid Fuel Cell Program. Support activities are directed towards two PAFC applications (multi-megawatt for electric utility use and multi-kilowatt for OS/IES use) with two specific development projects supported for each application. These projects are:

- UTC electric utility multi-megawatt power plant system,
- W/ERC electric utility multi-megawatt power plant system,
- UTC multi-kilowatt OS/IES, and
- Engelhard multi-kilowatt OS/IES.

The goal of support activities for these four projects is to conduct technology development towards specific applications and thus each activity is highly focused. The technology features of these development projects are addressed in Section 3. In addition, the following major efforts are being performed by the Phosphoric Acid Fuel Cell Program to support development of fuel cell systems: (1) research and technology efforts to augment and advance the technology base; (2) studies to define technology requirements of major potential applications and associated end-use sectors considering technical, economic, environmental, legal, institutional, and marketing factors; and (3) analyses to define system configurations, and associated system and subsystem performance and cost requirements.

### 2.3.1 Program Organization and Participants

The Phosphoric Acid Fuel Cell Program is under the direction of DOE's Division of Fuel Cells. The Division of Fuel Cells is within the Office of Coal Utilization and Extraction, which is under the Office of the Assistant Secretary for Fossil Energy. DOE has designated the NASA-Lewis Research Center (NASA-LeRC) to be the Lead Center for PAFC technology development. The Lead Center Office at NASA-LeRC is in the Solar and Electrochemistry Division of the Energy Programs Directorate. It operates in accordance with Interagency Agreement No. DE-AI01-80-ET-17088 between DOE and NASA. Management of contract efforts and inhouse analyses, studies, and evaluations is performed by NASA scientific and engineering personnel under the direction and control of the Lead Center Office. The Lead Center Office has two implementing project offices reporting to it: (1) System Support, and (2) System Technology Development. The Lead Center Office has been organized in this structure to effectively and efficiently manage and support the tasks required to develop multi-megawatt and multi-kilowatt power plant systems and the system support activities common to some or all of the developments (Ref. 2.1).

Multi-megawatt PAFC power plant systems for electric utility application are being developed independently by UTC and W/ERC. These development efforts are receiving considerable funding support from DOE and EPRI. In addition, DOE and EPRI are conducting and contracting for parallel PAFC research to advance development. The Electric Utility Fuel Cell Users Group was established to assist PAFC development. This group is composed of interested parties associated with the electric utility industry. It is working with the developers to identify the likely

applications of fuel cells based upon their unique characteristics, to quantify the value of the characteristics, to establish the specification for a cost effective commercial power plant, and to assess the market potential for that power plant. The group will develop an assessment of the PAFC market by aggregating the market penetration estimates of the individual utilities that can identify near to intermediate term penetration opportunities (Ref. 2.3). The users group members are listed in Table 2-1.

Several individual electric utilities are in the vanguard of fuel cell development. Consolidated Edison Company is acting as the host utility for a consortium of electric utilities testing the UTC 4.8 megawatt PAFC power plant in New York City. Southern California Edison (SCE) has requested W/ERC to prepare a program to develop and test a 7.5 MW power plant. Participants in this program presently include W/ERC as the performing organizations, DOE as the major funding organization, and SCE and the City of Santa Clara, California, as the participating utilities. W/ERC is providing all facilities for manufacturing fuel cell stacks, fuel cell test facilities, and some advanced component research work. The electric utilities have been providing information on their requirements and have been supporting initial design and planning activities (Ref. 2.1).

Multi-kilowatt PAFC power plant systems for on-site application are being developed independently by UTC and Engelhard. DOE is providing funding support for these development efforts. DOE and GRI are funding a parallel technology advancement program aimed at reducing the costs and improving the reliability and durability of on-site PAFC power plants. The On-Site Fuel Cell Users Group, composed of interested gas, electric, and gas-electric utilities, was established to assist the development of PAFC power plants for on-site applications. This group is coordinating with fuel cell developers in order to match power plant design and operational characteristics with the needs of the utilities.

The overall responsibilities and organization of the 40 kilowatt PAFC Field Test are detailed by a DOE/GRI Project Agreement (Ref. 2.4). This agreement established the Field Test Steering Committee (FTSC) which is composed of one GRI member and one NASA member. The FTSC is responsible for the conduct and coordination of field test activities. The field test is funded by DOE, GRI, and participating utilities. The utilities scheduled for participation in the field test are listed in Table 2-2. Business assessments prepared by each participating utility will examine and define the potential market penetrations for on-site PAFC energy service. UTC will fabricate the power plants for the field test (Ref. 2.5).

The Director of the DOE Fuel Cell Division serves as chairman of the National Fuel Cell Coordinating Group. This ad hoc group provides a forum for coordinating and orienting fuel cell programs in the United States. Representatives from the following not-for-profit funding entities serve as members: DOE, NASA, EPRI, GRI, Tennessee Valley Authority, Environmental Protection Agency, and the Department of Defense (Ref. 2.2).

### 2.3.2 PAFC Development Projects

The Phosphoric Acid Fuel Cell Program is supporting development of PAFC power plant systems for multi-megawatt electric utility applications and multi-kilowatt

**Table 2-1. Electric Utility Fuel Cell User Group Members (Ref. 2.2)**

Adam Electric Cooperative	Massachusetts Municipal Wholesale Electric Co.
Allegheny Electric Cooperative	Memphis Light, Gas and Water
Alpena Power Company	Mississippi Power & Light Co.
American Public Power Assn.	Missouri Basin Municipal Power Agency
Anchorage Municipal Light & Power	National Rural Electric Cooperative Assn.
Arizona Public Service Co.	Niagara Mohawk Power Corp.
Baltimore Gas & Electric Co.	Northeast Utilities Service Co.
Basin Electric Power Cooperative	Ohio Edison Co.
Boston Edison Co.	Ontario Hydro
Brazos Electric Power Cooperative	Philadelphia Electric Co.
Buckeye Power Co.	Provo City Power
Central Hudson Gas & Electric Corp.	Public Service Company of Oklahoma
Central Illinois Light Co.	Public Service Electric & Gas Co.
Colorado Ute Electric Assn., Inc.	Rural Electrification Administration
Commonwealth Edison Co.	San Diego Gas & Electric Co.
Consolidated Edison Co.	Santa Clara Electric Dept.
Dayton Power & Light Co.	Seminole Electric Cooperative
Delmarva Power & Light Co.	Southern California Edison Co.
Easton Utilities Commission	Southern Company Services, Inc.
Edison Electric Institute	Southern Maryland Electric Cooperative
Electric Power Research Institute	Tacoma Dept of Public Utilities
Green Mountain Power Corp.	Tampa Electric Co.
Hoosier Energy Division, Rural Electric Cooperative	Taunton Municipal Lighting Plant
Hydro-Quebec	Tennessee Valley Authority
Idaho Power Co.	Tokyo Electric Co.
Jacksonville Electric Authority	Toledo Edison Co.
Kansas City Power & Light Co.	United Power Assn.
Lee County Electric Cooperative	Virginia Electric Power Co.
Lincoln Electric Cooperative	
Long Island Lighting Co.	

Associate Members

Biltmore Development Co.	Ebasco Business Consulting Services, Inc.
Burns & McDonnell Engineering Co.	Johnson Matthey Research Centre
Burns & Roe, Inc.	NUS Corporation

**Table 2-2. Utilities Participating in the 40 kW Fuel Cell Field Test**

Atlantic Gas Light Co  
Baltimore Gas & Electric Co.  
Brooklyn Union Gas Co.  
Central Hudson Gas & Electric Co.  
Columbia Gas Services Corp.  
Consolidated Edison Co.  
Consumers Power Co.  
Dayton Power & Light Co.  
Florida Power Co.  
Gasco, Inc.  
Georgia Power Co.  
Memphis Light, Gas & Water  
Mountain Fuel Supply Co.  
National Fuel Distribution Co.  
Northeast Utilities  
Northern Natural Gas Co.  
Northwest National Gas Co.  
Pacific Gas & Electric Co.  
Public Services Electric & Gas Co.  
San Diego Gas & Electric Co.  
Southern California Gas Co.

on-site applications. Two competing development projects are being funded for each application: Multi-megawatt projects by UTC and W/ERC and multi-kilowatt projects by UTC and Engelhard Industries. As discussed in Section 3, each fuel cell manufacturer is using substantially different design approaches and unique technological features including electrodes, matrices, intercell cooling, electrolyte management, fuel selection, and system design philosophy. Each development program may proceed through some or all of the following intermediate development stages (Ref. 2.1):

- **Breadboard** - An assembly of components and subsystems used to prove the feasibility of a fuel cell system design, without regard to the final configuration or packaging of the parts.

- Preprototype - A fuel cell power plant configured and packaged to demonstrate operational feasibility. This power plant does not meet the cost and performance requirements of a prototype system. Although it is not commercially viable, a preprototype may, in certain instances, be of value in investigating institutional and operational issues.
- Prototype - A fuel cell power plant suitable for complete evaluation of mechanical and electrical form, design, and performance. It is constructed and packaged consistent with cost and performance requirements of the intended application.
- Proof-of-Concept - An OS/IES containing a prototype power plant and the necessary balance-of-system that is configured for a specific field test application.

#### 2.3.2.1 UTC Multi-Megawatt Utility System

This project is a continuation of the Fuel Cell Electric Utility Program initiated in 1971 by UTC, EPRI, and a group of nine utilities to develop PAFC power plants for terrestrial power generation. Two major milestones have been achieved thus far: (1) a 1 MW "breadboard" power plant configuration was tested at UTC in 1977, and (2) a 4.8 MW preprototype power plant has been fabricated and installed for field testing on the Consolidated Edison network. The goal of the current portion of the project is to advance the power plant technology to the preprototype level of development.

The plan is to build upon the current UTC 4.8 MW utility power plant technology and evolve a design which has the efficiency and manufacturing cost characteristics needed to attain prototype development status. The energy conversion efficiency objective is 44 percent at an 8300 Btu/kWh heat rate. Technology development will be required on several of the power plant subsystems to attain these goals. Development efforts are focused on improvements needed to advance the performance and lower the cost of the fuel cell stack, reformer, thermal management subsystem, and control subsystem. The approach is to evaluate materials, configurations, and processes resulting in cost effective hardware capable of operation at the higher operating temperature and pressure. The evaluation was initiated on laboratory-size samples and has now progressed to the process development of full-size hardware for individual testing and verification.

Design of the UTC prototype power plant continues and includes plans for an 11 MW power plant module. The plan philosophy with respect to fuel is that the power plant must be designed to operate on available fuels, which in the near term will continue to be naphtha and natural gas. In addition, however, the power plant must have the capability to handle simple coal-derived fuels, such as a medium Btu gas (Ref. 2.1).

#### 2.3.2.2 W/ERC Multi-Megawatt Utility System

The project plan is to build a prototype multi-megawatt PAFC power plant based upon technology previously developed during the W/ERC multi-kilowatt on-site

power plant project. The prototype power plant will use existing technology and new developments that can be thoroughly proven in the near term. The resulting power plant may not be optimized in terms of heat rate, capital cost, and operations and maintenance costs, but it will demonstrate the viability of W/ERC technology and should satisfy the initial requirements of selected electric utilities. W/ERC can then proceed to the next phase in which power plants can be sold to utilities whose requirements match the fuel cell system specifications. Each succeeding generation will incorporate technology advances to further optimize the power plant. The overall project goal is to develop a fuel cell system with a heat rate of 8000-9000 Btu/kWh for a basic size of 7.5 MW (Ref. 2.1).

The project is currently at the system definition and subsystem development phase. Technology activities will initially focus on the fuel cell stack, fuel processor, and power conditioner. Work is in progress to test the novel W/ERC air-cooled systems and components from the on-site program at the elevated pressures and temperatures characteristic of electric utility operating conditions. Conceptual power plant design studies have been completed and tradeoff studies of the possible fuels for use in initial power plants are underway (Ref. 2.1).

DOE will fund the majority of the technology development activities. This will be about 40 percent of the needed funding for the 7.5 MW power plant. W/ERC is responsible for providing or obtaining the remaining 60 percent of the required funding (Ref. 2.1).

### 2.3.2.3 UTC Multi-Kilowatt OS/IES

The UTC multi-kilowatt OS/IES project is a continuation of the UTC/gas utility program that developed a pilot 40 kW power plant. Its accomplishments include technological advancements in upgrading the pilot plant to a preprototype power plant suitable for OS/IES use. The project plan carries development from the current preprototype stage to a prototype power plant for OS/IES application. The project is composed of technology development and field test activities.

Technology development activities will serve to (1) complete the technology development supporting the field test of the preprototype 40 kW field test power plant, and (2) support the development of a more advanced early entry power plant. The major efforts in technology development will be conducted to lower the cost and increase the reliability of power plant components and subsystems.

The field test power plant has an overall efficiency of 80 percent (assuming full utilization of thermal power); half the energy output is electric and half thermal. Its overall cost is too high to be competitive and there are deficiencies in some components. To overcome these problems, work is being conducted in parallel with the field test to develop a power plant that meets the requirements of a limited production, early entry market. This power plant will be larger (200-400 kW range) than 40 kW to take advantage of economies of scale and may have reduced versatility in order to lower costs (Ref. 2.1).

The UTC OS/IES 40 kW concept has a number of unique technological and system characteristics including fuel cell stack structure, two-phase water cooling, and

broad fuel use flexibility. The 40 kW field test will evaluate these and other features of the preprototype power plant commencing in 1983. Approximately 51 UTC power plants will be installed over a range of attractive early entry applications and geographical areas to acquire data covering power plant performance and representative variations in electrical and thermal load use patterns, energy system configurations, climate, competitive service economics, and institutional, legal, and regulatory matters. The installations are to include a variety of residential, commercial, and light industrial applications. The operating goal for each of the power plants is 8000 hours. The field test will be carried out in two stages to permit incorporation of technological advances into the power plants being tested (Ref. 2.1). The field test is being funded by DOE (27 percent), GRI (56 percent) and the participating utilities (17 percent) (Ref. 2.6).

#### 2.3.2.4 Engelhard Multi-Kilowatt OS/IES

The Engelhard project plan is to develop a totally integrated OS/IES which includes the fuel cell power plant, the heating ventilating and air conditioning subsystem, and energy storage. The power plant fuel is to be methanol. The project has five phases. The first phase is technology base development and major progress has already been achieved in component development. This has included innovative bipolar plate structures, a novel matrix, and advanced electrocatalysts. The second phase of the project is to design a subscale 5 kW power plant. The remaining phases encompass the design, test, and evaluation of a breadboard power plant, a prototype power plant, and a proof-of-concept power plant. The overall plan is to develop a full-size 100 kW system made up of four 25 kW fuel cell stacks, two 50 kW fuel conditioners, and two 50 kW power processors to provide adequate reliability and redundancy (Ref. 2.1).

The subscale 5 kW power plant, including fuel processor, fuel cell stack, and power conditioner, is being assembled, tested and evaluated. The overall 5 kW system goal for electrical power efficiency is 33 percent. Development of power plant component design is continuing as the components are scaled up to breadboard size. The overall breadboard system goal for electrical power efficiency is 36 percent. The design of the prototype power plant is scheduled to start in 1983 (Ref. 2.1).

#### 2.4 Commercialization Timetable

The four DOE-sponsored PAFC projects are at various stages in the development of commercial power plant systems; e.g., marketable systems that are consistent with cost and performance requirements. These projects are striving toward commercial products by designing, fabricating, testing, and evaluating power plant components, subsystems, and systems. Each development project is proceeding in a step-by-step progression through various development stages (Ref. 2.1).

The Phosphoric Acid Fuel Cell Program Lead Center Operating Plan for 1982 (Ref. 2.1) schedules and describes future project development activities. Descriptions of the major development steps for each project accompanied by their estimated scheduling dates have been taken from this Plan and summarized in Table 2-3.

**Table 2-3. Project Development Timetable**

<u>Project</u>	<u>Activity</u>	<u>Date</u>
A.	UTC Multi-Megawatt Utility System	
	o Operate 4.8 MW Demonstration Power Plant	1/83-12/83
	o Complete Final Design of 11 MW Prototype Power Plant	11/83-1/85
	o Deliver First 33 MW Prototype Power Plant	1/85
	o Offer to Construct Twenty 11 MW Commercial Power Plants	1/85
	o Deliver First 11 MW Commercial Power Plant	5/87
B.	W/ERC Multi-Megawatt Utility System	
	o Complete Preliminary Design of 7.5 MW Prototype Power Plant	10/83
	o Complete Final Design of 7.5 MW Prototype Power Plant	10/84
	o Complete Construction of Full Prototype Power Plant	3/86
	o Install and Test Prototype Power Plant	11/86-11/87
	o Make Commercial Offer of 7.5 MW Power Plant	10/88
C.	UTC Multi-Kilowatt OS/IES	
	o Deliver Preprototype 40 kW Power Plants for Field Test	4/83-2/84
	o Operate Field Test	4/83-4/85
	o Develop Final Prototype Design	4/84-9/84
	o Fabricate Prototype Power Plant	4/84-6/84
	o Test Prototype Power Plant	7/84-12/85
D.	Engelhard Multi-Kilowatt OS/IES	
	o Fabricate, Test, and Evaluate Breadboard Power Plant	2/83-10/83
	o Design 100 kW Prototype Power Plant	5/83-10/83
	o Adapt Breadboard Systems to Prototype	8/83-4/84
	o Test and Evaluate Prototype	2/84-7/84
	o Fabricate Proof-of-Concept 100 kW Power Plant	5/84-11/84
	o Field Test and Evaluate Proof-of-Concept Power Plant	10/85-9/86



## 2.5 Other DOE Fuel Cell Programs

DOE sponsorship of fuel cell technology development extends beyond phosphoric acid fuel cells. The DOE Molten Carbonate and Advanced Fuel Cell Programs support development of (1) molten carbonate fuel cell systems, and (2) advanced fuel cell concepts such as solid oxide fuel cell systems. The Argonne National Laboratory is serving as the DOE Lead Center Office for these two programs. Organizations involved in the programs include EPRI, ERC, UTC, and General Electric Company.

Molten carbonate and solid oxide fuel cell systems are viewed as the technology of the future, potentially surpassing the performance of PAFC systems. Molten carbonate technology is at an early stage of development. Cell and stack technology development leading to practical stack configuration is underway. The present program will seek to develop mature technology that will yield commercial power plant configurations during the 1990s. Envisioned applications include large coal-fueled plants for both utility and industrial cogeneration configurations. Solid oxide fuel cell technology is less developed than molten carbonate technology, and like molten carbonate technology, is expected to find future applications in large coal-fueled power plants (Ref. 2.2). Consideration of the environmental impacts resulting from the commercialization of molten carbonate and solid oxide fuel cell technologies is not within the scope of this Environmental Assessment.

## 2.6 Previous Fuel Cell Environmental Assessments

In compliance with the National Environmental Policy Act (NEPA) and DOE implementation guidelines, two Environmental Assessments have been completed for DOE-sponsored PAFC field tests. The first field test involves a 4.8 MW power plant located at a Consolidated Edison site in New York City. The assessment for this field test concluded that the environmental impacts resulting from the installation and operation of this demonstration power plant would be minor (Ref. 2.7). Based on this conclusion, a determination was made that no formal Environmental Impact Statement (EIS) would be required for the field test.

The second DOE-sponsored field test will install and operate up to fifty-one 40 kW PAFC power plants at residential, commercial, and light industrial sites throughout the country. The Environmental Assessment prepared for this field test concluded that field test activities should have no major impacts on environmental quality or health and safety during normal power plant operation (Ref. 2.6).

## SECTION 2 REFERENCES

- 2.1 NASA-Lewis Research Center, Phosphoric Acid Fuel Cell Program Lead Center Operating Plan, January 1982.
- 2.2 Fuel Cell Management Review Task Group, Report of the Fuel Cell Management Review Task Group, Department of Energy, February 1980.

- 2.3 Electric Utility Fuel Cell Users Group, Report of the Systems Planning Subcommittee, March 1981.
- 2.4 Department of Energy and Gas Research Institute, Project Agreement - 40 kW Phosphoric Acid Fuel Cell Field Test, July 20, 1981.
- 2.5 Field Test Steering Committee, Project Plan - 40 kW Phosphoric Acid Fuel Cell Field Test, November 1981.
- 2.6 Department of Energy, Environmental Assessment of the 40 Kilowatt Fuel Cell System Field Test Operation, December 1981.
- 2.7 Department of Energy, Environmental Assessment - 4.8 MWe Fuel Cell Demonstration Plant, DOE/EA-0009, January 1978.

### 3. FUEL CELL TECHNOLOGY

Although Sir William Grove demonstrated the first fuel cell in 1839, few practical applications have evolved in the intervening years. The fuel cell's first roles could hardly have been more exotic; namely, providing electrical power for manned exploration of the oceans and space. To satisfy the requirements of such applications, a NASA-sponsored effort took the fuel cell from the status of a demonstration device to that of a sophisticated source of electrical power. Only recently has it become desirable to develop a commercially viable fuel cell system for more common terrestrial applications. To this end, a concerted federal and private fuel cell development effort is currently underway (Section 2). Although the systems under development are similar in many ways, different technological approaches are being taken for certain key subsystem components. Fuel cell technology is continuing to evolve; consequently, this section's discussion is limited to current fuel cell technology.

#### 3.1 Fuel Cell Power Plant Principles

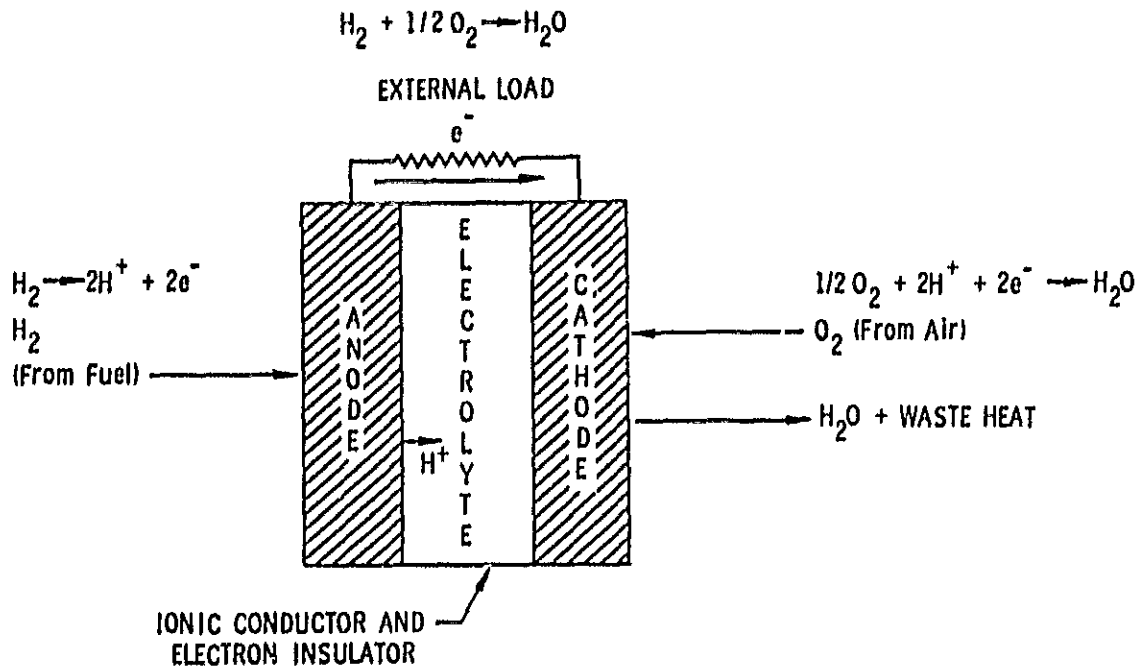
A fuel cell is an electrochemical device that continuously converts the chemical energy of a fuel and an oxidant directly to electrical energy. The fuel cell does not employ a Carnot limited cycle and therefore has intrinsically much higher efficiency than combustion machines. Because their efficiency is unrelated to size, power plants under development range from 1-2 kW to several MW. In contrast to batteries, fuel cells generate power rather than store energy, and continue to do so as long as a fuel supply is maintained; thus recharging is not required.

A simple fuel cell unit operates as illustrated in Figure 3-1. A hydrogen-rich fuel is fed to the anode and an oxidant, usually oxygen from air, is supplied to the cathode. Between the electrode pair is an electrolyte, usually a strong acid or alkali. The electrodes act as reaction sites where the electrochemical transformation of the fuel and oxidant occurs. At the anode, hydrogen molecules ( $H_2$ ) in the fuel are dissociated into hydrogen ions ( $H^+$ ) and electrons. In most fuel cells, a catalyst is used to facilitate this reaction. In an acidic electrolyte, the hydrogen ions migrate through the electrolyte to the cathode, where they react with oxygen to form water ( $H_2O$ ). The electrons from the oxidative half reaction flow from the anode to the cathode through an external circuit. This passage of electrons through the load resistance constitutes work done by the cell in the form of electrical (dc) current. Heat is produced in the fuel cell electrochemical reaction.

Fuel cell electrodes perform a number of functions simultaneously. In addition to carrying current and supporting the catalyst, they act as a barrier to prevent electrolyte escape into the gas compartment and they provide maximum area of interface between reactant gases, electrolyte, and catalyst surface. Electrodes are therefore made porous to allow gas to diffuse to reaction sites, and only a thin film of electrolyte covers the catalyst. Noble metals are the materials of choice as catalysts, due to their high exchange current densities and their resistance to oxidation and dissolution under operating conditions. Although carbon monoxide, a

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Figure 3-1. Components and Chemical Reactions of a Fuel Cell (Ref. 3.2)



byproduct from fuel reforming, can poison the catalyst, this problem can be minimized by operating the fuel cell at temperatures greater than 463 K (190°C) (Ref. 3.1).

The theoretical voltage attainable by a hydrogen-oxygen fuel cell at 298 K (25°C) is 1.229 volts. In practice, single fuel cells produce 0.5-1.0 volt dc depending on the current density. For commercial applications, single cells can be stacked and connected in series to permit generation of hundreds to thousands of volts. At present technology levels, a single fuel cell generates roughly one to two kilowatts of electricity per square meter of electrode area (Ref. 3.3). Connecting a number of single cells in a series/parallel arrangement permits power levels from kilowatts to megawatts.

Fuel cell operation with air requires the use of a nonalkaline electrolyte to avoid carbonation problems from atmospheric carbon dioxide. Acid, molten carbonate, and solid oxide electrolytes all work well with air. Because of its stability in the fuel cell environment, phosphoric acid is the preferred acid electrolyte despite its relatively low conductivity and highly corrosive properties. The selection of phosphoric acid, however, limits the range of operating temperatures from 423-473 K (150-250°C). Below 150°C, phosphoric acid has poor conductivity; above 250°C, the electrode materials become unstable.

Fuel cells based on nonacid electrolytes are also under development. The focus of these efforts is primarily on molten carbonate and solid oxide electrolyte fuel cells for use in both dispersed generation and central station applications. These fuel cell

systems offer higher energy efficiency but their development appears to be about 5-10 years behind phosphoric acid technology. A number of difficult problems (e.g., corrosion, electrolyte instability and electrode sintering) remain to be solved before these technologies reach commercial availability.

Hydrogen is the ideal fuel for use in fuel cells because of its high reactivity. Pure hydrogen, however, is expensive, difficult to handle on a large scale, and not abundantly available. For this reason, commercial fuel cell systems will run on hydrocarbon and alcohol fuels, employing a fuel conditioner to process them into a hydrogen-rich fuel prior to introduction into the fuel cell stack. A partial list of candidate fuels is given in Table 3-1. With light distillates, natural gas or methanol fuel, the fuel conditioner is a catalytic steam reformer of the type used in the petrochemical industry. Heavier liquid fuels can be conditioned in partial oxidizers or in advanced fuel processors presently being investigated. Coal must be processed in a coal gasifier of the same type proposed for use with combined-cycle power plants. It is expected that fuel cells will progress from operating on natural gas and petroleum-derived fuels in the short term to coal-derived products in the intermediate to long term because of availability and cost considerations. In the future perhaps, fuel cell systems may run on hydrogen produced from off-peak nuclear power plants.

Table 3-1. Candidate Source Fuels for Fuel Cells (Ref. 3.4)

<u>Fuel</u>	<u>Source</u>	<u>Composition</u>
Synthesis Gas	Biomass, Coal, Waste	H <sub>2</sub> , CO, and CH <sub>4</sub>
Methane	Coal-bed, Geopressurized, Biomass, Waste, LNG	CH <sub>4</sub>
Methanol	Currently wasted gas, Coal, Biomass	CH <sub>3</sub> OH
Naphtha	Distillation of petroleum	Various Hydrocarbons

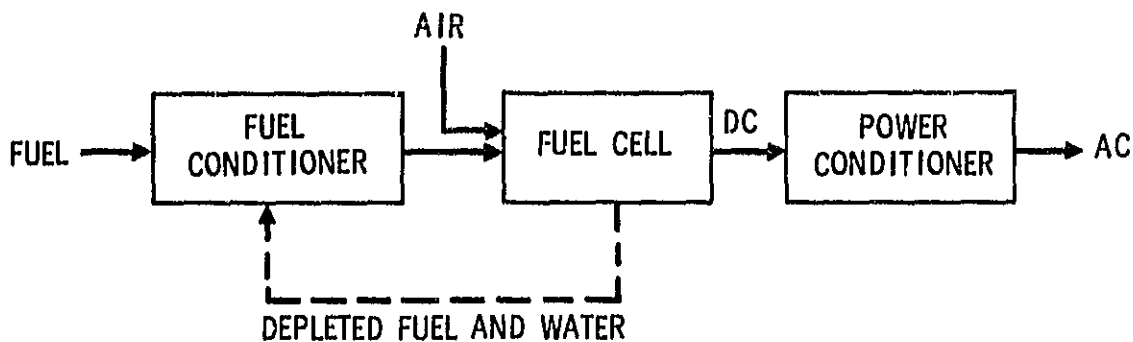
### 3.2 Phosphoric Acid Fuel Cell Development Efforts

Phosphoric acid fuel cell systems are currently under development by three domestic manufacturers sponsored by DOE: United Technologies Corporation (UTC), Westinghouse/Energy Research Corporation (W/ERC), and Engelhard Industries. Many generic technology features are common in all three development programs: (1) a concentrated phosphoric acid electrolyte operating at temperatures up to 478 K (205°C) and pressures ranging from atmospheric to about  $8.3 \times 10^5$  N/m<sup>2</sup> (120 psia); (2) an electrolyte contained within a silicon carbide matrix sandwiched between graphite electrodes; (3) platinum or platinum alloy electrocatalysts in the form of highly dispersed crystallites supported on a carbon substrate; (4) total cell catalyst loading less than 1 mg Pt/cm<sup>2</sup> of electrode geometric area; and (5) cell cooling accomplished by use of a liquid or gas. If a liquid coolant is used, it passes

through the fuel cell stack in isolated tubes and is either heated to an elevated liquid temperature or to a phase change. A gas coolant, usually air, may or may not be confined to isolated tubes when passing through the fuel cell stack.

The complete fuel cell system consists of three basic subsystems which, when integrated, compose the power plant unit (see Figure 3-2). These include: (1) the fuel processor for converting primary fuels into a hydrogen-rich gas; (2) the power section consisting of the stack of fuel cells containing planar electrodes and an electrolyte holding matrix as sandwiched sheets; and (3) a power conditioner for converting the dc electrical output to alternating current (ac) at a suitable voltage. In addition, a thermal management subsystem provides for power plant cooling and, if desired, controls the distribution of thermal energy for customer applications. Significant system and technological differences exist among the fuel cell development programs. These differences, which include intercell cooling, bipolar/separator plate design, electrolyte management, materials, fuel selection, and system design philosophy, are discussed in the following sections and summarized in Table 3-2. Photographs of power plants and power plant components produced by each manufacturer are provided at the end of this section in Figures 3-6 through 3-12.

Figure 3-2. Basic Power Plant Subsystems



### 3.2.1 Fuels and Fuel Processing

If a fuel cell power plant is to be a useful generator of power, it must use the type of fuel that is economically available to the user. This is made possible by the selection and design of fuel processing systems that convert available fuels into a hydrogen-rich gas suitable for fuel cell use. Fuel processing, which entails several steps, requires different technologies for different fuels. The processing requirements for using natural gas in fuel cells are compared below with those for naphtha and methanol fuels. The UTC utility power plant is designed to run on naphtha or

Table 3-2. Projected Characteristics of Early Commercial Power Plant<sup>1</sup> (Ref. 3.5)

	UTC Electric Utility	UTC On-Site	W/ERC Electric Utility	Engelhard On-Site
Rated Electrical Power Output <sup>2</sup>	10 MW	300 kW	7.5 MW	100 kW
Fuel	Natural Gas or Naphtha	Natural Gas	Natural Gas or Naphtha	Methanol
Electrical Efficiency (%)	41	40	40	41
Pressure, N/m <sup>2</sup> x 10 <sup>3</sup> (psia)	690-828 (100-120)	101 (14.7)	414-483 (60-70)	101 (14.7)
Temperature, K (°F)	491 (425)	477 (900)	477 (400)	477 (450)
Acid Addition	Not required	Not required	Required	Required
Cooling Method <sup>3</sup>	Liquid (2 Phase Water)	Liquid (2 Phase Water)	Air	Liquid (Dielectric Fluid)
Heat Recovery	Possible with Minor Modifications	Available	Customer Option	Available
Cell Size, m <sup>2</sup> (ft <sup>2</sup> )	.92 (10)	.34 (3.7)	.12 (1.25)	.18 (2)
Power Density <sup>4</sup> , W/m <sup>2</sup> (W/ft <sup>2</sup> )	1793 (165)	1413 (130)	2500 (230)	978 (90)
Pt Loading <sup>5</sup> , mg/cm <sup>2</sup>	.75	.75	.75	.75
Pt Loading, mg/W	4.22	5.36	3.03	7.74

<sup>1</sup> All characteristics are subject to change as a result of technology improvements, further study, and changes in customer requirements.

<sup>2</sup> Other power plant sizes will be produced as the market matures.

<sup>3</sup> Two phase water cooling generates steam for reforming directly.

<sup>4</sup> Design power density is selected based on a tradeoff between heat rate and capital cost; power density is based on DC power output of stack.

<sup>5</sup> In addition to platinum, the cathode contains some vanadium (approximately 2/3 of catalyst for cathode, 1/3 for anode).

natural gas while the UTC on-site power plant is designed to run on natural gas. The Engelhard on-site and W/ERC utility power plants are being designed to run on methanol and natural gas (or naphtha), respectively.

The fuel processor for the UTC 40 kW on-site units has been designed to handle virtually all normal pipeline gases, including supplemental gas supplies such as imported liquefied and synthetic natural gas (LNG, SNG), and propane-air peak shave mixtures, as will mature commercial power plants. Early commercial offerings may be designed for less fuel flexibility to hold down power plant costs. The platinum catalysts in the anode structure and the nickel and platinum catalysts in the fuel processor subsystem are sensitive to fuel impurities, particularly sulfur compounds and, to a lesser extent, carbon monoxide. The concentrations of these impurities must therefore be reduced prior to contact of the fuel stream with the platinum and nickel catalysts. Even very low concentrations of sulfur can result in deleterious impact on catalyst performance and lower overall power plant performance.

The removal of fuel impurities is accomplished by a fuel preprocessor subsystem consisting of an adiabatic preoxidizer, a hydrodesulfurizer, a sulfur absorber, and a hydrogenator operating at subatmospheric pressure. The preoxidizer removes oxygen in propane-air peak-shaving gas by catalytic combustion with recycled hydrogen from the process gas stream to form water vapor. The hydrodesulfurizer converts organic sulfur compounds in the gas to hydrogen sulfide which is absorbed in a zinc oxide bed. The hydrogenator reduces propylene in the peak-shaving feed gas to a safe level to avoid coking in the reformer.

After mixing with steam, the fuel enters the fuel processing subsystem (reformer and shift converter) where the fuel and steam are catalytically converted into a hydrogen-rich gas. Hydrocarbons in the fuel are reformed to produce  $H_2$ ,  $CO$ , and  $CO_2$ , and the  $CO$  is subsequently shifted with water to produce still more  $H_2$  and  $CO_2$ . Methane reformers operate endothermically with exit fuel and exhaust gas temperatures of about 617 K ( $344^\circ C$ ) (Ref. 3.2). The process fuel stream exits the exothermic shift converter at 506 K ( $233^\circ C$ ). The hydrogen-rich gas from the fuel processor subsystem is cooled, filtered, and flows to the power section.

Typically, 80 percent of the hydrogen in the fuel stream is used in the power section. After the depleted fuel leaves the power section, it flows to the reformer burner where the remaining fuel is burned with air from the process air system to produce the thermal energy required for the steam reforming process. Reformer burner exhaust combines with depleted air from the power section and flows to the heat exchangers to be cooled for heat and water recovery. The water subsequently is used for fuel processing needs.

Methanol, another candidate fuel for phosphoric acid fuel cell (PAFC) power plants, will be used to power Engelhard's on-site systems. Although this fuel can be used directly in fuel cells, current technologies employ a water-methanol mixture that is reformed to hydrogen at about 505 K ( $232^\circ C$ ) before passing into a normal hydrogen air fuel cell. Methanol reformers have also been built and operated by ERC and UTC while developing fuel cell units under Army sponsorship. The equipment, energy, and catalyst necessary to operate these steam reformers are all relatively



inexpensive. Since the methanol contains no oxygen gas, there is no need for the preoxidizer and its supporting components. In addition, since methanol has no sulfur or unsaturated (propylene) components, desulfurization and hydrogenation equipment is not required. However, the level of impurities in methanol from coal is presently unknown. Additional components which are required include a liquid fuel pump, a fuel vaporizer, and controls for these components.

The use of methanol increases overall plant efficiency by about 2 percent since this fuel is not as difficult to reform and shift as natural gas. It is readily transportable by truck or pipeline, and on-site storage is practical. Further, methanol is envisioned as readily producible from coal, biomass, or wasted natural gas (flare gas) with essentially existing technology.

The use of naphtha, as planned in the UTC 4.8 MW unit, also requires a high temperature reformer. Like the methanol system, the reformer for this system differs from its 40 kW cousin in that a preoxidizer, hydrogenator, and gaseous fuel control valves are not required. Several new components, however, are necessary to pump, vaporize, meter, condition, and clean up the liquid naphtha fuel. The most significant of these are the high temperature shift converter, reformer steam preheaters, fuel vaporizers and mixers, and gas storage tanks. The latter consists of a nitrogen gas tank required for fuel preprocessor purge on shutdown and hydrogen and nitrogen gas tanks required for startup preheat and vaporization. In addition, several of the processor components used in the natural gas units have been redesigned to operate at a higher temperature and pressure (60 psia) (Ref. 3.6). Demonstrations have shown that a single reformer and CO shift subsystem can accommodate either natural gas or naphtha. For multi-megawatt systems, cost tradeoffs usually favor multi-stage shift conversion systems (high and low temperature). This contrasts with multi-kilowatt systems, in which single-stage shifts are generally more suitable.

The development of fuels compatible with the desired characteristics of fuel cell power plants is a continuing area of research and efforts are underway to expand the variety of alternatives. Potential fuels of the future include heavier distillate oils and coal-derived liquid and gaseous fuels. The latter are of particular importance as they will draw upon the nation's enormous coal resource base. The long range objective of integrating a fuel cell system and gas made from coal will require the development of an economically viable coal gasification industry. At this time, a substantial research and development effort is committed to this goal.

### 3.2.2 Power Section

The power section of a fuel cell system consists of individual fuel cells connected in series to attain a usable voltage, and stacks of fuel cells connected in parallel to achieve the desired power. Each cell consists of an electrolyte holding matrix sandwiched between two electrodes. Bipolar separator plates prevent mass transfer from one cell to the next. As the cells electrochemically consume hydrogen from the hydrogen-rich gas and oxygen from the process air system, they produce direct current electricity and heat. The heat, which is removed by the cooling system, is used in the fuel processing subsystem and, if excess is available, to provide for customer thermal demands. The materials and principles of operation are similar

for all PAFC systems currently under development; however, different approaches are being pursued for the cell structure and stack cooling systems. These efforts are aimed at improving efficiency and reducing the cost of the power section.

Since fuel cell performance improves with increased pressure and temperature, development efforts are attempting to increase these two operating variables. The on-site units, in general, are presently designed to operate at atmospheric pressure and 464 K (191°C) over a load profile from about 25 percent to full-rated load (Ref. 3.7). Although the UTC 4.8 MW power plant is to operate at 464 K and  $3.4 \times 10^5$  (50 psia) over a profile from 25 percent to full rated load, the next commercial plant planned by UTC will utilize a large area cell operated at approximately 478 K (205°C) and up to  $8.3 \times 10^5$  N/m<sup>2</sup> (120 psia). However, higher temperatures and, to a lesser extent, pressures cause an acceleration in the decay rate of the cell, primarily by increasing corrosion of the electrode catalyst support and sintering and/or dissolution of the catalyst. From an overall plant standpoint, the optimum pressure and temperature depend not only on stack technology and development, but also on the cost and performance implications upon the balance of the system (turbocompressors, heat exchangers, piping, etc.).

Improving the conventional cell structure, which basically consists of electrolyte-containing matrices, bipolar/separator plates, and electrodes, is another object of technology development activity. Figures 3-3 through 3-5 illustrate the different fuel cell structural designs which are being used by the three manufacturers. As shown by these figures, the shape of the stack cross-section varies from square (UTC) to rectangular (W/ERC and Engelhard). The thickness of the stack repeating section varies somewhat between manufacturers but is typically 3.5 to 4 centimeters. The stack repeating section usually consists of a cooling plate and 4 to 5 power cells, although the number of power cells can vary among manufacturers.

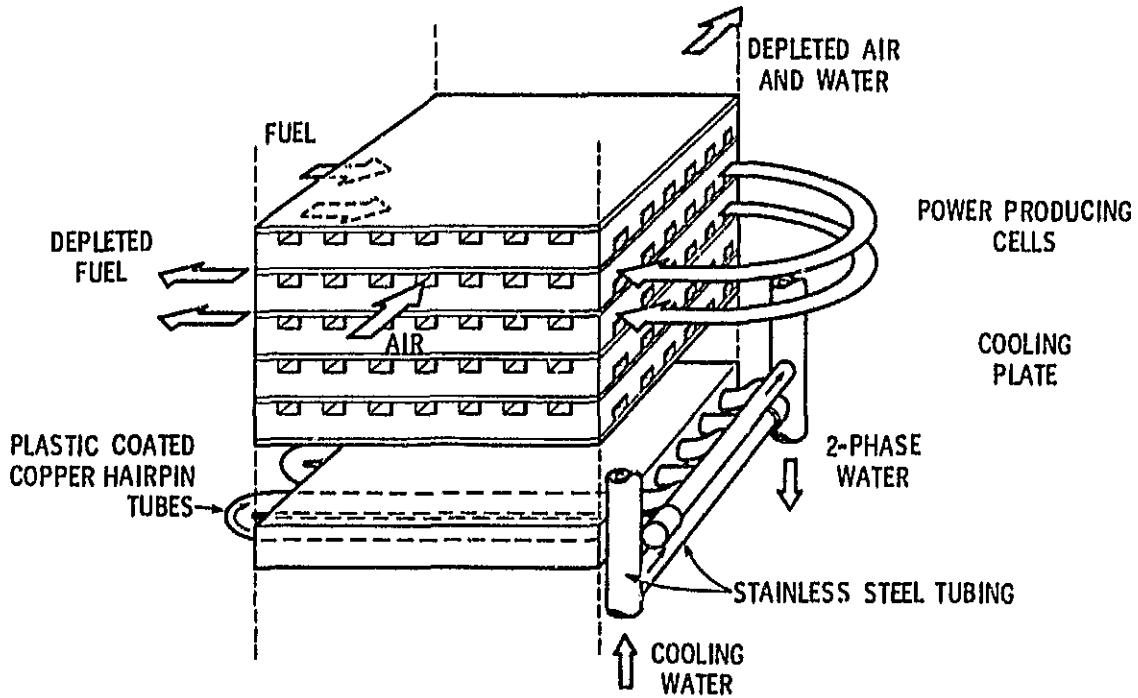
In an attempt to lower cell system cost and increase electrolyte capacity, UTC has developed a cell structure concept commonly called integral ribbed substrate (Ref. 3.7). The unique features of the integral ribbed substrate concept involve: (1) replacing the complex bipolar/separator plate (which normally contains a ribbed reactant flow field on either side perpendicular to each other) with a simple impervious flat plate, and (2) transferring the flow field function onto a ribbed porous element which, after deposition of catalyst and silicon carbide on one side, becomes an electrode and is also designed to act as an electrolyte reservoir. Ribbed substrate manufacture is available in a continuous production line process. The UTC cell and stack structures are illustrated in Figure 3-3.

Engelhard is also attempting to improve the efficiency and durability of the fuel cell structure. Its approach is to split the bipolar plate into three sections, an impervious center section (for reactant separation), with an open cell section, with or without channels, on either side for reactant flow (see Figure 3-4). All sections are made from organic precursors that are graphitized, then densified. This process is very compatible with mass production and promises considerable cost savings over one-piece, bipolar plates which must be individually molded. Improvements in the electrolyte matrix emphasize the development of materials capable of operating at temperatures up to 478 K (205°C) and construction that results in good electric and thermal conductivity, good transport (flow) properties, and satisfactory reactant crossover resistance.

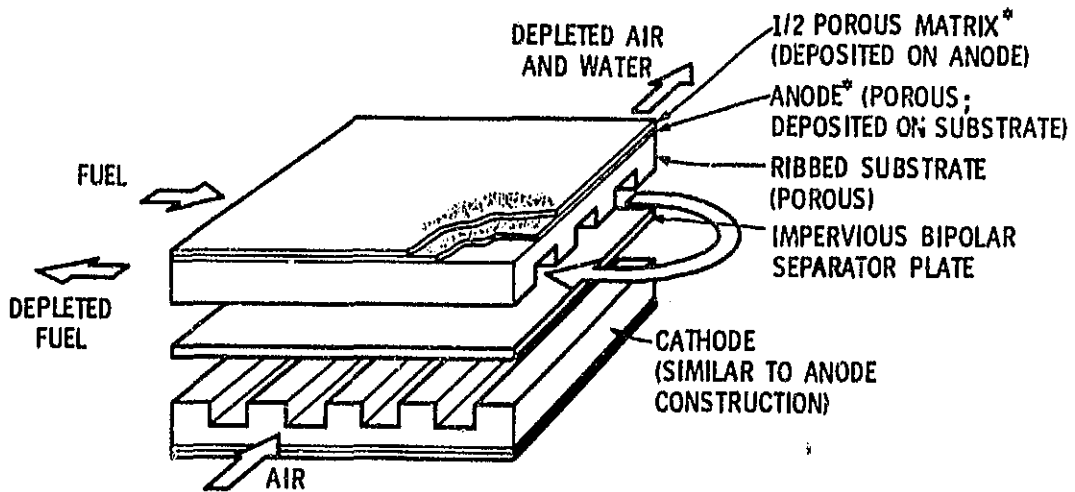
Figure 3-3. United Technologies Corporation Stack Concept

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(a) Stack Repeating Section



(b) Details of Power Producing Cell

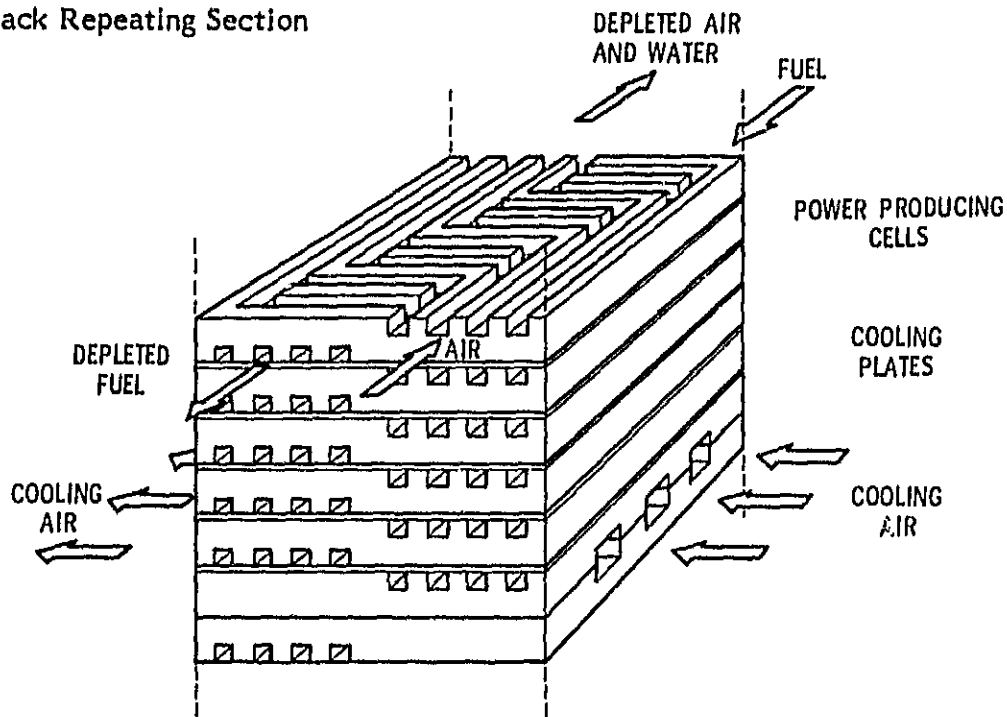


\*THICKNESS EXAGGERATED

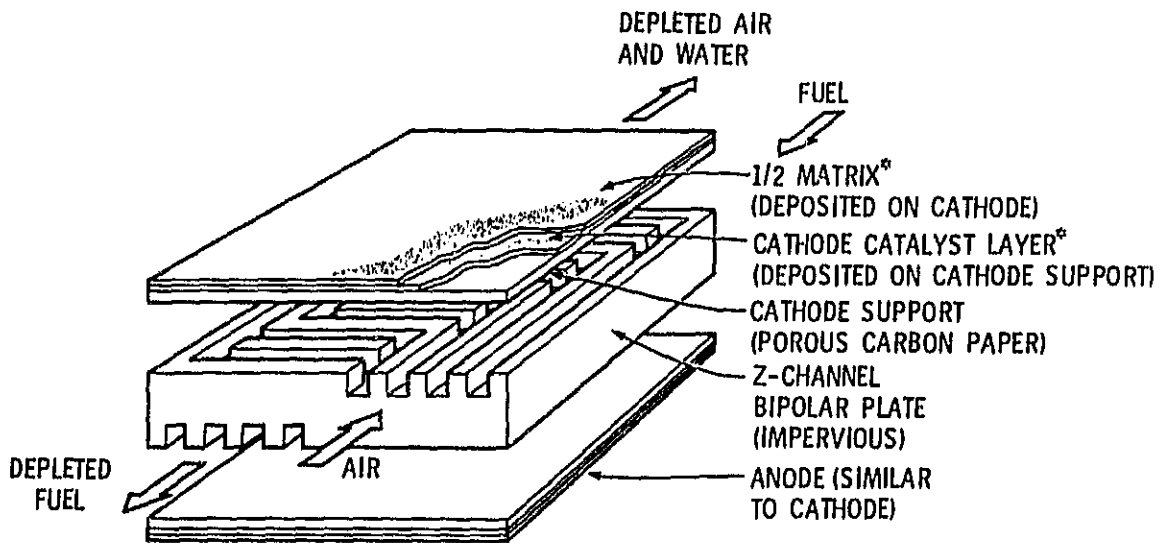
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Figure 3-4. Westinghouse/Energy Research Corporation Stack Concept

(a) Stack Repeating Section



(b) Details of Power Producing Cell

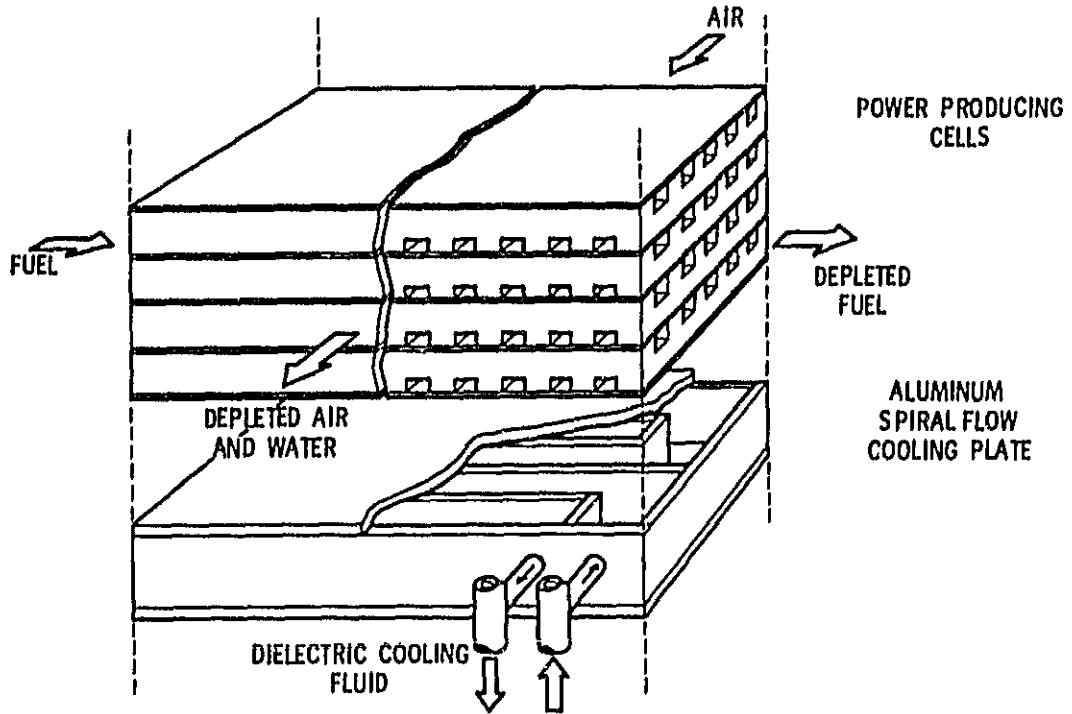


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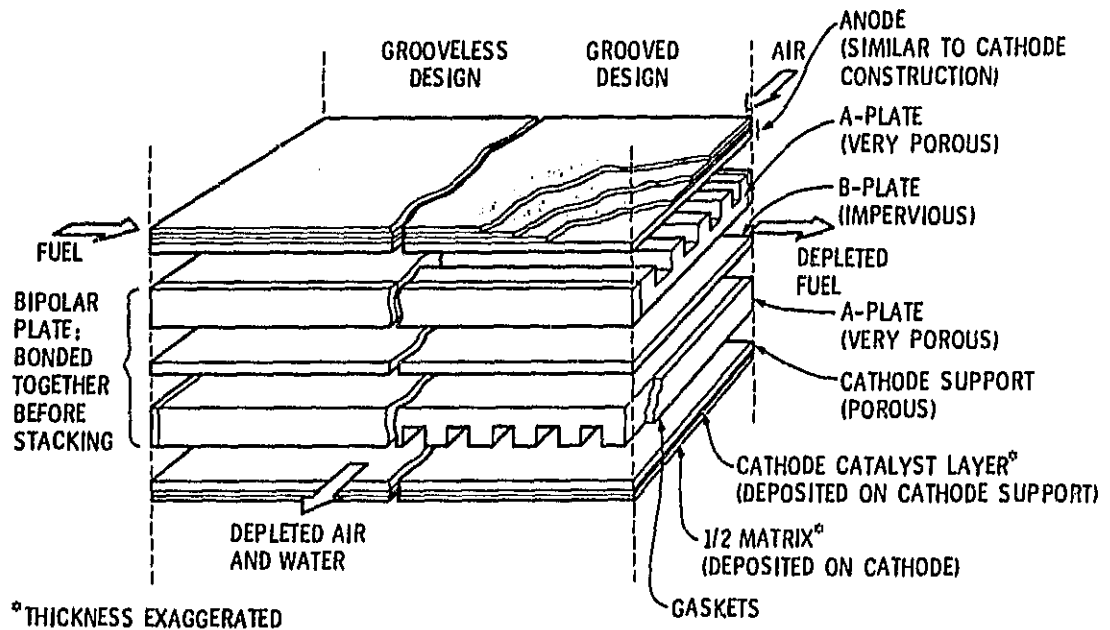
Figure 3-5. Engelhard Stack Concept

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(a) Stack Repeating Section



(b) Details of Power Producing Cell



Removal of waste heat from the fuel cell stack can be accomplished either by a liquid or gas cooling system. UTC, W/ERC, and Engelhard have each chosen different cooling methods. UTC fuel cell power plants employ a two-phase water cooling method in which copper tubing with an exterior coat of Teflon (to protect against the acid environment) passes through the stack to allow the passage of cooling water.

W/ERC fuel cell power plants will employ the separated gas cooling system illustrated in Figure 3-4. This type of cooling keeps the cathodic reactant air separate from the cooling system. Cathode air and anode hydrogen-rich gas enter and leave on the same side of the fuel cell stack using special manifolds that keep them separated. The cooling gas is passed through cooling plates placed every fifth cell. The use of this cooling system reduces the need for acid resistant heat exchangers in the cooling stream.

The Engelhard system will employ a liquid intercell cooling approach using a dielectric fluid. This approach makes use of baffles to provide good heat transfer control and is designed for ease of fabrication. A more chemically resistant alternate system is being designed. A comparison of gas and liquid cooling schemes for phosphoric acid fuel cell systems is presented in Table 3-3.

**Table 3-3. Comparison of Gas and Liquid Cooling Schemes for Fuel Cell Systems (Ref. 3.7)**

	<u>Liquid Cooling</u>	<u>Separate Gas Cooling</u>
Construction Simplicity	Complex	Simple
Electrolyte Loss	Low	Low
External Heat Exchange	Good	Fair
Cost of Cooling Subsystem, % Stack Cost	25-50	5
Total Differential Temp. (K)	11	25
$T_{cell}$ in stacking direction (K)	8	8
$T_{cell}$ in flow direction (K)	3	17
Total Auxiliary Power Req't., %	1	2
Stack Auxiliary Power Req't., %	0.5	0.5
Balance of System Aux. Power Req't., %	0.5	1.5
Pressure Drop Across Cell (N/m <sup>2</sup> )	100	100

For electrolyte management, W/ERC and Engelhard PAFC power plants will have built-in acid replenishment systems. Besides adding acid to the stack, the systems will also accommodate acid volume changes due to differing operating conditions.

### 3.2.3 Power Conditioning

The power conditioning subsystem includes equipment necessary to collect the dc electric power from the fuel cell stacks, convert it to ac, and transform it to load and/or line voltage. Current emphasis in this technology is on solid-state inverters, and the advances in solid-state technology have resulted in significant decreases in

cost and size with conversion efficiencies exceeding 90 percent. The inverter for the UTC 40 kW unit is a three-phase solid-state device which provides a regulated ac voltage at a nominal level of 120/208 volts. Single-phase, 120 volt ac is provided through use of a neutral forming autotransformer (Ref. 3.2). Larger dispersed power plants produce power at higher voltages for transmission to substation transformers. For example, an electrical output of 13.8 kV will be produced by the UTC 4.8 MW unit.

#### 3.2.4 Thermal Management

Heat is continuously being generated as a byproduct of the fuel cell electrochemical reaction and from the operation of the fuel processing system. Waste heat removal and recovery are controlled by the thermal management subsystem, which cools the fuel processing exhaust stream, and removes excess heat from the power section by circulating a gas or liquid coolant throughout the stack. The exit exhaust gas temperature from a methane fuel processor subsystem is about 506 K (233°C). The temperature of the stack coolant, a function of output power, ranges from about 448-473 K (175-200°C) (Ref. 3.7). In the multi-megawatt facilities, an external loop to a cooling tower allows for the dissipation of excess heat. UTC's 4.8 MW power plant will use two small dry cooling towers for this purpose. The smaller on-site units can be adequately cooled with forced- or natural-draft ventilation of the cabinet.

The need for increased end-use energy efficiency makes the recovery of waste heat for heating and cooling an attractive option, particularly for on-site units. This can be accomplished by transferring waste heat to a secondary customer water loop by means of a high or low grade heat exchanger. Heat transfer is more efficient with a liquid or two-phase liquid cooling system. With recirculating air systems, heat transfer becomes more difficult. In the high grade heat exchanger, the water temperature in the customer loop may be heated to temperatures of around 408 K (135°C) (Ref. 3.2). Although these temperatures are satisfactory for most residential and commercial applications, for some industrial and utility power plant uses the temperature and/or pressure of the fuel cell waste heat is not sufficient to meet major requirements. Advanced fuel cell technologies, which may be able to provide a small amount of reject heat at temperatures approaching 811 K (538°C), will be more useful for these additional applications (Ref. 3.8).

The recovery of thermal energy is an option that is likely to be pursued at most fuel cell installations, since it can raise the overall efficiency of the fuel cell from 40 to around 80 percent. There are a number of applications where the on-site fuel cell with heat recovery, coupled with heat pumps, can provide all of the building energy needs using less fuel resources than would normally be required just to supply the conventional heating requirements of the building. However, there are limitations on the recovery and use of thermal energy which should be realized, including problems with the quality of heat, matching thermal and electric loads, heat recovery and distribution costs, and some operation issues. Depending on the specific application at hand, the requirements for thermal energy and electricity may be totally disproportionate or may not occur at the same time. Thus, if both demands are to be satisfied, methods must be devised for matching them with respect to size and decoupling them with respect to the time at which they occur.

### 3.2.5 Environmental Characteristics

PAFC technology is noted for its environmentally benign characteristics. Chief among these are air emissions, water demand, water discharge, noise, and vibration values that are substantially lower than those of most comparable conventional energy technologies. These values are quantified in the environmental impact discussion of Section 5. In general, the power plant systems of all four DOE-funded PAFC development projects will have about the same environmental traits since all employ the same basic technology. These traits are compared to those of other energy technologies in the Appendix.

PAFC power plants are able to achieve low air emission rates for two reasons: (1) much of the sulfur and other fuel impurities are removed during fuel processing since they reduce power plant performance, and (2) the fuel cell uses an electrochemical rather than a combustion energy conversion process and so limits formation of combustion products. Catalysts used for fuel reforming and power production have a low tolerance for sulfur compounds and therefore most of the sulfur is removed from the fuel prior to reforming. This results in sulfur air emission rates that are orders of magnitude less than federal power plant standards.

Although combustion does not occur in the fuel cell stack, fuel not consumed by the stack is combusted in a burner to provide heat for fuel reforming. This combustion is the principal source of power plant air emissions. The reformer burner temperature is low enough, however, so that only a small amount of thermal nitrogen oxides is produced. Nitrogen oxides are present in power plant exhausts because of bound nitrogen in the fuel, but their emission rates are substantially less than federal standards.

Fuel cell power plants differ fundamentally in their water demand and discharge characteristics from conventional power generating equipment because of the water producing nature of the fuel cell reaction. The electrochemical reactions within the cell stack produce a sufficient quantity of water to compensate for steam consumption in the fuel reformer and water vapor loss via the exhaust stream. Water self-sufficiency is made possible by recovery, purification, and reuse of a portion of this byproduct water. During normal power plant operation, little or no make-up water is required for fuel processing and cooling (in water-cooled systems) and water discharges are limited to occasional system overflow and periodic system blowdown.

The quiet electrochemical conversion process of the fuel cell eliminates many of the noise and vibration sources associated with traditional combustion energy systems. PAFC power plants have relatively few moving parts and noise and vibration sources are generally limited to electric fans and pumps. They are much quieter than power generation systems using fuel combustion as an energy source.

### 3.2.6 Advanced Research

Phosphoric acid fuel cell technology and development efforts for both the electric utility and OS/IES applications are directed toward reducing cost, increasing performance, improving reliability, and increasing fuel cell life. In the technology area, the longstanding barrier to the attainment of these goals has been materials.



In the cell catalyst layer, the carbon support must resist oxidative corrosion while the catalyst must resist dissolution and sintering at the operating temperature, pressure, and potential. Both cell and fuel processor catalysts must possess sufficient tolerance to fuel contaminants, and cell and stack materials must possess the right combination of structural properties. The seals must function effectively, be durable, and not contaminate. Metal parts throughout the system must possess the right structural and thermal properties, and also be durable. Finally, all materials must be cost effective and be easy to manufacture. It has been very difficult to find and to develop materials that could meet cost and reliability goals simultaneously. The approach to solving these problems has involved technology/-development efforts guided by system tradeoff studies (Ref. 3.7).

For electric utility applications, UTC and W/ERC are pursuing higher operational temperature and pressure designs. However, the performance gains which may result from the use of increased temperatures and pressures must be balanced against possible shorter cell life as well as the cost and performance implications upon the balance of the system.

Another recent research area has focused on improving the cathode, since this is the greatest source of fuel cell inefficiency. Improved cathode electrochemical activity would permit either greater electrical efficiency or higher power density at the present operating temperature, or the option of the same efficiency and power density at lower operating temperatures. Lower temperature operation may be desirable in order to lower material costs and to increase cell life. Another goal is to find a suitable, less expensive replacement for the platinum (Pt) catalyst material.

DOE-sponsored electrode research is being pursued in four areas: (1) developing a new non-Pt solid electrocatalyst material, (2) optimizing the electrode manufacturing process through a parametric investigation of electrode component materials and technology, (3) using the present electrocatalyst (Pt) in ways that are more electrically efficient, stable, and resistant to poisoning, and (4) developing Pt alloy catalysts. With total Pt electrode loading reduced to less than 1 mg/cm<sup>2</sup>, the Pt cost in the fuel cell system has been reduced to lesser importance than years ago when unsupported electrocatalysts were used. However, the recent sharp rise in Pt cost has increased the importance of electrocatalyst cost, particularly for the OS/IES systems which operate at a lower power density.

### 3.3 Technology Conclusions

DOE is supporting competitive PAFC development projects in order to promote technology innovation and advancement. Each project is using the same technology base but will employ different subsystem designs, operating conditions, and materials. Reliability, costs, and fuels will also differ from one project to the next. In spite of these distinctions, similarly sized power plants produced by competing projects are expected to have basic similarities in terms of external characteristics important to power plant users. These external characteristics include power quality, power plant performance, and environmental suitability. It should be noted that power plant designs and specifications described in this section are based on current information and projections, and are subject to change at any time as a result of technology improvements, further study, or changes in customer requirements.

Figure 3-6. UTC 40 kW Preprototype Power Plant (Field Test Power Plant)



Figure 3-7. UTC Electric Utility 240 kW Preprototype Stack

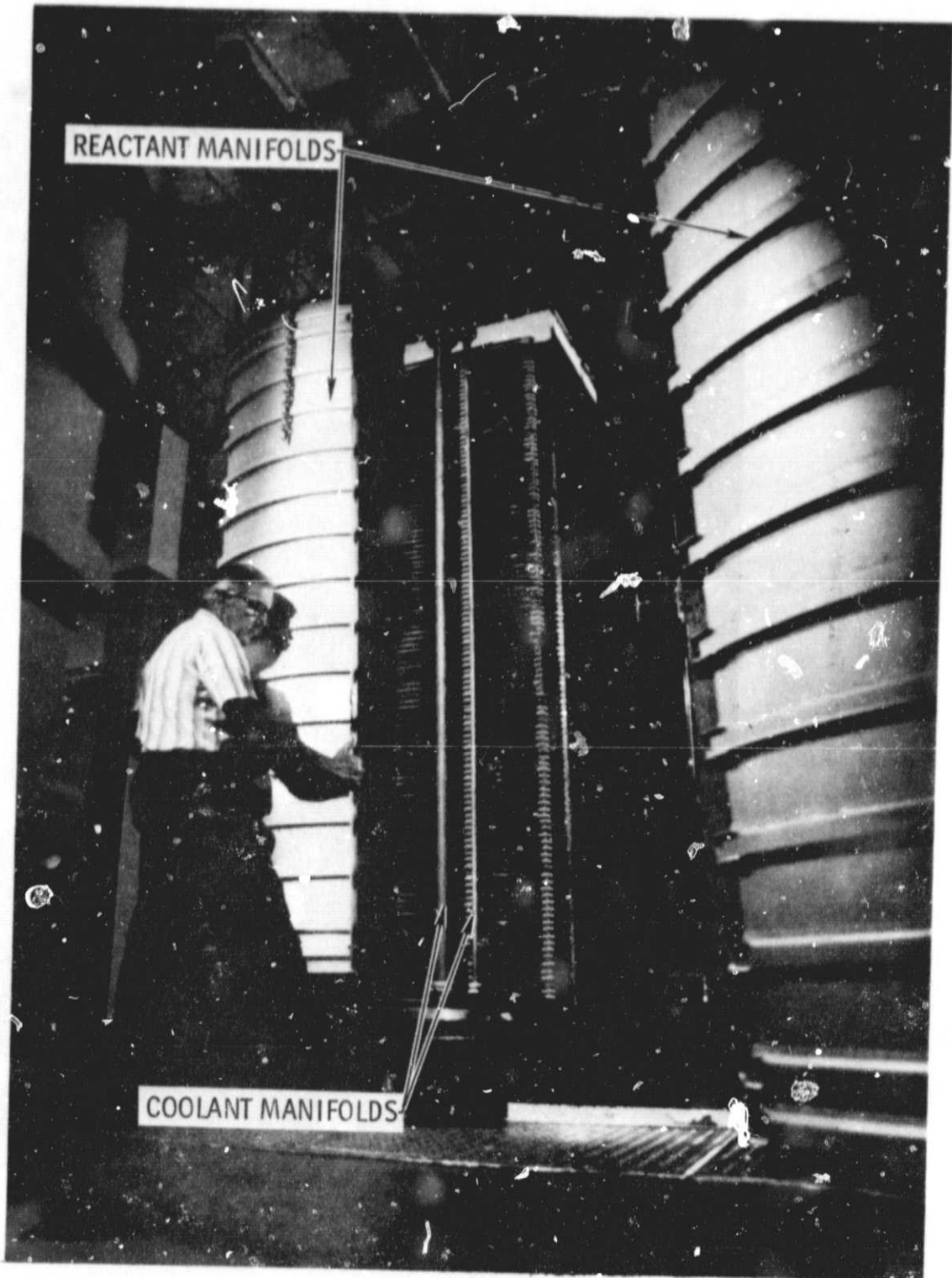


Figure 3-8. UTC 4.8 MW Demonstrator Consolidated Edison Test Site  
(power section not yet installed)

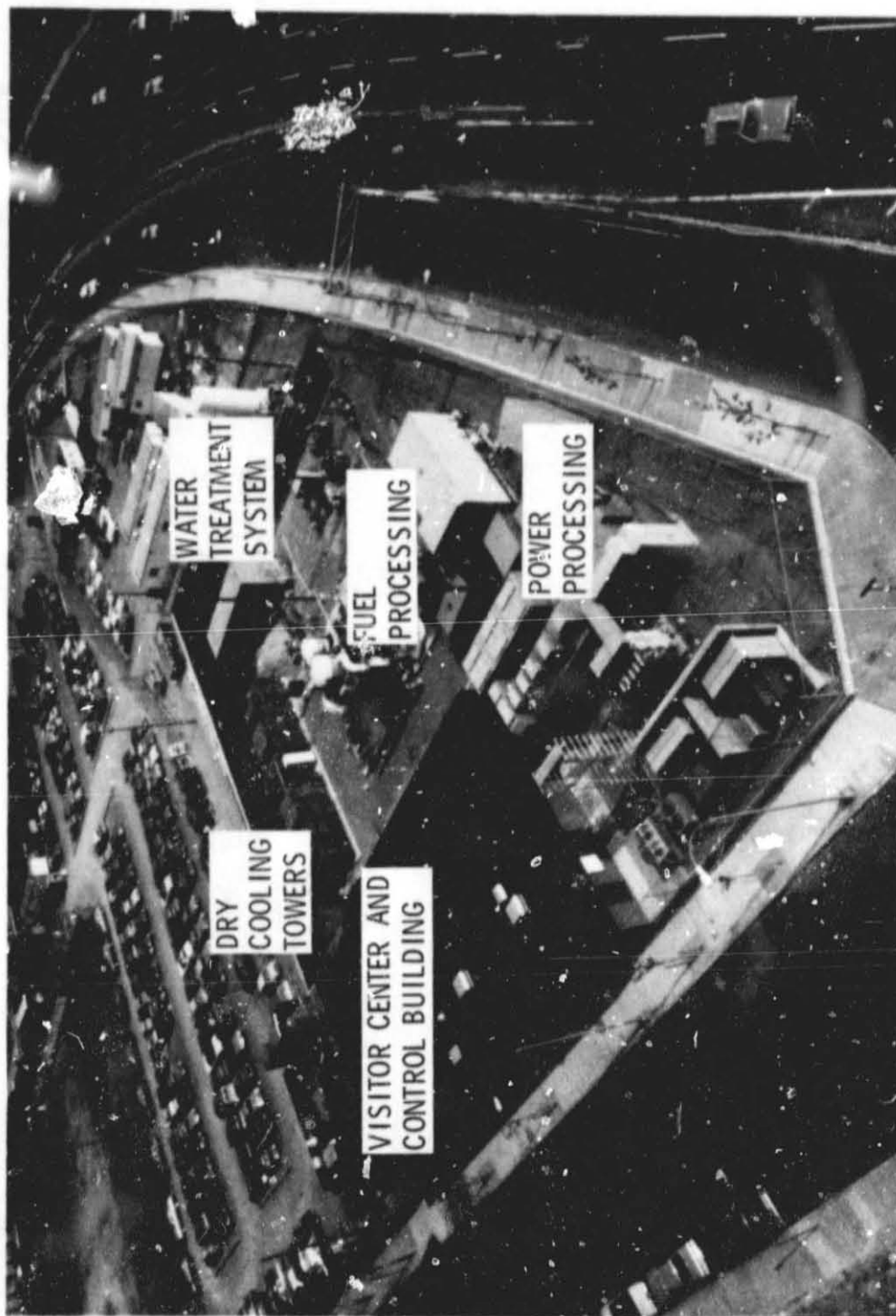


Figure 3-9. Westinghouse 4x100 kW Stack Model

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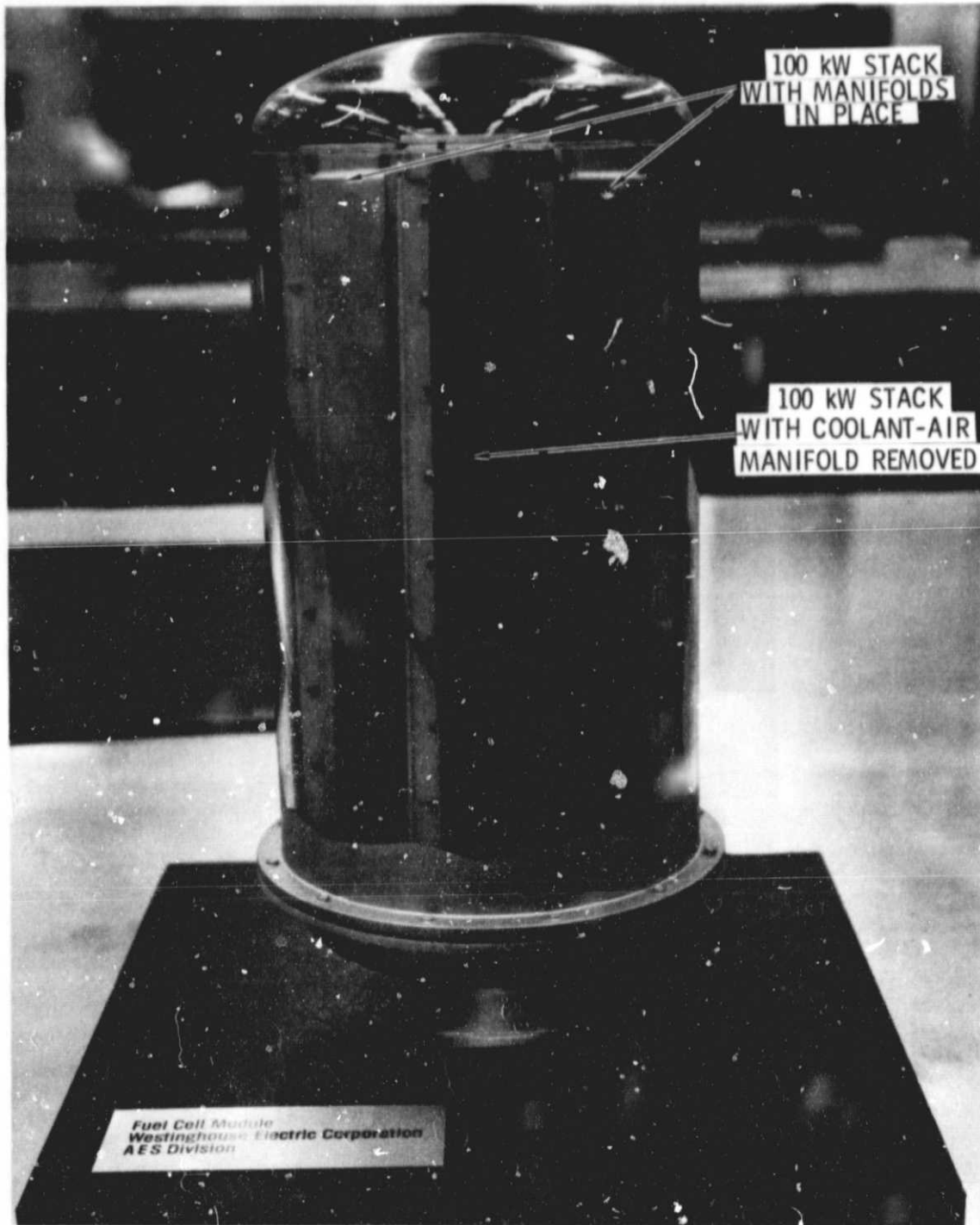


Figure 3-10. Westinghouse 7.5 MW Fuel Cell Power Plant Model

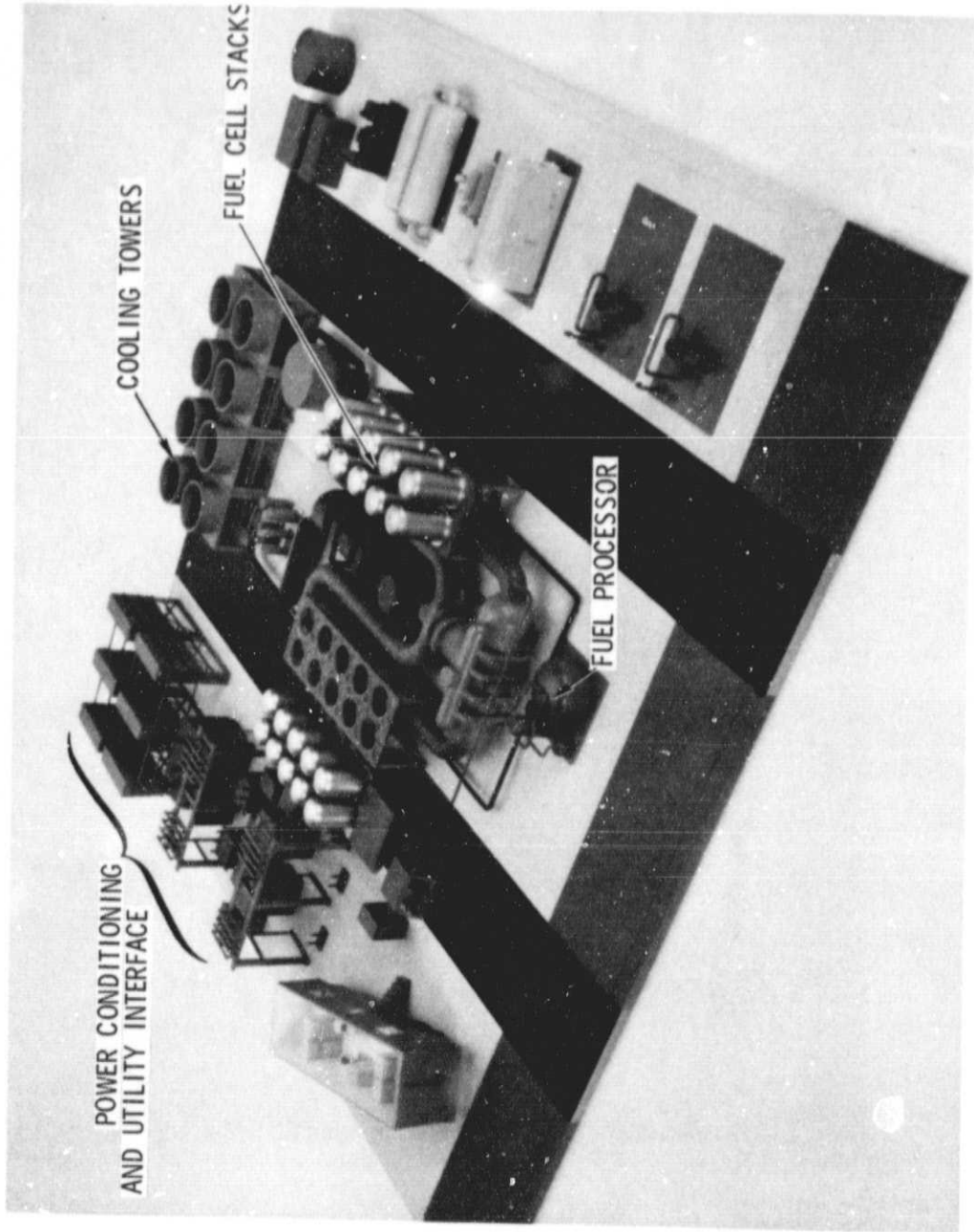


Figure 3-11. ERC 8 kW Test Stack (without manifolds)

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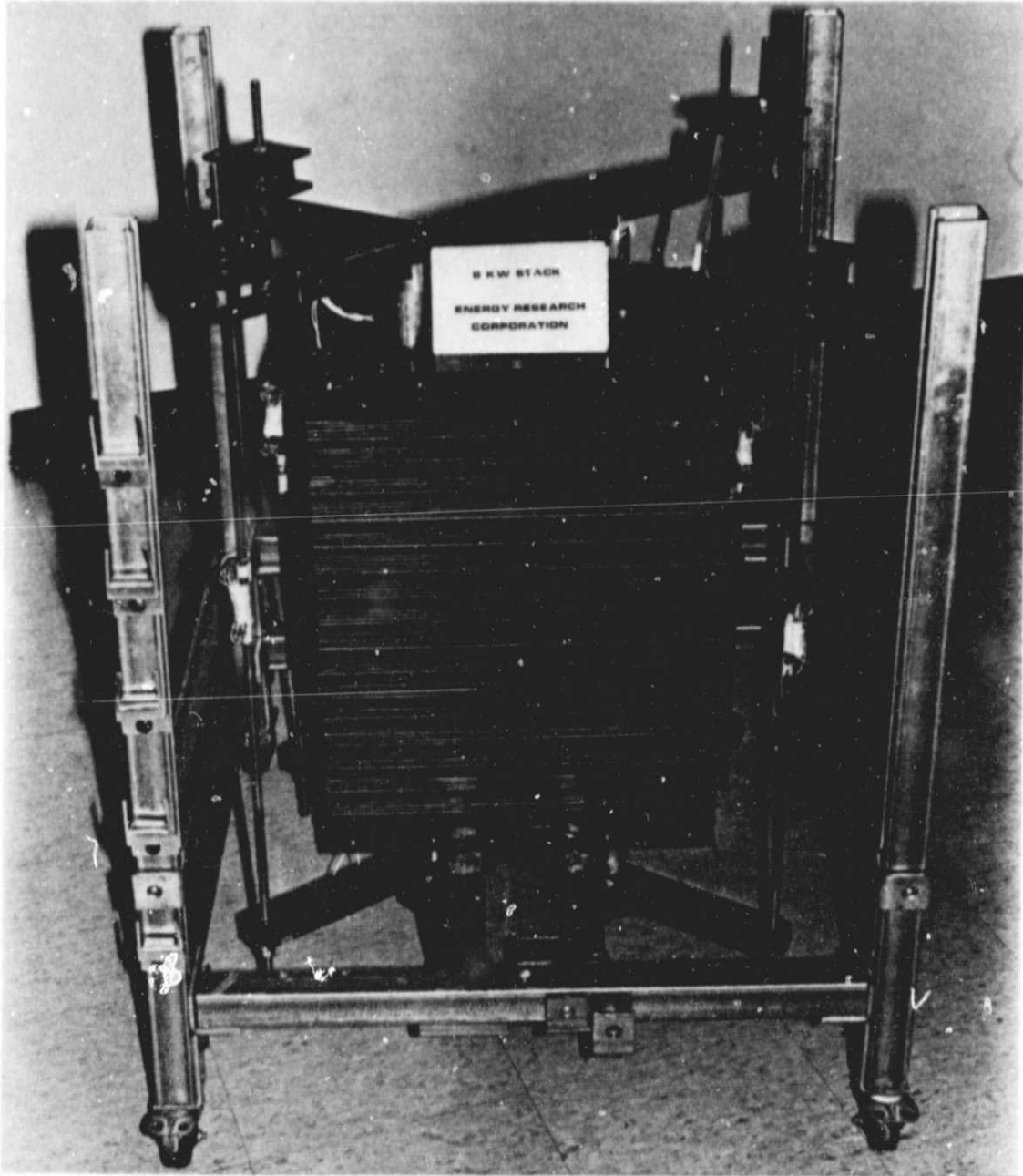
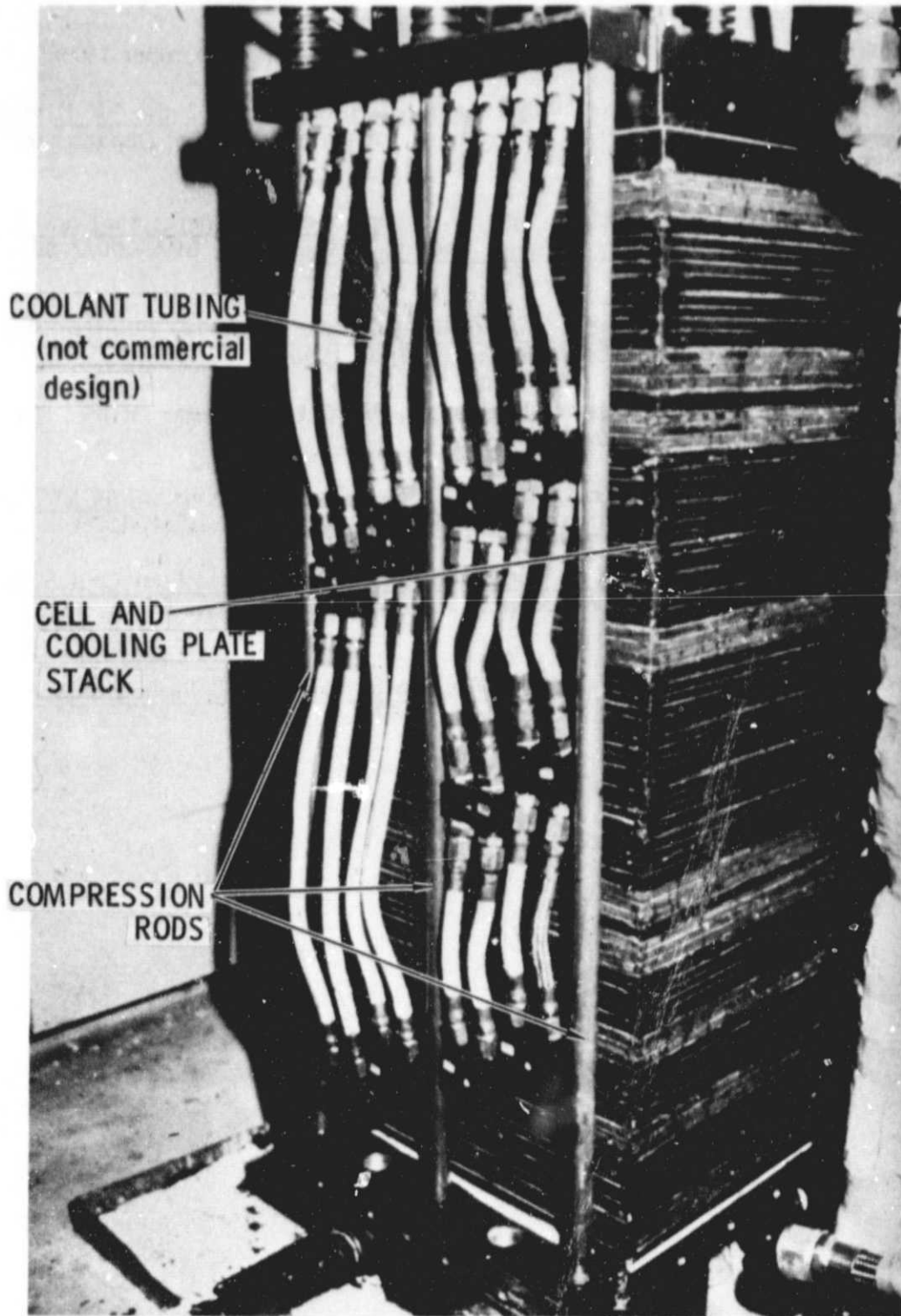


Figure 3-12. Engelhard 5 kW Test Stack (without manifolds)

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## 4. ENERGY AND ENVIRONMENTAL SETTING

In the years since the National Environmental Policy Act of 1969 was enacted, significant progress has been made in the identification and reduction of many of the environmental problems which plague the nation. The pressures of growth and development, however, continue to challenge our nation's ability to attain and preserve a healthy and safe environment. In this past decade, our collective attention has also been focused on the significance and value of energy resources and the need to develop alternative energy supplies. Rising concerns for both energy development and environmental protection have precipitated innumerable conflicts and polarized attitudes, often to the detriment of both problems.

Energy facilities contribute significantly to national environmental problems involving air and water quality, land use, climate, and solid waste disposal. In the first part of this section, the infrastructure which supplies energy to the consumer (i.e., gas and electric utilities) is described and sector and regional influences on energy demand patterns are identified. The remainder of the section reviews national environmental problems and trends and discusses the overall contribution of electric energy generation sources to environmental problems.

### 4.1 Energy Supply and Demand

Energy is extracted from a variety of resources including fossil fuels, uranium, and several direct and indirect solar energy resources. This energy is transformed to perform three main work functions--transportation, heat production, and electricity. The total resources consumed for energy production in the United States in 1979 are listed in Table 4-1. As seen in this table, fossil fuels provided over 90 percent of the country's energy requirements with most of the remainder extracted from nuclear and hydropower resources. Energy demands of the four major market sectors--residential, commercial, industrial, and transportation--are identified in Table 4-2. Figure 4-1 illustrates this consumption profile.

As presently conceived, fuel cells will be used to produce electricity and thermal energy for residential, commercial, and industrial consumption. This constitutes approximately 75 percent of the total energy consumed in the United States. The remaining 25 percent, energy consumed by the transportation market, will not be directly affected by fuel cell commercialization. Electricity and thermal energy are supplied to consumers by the energy utilities (gas and electric) and on-site generation systems. On-site generation of thermal energy, either independently or in combination with electricity production (cogeneration), has been primarily restricted to the industrial sector. The residential and commercial sectors rely almost exclusively on utility service to provide for their energy needs.

#### 4.1.1 Electric Utility Industry

The electric utility industry is the largest in this country--in terms of both capital assets and its interaction with the financial markets. Annual revenues exceeded \$77

Table 4-1. U.S. Energy Supply in 1979  
(In Trillion Btu) (Ref. 4.1)

<u>Activity and Fuel</u>	<u>Energy</u>
Production	
Crude Oil and Lease Condensate	18,020
Natural Gas Plant Liquids	2,380
Natural Gas (Dry Marketed)	19,190
Coal	17,410
Nuclear Power	2,750
Hydropower	2,960
Other <sup>(1)</sup>	90
Total Production	<u>62,800</u>
Imports	
Crude Oil	13,530
Refined Petroleum Products	4,110
Natural Gas <sup>(2)</sup>	1,270
Other	380
Total Imports	<u>19,290</u>
Adjustments (balancing item)	-1,180
Exports	<u>-2,890</u>
Total Supply	<u>78,020</u>

(1) Geothermal, wood, refuse, and other vegetal fuels.

(2) Includes bituminous, lignite, and anthracite coal, as well as coke made from coal, and hydropower.

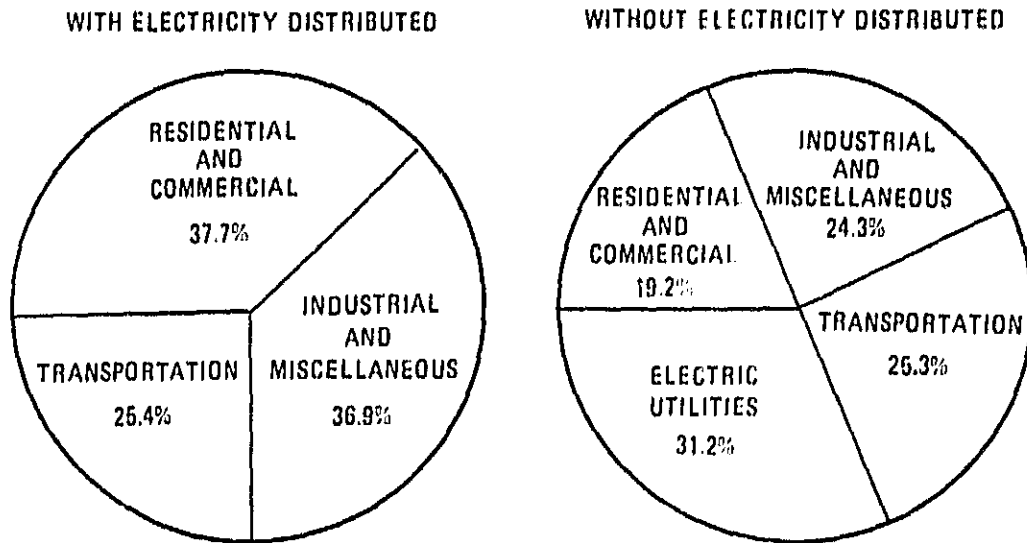
Table 4-2. National Energy Consumption - 1977  
(In Trillion Btu) (Ref. 4.2)

	<u>Electric Utilities</u>	<u>Residential</u>	<u>Commercial</u>	<u>Industrial</u>	<u>Transportation</u>	<u>Total</u>
Petroleum (Total)	4,028	2,988	3,512	8,067	18,937	37,532
Gasoline	--	2,011	106	192	11,653	13,962
Residual	3,580	--	1,065	1,461	927	7,033
Distillate	448	--	1,119	807	2,879	5,253
Diesel	--	--	--	365	1,540	1,905
Jet Fuel	--	--	--	--	1,923	1,923
LPG	--	616	68	437	17	1,138
Kerosene	--	361	--	--	--	361
Other*	--	--	1,154	4,802	--	14,228
Coal	10,271	84	49	3,824	--	5,956
Natural Gas	3,292	4,983	2,576	8,740	549	20,140
Nuclear	2,634	--	--	--	--	2,634
Hydro	<u>2,290</u>	--	--	--	--	<u>2,290</u>
Total	22,515	8,055	6,137	20,631	19,486	76,824
Purchased Electricity	--	13,335**	13,335**	9,140	40	22,515

\* Asphalt and road oils, feedstocks, lubes and waxes.

\*\* Total amount of electricity purchased by both the residential and commercial sectors combined.

Figure 4-1. Consumption of Energy by Sector (Ref. 4.1)



billion in 1979 (Ref. 4.3). Historically, the industry was organized in a holding company structure. The growth of this organizational structure, which developed in the 1920s, reached a peak in the early 1930s. By 1932, consolidation of their numbers led to concentration in the industry, with some 16 electric power holding companies controlling 75 percent of the electric generation produced in the United States (Ref. 4.4).

The Public Utility Holding Company Act of 1935 unraveled and reorganized the electric power industry. Because of the inherent economies of scale associated with the operation of power supply systems, the Federal Power Commission franchised electric utilities to operate as public regulated monopolies in specific service areas. The current ownership pattern in the industry can be compartmentalized as follows:

- Private investor-owned utility systems;
- Cooperative systems owned by communities, companies, and/or individuals; and
- Public, non-profit systems.

The industry is composed predominantly of private investor-owned systems which comprise approximately 77 percent of this country's generating capacity.

In order to maintain the balance of power supply to demand in an economic and reliable manner, utilities have formed cooperative agreements. Specifically, individual utilities have formed regional and interstate networks to distribute power on a demand-response basis. These interconnecting power grids must be coordinated in an effort to assure the system is operating in an efficient and reliable manner such that "brownouts" and "blackouts" are minimized.

At present, regulatory authority is predominantly vested at the state level, usually in state public utility commissions (PUC). Each utility is normally granted a franchise with its state's PUC providing the right to operate as a single-source supplier in a given region. The PUC has broad authority to control the development and pricing practices of the utility and to exercise power of eminent domain in the interest of assuring a reliable and economic power supply. In addition to commission surveillance, the federal government has also exercised increasing leverage on development patterns of the utility industry as a result of environmental legislation over the past decade and the recent enactment of the National Energy Act (Ref. 4.4).

#### 4.1.1.1 Electric Energy Production and Installed Generating Capacity

The total installed generating capacity of electric utilities in the United States was 598,297 MW in 1979, up 3.3 percent from 1978 (Ref. 4.5). The mix of technologies which made up this capacity and their contributions are described in Table 4-3. In 1979, utilities produced a record 2,245 million MW-hours of electricity, up 1.9 percent from 1978. The amounts and types of fuels consumed to produce this electricity are identified in Table 4-4. The relatively small amounts of oil and gas used for the production of peaking electricity in comparison to the peaking capacity reflects the intermittent utilization of these systems. A further breakdown of petroleum consumption for electricity generation is provided in Table 4-5.

**Table 4-3. Electric Utility Generation Capacity - 1979 (Ref. 4.3)**

<u>Type/Size of Prime Mover</u>	<u>Number of Prime Movers</u>		<u>Capacity (million kW)</u>	
	<u>Privately Owned</u>	<u>Publicly Owned</u>	<u>Privately Owned</u>	<u>Publicly Owned</u>
Steam, Conventional	620	305	350.9	61.5
Under 100,000 kW	135	195	5.6	6.2
100,000-500,000 kW	237	75	63.3	17.6
Over 500,000 kW	248	35	281.9	37.6
Steam, Nuclear	43	8	46.1	8.5
Over 500,000 kW	37	7	44.8	8.5
Hydro	733	412	23.9	51.4
Over 25,000 kW	173	186	20.7	50.3
Gas Turbine	406	131	41.4	9.1
Over 25,000 kW	279	65	39.3	8.1
Internal Combustion	285	630	1.8	3.7
Under 5,000 kW	172	361	0.4	0.7
Over 5,000 kW	<u>113</u>	<u>269</u>	<u>1.4</u>	<u>3.0</u>
Total	2,087	1,486	464.0	134.3

**Table 4-4. Energy Resources Used by the Electric Utility Industry - 1979 (Ref. 4.6)**

<u>Energy Resource</u>	<u>Quantity Used (Millions)</u>	<u>Output (Million MW-hr)</u>	<u>Percent</u>
Coal	556.6 tons	1075	47.8
Oil			
Steam	489.0 bbls	287	12.8
Peaking	27.4	15	0.7
Total Oil	516.4	303	13.5
Gas			
Steam	3,248.6 Mcf	317	14.1
Peaking	130.2	12	0.6
Total Gas	3,378.8	329	14.7
Hydroelectric	--	279	12.4
Nuclear	--	255	11.4
Other*	--	4	0.2
<b>Total</b>		<b>2245</b>	<b>100.0</b>

\* Geothermal, wood, waste, etc.

**Table 4-5. Petroleum Fuels Used for Utility Electricity Production - 1979 (Ref. 4.6)**

<u>Petroleum Fuel</u>	<u>Steam Electric</u>		<u>Peaking Units</u>	
	<u>(Million bbls)</u>	<u>% Total</u>	<u>(Million bbls)</u>	<u>% Total</u>
Jet Fuel, Kerosene	0.0	0.0	3.2	11.7
Distillate (FO2)	19.6	4.0	23.5	86.1
FO4, FO5	4.6	0.9	0.0	0.0
Residual (FO6)	464.0	94.9	0.6	2.2
Crude, Topped Crude	1.0	0.2	0.0	0.0
<b>Total</b>	<b>489.2</b>	<b>100.0</b>	<b>27.3</b>	<b>100.0</b>

Present and projected fossil fuel requirements for electricity generation are presented by region in Figure 4-2. With a couple of exceptions, coal is used more or less equally by each of the nine National Electric Reliability Council (NERC) regions. The East Central Area Reliability (ECAR) region consumed the greatest amount of coal in 1980 (152 million tons or 26.7 percent of the total), and the Northeast Power Coordinating Council (NPCC) region consumed the least (10 million tons or 1.8 percent of the total) (Ref. 4.7). Coal use is expected to grow by about 40 percent over the next 10 years with regional consumption remaining at close to the same proportions.



Oil and natural gas consumption by the electric utilities was much more region-dependent, with three regions dominating in each case. Although the trend in oil use projects a more equal consumption pattern throughout the country by 1990, natural gas will continue to be consumed primarily by the western and southwestern states. By 1990, projections show that the three NERC regions encompassing these states will account for almost 96 percent of the natural gas consumed by the nation's electric utilities. By that time, the amount of gas consumed by electric utilities will be less than one-half of the present amount.

The demand for electricity is highly variable with daily, weekly, and seasonal fluctuations imposed upon a constant base load. To meet this fluctuating demand at the lowest possible cost consistent with adequate reliability, utilities have traditionally set up combinations of generating plants with different operating and economic characteristics. While the utility must have the capacity to supply the peak demand, much of this capacity is idle part of the time. This situation results in an average use of less than 50 percent of the total U.S. capacity. Typically, the demand profile is handled by:

- Large coal and nuclear units of the highest efficiency and lowest cost fuels to provide the base demand (between 40 and 50 percent of a systems load)
- Less modern and less efficient fossil-fuel (coal, oil or gas) units, hydroelectric-power units where they are available, and gas-turbine units where they are needed to handle the intermediate parts of the demand peaks (another 30 to 40 percent of the load)
- Still older fossil-fuel units, hydroelectric power, gas- or oil-fired turbines and gas or diesel combustion generators to provide for the brief peaking demands at the very top of the daily and weekly cycles.

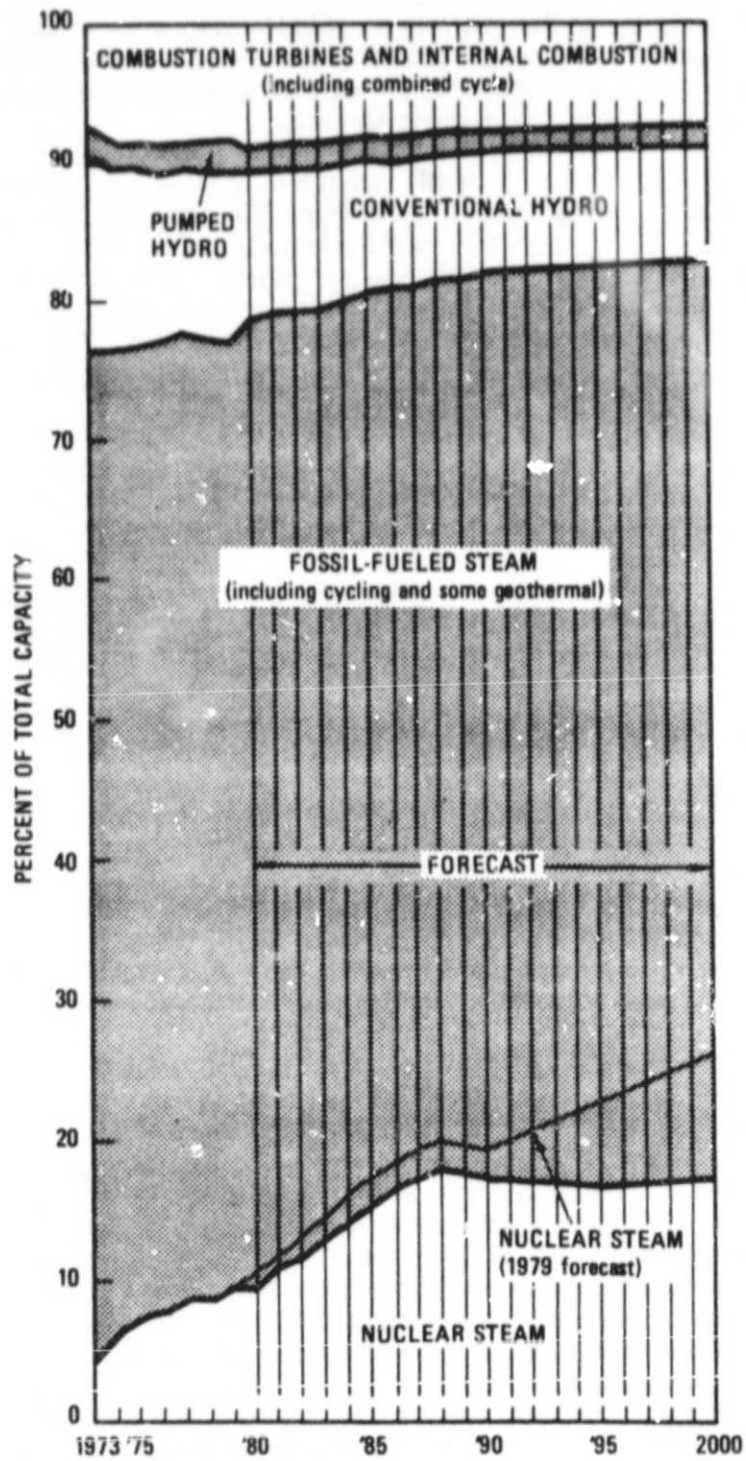
Peaking and intermediate technologies are operated for only a fraction of each year and are capable of being cycled up and down through a wide output range, or of being turned on and off on a daily basis. Base load units are operated continuously for most of the year, intermediate plants for perhaps 1,500-4,000 hours, and peaking plants for a few hundred to 1,500 hours per year.

#### 4.1.1.2 Future Trends

The probable mix of electric generating capacity to the year 2000, as predicted in the 31st Annual Electrical Industry Forecast, is illustrated in Figure 4-3. As can be seen, they anticipate little change from the present technology mix. Capacity additions to the year 2000 are projected in terms of five generation modes in Table 4-6. The values given in this table are gross rather than net additions since gross figures provide the basis for new-construction estimates. In deriving the need for this capacity therefore, retirements and adverse hydro conditions are accounted for. Although accelerated programs could result in a substantial market penetration of the advanced technologies currently under development, utilities are reluctant to include them in energy forecasts due to the uncertainty surrounding energy supplies, government incentives, and technical or commercial feasibility. The transition from



Figure 4-3. Probable Mix of Net Generating Capacity (Ref. 4.9)



**Table 4-6. Generating Capacity Additions, MW  
(Based on Date of Commercial Operation) (Ref. 4.9)**

	<u>Conventional Hydro</u>	<u>Pumped Hydro</u>	<u>Fossil Steam</u>	<u>Nuclear Steam</u>	<u>Combustion Turbine &amp; I.C.</u>	<u>Total</u>
1969	796	789	14,901	1,163	4,642	22,291
1970	1789	313	16,800	2,513	6,126	27,541
1971	624	219	17,564	2,194	5,705	26,306
1972	382	286	18,455	6,613	6,474	32,210
1973	1594	3,622	24,217	5,770	5,066	40,269
1974	720	1,087	18,874	9,196	6,236	36,113
1975	2,064	305	21,726	7,281	3,524	34,900
1976	300	235	11,908	4,457	2,600	19,500
1977	1,438	485	16,509	5,530	1,647	26,609
1978	1,265	841	14,854	2,162	2,213	23,935
1979	2,632	1,200	10,999	1,874	370	17,075
Forecast						
1980	312	312	17,789	5,034	620	23,967
1981	990	305	10,499	11,880	1,400	25,174
1982	962	862	10,257	8,850	1,780	22,711
1983	1,407	0	8,822	11,900	1,410	23,539
1984	150	0	7,025	11,931	150	19,256
1985	150	92	9,941	10,995	240	21,418
1986	675	675	5,900	12,197	675	20,122
1987	0	0	6,068	5,366	250	11,684
1988	0	0	1,895	7,723	250	9,868
1989	0	0	8,484	1,067	250	9,801
1990	0	0	21,802	0	450	22,252
1995	0	0	28,927	0	800	29,727
2000	0	0	20,000	10,900	1,100	32,000

scientific feasibility to commercial availability for a new energy technology typically takes 20 to 40 years, assuming everything works perfectly. Similarly, decades may be required from the time of commercial introduction to the time of significant energy impact. Virtually all proposed alternative energy technologies have a long way to go before the demonstration of a system that is feasible technically, economically, and institutionally.

The three-level combination of base, intermediate, and peak generating plants has become increasingly less attractive as sharply rising fuel costs penalize the less efficient peaking units. The need for peaking units can be diminished by time-of-day pricing and the deployment of load management technologies such as utility

storage. In addition, the use of on-site total energy systems employing storage options can provide the flexibility required for peak demands in an energy efficient manner. Nevertheless, the probability is high that the demand for peaking and intermediate units in the year 2000 will be about the same as today. The required reserved capacity is expected to be in the 20-30 percent of installed capacity range under a broad range of growth and load management scenarios (Ref. 4.8). Advanced technologies which make use of renewable energy sources or more efficient use of conventional fuels, will play an important role in meeting these future demands. Fuel cells in utility systems will be competing with these energy storage and generation technologies as well as other conventional technologies to fill this role.

Conventional fossil fuel, nuclear, and hydroelectric technologies have years of operating experience and an established commercial market which enables reasonable projections as to their future utilization. These projections nevertheless, are subject to the various political, economic, and social uncertainties which affect energy use patterns. Market penetration projections for alternative generation technologies, such as fuel cells, solar thermal, and wind, or storage technologies, such as underground pumped hydroelectric, are much less certain. Supporters of these technologies, heralding their potential benefits, tend to be overly optimistic in projecting their commercial potential. This results principally from idealizing market conditions and government support, and from failure to consider the alternative technologies competing for the same market.

#### 4.1.2 Gas Utility Industry

The gas utility industry consists of pipeline and distribution companies involved in the transport of natural, manufactured, mixed, and liquid petroleum gas. It does not include any activities related to natural gas production. Like electric utilities, gas utilities are regulated by public utility commissions and can be either privately or municipally owned. In 1979, gas utility transportation and distribution pipeline systems totalled more than one million miles and sales resulted in nearly \$40 billion in revenues (Ref. 4.3).

Natural gas sales for 1979 are presented in Table 4-7 by region and end use sector. The gas sales of  $1.5 \times 10^{10}$  Mcf to end users other than the electric utility industry are much greater than the  $3.4 \times 10^9$  Mcf consumed by the electric utility industry. The greatest consumption of natural gas occurs in the Midwest, Southwest, and Far West. Gas sales are comparatively low in New England, and to a lesser extent the Southeast and Mountain States. Industry, with the fewest customers, consumes the greatest amount of gas, followed in order by the residential and commercial sectors.

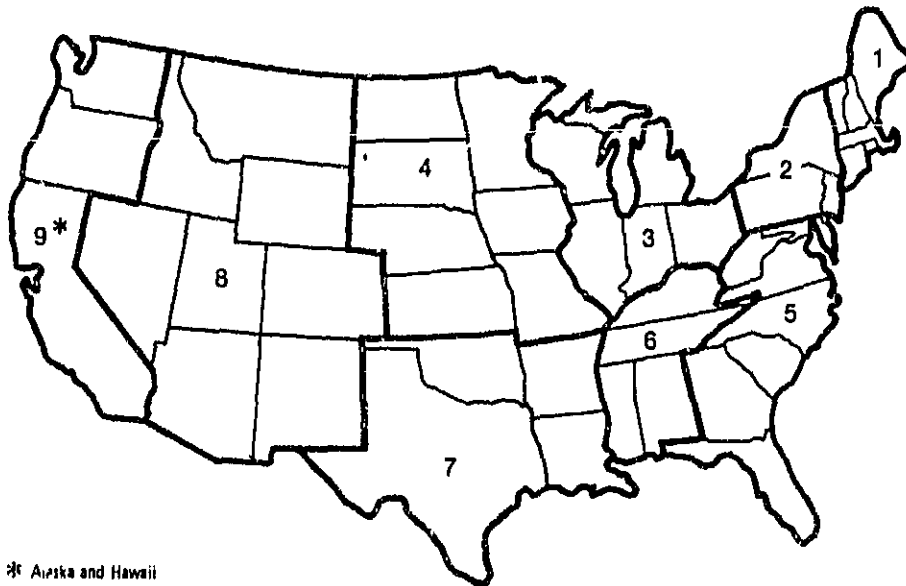
#### 4.1.3 The National Energy Act and Utilities

The National Energy Act of 1978 is composed of five separate pieces of legislation, three of which may influence the degree of penetration and applications of fuel cells in the utility system. The first of these, the Public Utilities Regulatory Policies Act (PL 95-617) encourages utilities to structure their retail rates in a way that would promote conservation of energy, efficient use of facilities and resources, and equitable rates to electric consumers. Cogeneration is encouraged through exemption from certain federal and state regulations and the requirement that electric utilities purchase excess electrical production from grid-connected cogenerators.

Table 4-7. Gas Utility Industry Sales for 1979 by Sector and Region  
(Does not include sales to the electric utility industry)  
(In Trillion Btu) (Ref. 4.3)

<u>Region</u>	<u>Residential</u>	<u>Commercial</u>	<u>Industrial</u>	<u>Total</u>
1	137	73	72	286
2	775	281	504	1,593
3	1,642	748	1,502	2,902
4	550	313	615	1,489
5	348	206	615	1,236
6	213	115	452	799
7	459	254	2,362	3,220
8	278	175	435	908
9	<u>681</u>	<u>321</u>	<u>999</u>	<u>2,009</u>
Total	5,083	2,486	7,555	15,440

Regions Defined



\* Alaska and Hawaii

Electric and gas utilities can be expected to respond to this law by deploying fuel cells as cogenerators as much as possible. Although this has been a prime objective of the gas utilities for on-site systems, it is less of a concern for the electric utility multi-megawatt dispersed systems. Because gas utility fuel cell customers will be able to sell excess electricity to the grid, they can increase the efficiency of the fuel cell system by tailoring its operation to particular load requirements. Conversely, since the electric utility must purchase small amounts of electricity from many disparate independent producers, the timing and volume of their input may not

be as reliable as utility generated power. The electric utility will be left to match supply regularities with grid demands and thus may require a larger and costlier generating reserve. These problems are further discussed in Section 4.1.4.

The two other acts which will influence the way utilities deploy fuel cells concern fuel use. The Power Plant and Industrial Fuel Use Act (PL 95-620) is designed to eventually phase out the combustion of natural gas and oil in power plants while increasing the use of coal. The Natural Gas Policy Act (PL 95-621) calls for the decontrol of natural gas and establishes other measures designed in part to encourage production of natural gas. Taken together, these Acts would increase natural gas supplies for uses other than power plant combustion. Although the utilization of natural gas in fuel cell power plants is presently not restricted, a significant market penetration of natural gas-dependent fuel cell units would be contrary to the intentions of these two Acts. Electric utilities realize that commercial success will depend upon the development of fuel cell systems capable of using synthetic coal fuels. On the other hand, the increased gas supplies available to the gas utilities from deregulation and steam power plant fuel restrictions should serve to encourage the growth of on-site fuel cell units powered by natural gas.

#### 4.1.4 Cogeneration: Applications and Utility Involvement

In broad terms, cogeneration denotes any form of the simultaneous production of electrical or mechanical energy and useful thermal energy (usually in the form of hot liquids or gases). Cogeneration systems include dual-purpose power plants, waste-heat utilization systems, certain types of district-heating systems, and total-energy systems. The fundamental difference between a conventional energy system and a cogeneration system is that the conventional system produces either electricity or thermal energy, and the cogeneration system produces both. In most market sections, thermal energy is produced through the operation of equipment such as boilers and furnaces, and electricity is purchased from a utility.

Cogeneration systems are used to some extent by each of the major market sectors of the United States. Over the years, the industrial sector has been cogeneration's steadiest customer in the United States. In 1939, the manufacturing industries purchased 64 percent of the electricity they needed and generated the remainder (Ref. 4.10). Since that time however, industrial firms have been shifting away from cogeneration and relying increasingly on the electric utility industry. By 1977, the purchased share had increased to more than 90 percent. During this period, the quantity of purchased electricity increased 15-fold while self-generated electricity only slightly more than doubled (Ref. 4.10). Because of the changing energy picture and proposed changes in utility rate structures and rules, it appears that cogeneration is once again becoming an attractive option for the future.

Cogeneration systems installed in residential/commercial buildings have never accounted for a large percentage of the total power generated in the United States; currently, they account for less than 1 percent (Ref. 4.11). The development of cogeneration in this sector is a relatively recent phenomenon. Although some installations were in place as early as the 1920s, most did not begin operating until the 1950s. Similarly, cogeneration has never been widely practiced by United States utilities, and currently represents only a small percentage of the total power cogenerated in this country.

The most important internal user requirements that influence system choice are: electrical demand; thermal demand (for process heat, process steam, and heating and cooling); and operational cycle (or the actual time of day that peak energy demands occur). External factors considered in evaluating design options include: the cost and availability of various fuels and hardware; relationships with the local utility; regulations affecting operation; and the proximity of the plant to users (Ref. 4.11). Three broad cogeneration approaches can be pursued by users:

- A system operating independent of the utility grid with no grid connection. Although this approach eliminates the risk of potential utility power blackouts, it is effective only if sufficient equipment redundancy or overcapacity is built-in to ensure reliability. Independent systems have traditionally been sized to meet peak electrical requirements.
- A system operating independent of the utility grid, but having a grid connection for emergency power backup. This approach eliminates the need for on-site emergency backup, while also eliminating most of the risk of potential utility power blackouts.
- A grid-connected system that purchases supplemental electricity from the grid on a regular basis. Equipment is sized to meet the user's normal baseload electrical requirements, and electricity is purchased for peak load requirements. Supplemental thermal energy and some redundancy in standby equipment may be required.
- A grid-connected system that regularly purchases supplementary electricity from the grid during peak demand periods and sells excess electricity to the grid during periods of low demand. Equipment can be sized to achieve the optimal combination of performance, cost, and revenue factors.

Significant cogeneration development in a utility service area could severely affect the financial position of the utility. The loss of baseload customers, particularly large industrial users, could alter the utility electric load patterns so as to increase the cost of producing a unit of electricity. The revenue lost by the utility as a result of the loss of large customers, coupled with the increased cost per kilowatt-hour of electric energy produced, could sharply reduce the financial return to the utility.

Interconnections between utility grids and cogeneration plants also create concerns for utility managers. Generally, the utilities want to maintain dispatching control over the electric power entering the grid to ensure system stability and security. If the purchased power is significant in amount, the utilities want guarantees as to the time of delivery, the amount, and the length of the agreement, among other considerations. In addition, virtually all utilities are concerned about precipitous government action that recognizes only the industrial point of view, and fails to take into account the total economics of the utilities, and the impact on the various consumers of electric power (Ref. 4.12).

Most utility concerns would be eliminated, or greatly negated, under utility ownership, joint ownership, or third-party ownership arrangements. Utilities with ample capacity (high reserve margins), however, might still regard industrial cogeneration negatively unless the return from these plants was increased. This issue was addressed in the Public Utilities Regulatory Policies Act of the National Energy Act which exempted cogenerated power from certain state and federal regulations pertaining to electric utility rates. This exemption allows utilities to receive a greater than regulated rate of return, if the economics otherwise allows it.

#### 4.1.5 Heating, Ventilation, and Air Conditioning Systems

On-site fuel cell units, and to a lesser extent utility fuel cell systems, will substantially affect the way in which buildings are currently heated and cooled. Three approaches can be employed for building heating and cooling, including: (1) on-site combustion of fossil fuels, (2) on-site equipment utilizing electricity, and (3) hot water or steam brought in from off-site. Several heating, ventilation, and air conditioning (HVAC) systems in a variety of configurations have been designed using these approaches.

As cogenerators, fuel cells produce both electricity and excess thermal energy; thus they can be easily interfaced with equipment which uses these energy forms. However, to maximize the efficiency of the fuel cell it is desirable to use thermal energy for room conditioning where possible, conserving electricity for more appropriate uses. For this reason, fuel cell deployment should spark demand for such thermal heating and cooling equipment as cast-iron radiators and convectors and adsorption chillers. Conversely, demand for electric HVAC equipment such as air conditioners and resistance heaters may decrease. In addition, the deployment of on-site fuel cell units will substitute the use of byproduct thermal energy for conventional fossil fuel-fired furnaces, stoves, and burners. This will correspondingly reduce demand for these types of heating equipment.

Central air conditioning systems are widespread in commercial and many residential buildings although individual room units are often used in the latter. Most systems rely on a mechanical compression cycle utilizing a compressor-condensing unit, a refrigerant circulation system, and an air moving device (fan). Another option, adsorption chillers, substitute a physiochemical process for the purely mechanical process of the compression cycle. Since waste thermal heat rather than electricity provides the energy source in this system, it is ideal for fuel cell applications.

Heat pumps operating in reverse can also be used to provide space cooling. Since these devices are designed to function in a moderate climate where the air conditioning load is larger than the space heating load, they are more often found in mid to southern regions. Because heat pumps provide both winter heating and summer cooling, sizing of the unit to meet a particular building's heating and cooling loads most economically is more complicated than for furnace/air conditioner applications. The situation is somewhat simplified because the heat pump need not be designed to meet the maximum heat load; supplementary thermal heating can be used when required.

Several types of heating equipment can be used depending on the available energy source. Generic categories include central furnaces, unit heaters, radiant panel heating, radiators, heating stoves, and mechanical stokers. Energy sources for this equipment range from electricity and fossil fuels to solar energy. Production figures for several types of heaters are provided in Table 4-8, along with similar information concerning cooling equipment.

Table 4-8. Quantity of HVAC Units Manufactured in 1978 (Refs. 4.13, 4.14)

<u>Description</u>	<u>Quantity</u>
<u>Heating</u>	
Oil Burners (burners and units)	
Residential	742,080
Commercial and Industrial	68,442
Cast-Iron Boilers (1000 lb)	135,685
Cast-Iron Radiators and Convectors (1000 ft <sup>2</sup> )	6,900
Domestic Heating Stoves	2,053,589
Other Heating Equipment (except electric)	
Floor and Wall Furnaces	432,868
Gas-Fired Unit Heaters	178,020
Duct Furnaces	25,422
Hot Water Storage Tanks	6,448
Mechanical Stokers	1,207
Solar Energy Collectors	170,611
Electric Comfort Heating Equipment	
Central Systems	361,255
Air Space Heaters	9,512,111
<u>Cooling</u>	
Room Air Conditioners and Dehumidifiers	4,379,446
Unitary Air Conditioning	3,224,353
Heat Pumps (except room air conditioners)	613,772
Adsorption Chilling Systems	2,704

#### 4.2 The National Environment: Impacts of Electricity Generation on Environmental Quality

According to the Council on Environmental Quality, air and water quality throughout the nation has generally been improving. However, problems remain in many areas, and in a few, conditions are actually deteriorating. Solid waste disposal hazards have only recently been addressed and the climatic phenomena of acid rains and atmospheric CO<sub>2</sub> buildup are still the topics of heated debate.



The production and conversion of energy resources contribute significantly to pollution problems throughout the country. Indirectly, by requiring less energy resources than conventional systems to generate a unit of electricity, fuel cells will proportionately reduce the environmental impacts associated with energy development, production, and transportation. However, since these benefits are peripheral, they are not the primary focus of this assessment. On the other hand, the operation of fuel cell power plants provides substantial environmental benefits when compared with conventional electricity generation systems. Environmental data from these systems are therefore presented where possible, forming an information base which can be used to evaluate the impacts of fuel cell commercialization (Section 5).

#### 4.2.1 Air Quality

In general, air quality throughout the nation has been improving. Combined data from 23 major metropolitan areas show that the number of unhealthful days declined by 18 percent between 1974 and 1978 (Ref. 4.15). Air quality is defined as unhealthful when any one of five primary air pollutants (particulates, carbon monoxide, sulfur dioxide, nitrogen dioxide, and oxidants) exceeds the National Ambient Air Quality Standards (NAAQS). The nation as a whole is showing similar improvements; nevertheless, severe air quality problems continue to plague several major urban areas. Data compiled in 1978 indicate that New York and Los Angeles experienced air quality in the unhealthful range for 174 and 206 days, respectively. In other cities such as Kansas City and Houston, air quality deteriorated over the 1974-1978 period.

The five primary pollutants account for more than 90 percent of the nationwide air pollution problem. The major sources of each are summarized in Tables 4-9 and 4-10. According to the information in these tables, transportation, which is the main source of carbon monoxide (CO), also contributes significantly to the nitrogen oxide (NO<sub>x</sub>) and hydrocarbon (HC) load. Stationary combustion sources are responsible for a large percentage of particulate and NO<sub>x</sub> emissions and most of the sulfur oxides (SO<sub>x</sub>) produced in the nation. Since fuel cells will displace conventional stationary combustion sources, problems associated with these last three pollutants are the most relevant. Figures 4-4 and 4-5 identify the areas which are not expected to be in compliance with national standards for sulfur oxides and particulates by 1982. High NO<sub>x</sub> levels are expected to remain a problem in parts of Southern California, Cook County (Chicago), and Denver (Ref. 4.16).

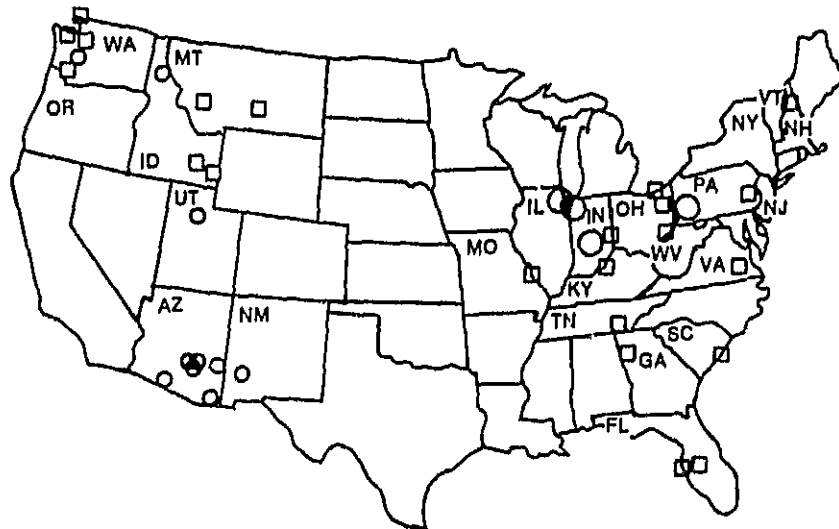
Table 4-9. Major Air Pollution Sources — United States 1975 (Ref. 4.17)

Source Category	<u>10<sup>6</sup> metric tons/year</u>				
	<u>Particulates</u>	<u>SO<sub>x</sub></u>	<u>NO<sub>x</sub></u>	<u>HC</u>	<u>CO</u>
Transportation	1.2	0.7	9.7	10.6	70.4
Stationary Combustion	6.0	23.9	11.3	1.3	1.1
Industrial Processes	7.9	5.2	0.6	3.2	8.6
Solid Waste	0.5	0.1	0.2	0.8	3.0
Miscellaneous	<u>0.7</u>	<u>0.1</u>	<u>0.2</u>	<u>12.2</u>	<u>4.5</u>
Total	16.3	30.0	22.0	28.1	87.6

Table 4-10. Emissions from Stationary Combustion Sources  
(Percent of total) (Ref. 4.17)

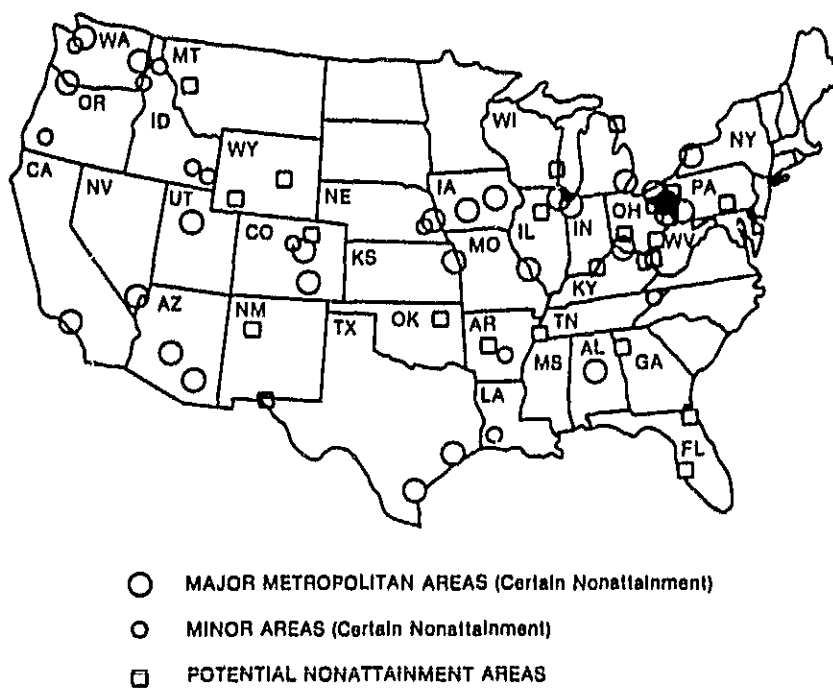
Source	Particulates	SO <sub>x</sub>	NO <sub>x</sub>	HC	CO
Electric Generation	63.8	72.5	64.8	34.0	33.6
Industrial	28.3	14.5	24.7	22.3	14.9
Commercial/ Institutional	4.9	6.7	7.3	12.2	7.7
Residential	<u>3.0</u>	<u>6.3</u>	<u>3.2</u>	<u>31.5</u>	<u>44.7</u>
Total	100.0	100.0	100.0	100.0	100.0

Figure 4-4. Areas Not Expected to Be in Compliance with the Sulfur Dioxide  
Primary Standard by 1982 (Ref. 4.16)



- MAJOR METROPOLITAN AREAS (Certain Nonattainment)
- NONFERROUS SMELTER AREAS (Certain Nonattainment)
- POTENTIAL NONATTAINMENT AREAS

Figure 4-5. Areas Not Expected to be in Compliance with the Total Suspended Particulates Primary Standard by 1982 (Ref. 4.16)



The major source of sulfur oxides in the atmosphere by far is the combustion of fossil fuels for electric power generation. Over the past two decades, the shift to cleaner (low sulfur) fuels such as oil and natural gas resulted in a significant decline in  $SO_x$  emissions. This trend has leveled off in recent years and further improvements are jeopardized by new federal policies encouraging the use of coal for power generation. The increased  $SO_x$  emissions from this fuel shift however, is expected to be mitigated through pre-combustion coal cleaning, improved air pollution control equipment, and the growth of clean alternative generation technologies based on synthetic fuels.

As seen in Figure 4-4, particulates are a widespread air pollution problem, and virtually no area of the country is free from violations of the national standard. On this map the total air quality control region is shaded even if only one monitoring station reports a violation; thus, the actual number of people exposed is exaggerated. During the 6 years from 1973 to 1978, the average annual particulate concentration decreased about 7 percent (Ref. 4.16). This reduction is largely the result of controls on industrial facilities and other stationary sources of emissions. Despite this improvement, approximately 20 percent of the nation's population still live in areas where the annual standard is exceeded. Improvement rates have differed in various parts of the country, with greater improvement in the Northeast and Great Lakes areas and lower rates in some Western states which have significant natural sources of particles.

The clean power from fuel cells can help alleviate another problem which has recently received public attention--acid rainfall. NO<sub>x</sub> and SO<sub>x</sub> emissions, primarily from stationary combustion sources, combine with water in the atmosphere to form acids thereby lowering the pH of the subsequent rainfall. Acid rains harm crops, fish, and timber, and also damage building materials, outside stone and concrete work, and some metallic equipment. In general, the eastern half of the country is experiencing the greatest problems from acid rainfall. Emissions originating from stationary combustion sources in the Midwest in particular have been blamed for acid rainfall conditions in the Northeast states and eastern Canada.

#### 4.2.2 Water Quality

The Water Resources Council in its Second National Assessment has analyzed the water data base in an effort to identify and describe water resource problems in the United States (Ref. 4.18). By establishing a base period, 1975,\* and studying future water use and consumption trends, the Council has projected water resource conditions over a 25 year period ending in the year 2000. The water resources of the nation have been characterized according to the general level of quality and quantity based on data supplied by 21 water resource regions throughout the country. These 21 regions in turn represent 106 subregions which are the basic data collecting units. Subregional data point out problems that are primarily basinwide in nature and thus may not adequately identify specific local or point source problems. Overall, however, data aggregated from the subregions portray both regional and national conditions, and also the wide contrasts in both regional and national water sources and uses.

Several regions are now, or will soon be, suffering from water resource problems related to the increasing water demands of various competing users. The areal extent of these problems, as identified by federal and state/regional study teams, is mapped in Figures 4-6 through 4-11. Nationally, the United States has an ample supply of water from both surface and underground sources. However, there can be regional or local shortages of water because of the uneven distribution of precipitation. Water shortages, which can occur in any season and in any part of the nation, generally are associated with the arid West, but many humid eastern localities also have periodic water supply problems. At times, inadequate water supplies can be caused by poor quality of water or by economic, social, and environmental constraints.

Environmental control efforts over the last decade to improve surface water quality are beginning to show results. Data suggest that the quality of surface waters is no longer deteriorating despite the increasing demands on this resource. Factories, municipal treatment facilities, and other point sources of pollution are gradually coming under control, although street and farm runoff and other nonpoint sources remain serious sources of surface water pollution. There is increasing evidence that the groundwater resources of many locations are being contaminated and serious efforts to contain and reverse this trend have just recently been initiated.

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\*1975 is the base year for the Second National Water Assessment data. It represents assumed average conditions at that time rather than actual 1975 data.

Figure 4-6. Inadequate Surface Water Supply and Related Problems (Ref. 4.18)

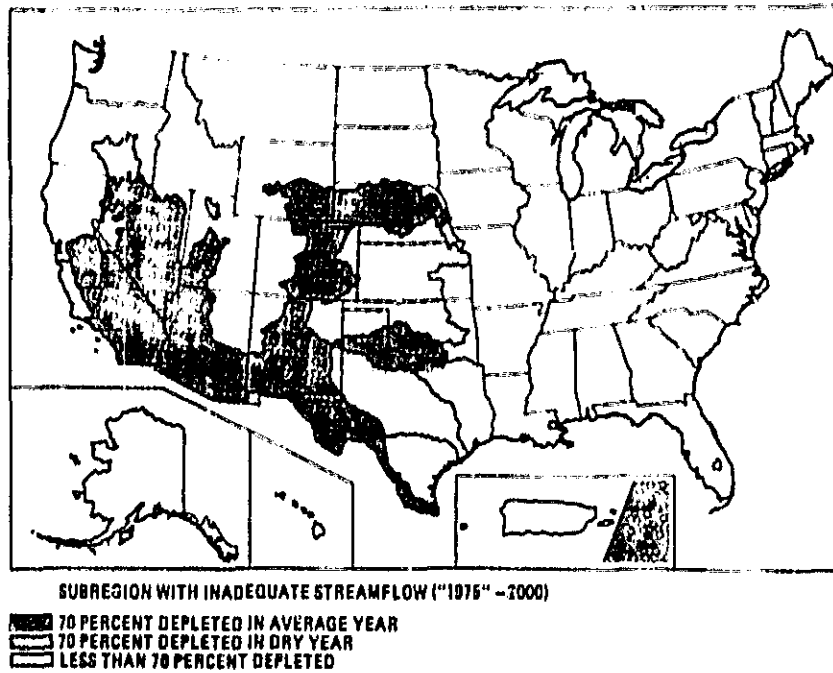


Figure 4-7. Ground Water Overdraft and Related Problems (Ref. 4.18)

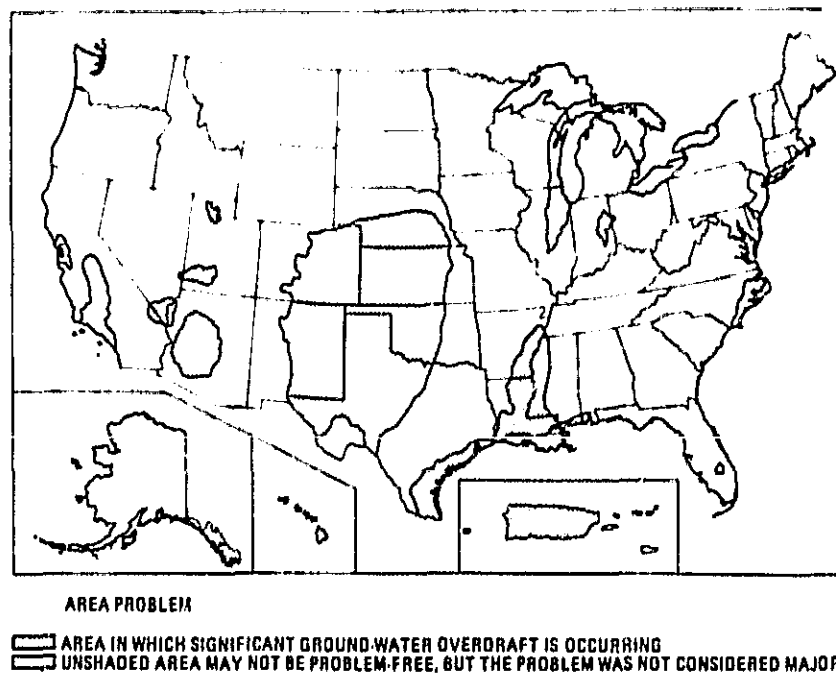


Figure 4-8. Surface Water Pollution Problems from Point Sources  
(Municipal and Industrial Waste) (Ref. 4.18)

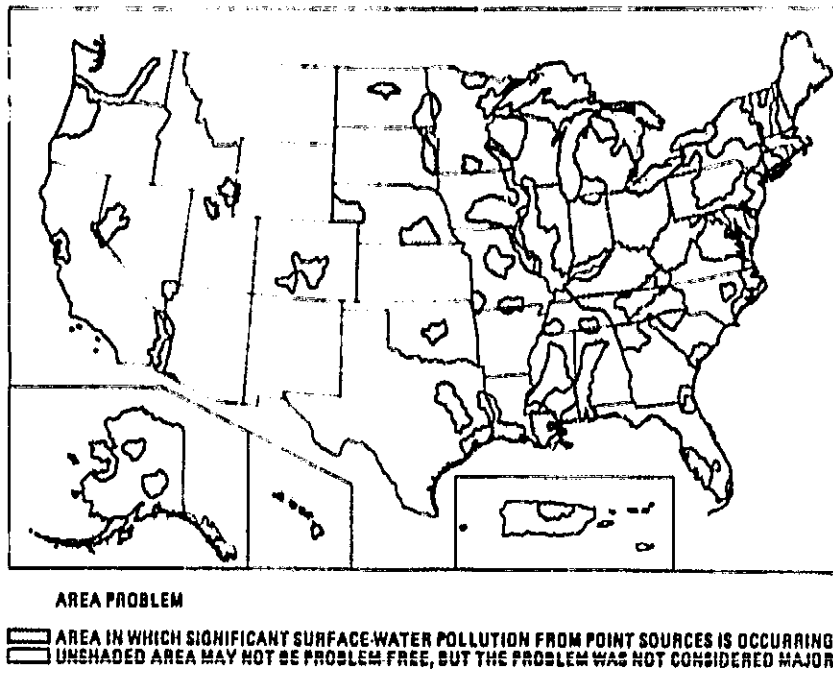


Figure 4-9. Surface Water Pollution Problems from Nonpoint Sources (Ref. 4.18)

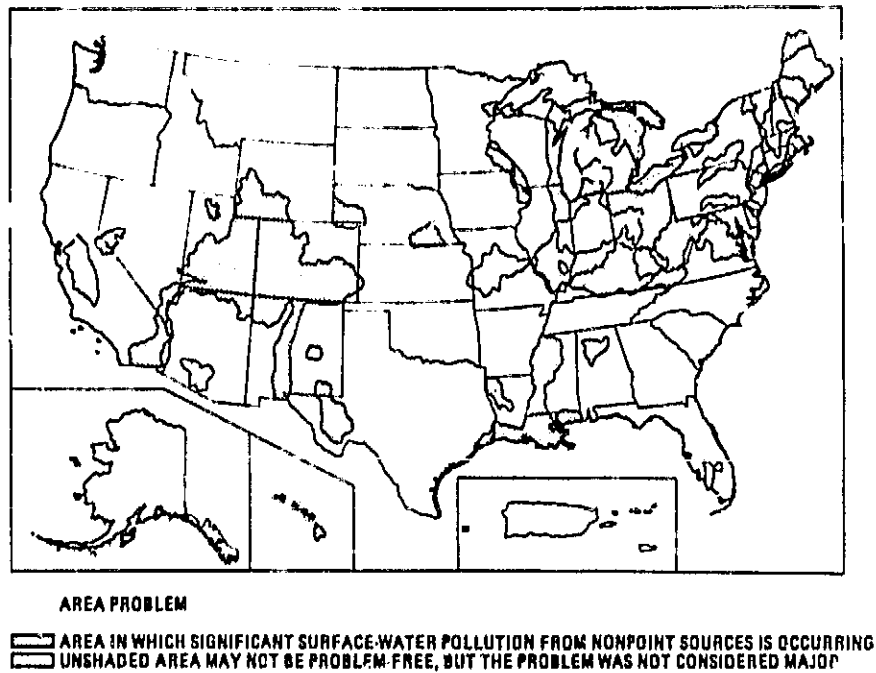


Figure 4-10. Ground Water Pollution Problems (Ref. 4.18)

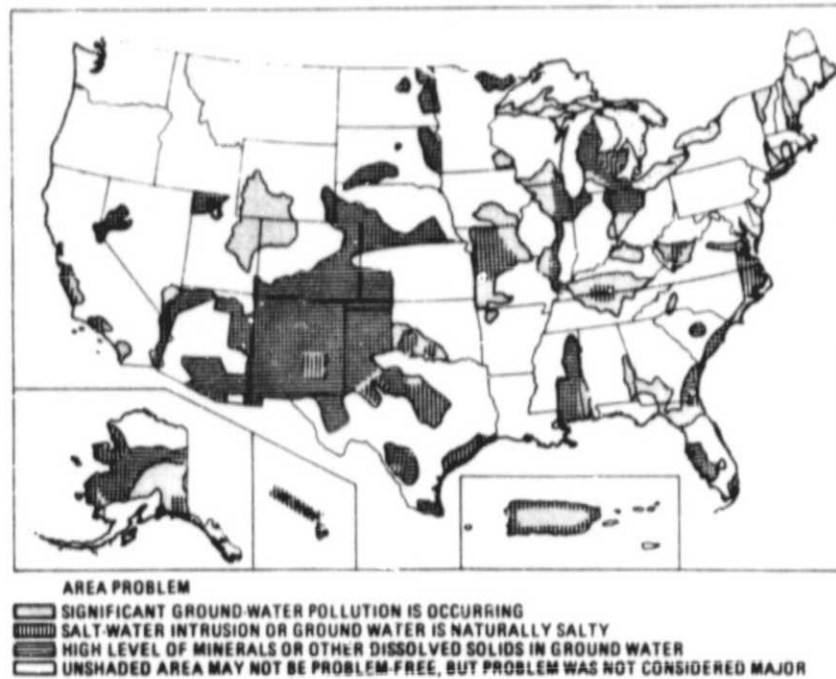
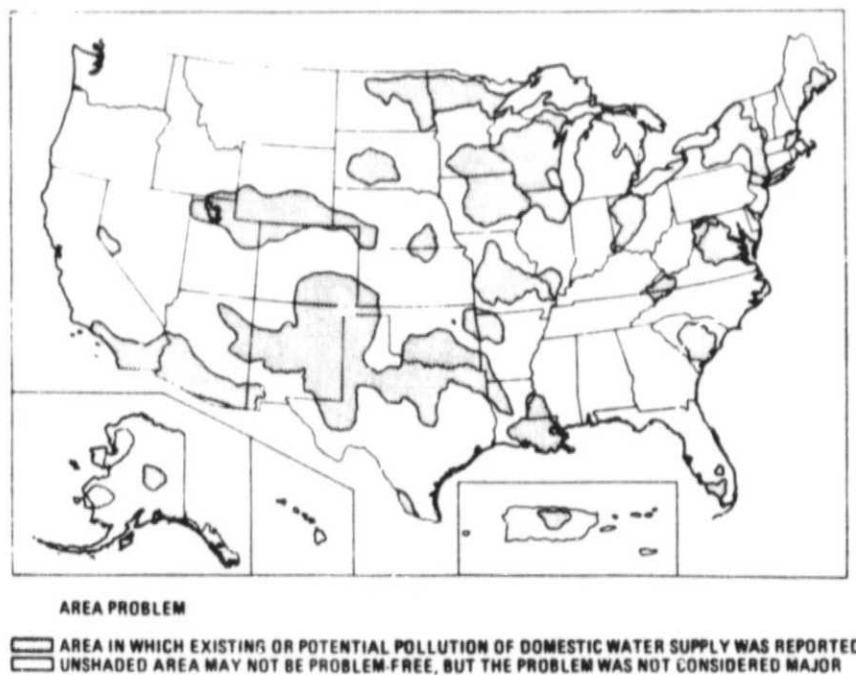


Figure 4-11. Drinking Water Quality Problems (Ref. 4.18)



The production, distribution, and conversion of energy resources pose serious problems with regard to water quality and availability. The widespread use of fuel cells can serve to mitigate many of these impacts, primarily those which are associated with the generation of electricity. The most serious water resource impacts from the operation of conventional power generation systems stem from the use of large quantities of water for cooling purposes. Withdrawal of cooling water results in biological impacts through the entrainment and impingement of aquatic organisms at the intake structures, and water quality degradation from the lowered dilution capacity of the source stream. In completing the cycle, this cooling water is often returned to a receiving body of water at a temperature perhaps 10°C higher, a practice generally detrimental to the biota near the point of discharge.

In water-short areas, the need for water for power generation must be balanced against other major water needs such as agriculture and municipal water supplies. Currently the water requirements for steam-electric energy facilities comprise a major portion of total withdrawal and a smaller portion of total consumption in most river basins of the eastern United States, reaching 74 percent of withdrawal and 18 percent of consumption on the Tennessee River (Ref. 4.19). Withdrawal refers to the entire volume of water required for circulation through a facility, whereas consumption refers only to the portion that is consumed and is not available for further use (e.g., evaporative loss). In the western part of the country, percentages of withdrawal and consumption are much lower, due to the large requirements of irrigation and the lower electricity demand. Nonetheless, water shortages are already apparent and in many areas, new uses for energy will have to come at the expense of traditional consumers. Table 4-11 describes the total national water use by steam-electric power plants in the United States in 1975 and gives projections for the years 1985 and 2000.

**Table 4-11. Water Use by Steam-Electric Power Plants (Ref. 4.20)**

	<u>Withdrawal (<math>10^6 \text{ m}^3/\text{day}</math>)</u>			
	<u>Fresh</u>	<u>Saline</u>	<u>Ground</u>	<u>Total</u>
1975	350.0	176.9	1.0	527.9
1985	328.0	298.0	1.4	627.4
2000	265.0	355.6	0.6	621.2
	<u>Consumption (<math>10^6 \text{ m}^3/\text{day}</math>)</u>			
1975	4.6	1.2	3.1	8.9
1985	14.6	3.0	0.6	18.2
2000	34.3	8.8	0.3	43.4



There are four major options to provide cooling for steam-electric power plants: (1) once-through cooling, (2) cooling ponds, (3) wet cooling towers, and (4) dry cooling towers. Once-through systems have been the preferred choice of utilities in the past because of their low cost and the fact that they require no additional land for the power plant. However, because there have been growing concerns about the potential environmental impacts of these systems (i.e. thermal pollution, biological entrainment, and water requirements), the federal government has attempted to restrict their use. Thermal discharges from once-through cooling systems are prohibited by the Federal Water Pollution Control Act (PL 92-500) after July 1981 for plants built subsequent to January 1, 1970 unless the utility can demonstrate that the thermal limitations are unnecessarily stringent. It should be noted that although once-through systems require a large intake of water, they consume very little.

Any one of the other three closed-cycle cooling systems may be chosen to reduce the dependence on large amounts of water. Cooling ponds are usually the next most economic and efficient. However, they require substantial land areas, and pond evaporation represents a significant amount of water consumption. Wet cooling towers (natural or forced draft) require much smaller amounts of water than once-through systems and need less land compared to cooling ponds. Environmental concerns for these systems center on the possible local climatological effects of humidity and fogging from evaporation, and the impact of the large tower structures and their associated plumes on visual aesthetics. Although dry towers avoid the problems associated with open evaporation and consume very little water, they tend to reduce plant efficiency and cost three to five times as much as wet towers (Ref. 4.21). A comparison of the characteristics of these four cooling systems is provided in Table 4-12.

**Table 4-12. Typical Characteristics for Cooling Systems  
Based on a 1000 MWe Plant (Ref. 4.21)**

Cooling System	Capacity (MW)		Water ( $10^6 \text{ m}^3/\text{yr}$ )		Land Requirement (hectares)	Plant Efficiency	Incremental Cost of Electricity Above <sup>a</sup> once through**
	1975	2000	Withdrawn	Consumed			
Once-through	249,000	322,000	1,140	small	0	38	--
Cooling Ponds	54,000	218,000	34	21	420	38	6.0
Wet Cooling Towers	79,000	1,312,000	22	13.6	Unknown	37.5	2.5
Dry Cooling Towers	23	67,000	0.25	0	Unknown	35	17.0

<sup>a</sup>In 1970 U.S. dollars/kWe

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OF POOR QUALITY

Although water consumption for power generation will continue to grow, the trend toward closed-cycle systems will level off water withdrawal demands by 1985 (see Table 4-11) by reducing the number of individual power plants which require massive amounts of operational cooling water. Once-through systems, which accounted for approximately 65 percent of the cooling in 1975, are projected to account for only 16 percent by the year 2000 (Ref. 4.20). They will remain the second most popular system however, employed almost exclusively on the Great Lakes and coasts. Approximately two-thirds of the cooling requirements in 2000 are expected to be met by wet towers, which the Environmental Protection Agency (EPA) has endorsed as the "Best Available Technology". A small but significant fraction of new plants are slated to employ dry cooling systems.

Waste heat, either discharged into the water (once-through systems) or air (cooling towers), can produce significant environmental impacts. The temperature rise for water passing through the cooling system is generally from 6-11°C (Ref. 4.20). A water temperature increase of 10°C will double the oxygen consumption of fish and at the same time reduce the available oxygen in the water. Other effects of elevated temperatures on aquatic organisms are a decreased ability to resist predators, decreased resistance to fungus and disease, increased respiration and metabolic rates, increased growth rates affecting productivity and mortality, and interference with spawning activities. In addition, temperature changes can alter species composition through competitive replacement of some species by others more tolerant of the new temperature regime. Thermal discharges from cooling towers may result in fogging or icing conditions creating hazards for local surface vehicles.

#### 4.2.3 Noise

One of the major benefits of fuel cell power systems is that they are relatively quiet, an important quality which allows them to be sited near population centers. The large multi-megawatt units will for the most part be sited in areas zoned for industrial development and their noise levels, which are low by industrial standards, will be of little concern. Since the smaller on-site units will be located in residential and commercial areas as well, their operational noise emissions will need to be much more closely scrutinized.

The past two decades have seen a dramatic increase in the number of noise sources. There are more vehicles on our highways, more typewriters, air conditioners, noise producing "labor-savers," and more industrial plants. One finding of the Urban Noise Survey, conducted by the EPA in 1976, is that no single noise stands out in people's minds. In areas not directly exposed to freeway or aircraft noise, most people think of community noise as a general din, made up of many sources rather than one or two (Ref. 4.22). When specific noise sources were cited, motor vehicles ranked highest.

An estimated 15 million Americans regularly work in potentially hazardous noisy environments. Records from an insurance industry study show that noise-induced hearing loss is the occupational health hazard that affects most workers and for which financial claims are greatest. Since 1969, nearly \$200 million has been paid for such claims to federal employees alone, and the prospect is that the number of claims and amount of awards will increase rapidly in the next 10 years (Ref. 4.22).

Noise can effect people, wildlife, structures, and sensitive equipment in a variety of ways. Effects of noise on people are defined as either primary (temporary or permanent hearing damage) or secondary (interference effects on speech, recreational activities, or sleep). Principal impacts on wildlife involve interference with behavioral patterns. Many animals use acoustic signals for detection of prey or predators, locating young, establishing territoriality, and for mating calls. Noise sources can also weaken structures, either from a sudden intense vibration or from continuous low-level vibration producing material fatigue.

EPA guidelines to protect against primary and secondary health effects are listed in Table 4-13. The level required to protect against activity interference is based on the ability to understand speech sounds with 100 percent intelligibility. To protect against hearing loss and health effects, EPA has recommended that the maximum average 24 hour exposure to noise sources be limited to 70 dBA. A level of 75 dBA may be considered safe for an 8 hours workday so long as the exposure over the remaining 16 hours is low enough to result in a negligible contribution to the 24 hour average, i.e., no greater than a level of 60 dBA (Ref. 4.23).

Annoyance resulting from noise involves the subjective response of people. In general, as noise levels increase, community reaction increases in magnitude and intensity. About 90 million people in the United States presently live in noise environments exceeding an  $L_{dn}$  of 55 dBA; thus, achieving the recommended EPA guidelines for the whole population would be quite difficult. Average noise levels for urban areas range from 60-70 dBA while quiet suburban residential areas have an average  $L_{dn}$  of 50 dBA. Typical noise levels in rural settings are 30-35 dBA, and in wilderness locations they are on the order of 20 dBA (Ref. 4.23). Examples of noise levels from individual sources are presented in Table 4-14.

Noise standards and criteria have been developed at all levels of government based on consideration of the various effects of noise. While primary responsibility for control of environmental noise rests with state and local agencies, federal action is often the most effective way to deal with the control of major noise sources such as transportation or construction equipment. The importance of government noise regulations, practices, and guidelines with regards to fuel cell commercialization is detailed in Section 7.2.4.

Several noise sources are associated with energy technologies. Most of the noise emissions are not unique to any one technology or even to the energy field as a whole, and generally are many of the same sources that Americans encounter daily. The noise characteristics of conventional power generation technologies are well known. Typical noise sources include:

- Coal-handling machinery (stacker reclaimers, bulldozers, conveyors, car shakers, crushers)
- Burners
- Boiler draft fans
- Pumps for condensate, boiler feed water, condenser cooling water, etc.
- Steam valves and piping

Table 4-13. Yearly Average Equivalent Sound Levels Identified As Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety (dBA) (Ref. 4.24)

Measure	Indoor			Outdoor		
	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects
Residential with Outside Space & Farm Residences	45	— 70	45 —	55 —	— 70	55 —
Residential with No Outside Space	45	— 70	45 —	NA	NA	NA
Hospitals	45	— 70	45 —	55 —	— 70	55 —
Educational	45	— 70	45 —	55 —	— 70	55 —
Commercial	*	70	70	*	70	70
Inside Transportation	*	70	70	NA	NA	NA
Industrial	*	70	70	*	70	70
Recreational Areas	*	70	70	*	70	70
Farm Land & Genl Unpopulated Areas	NA	NA	NA	*	70	70

\* Since different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult except in those circumstances where speech communication is a critical activity.

$L_{dn}^{eq}$  = The weighted average of the noise of the nighttime hours as compared to that occurring during daytime hours of greater activity.

$L_{eq}$  = Equivalent, steady noise level that, in a stated period of time, would contain the same noise energy as the time-varying noise during the same time period.

- Precipitator rappers
- Safety valves
- Ash-handling equipment
- Cooling towers or spray ponds
- Other auxiliary equipment.

When cooling towers are installed at large, carefully designed steam-electric generating stations, they are usually the dominant noise source affecting the surrounding community. Thus, they set the limit for compliance with applicable community noise ordinances. Transformers, at substations as well as electric power plants, are a familiar community noise source. Forced- and induced-draft fans, which are used on all large, modern fossil-fueled boilers, can produce high noise and vibration levels. They are a common source of community noise complaints, particularly when the fan flow is reduced for low-load operation. Smaller intermediate and peaking units generally have lower noise emissions, and since they are designed to operate during daylight hours and on weekends, noise effects on the public will be less severe.

**Table 4-14. Scale of Noise Levels from Various Sources (Ref. 4.23)**

<u>dBA Level</u>	<u>Example</u>	<u>Potential Effect</u>
20	Studio for sound pictures	Threshold of hearing
30	Studio for speech broadcasting	-----
40	Very quiet room	Slight sleep interference
50	Residence	Moderate sleep interference
60	Conventional speech	Communication interference
70	Street traffic at 30 m	Smooth muscles/glands react
80	Light trucks at 6 m	Moderate hearing damage
90	Subway at 6 m	Affect mental and motor behavior
100	Looms in textile mill	Awaken everyone
110	Loud motorcycle at 6 m	Maximum vocal effort
120	Peak level from rock band	Pain threshold
140	Jet plane on the ground at 6 m	Potential hearing loss high

#### 4.2.4 Solid Waste

The amounts of solid wastes generated in the United States are continuously rising. For the most part, these wastes are disposed of on land. The EPA estimates that industrial wastes (including electricity generation facilities) generated in 1977

totaled about 344 million metric tons and that this rate is growing about 3 percent each year (Ref. 4.25). An additional 135 metric tons of solid wastes originated from residential and commercial sources. Sludge and other residues from pollution control are increasing as regulation of pollutants discharged into the air and water becomes stricter.

The principle concerns of solid waste disposal involve the costs of waste management, the shortage of disposal sites in urban areas, and the potential environmental and health effects of disposal. Finding sites for processing and disposal of the growing burden of wastes is increasingly difficult. Land is harder to find and prices are rising, especially in urban areas, and state and federal environmental standards are becoming stricter. In addition, public opposition to waste management operations often block the siting of facilities in areas that are acceptable from environmental and economic viewpoints. The Resource Conservation and Recovery Act of 1970 (see Section 7.2.6) marked the beginning of a concerted federal effort to deal with these problems.

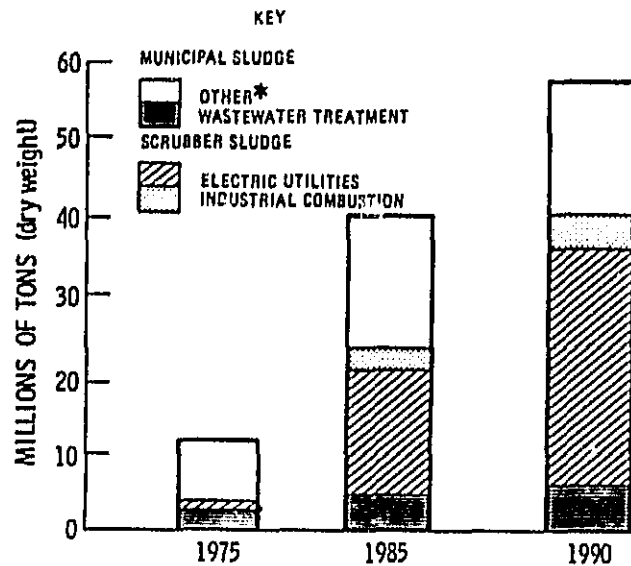
Two types of solid waste are generated by utilities--sludge and noncombustible solid wastes. Sludge is defined as any semi-liquid waste from a chemical or industrial process including scrubber sludge, municipal wastewater treatment sludge, and sludges from other chemical and industrial processes. Most often it is a muddy or slushy deposit requiring special handling for disposal. Noncombustible solid waste (fly and bottom ash, spent shale, etc.) consists primarily of material remaining after combustible material is thoroughly burned or otherwise oxidized. Also included is fly ash which particulate removal devices have captured. While generally less difficult to handle than sludges, the larger volumes and potentially harmful soluble compounds forming noncombustible wastes may create local disposal problems.

Scrubber sludge results from removal of sulfur compounds from the stack gases of sulfur-emitting facilities (primarily coal-fired utilities and industrial boilers) by air pollution "scrubbers." Typically, this sludge is not easily dewatered, and produces an effluent with high concentrations of dissolved solids, primarily sulfates, and heavy metals. The solids also contain leachable, potentially toxic salts. Total sludge generation from all sources is expected to increase nationally by a factor of six between 1975 and 1990. As seen in Figure 4-12, electric utilities did not contribute much to the total sludge generation in 1975; however, due mainly to the New Source Performance Standards (NSPS) of the Clean Air Act Amendments, utilities are projected to contribute more than half of the total by 1990.

Although the percent of total noncombustible solid waste due to electric utilities will decline from about 50 to 40 percent between 1975 and 1990, total volumes are expected to double (see Figure 4-13). Spent shale volumes are forecast to grow from negligible in 1975 to one-fourth of the national total in 1990. Ash resulting from industrial combustion, especially coal, is expected to increase by a factor of about three between 1975 and 1990 (Ref. 4.26).

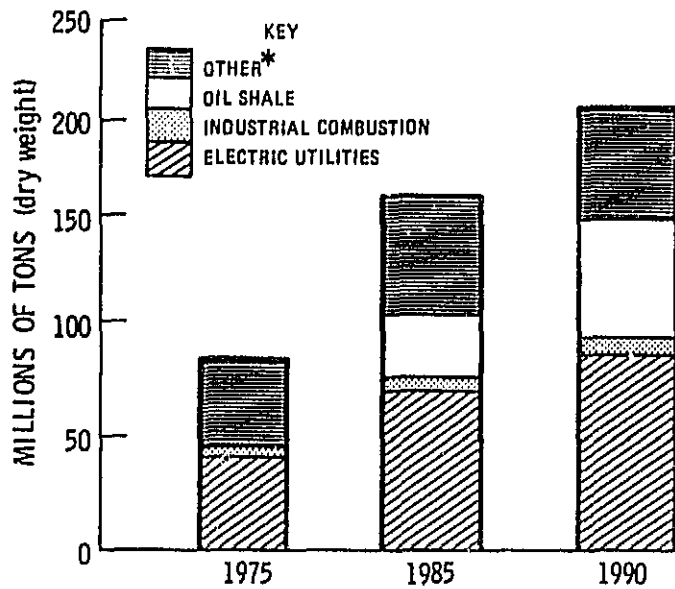
The regions projected to generate the greatest amount of sludge are EPA Regions 2 (New York, New Jersey), 3 (Middle Atlantic), 4 (Southeast), and 5 (Great Lakes). These same regions are also significant producers of ash wastes. In Region 9 (West), sludge generation should remain low in 1990 because of the low sulfur content of the

Figure 4-12. Sludge Generation by Source (Ref. 4.26)



\* INCLUDES RESIDUES FROM PULP, ASPHALT, OIL REFINING, STRUCTURAL MATERIAL, AND STEELMAKING PROCESSES.

Figure 4-13. Noncombustible Solid Waste Generation by Source (Ref. 4.26)



\* INCLUDES PRIMARILY WASTE FROM THE CEMENT AND OIL INDUSTRIES.

coal to be used in that area. The greatest accumulation of noncombustible solid waste is projected to occur in Region 8 (Mountain) because of the huge volumes of spent shale associated with oil shale development in that region.

By 1990, electric utilities and industrial boilers are projected to be the largest sources of both sludge and noncombustible solid wastes. Large volumes of ash and scrubber sludge are difficult to handle and dispose of, particularly in urban areas with high land prices. At present, disposal costs and methods are uncertain, partially because of the regulatory uncertainty surrounding the implementation of the Resource Conservation and Recovery Act (RCRA) (PL 94-580). The total national cost (including operating, maintenance, and annualized capital) of sludge disposal from coal-fired electric utilities in 1990 is projected to be between \$200 and \$500 million (in 1972 dollars) (Ref. 4.26). National costs for ash disposal at this time will range between \$430 and \$800 million.

#### 4.2.5 Climate

The byproducts of energy production and consumption released to the atmosphere, namely waste heat, gases (including water vapor), and particles, can affect climate on a local or regional scale, usually by affecting the atmospheric radiation balance. This can result in changes in local and regional temperature and precipitation patterns. In addition, any technology that alters the characteristics of the surface of the earth over extensive areas (such as the projected use of solar collectors) can also have climatic effects by altering the energy and moisture balances at the surface. Projecting energy use and consumption (and the resulting emission patterns) into the next century reveals that several effects of energy production and consumption have the potential of extending beyond the regional scale, eventually to global proportions (Ref. 4.27).

The buildup of carbon dioxide in the atmosphere has the greatest apparent potential for disturbing the global climate over the next few centuries. The main source of this increase is thought to be the combustion of fossil fuels, although land use practices, particularly deforestation and oxidation of humus, could also be contributing sources. The available reserves of fossil fuel resources are well enough known today to argue that, if burned rapidly enough, atmospheric CO<sub>2</sub> will continue to increase to several times its present value.

The consequences to the climate of increased atmospheric CO<sub>2</sub> have been estimated from computer simulations. These simulations, which indicate that a doubling of CO<sub>2</sub> concentrations would increase the global mean temperature of the lower atmosphere by between 1.5 and 3.0°C, are crude and omit several factors thought to be important (Ref. 4.27). Concerns have been expressed that this temperature rise may result in disruption of ecosystem stability through shifts of temperature and precipitation patterns, erratic or reduced agricultural yields, or rising sea levels from polar ice melting. In addition, marine organisms could be affected by increases in dissolved CO<sub>2</sub> and changes in oceanic circulation. Certainly, both more efficient use of energy and the development of non-fossil energy resources would help reduce the CO<sub>2</sub> growth and could conceivably delay the onset or even solve these potential problems.



Other fossil fuel combustion products may also affect weather and climate. Waste heat contributes to the "urban heat island" effect which causes urban areas to be typically warmer than the surrounding rural regions, in effect creating a distinct microclimate. Particulate and gaseous emissions can induce strong scattering of solar radiation and subsequent temperature changes. Atmospheric particles may also affect the nucleation and condensation of water vapor to form cloud droplets, and thus influence the rates and pattern of precipitation. Heat and moisture from cooling towers have been observed to affect the generation of cumulus clouds. Evaporation processes used to dissipate waste heat may also cause fogging and icing.

#### 4.2.6 Land Use and Aesthetics

Historically, neither the land use planners and developers nor the utilities and oil companies have had to consider the land use implications of producing and consuming energy. The extended period of time in which non-urban land was cheap and energy carriers were highly flexible and inexpensive, encouraged what is commonly referred to as urban sprawl, supported by large, centrally located energy production-distribution systems. There are now clear indications that this pattern of development is encountering severe obstacles and, in many urban and suburban areas, energy planners are now examining the environmental benefits, siting flexibility, and economical attractiveness of the use of small distributed energy systems to meet community requirements. Fuel cell power plants are specifically suited for such applications.

Because central power stations are large industrial facilities with significant pollution emissions, they are located away from population centers in areas considered compatible with energy production activities. The large amounts of land required are relatively inexpensive and alternative land use pressures are few. On the other hand, smaller distributed energy systems are generally sited on more valuable land in suburban and urban areas. On a per megawatt basis, land requirements for these plants may be equal to or greater than central generation facilities. The additional land required for the extensive transmission systems of centrally located utilities tends to equalize this difference in values.

Although the impacts on visual aesthetics are greater for large central stations than dispersed facilities, they may be of less concern since fewer people are affected. Nevertheless, these impacts are considered significant, particularly when energy facilities are constructed in pristine areas. Visual pollution problems characteristic of central generation activities include air emission plumes, reduction in long-distance visibility and depth and color perception resulting from air emissions, power transmission lines and corridors, and the power plants themselves which often modify otherwise undisturbed landscapes.

#### 4.2.7 Health and Safety

While the public health and safety risks associated with nuclear power plants have been the object of significant research, non-nuclear power plant hazards have not been extensively identified or researched to determine their effects on the general public. Not only do these hazards need to be defined, but their impact on the public and the public's willingness to accept the risk, once disclosed, must also be

evaluated. Emissions from power plants are considered the greatest health threat to the general public, with air pollutants constituting the single greatest hazard (Ref. 4.26). Solid waste, noise, and wastewater emissions present a continuous (although controllable) threat to the health of large numbers of people. Of less public concern are those hazards generated by abnormal occurrences, either inside the plant or due to external forces, which result in fires, explosions, or chlorine releases at the plant. These events are considered unusual occurrences and the impacts are limited to a small group of people immediately adjacent to the power plant. Power plant hazards of concern to operating personnel are generally more closely scrutinized and the safety of a power plant is considered a reflection of its injury rate, death rate, and lost-man-year statistics.

Health and safety impacts which affect operating personnel are in general different from those which are of concern to the general public. Worker injuries range from minor industrial accidents to catastrophic system failures resulting in fires, explosions, toxic chemical releases, etc. Compared with these sources of injury, hazards posed by exposure to power plant emissions (air, water, noise, solid waste, etc.) are less significant. Worker health and safety statistics for typical 800 MW oil- and gas-fired steam electric power plants are presented in Table 4-15.

**Table 4-15. Occupation Safety and Health Statistics  
for Representative 800 MW Oil- and Gas-Fired Electric Power Plants  
(Workers/Year) (Ref. 4.28)**

<u>Power Plant</u>	<u>Deaths</u>	<u>Injuries</u>	<u>Mandays Lost</u>
Oil-Fired	0.00181	0.173	7.20
Gas-Fired	0.00175	0.167	6.94

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## 5. DESCRIPTION AND IMPACTS OF PAFC DEPLOYMENT SYSTEM

To estimate the environmental impacts of widespread phosphoric acid fuel cell (PAFC) power plant deployment, this assessment will consider the total system or network of interrelated activities which support deployment. Eleven such system activities have been identified that cover not only the highly visible issues of fuel cell production, operation, and fuel consumption, but also address the less obvious aspects of deployment. This section briefly describes each activity and its expected environmental impacts. Projected penetration levels of PAFC power plants into the electric utility and on-site markets are derived. These levels are subsequently used throughout the section to provide a measure of impact quantification. The following is a summary of system activities indicating the section paragraphs that contain complete activity and impact descriptions.

It should be noted that most of the impacts identified by this section are incremental in nature; i.e., they replace to a degree the impacts of energy technologies displaced by PAFC market penetration. Exceptions to this generalization include increases in platinum demand and decreases in on-site energy, equipment demand that will not be offset by energy technology displacement. PAFC commercialization should not have a measurable effect on the total national demand for electricity and hence should not produce expansion of the nation's power supply system.

### Power Plant Production Activities

- Raw Material Acquisition and Processing (5.2.1)

The acquisition of raw materials for power plant fabrication includes the mining of ores and the extraction of petroleum and natural gas for use as feedstock. These raw materials are processed into metals, chemical feedstocks, carbon, and other products that can be converted into power plant components. The processing is accomplished by smelters, refineries, chemical plants, and other facilities.

- Construction of Primary Production Facilities (5.2.2)

Primary production facilities will manufacture the fuel cell stack and various power plant components and will assemble the components into complete power plant systems and subsystems. Construction of several of these facilities may be required to meet fuel cell demand.

- Operation of Primary Production Facilities (5.2.3)

The manufacture and assembly of power plant parts will require many industrial processes and the use of various chemicals and plastics. Many of these processes will likely be automated in the mature production facility.

- Operation of Secondary Production Facilities (5.2.4)

Secondary production facilities supply raw and finished products to the primary production facilities for additional processing or assembly. These facilities also manufacture the heat pumps, chillers, heat exchangers, and other energy equipment that will be teamed with on-site power plants to form on-site integrated energy systems. Many different industrial processes are involved.

### Power Plant Installation and Operation Activities

- Power Plant Site Preparation (5.3.1)

Site preparation activities are required for the installation of both on-site and utility power plants. On-site power plants will probably require only minor preparation work, but utility sites may need substantial excavation and construction work for the installation of fuel tanks, foundations, and other auxiliary facilities.

- Power Plant Transport and Installation (5.3.2)

Power plants and components will be transported from the production facilities to installation sites. Transport will likely be by truck or rail. Installation will consist of moving components into place, connecting fuel, water, and electrical lines, and testing operations. Installation activities for on-site units will be minor and relatively simple while activities for utility units may require more time and effort.

- Power Plant Operation (5.3.3)

Power plant operation considers both on-site and utility applications as well as the displacement of conventional generators by fuel cell penetration.

- Recycle of Power Plant Material (5.3.4)

Various components are periodically removed from the power plant and returned to the manufacturer or sent to local vendors for reprocessing and recovery of materials. These components include the fuel cell stack, fuel and water filters, and reaction beds.

- Utility Operations (5.3.5)

All utility power plants, and probably most on-site power plants, will have an interconnection with the utility electrical grid. The assigned power plant load, whether it be base, intermediate, or peak power, will have a great influence on the manner in which the other grid power generators are operated. Also, the incorporation of fuel cells into a grid may affect grid reliability, responsiveness, and other characteristics which alter the margin of required backup generation capacity. Both electric and gas utilities could be economically impacted by fuel cell penetration.

## Fuel Systems Activities

- Fuel Production (5.4.1)

PAFC power plants will initially be fueled by natural gas, naphtha, and methanol. Planning for future applications includes the capability to use most liquid and gaseous hydrocarbons including synthetic fuels. The production of these fuels consists of the extraction of raw resource (gas, oil, coal, oil shale, tar sands, etc.) and the various processing steps required to refine the fuel into a usable form.

- Fuel Transport, Distribution, and Storage (5.4.2)

Fuel must be transported from its origin to the power plants. The fuel type will determine the character of the transport system but all systems will have to have bulk transport, distribution, and storage capabilities. Truck and pipeline are the two most likely forms of transport.

### 5.1 Market Penetration

The magnitude of the environment impact produced by PAFC power plant commercialization is directly linked to the level of installed fuel cell generating capacity. A greater number of fuel cell power plants in the field will produce more of an impact, whether beneficial or adverse. In order to assess the possible impacts of fuel cell deployment, certain basic assumptions must be made regarding the level of penetration of fuel cells into the electric utility and on-site markets. Since it is not the purpose of this assessment to make projections on electric generating capacity growth rates or market penetration percentages, certain values based on previous studies will be assumed. Fuel cell market penetration potential will be clarified by several future studies. Participating utilities will conduct market assessments for on-site power plants during the 40 kW field test and for dispersed power plants as part of the electric utility program. The values included in the following discussions are the most current and are not intended to be absolute since they are based on projection uncertainties. The assessment does not require specific values to evaluate impact trends.

Numerous studies have been completed during the past five years that have attempted to forecast the level of market penetration of both on-site and utility PAFC power plants at a future date, generally the year 2000. Each study is based on a set of assumptions addressing power plant size, fuel availability, financial incentives, and penetration initiation dates. Taken as a whole, these studies have predicted total fuel cell penetrations by 2000 that range from a high of 400,000 MW to a low of 180,000 MW (Refs. 5.1 through 5.4). Based on a total generating capacity of 1,100,000 MW in 2000, these penetration figures are equivalent to total penetration of 36 percent and 16 percent, respectively. However, because of declines in the generation capacity growth rate and delays in the initiation of PAFC commercialization that have occurred since the studies, these forecasts are now regarded as highly optimistic. The current consensus within the fuel cell community is that PAFC penetration in the United States will reach a range of 20,000-40,000 MW by the year 2000 (Ref. 5.5). This will represent approximately 2-4 percent of the total national generation capacity by that date.

This assessment will use three possible market penetration levels in the year 2000 to facilitate the quantification of environmental impacts. These three penetration levels are a low level (20,000 MW), a medium level (50,000 MW), and a high level (100,000 MW). The low and medium levels closely correspond to the ranges of current PAFC market penetration predictions. The high level is included as a hedge against unexpected penetration growth by PAFC power plant. This high level lies approximately midway between the upper ranges of current penetration predictions and the lower ranges of past, outdated penetration studies.

The previously mentioned fuel cell penetration studies consistently assigned between 5 percent and 10 percent of the total penetration to on-site power plants and the remainder to utility power plants. This assessment assumes an intermediate value of 7 percent total penetration for on-site power plants and remaining 93 percent for utility power plants. This assignment results in the following division of generating capacity for the high and low penetration levels in the year 2000:

	<u>High</u>	<u>Medium</u>	<u>Low</u>
On-Site (MW)	7,000	3,500	1,400
Utility (MW)	93,000	46,500	18,600

It is useful for certain portions of the assessment to break these figures down into numbers of power plant units. Average power plant sizes must be assumed in order to do this since both on-site and utility power plants are expected to be available in a range of sizes. The assessment assumes an average on-site power plant size of 100 kW and a total utility power plant installation size of 25 MW. (Both are representative of those sizes currently under consideration by fuel cell manufacturers.)

Based on the foregoing size, penetration, and generating capacity assumptions, the following number of on-site and utility fuel cell power plants will be produced and operating in the field by the year 2000:

	<u>Penetration</u>		
	<u>High</u>	<u>Medium</u>	<u>Low</u>
On-Site (100 kW units)	70,000	35,000	14,000
Utility (25 MW units)	3,720	1,860	744

In summary, the following market penetration assumptions are made by this assessment for the purpose of quantifying environmental impacts:

- A high fuel cell penetration of 100,000 MW, a medium penetration of 50,000 MW, and a low fuel cell penetration of 20,000 MW by the year 2000,
- A division of fuel cell penetration into 7 percent for on-site power plants and 93 percent for utility power plants, and



- Average power plant installations of 100 kW for on-site and 25 MW for utility.

These assumptions have been made to facilitate quantification of fuel cell commercialization impacts. The resulting penetration levels and power plant production figures will be used to provide a clearer indication of impact magnitudes. They represent three penetration and production levels and it is acknowledged that alternative assumptions can be substituted for the ones made here. The assessment is made somewhat pliable, however, by providing impact rates per megawatt units for each impact parameter. Alternative penetration and production levels can therefore be applied to these rates to derive the impacts of alternative scenarios. Section 6.8 discusses the effect that the level of fuel cell market penetration has on the various parts of the deployment system.

## 5.2 Power Plant Production

The power plant production sector of the PAFC deployment system is divided into four activities: (1) raw material acquisition and processing, (2) construction of primary production facilities, (3) operation of primary production facilities, and (4) operation of secondary production facilities. These four production related activities and their resulting environmental impacts are described in this section.

### 5.2.1 Raw Material Acquisition and Processing

Fuel cell power plants will be constructed of a variety of materials including steel, copper, nickel, platinum, plastic, graphite, and phosphoric acid. Acquiring the raw materials for producing these substances will require the mining of ore and drilling for petroleum and natural gas. The production and processing of ores, petroleum, and natural gas are major industries with sizable impacts to the environment. The increase in environmental impact caused by the production and processing of these materials for fuel cell use is the subject under discussion. However, it appears that for all materials but platinum, the net changes in volumes of materials required for fuel cell production are small enough, in comparison with existing and projected total production volumes, so that no significant environmental or supply market effects will occur.

#### 5.2.1.1 Platinum

Among the construction materials, only platinum will be used in amounts significant enough to impact materials manufacturing industries. Phosphoric acid fuel cells currently use platinum as a catalyst in the anodes and cathodes of the fuel cell stack. As indicated by Table 3-2, the average platinum demand for early commercial PAFC power plants is projected to be 6.55 kg/MW for on-site power plants and 3.63 kg/MW for electric utility power plants. A recently completed NASA study evaluated the potential effects of expected PAFC platinum demand on the national and world platinum markets\*. This study projects that these platinum use rates will decline by 60 percent by 1990. Based on these lower use rate projections and the assumed division of on-site and electric utility capacity, Table 5-1 lists the cumulative PAFC platinum requirements to the year 2000 for each market penetration level.

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\* National Aeronautics and Space Administration, Lewis Research Center, Phosphoric Acid Fuel Cell Platinum Use Study, March 1983.

**Table 5-1. Fuel Cell Platinum Requirements to Year 2000  
Assuming Complete Recovery and Reuse**

<u>Penetration Level</u>	<u>Total Platinum Required (Million troy ounces)</u>
High (100,000 MW)	5.4
Medium (50,000 MW)	2.7
Low (20,000 MW)	1.1

This cumulative platinum demand assumes a 92 percent recovery and recycling of the platinum catalyst. In normal uses, platinum is virtually indestructible and can easily be separated from other less chemically stable materials for nearly complete recycling. Moreover, the high cost of this metal insures that every effort will be made by industry for its conservation and recovery.

Platinum is nearly indispensable in modern industry because of its extraordinary physical and chemical properties. It is refractory, chemically inert toward a wide variety of materials and displays a high catalytic activity. The major world sources of platinum are South Africa, USSR, and Canada. The ore is recovered from underground platinum mines in South Africa and as a byproduct of copper and nickel mining in the USSR and Canada. The heavy dependence on a few countries for this critically important metal has strategic and adverse economic implications. Platinum is therefore classified as a strategic material and the National Defense Stockpile maintains an inventory of 453,000 troy ounces with a storage goal of 1.3 million troy ounces. The current stock would supply domestic industry for about four months at 1979 rates of industrial consumption (Ref. 5.6).

In 1978, U.S. production of platinum was only about 1,000 troy ounces of a total world production of 2.7 million troy ounces. Although the U.S. has large platinum-group metal resources (i.e., platinum, palladium, rhodium, iridium, ruthenium, and osmium) estimated at over 300 million troy ounces, its reserves of these metals (resources economical to mine) are only about one million troy ounces. The Bureau of Mines believes that these reserves could be increased dramatically if exploration and feasibility studies prove deposits in several key locations are economical and mineable. Total world reserves of platinum are estimated to be 520 million troy ounces. U.S. platinum demand (minus fuel cell demand) is forecast to grow at an annual rate of 2.3 percent for the remainder of the century. At this rate of growth, the U.S. will require 24.3 million troy ounces of platinum between 1978 and 2000. Platinum demand for the entire world, including the U.S., is forecast to grow at an annual rate of 3.2 percent for a cumulative demand of 75.7 million troy ounces from 1975 to 2000. World reserves and resources are more than adequate to meet this demand (Ref. 5.6).

The commercialization of PAFC power plants will increase the cumulative U.S. demand for platinum. The magnitude of this increase will be determined by platinum loading rates, platinum recycling rates, and the level of fuel cell penetration into the utility market. For example, the high, medium, and low market penetration levels of Table 5-1 will increase the cumulative U.S. platinum demand to the year 2000 by approximately 22 percent, 11 percent, and 4 percent, respectively.

It is obvious that world reserves of platinum (520 million troy ounces) are more than sufficient to meet even the highest demand increases prompted by PAFC commercialization throughout the remainder of this century and well into the next century. Demand increases will have to be met primarily by the handful of large South African mining companies that effectively control the world supply of platinum (Ref. 5.6). The moderate growth rate projected for world platinum demand and the relatively small increase that PAFC commercialization will add to this demand should not overly stress the ability of the platinum producers to keep pace with demand. Following initial short-run price impacts, moderate shifts in platinum demand caused by PAFC commercialization will likely have little effect on the price of platinum since general economic conditions are likely to overshadow any further price impacts.

Increased platinum production will increase the environment impacts associated with mining and processing. Relatively few persons are engaged in producing platinum domestically, the number involved through the semifabrication stage is probably less than 500 (Ref. 5.6). The increased demand resulting from widespread fuel cell commercialization will probably be met through increased imports rather than any significant expansion of domestic production, although some expansion of catalyst reprocessing facilities may be necessary. For this reason, no additional national environmental impacts are expected from this aspect of fuel cell production. The automobile chemical, dental, medical, petroleum, and electrical industries are major users of platinum in the United States. Increased use of platinum in fuel cells may force these industries to find substitutes for their platinum use. Research is underway to find substitute catalysts for use in the fuel cell stack. The availability of such a substitute could forestall demand jumps and their effects on the platinum market. Section 6.1.1 discusses the possible effects of catalyst substitution.

#### 5.2.1.2 Other Materials

Among the ores mined for fuel cell metallic components are iron, copper, nickel, and platinum. Phosphate rock is mined for phosphoric acid production. Most of these ores are obtained from large surface mines that produce the environmental impacts typical of mining operations: air and water pollution, solid waste, aesthetic and habitat disruption, and occupational hazards. The refining and smelting of the ores are sources of air emissions, water effluents, and water demand.

Although the volumes of steel, copper, and nickel required by a fuel cell power plant network program have not been quantified, the total U.S. and worldwide production figures for these metals are sufficiently large to indicate that any increase in production caused by fuel cell deployment would be a very tiny percentage of the total production. For example, the 1978 U.S. and worldwide (in parentheses) production of steel, copper, and nickel was 125 (714) million metric tons, 1.36 (7.53)

million metric tons, and 10,200 (664,000) metric tons, respectively (Ref. 5.6). The net change in demand for these metals caused by fuel cell deployment will be less, in fact, when consideration is given to the simultaneous drop in demand resulting from the displacement of alternative electric generators (turbines, diesels, etc). Because fuel cell power plants will be located at or near the load, the material requirements for installing electric power transmission and distribution systems will be reduced. Since these systems require substantial amounts of aluminum, copper, and steel for cables, transformers, and towers, some savings will result. On the other hand, more fuel gas or liquid pipelines requiring large amounts of steel may be needed to service the needs of fuel cell power plants. Potentially, this may exceed the steel required for a corresponding electricity transmission system. U.S. and world reserves of iron, copper, and nickel are ample to supply forecasted demand through the year 2000 (Ref. 5.6). Demand for fuel cells is not expected to significantly affect these reserves even under the most optimistic market penetration conditions.

Phosphoric acid fuel cells use phosphoric acid as the electrolyte. Based on the acid loading of the United Technologies Corporation (UTC) 40 kW fuel cell power plant, about 1600 liters of phosphoric acid are required per megawatt of installed capacity. With a projected stack life of 40,000 hours of operating time before reprocessing and refilling is needed, phosphoric acid is therefore required at a maximum rate of 320 liters per megawatt-year of installed capacity assuming near-continuous operation. Multi-megawatt PAFC systems may require only 60-80 percent of this phosphoric acid loading rate because of their higher power densities. However, based on the UTC 40 kW loading rate, the high market penetration level (100,000 MW) would need 32 million liters of phosphoric acid per year while the medium market penetration level (50,000 MW) would need 16 million liters per year, and the low market penetration level (20,000 MW) would require 6.4 million liters per year. Total annual U.S. production of phosphoric acid is about 4 billion liters. As mentioned in Section 6.1.1, fuel cell research is attempting to lengthen cell life by improving catalysts, corrosion resistance, and electrolyte management. A longer cell life will reduce reprocessing frequency and thereby reduce demand for phosphoric acid.

Phosphoric acid is produced from phosphate rock. The U.S. has large phosphate rock reserves and will be a phosphate rock exporter until at least the mid-1990s. Major deposits occur in Florida and North Carolina. In 1978, 50 million metric tons of phosphate rock were mined in the U.S. and over half was processed into phosphoric acid (7.3 million metric tons of  $P_2O_5$ ) (Ref. 5.6). Most of this phosphoric acid was used for fertilizer production. Even the high market penetration requirement of 32 million liters per year (60,000 metric tons) is a small percentage of 7.3 million metric tons of  $P_2O_5$  and no significant market effects are foreseen.

Phosphoric acid is produced by two principal methods, the wet process and the thermal process. The wet is usually employed when the acid is to be used for fertilizer production. Thermal process acid is normally of higher purity and is used in the manufacture of high grade chemical products such as is required for the fuel cell electrolyte. In the thermal process, phosphate rock, siliceous flux, and coke are heated in an electric furnace to produce elemental phosphorus. The phosphorus vapors are mixed with air to form  $P_2O_5$  and then hydrated by water to form the

acid. Expansion of chemical-grade phosphoric acid production facilities may be required. The principal emission from the thermal-process is  $P_2O_5$  acid mist in the tail gas. All plants, however, are equipped with acid-mist collection systems (Ref. 5.7).

Plastics and resins are used in the fuel cell stack and throughout the rest of the power plant for various components and as acid-resistant coatings. The petrochemical industry produces the majority of plastic and resin raw materials. About 40 basic types of plastic materials are presently manufactured. For most of these, the ability to vary molecular weights, copolymers, colorants, plasticizers, and other additives--together with the ability to vary processing parameters such as temperature, time, and pressure--have led to production of thousands of different formulations, custom-tailored to specific end uses. Petroleum and natural gas are the basic raw materials of the plastic materials/synthetic resins industry. Enormous quantities of naphtha are cracked to form ethylene and propylene which are in turn processed into basic monomers for further processing by the plastics industry.

Capital expenditures by the plastics industry for new facilities and equipment have been increasing to meet the burgeoning demand of the last decade. At the same time, the plastics industry is developing new materials, processes, and equipment to comply with environmental and safety regulations. The quantity of plastic and resin monomers required by fuel cell development is so minute in comparison to the total produced that no significant increase can be expected in either the production or processing of naphtha by the petrochemical industry. Given this situation, the demand for plastic materials by the fuel cell industry should be easily assimilated by the existing industry structure with a minimum of additional environmental impact caused by petroleum, gas, or synfuel production, or by operation of plastic production facilities.

Current fuel cell technology uses graphite in the construction of electrodes. Graphite is manufactured from petroleum coke at 24 plants in the U.S. In 1976, 260,000 metric tons of graphite were produced of which 209,000 metric tons were used in the manufacture of anodes and electrodes (Ref. 5.8). Some industrial expansion may be required to meet fuel cell needs for graphite. The supply of coke should be sufficient to meet all requirements. Graphite use for fuel cell electrodes may eventually be replaced by other materials.

### 5.2.2 Construction of Primary Production Facilities

Primary production facilities will manufacture the complete on-site fuel cell power plants and the major components for the larger utility fuel cell power plants. They will be the hub of production activities where supplies of raw products and manufactured subcomponents arrive for processing and assembly. The facilities will consist of separate areas for production of power plants components, assemblage of components, and storage of raw and finished products.

To be economically feasible, fuel cell power plants and components must be mass produced. The construction of facilities and equipment for mass producing fuel cells will of course be a substantial undertaking but is not expected to be nearly as

complex as the construction of facilities for producing many other types of technological equipment. It has even been suggested that large investments in new facilities may not be required but that existing facilities can more easily be refitted. For example, UTC has already constructed a 200,000 square foot fuel cell research and development facility. This facility may be used for initial commercial production (Ref. 5.9). Energy Research Corporation (ERC) has a large existing R&D facility that could be used for commercial production. Construction economics will determine if this facility is utilized or a new facility is constructed (Ref. 5.10).

With automation and the development of new processes, several primary production facilities will probably be sufficient to meet the demand for power plants and parts. In fact, each of the handful of fuel cell manufacturers may have its production activities centered at one or possibly two facilities. Construction of these facilities will produce the types of impacts expected from the construction of any large manufacturing facility. Typical impacts will include dust, noise, water runoff, erosion, traffic, and general aesthetic disruption. The degree of impact will depend on the site characteristics and the nature of the surrounding environment. Construction activities will likely last for several years. The adaptation of existing facilities for production would substantially reduce the magnitude and duration of these impacts. The production of fuel cells does not require any specialized structures whose construction might produce unusual impacts.

### 5.2.3 Operation of Primary Production Facilities

Once operational, the primary production facilities will manufacture fully assembled multi-kilowatt power plants for on-site use and the major power plant components for the larger multi-megawatt utility power plants. The operations of these facilities will have to comply with all appropriate government regulations for the protection of environmental quality and worker health and safety. The on-site power plants shipped from these facilities are projected to be available in a family of sizes (tens of kilowatts to several hundred kilowatts) and will be ready for immediate installation and operation at the sites. Components for shipment to multi-megawatt utility power plant sites include the fuel cell stacks, fuel processors, inverters, water coolant and treatment units, and control units. These components will be integrated with other sections of the power plant constructed at the power plant sites such as the fuel tanks, cooling tower, control room, electric transmission facilities, etc.

A primary production facility will likely consist of separate areas for manufacturing components, assembling components, and storage for the materials, chemicals, and subcomponents shipped in from secondary production facilities. The variety of parts to be produced will require a number of specific mass production procedures and equipment. The scale of activity will largely depend on the availability of standard "off-the-shelf" subcomponents able to meet power plant requirements. If mass produced subcomponents (e.g., heat exchangers, blowers, pumps, valves, electrical devices) from secondary producers can be adapted to power plant use, activities at a primary production facility can be confined to the production of fuel cell specific components (e.g., electrodes, matrices, fuel stack plates, reformer, etc.) and the assembly of the components. (For a further discussion of the effects of decentralizing power plant production by utilizing standard subcomponents from secondary manufacturers, please refer to Section 6.2.)

The fuel cell stacks are the basic component of a fuel cell power plant. Each of the stack subcomponents must be produced prior to assembly of the stack in the factory. Since the majority of these stack subcomponents are specialized for fuel cell use, most will be mass produced at the primary facility. Their production requires a variety of chemical ingredients, as well as heating, mixing, rolling, drying, and other physical processes. Most of these activities will probably be automated in the mature production facility.

Following their manufacture, the stack components are assembled in the proper order in the fuel cell stack. Phosphoric acid for the stack is prepared by heating reagent grade acid (85 percent  $H_3PO_4$ ) to the desired concentration (99 percent). The acid can be applied to the stack matrix and electrodes prior to assembly (wet assembly) or introduced into the stack after assembly (dry assembly). Either method requires work with heated acid and a heated fuel cell stack. An alternative method permits addition of acid to the stack following the assembly of the complete power plant. During stack assembly, gaskets and seals are added to prevent leakage of acid, air, and fuel. Assembly is completed with compression of the stack and addition of the fuel and air manifolds. The graphite, resins, silicon carbide, platinum, carbon supports, and other fuel stack ingredients are specific brand name products readily available from suppliers.

The stainless steel reformer vessel will likely be produced and assembled at the facility. Assembly includes packing with the reaction catalyst. The fuel pre-processors (preoxidizer, hydrodesulfurizer, and hydrotreater) will likewise be produced and assembled with catalyst beds at the facility. The catalyst material used is generally obtained directly from suppliers without additional modification.

The inverter will likely be manufactured at a secondary production facility and shipped to either the primary production facility or the power plant site for integration with the power plant. The water treatment system includes charcoal filters and demineralizers for removing impurities in the cooling and process water. The charcoal and resins for these devices will be supplied to the facility for assembly. The metallic and plastic tanks, pipes, pumps, and valves for the water system will either be produced at the facility or supplied for assembly.

The only noteworthy environmental impacts expected from the operation of the primary production facilities are air emissions, and possibly waste water effluents and solid waste disposal. These would arise during the storage and handling of metals, plastics, and other power plant production materials. The major sources of air emissions during plastics production are the emissions of raw materials or monomers, emissions of solvents or other volatile liquids during reaction, and emissions of solvents during storage and handling. The emission rates for these hydrocarbon particulates and gases are unknown since they will be determined by the as yet undefined production procedures, equipment, raw materials, and pollution control equipment. Some worker health impacts may result from exposure to plastic and resins and their particulates and gases.

The high temperatures attained in the converting and forming of metals can cause volatilization of a number of trace elements in the metals or metal concentrates. Raw waste gases can contain not only metallic fumes but also dust and sulfur oxide.

Carbon monoxide and nitrogen oxide may also be emitted. The air emission rates of these constituents, as well as the wastewater discharge rates from these and other procedures, are not currently known and will be determined by production procedures, equipment, raw materials, and pollution control equipment.

The manpower needed to operate the primary production facilities will depend on output volume and degree of automation. Automation is expected to eliminate many of the labor intensive production procedures of power plant manufacture. Fuel cell manufacturers already employ a substantial number of workers for R&D activities (UTC, for example, employs more than 600 persons at its large fuel cell facility, Ref. 5.9), and thus shifts in manpower location resulting from fuel cell production will be primarily in terms of increased employment of production personnel.

The production impacts of fuel cells are difficult to compare to the production impacts of other energy technologies because of the limited data. They are comparable to many types of industrial production activities however. The relatively large use of plastics and resins may distinguish fuel cell impacts from those of other energy technologies.

#### 5.2.4 Operation of Secondary Production Facilities

Secondary production facilities are those that produce (1) the materials and finished subcomponents that supply the primary production facility, (2) the materials that are used in preparing the utility power plant sites, and (3) the heat pumps and other on-site integrated energy system (OS/IES) equipment that are integrated with the on-site power plants. In general, these facilities can be thought of as comprising the industrial infrastructure that supports the production and installation of fuel cell power plants. Facilities for producing these materials already exist in most cases since the materials are usually commercially available; however, it is possible that increases in material demands caused by fuel cell commercialization could necessitate the expansion of existing facilities or construction of new production facilities. Production facilities that manufacture conventional energy equipment may experience negative economic impacts caused by fuel cell competition.

The types of materials manufactured by the secondary production facilities are diverse and hence a specific characterization of their possible operational impacts is not feasible. Included among these products are, for example, plastics, resins, chemicals, raw and finished metallic products, and finished energy equipment. Typical industrial impacts can be expected during their production including impacts to air and water quality, land use, aesthetics, and worker health and safety.

Several factors will influence the quantities of assembled subcomponents and energy equipment demanded by fuel cell production and use. As discussed in Section 6.2, a shift towards the use of commercial "off-the-shelf" parts as replacements for custom-designed power plant parts will not only broaden the secondary production support infrastructure but will also increase the demand for specific components (heat exchangers, valves, blowers, pumps, etc.) from specific suppliers. Secondly, as discussed in Section 6.3, the type of OS/IES equipment employed at on-site locations will determine the demand for heat pumps, chillers, and other small pieces of energy



equipment. In order to meet these product demands, the suppliers may have to expand their production capabilities by purchasing new equipment, hiring more employees, and possibly constructing new facilities.

Deployment of fuel cell power plants will displace existing or planned conventional generators such as internal combustion generators and steam, oil, and gas turbines. Reduction in the future market demand for these products could have an adverse effect on the industries that supply the generators. Multi-megawatt fuel cell power plants are expected to compete with turbines and diesels for the intermediate and peak load generator markets, while multi-kilowatt fuel cell power plants may reduce demand for turbines and both large and small diesels.

Turbine manufacturing and diesel generator manufacturing are both major industries in the United States. The turbine and turbine generator set industry is a multi-billion dollar industry that directly employs approximately 39,000 workers. In 1980, 38 major production establishments manufactured nearly 29,000 MW of turbine generating capacity. Turbine production has declined over the past several years but the industry is expected to recover and experience moderate growth throughout the rest of the century (Ref. 5.11). The gas, gasoline, and diesel engine-driven generator set industries produced nearly three-quarters of a billion dollars of equipment and directly employed 5,400 workers in 1977. The diesel industry accounted for over two-thirds of these production figures (Ref. 5.12).

The degree to which these industries are adversely affected by fuel cell deployment will be a function of the fuel cell operational modes and market penetration level. The uncertainty of these factors precludes a reliable prediction of economic impact; however, under the market penetration levels assumed in Section 5.1, it does not appear likely that a severe economic impact would occur. Other power equipment industries may also be affected by fuel cell competition. Production of boilers, condensers, heat exchangers, and numerous other power components may be reduced because of fuel cell competition. The economic impacts of fuel cell market penetration on all competing industries will probably be distributed among the industries and thus the entire brunt of displacement should not fall on a single industry that produces a particular type of generating equipment. Nevertheless, some competing industries could face reductions in product demand that may result in some layoffs of employees and closures of facilities. These impacts may be mitigated by: (1) manufacturers adapting their products for use by fuel cells or (2) manufacturers of convention generating equipment developing the capability to produce fuel cell power plants.

### 5.3 Power Plant Installation and Operation

The activities and impacts of PAFC power plant installation and operation are discussed herein. Activities considered are power plant site preparation, transport, installation, operation, and material recycle. The effects of PAFC deployment on utility grid operations are also covered. A discussion of the displacement of conventional electric generating technology is included in the power plant operation description.

### 5.3.1 Site Preparation

Fuel cell power plant sites require preparation prior to the arrival of the power plants and components. Construction work will occur at both on-site and utility power plant sites; however, due to the difference in power plant size, the activities will be substantially greater in intensity, duration, and variety at the utility sites.

Preparation of utility power plant sites is expected to take from one to two years. This compares very favorably with the four to five years of construction required for a gas- or oil-fired steam power plant. The construction site for a 25 MW fuel cell power plant installation should be approximately one to two acres in size (refer to Section 5.3.3.6). Activities during this period include excavation work, placement of piles and foundations, erection of a control building, and installation of various power plant support systems. Support system installation will include burial of fuel and water tanks, trenching for fuel and water lines, and construction of the electrical connection with the grid. The magnitude of these construction activities will be much less than those accompanying conventional steam power plants, because the PAFC power plants are smaller and have many of their components fabricated prior to delivery. This benefit is offset to some degree by the fact that more of the smaller PAFC power plants will have to be constructed to fulfill the same generating capacity.

These construction activities are basically typical of those which would occur during the erection of most industrial facilities and they will employ the same type and number of construction workers as would be required by the construction of an industrial facility of the same size. Site preparation does not represent a particularly large construction effort and the presence of heavy construction equipment such as excavation machinery, pile drivers, and cranes is only temporary. An Environmental Assessment prepared for the 4.8 MW Fuel Cell Demonstration Plant in New York City (Ref. 5.13) concluded that construction of the site for that plant would not represent a substantial visual or aesthetic impact even though the site was only 275 meters from a large housing project. This assessment also concluded that the preparation of this site would produce no significant impacts from fugitive dust, storm water runoff, increased traffic, or noise. The evaluation of impacts is naturally dependent on the site under consideration, but in general it appears that the construction of utility power plant sites will not produce environmental impacts above levels expected from typical industrial construction projects of a similar size, and in many instances the impacts will not be significant. The referenced environmental assessment provides a complete discussion of construction activities and impacts related to the site preparation for that plant.

Site preparation activities for the smaller multi-kilowatt power plants will not require any major construction. A small foundation pad will be constructed at outdoor sites and roof-top sites may require some additional roof support. A fuel line will be installed and interfacing the power plant with the site energy system will require the installation of various pipes and wires. Site preparation will also include the installation of heat pumps and other types of OS/IES equipment. Preparation will be completed with the installation of aesthetic, security, and noise attenuation structures. These activities should be completed in several days and require no more than a handful of service personnel.

An environmental assessment prepared for a field test of a 40 kW on-site fuel cell power plant determined that the environmental impacts produced by site preparation activities would be both brief and insignificant. Minor quantities of dust and erosion runoff may be generated at outdoor sites and intermittent noise from the operation of equipment may last several days. The 40 kW power plant requires only approximately 24 square meters for its foundation and this includes adequate space on all sites for access. A complete description of site preparation activities and impacts for the 40 kW power plant is provided in the document entitled "Environmental Assessment of the 40 Kilowatt Fuel Cell System Field Test Operation," (Ref. 5.14). Both the size and projected impacts of the 40 kW power plant are typical of on-site units being developed by other manufacturers.

### 5.3.2 Power Plant Transport and Installation

Among the advantages attributed to fuel cell power plants is the ability to mass produce them at a central production facility. This technique lowers production costs, lessens construction work at the power plant site, and shortens construction lead time. Entire multi-kilowatt power plants can be assembled at the factory for shipment to the sites. The major components of multi-megawatt power plants including fuel processors, fuel cell stacks, and power processors can be assembled at the factory and shipped to the sites for integration with other power plant components.

This type of a centralized production system requires a means of transporting the power plants and components from the factory to the power plant sites. The on-site power plants are small enough so that they can be transported as single units either by truck or rail. In fact, several on-site units can probably be transported by a single standard tractor truck and trailer.

Forklifts, cranes, and other equipment will be used to move and install the on-site power plants and utility power plant pallets at the sites. The on-site power plants will be installed indoors, outdoors at ground level, or on rooftops and will be connected with the site energy system interfaces that were previously installed during site preparation. All or parts of the site gas, electric, and water systems will have to be shut down for several hours so that the actual hookup of the power plants to these systems can take place. The installation of on-site power plants should be complete within a day.

The components for multi-megawatt power plants will be assembled on pallets of a size transportable by truck or rail. The fuel processor and power section of the 4.8 MW Fuel Cell Demonstrator Power Plant was assembled on pallets and moved by truck to the site in New York City. The five large pallets were then unloaded and moved into position at the site. UTC plans for an 11 MW fuel cell power plant call for the fuel processor, power section, and inverter to be assembled on 16 pallets (Ref. 5.9). Larger utility power plants will require the transport of proportionately more pallets. Assuming that two pallets can be moved per standard truck load, a 25 MW plant would require about 20 truck trips to move the fuel processor, power section, and inverter to the site. Transport by rail will probably be used only for long distances and will still require the use of trucks to and from the rail line.

The multi-megawatt pallets will be installed at the ground-level sites prepared for them. Installation activities will consist of integrating the pallets with one another at the sites and with the auxiliary power plant systems.

The principal impact of concern related to the transport of the power plants and components is the operation of trucks on public highways and streets. Trucks are a safety hazard due mainly to their size and weight and are more damaging when they collide with another vehicle or person than the standard automobile. The transport of between 14,000 and 70,000 100 kW on-site power plants during the next twenty years will require anywhere from about 7,000 to 70,000 truck trips (1/2 to 1 trip per 100 kW capacity). Moving pallets for between 744 and 3720 25 MW utility power plants will require anywhere from about 14,880 trips to about 74,400 trips during the same period (20 trips per 25 MW capacity). Thus the total number of truck trips required to move fuel cell power plants and parts during the next 20 years will range somewhere between approximately 22,000 and 144,000. These trips could each run anywhere from under a hundred miles to several thousand miles. The fuel cell power plants are not a particularly hazardous cargo since they will not contain fuel during transport and, if phosphoric acid is present during transport, it will be absorbed within the cell matrix rather than available for spillage as a liquid.

Although this is a tremendous number of trips and miles, when compared with the total number of miles that trucks travel in the United States during a single year (307 billion miles in 1976 (Ref. 5.15)), these figures are an insignificant addition. Consideration must also be given to the number of truck miles that would normally serve the construction of power plants displaced by fuel cells. The subtraction of these miles will further reduce the already insignificant increase.

The fuel use and air emissions from truck transport of fuel cells are substantial when aggregated over 20 years, but when compared against the total fuel use and air emissions of all truck traffic, they are also insignificant.

The environmental assessments prepared for the 4.8 MW Fuel Cell Power Plant and the 40 KW Fuel Cell Power Plant Field Test have both determined that there will be no significant impacts from the actual installation of the power plants and components at the power plant sites.

### 5.3.3 Power Plant Operation

The cumulative environmental impacts resulting from the operation of several thousand megawatts of fuel cell power plants will undoubtedly be substantial. However, since the fuel cell is merely one of several energy generation alternatives, it is more important to evaluate the relative impacts of this technology rather than to detail the impacts of fuel cells absolutely. The true costs or benefits to society resulting from the use of fuel cell power plants are defined by the difference between using this or some other technology for a given application. Therefore, whenever possible, the following impact analysis seeks to compare the environmental impacts of fuel cell systems with other conventional and advanced energy generation systems capable of providing the same services. Although sample penetration assumptions are provided in Section 5.1 and applied to several environmental parameters in the section summary, it is not the objective of this section to

arrive at specific environmental impact statistics, but rather to provide a means for environmental comparison among the many energy generation options.

In Sections 5.3.3.1-9, the environmental characteristics of fuel cells are compared with representative 500 and 800 MW fossil-fueled steam electric power plants. Emissions data for fuel cell systems come primarily from tests of the 40 kW UTC units and technology goals established for the 4.8 MW units being tested in New York City. The environmental characteristics of the steam electric technologies have been well established and data are readily accessible. Since these systems represent close to 65 percent of the national generation capacity, it is apparent that a significant amount of fuel cell penetration will come at their expense.

Fossil fuel steam-electric power plants, however, are not the only generators which will be displaced as fuel cells penetrate the market. Current peak power technologies such as internal combustion engines and gas turbines are also targeted for potential replacement by fuel cell power plants. In addition, since fuel cells will be used in many capacities that could be equally satisfied by other proven advanced generation and storage technologies, it can reasonably be argued that fuel cells will be displacing the environmental impacts which would result from the use of technologies such as solar, geothermal, or energy storage. For this reason, it is useful to evaluate the environmental impacts of these advanced technologies even though the ability to quantitatively assess their contribution to future energy mixes is limited. Section 5.3.3.10 compares the environmental impacts of fuel cells with several other alternative energy technologies.

#### 5.3.3.1 Air Quality

Fuel cell power plants characteristically produce very low levels of air pollutant emissions when compared with conventional electric power generators. Measured emissions from experimental and preprototype power plants have shown that the rate of air pollutant emissions from fuel cell units is 3 to 4 orders of magnitude lower than EPA standards for modern fossil fuel power plants. Emission rates are low for two reasons: (1) much of the sulfur and other impurities are removed during reforming, and (2) the fuel cell employs an electrochemical rather than a combustion process. Nevertheless, a portion of the fuel cell fuel stream must be combusted to meet the thermal requirements of the reformer system. In the 40 kW on-site power plants, approximately 80 percent of the hydrogen is consumed in the power stack while the remaining hydrogen and residual hydrocarbon fuel components are combusted in the reformer burner (Ref. 5.11). This combustion process is the principal source of fuel cell air emissions; however, small quantities of phosphoric acid vapor which originate in the fuel cell stack may also be emitted in very low concentrations.

Under normal operating conditions, the burner fuel is converted almost exclusively to  $\text{CO}_2$  and water vapor. The reformer burner temperature is low enough so that little thermal  $\text{NO}_x$  is produced.  $\text{NO}_x$  will be present in the emissions, however, as a result of bound nitrogen in the fuel. Reformers which are currently being developed to enable fuel cells to use coal and heavy petroleum-derived fuels will likely operate at higher temperatures and require the combustion of greater amounts of fuel. Thus, proportionately higher levels of all pollutants may result. Even at these

elevated temperatures, however, NO<sub>x</sub> emissions should remain significantly below those of fossil fuel combustion technologies.

Since the catalysts used for reforming and power production have a low tolerance for sulfur compounds, most of the sulfur is removed from the fuel prior to reforming. Any halogens and sulfur that happen to pass through the fuel cleanup system are emitted in the exhaust; however, emission tests have proven sulfur emission levels to be extremely low. Future technological developments in the reformer and power stack subsystems will apparently result in more sulfur-tolerant catalysts lessening the requirements for sulfur removal. Without the use of sulfur removal systems, advanced fuel cell technologies may have higher SO<sub>2</sub> emission rates. Nevertheless, overall power plant emissions should remain low and well within EPA limitations for steam electric generators.

Very small quantities of phosphoric acid (1 ppm in the 40 kW system) normally exit the cathode with the exhausted air flow. The vast majority of this acid emission is removed by the power plant acid recovery system. Most of the acid that escapes this recovery (less than 0.1 ppm) is removed from the exhaust flow during the recovery of water vapor in the condensers. Once this flow is diluted by combination with the burner exhaust flow, the concentration of phosphoric acid has been calculated by UTC to be below detectable levels. Phosphoric acid is not considered to be a particularly toxic chemical and OSHA regulations prescribe a safe time-weighted air exposure limit of 1 mg/m<sup>3</sup> (0.2 ppm). This is a much higher air concentration than that emitted by the 40 kW power plant and expected to be released by the larger 4.8 MW units.

Emission rates for the major air pollutants are expected to be uniformly low for all fuel cell power plants regardless of fuel type or size. However, technology differences, alternative fuels, and future technological developments will cause some variation. Few emission tests have been performed on full scale operating units and therefore emission characteristics are not precisely known. Tests performed on the 40 kW on-site system using natural gas as a fuel resulted in the characteristic emissions described in Table 5-2. The emission rates for zero, half, and full-rated power are given for comparison. Although emission measurements have not been taken for non-steady-state conditions (startup and load response transients), it is likely that emission rates will be somewhat higher. Fuel for startup bypasses the fuel processing subsystem and the emissions will consequently have a higher concentration of SO<sub>2</sub>. Those power plants which are sited indoors will have hoods and flues to supply fresh air and ventilate all exhausts to the outside and thus preserve indoor air quality.

In Table 5-3, the emission rates for the UTC 40 kW unit and the UTC 4.8 MW demonstration plant are compared with those for fossil-fueled steam electric power plants emitting at rates permitted by the revised federal New Source Performance Standards (NSPS). Since the 4.8 MW naphtha-powered unit is not yet operational, the environmental characteristics of this generator are estimated from test data of earlier generation models, primarily the 1.0 MW test unit. The two fuel cell power plants are assumed to have energy conversion efficiencies of 40 percent and the fossil-fueled steam electric power plants are assumed to have energy conversion efficiencies of 35 percent. The emission rates for the two fuel cell power plants are

**Table 5-2. 40 kW Fuel Cell Power Plant Exhaust Emissions  
in kg/GJ Heat Input for Various Net Output Levels  
(lb per million Btu) (Ref. 5.14)**

	<u>0 kW Net Power</u>	<u>20 kW Net Power</u>	<u>38-1.2 kW Net Power</u>
NO <sub>x</sub>	.0027 (.0056)	.00062 (.0013)	.00029 (.00060)
SO <sub>2</sub>	.000017 (.000035)	.000015 (.000032)	.000016 (.000034)
Particulates	.00072 (.0015)	.0010 (.0021)	.0000 (.0000)*
Smoke	None	None	None
THC	.021 (.043)	.0031 (.0065)	.0012 (.0025)

\* Possible sampling problem

**Table 5-3. A Comparison of Air Pollutant Emission Rates for Fuel Cells  
and Fossil-Fueled Steam Electric Power Plants  
(kg/MW-hr) (Refs. 5.14, 5.15)**

<u>Pollutant</u>	<u>Fuel Cell Units</u>		<u>Steam Generating Unit</u>		
	<u>40 kW</u>	<u>4.8 MW</u>	<u>Gas-Fired</u>	<u>Oil-Fired</u>	<u>Coal-Fired</u>
NO <sub>x</sub>	0.0019	0.064	0.7	1.1	2.2
SO <sub>2</sub>	0.0001	0.0001	2.9	2.9	4.3
Particulates	0.0067	0.00001	0.11	0.11	0.11
THC	0.0079	--	--	--	--

seen to be significantly less than the emission rates for fossil-fueled units regardless of their fuel type. Substantial environmental benefits can therefore be expected as fuel cells penetrate the energy market.

The emission rates of on-site power plants also compare very favorably with the emission rates of a domestic gas furnace. As seen in Table 5-4, the air emissions associated with fuel cell thermal energy production are superior when compared to those of the gas furnace. Similarly, OS/IES applications in the commercial and industrial sectors can displace combustion processes which currently provide for thermal requirements. Almost without exception, these systems have higher emission rates than fuel cells. As a result, the widespread application of OS/IES fuel cells in a region would measurably reduce the pollutant loadings from these dispersed and varied on-site sources.

**Table 5-4. A Comparison of Air Pollutant Emission Rates for the 40 kW Fuel Cell Power Plant and a Domestic Gas Furnace (Ref. 5.14)**

<u>Pollutant</u>	<u>Emissions in gm/hr (lb/hr)</u> While Supplying 150,000 kJ/hr of Thermal Energy	
	<u>Fuel Cell</u>	<u>Gas Furnace</u>
NO <sub>x</sub>	0.10 (0.00020)	8.6 (0.018)
SO <sub>2</sub>	0.006 (0.000013)	0.064 (0.00014)
Particulates	0.38 (0.00084)	1.1 (0.0024)
THC	0.46 (0.0010)	0.86 (0.0018)

Certain regions of the country periodically or chronically suffer from air pollutant levels which exceed EPA primary standards for the protection of public health. Electric generation facilities are major contributors to this poor air quality in many instances, particularly in the cases of particulates and SO<sub>2</sub>. Initially, fuel cell power plants are likely to replace older fossil-fuel fired units of intermediate size located within or close to urban regions. Since these are the regions which generally have the poorest air quality, a significant level of fuel cell penetration would contribute substantially to improved air quality conditions. Epidemiological studies reveal that improvements in air quality lead to reduced morbidity and premature deaths due to lung cancer, heart disease, lower respiratory diseases and chronic obstructive lung diseases. This results in a direct reduction of costs due to hospitalization, physicians' visits and drug consumption, and an indirect cost reduction from foregone earnings. Also, reduced damage to vegetation and materials can be realized for specific locations.

Because fuel cell power plants have such relatively low exhaust emissions per unit of energy produced, they are likely to be sited in areas of the utility's system hitherto inaccessible as generation sites because of their proximity to existing or planned residential or commercial areas. On-site units and dispersed utility megawatt systems will probably be located closer to population centers than would be the case with conventional energy generation systems. However, the increased atmospheric loading in these local areas will be insignificant since, as noted before, the exit concentrations of all air pollutants from any individual facility are negligibly small. These emissions are further diluted by plume dispersion within a short distance from the stack.

For example, at a wind speed of 10 mph and under worst case atmospheric conditions (stability Class F), the sulfur dioxide emissions from a group of five 4.8 MW power plants would be diluted to a concentration of 2.3 ug/m<sup>3</sup> at a distance of 0.1 kilometer. At one kilometer, this concentration would be further reduced to about 0.1 ug/m<sup>3</sup>. This increase above ambient levels is insignificant when compared to the SO<sub>2</sub> 24 hour air quality standard of 365 ug/m<sup>3</sup>. These calculations indicate that the emissions from any individual fuel cell facility will have only a marginal effect on the concentrations of air pollutants in the near vicinity of the power plant and will cause no adverse health effects or property damage.



### 5.3.3.2 Water Quality and Supply

The fuel cell power plant differs fundamentally in its water supply and discharge characteristics from conventional electric generating sources because of the water producing nature of the fuel cell itself. The electrochemical reactions within the fuel cell stack produce a sufficient quantity of water to compensate for steam consumption in the fuel reformer and water vapor loss via the exhaust stream. This self-sufficiency is made possible by the recovery of a portion of the byproduct water from the fuel cell exhaust stream and reformer exhaust flow. Power plant condensers feed the recovered water back to the water tank and purification unit where it is again available to meet cooling and fuel processing needs. Thus, for normal power plant operation, all treated water is recycled and only a small amount of make-up water may be required.

As discussed in Section 4.1.2, conventional central generating stations have major water requirements for waste heat dissipation. The amount of water withdrawn and consumed\* depends on the cooling system used; much greater amounts of water are required for once-through cooling systems than for a closed-cycle system which employs cooling towers operating as a closed loop. However, even with the use of cooling towers, water requirements for large facilities can be substantial. In 1975, steam electric power plants (installed capacity of 437,403 MW) withdrew 139,284 million gallons of water per day from surface waters. (Ref. 5.17) Assuming a national generation capacity usage rate of 55 percent, this translates to approximately 24,000 gallons of water withdrawn per MW-hr of electricity produced. Since most of this water was eventually returned to a receiving stream, actual water consumption was significantly less.

The environmental benefits associated with energy conversion without the use of substantial quantities of water are significant. In areas of the country in which surface water supplies are inadequate to meet rising demands (see Figure 4-4), water withdrawal for energy generation can be especially costly and water availability becomes an important factor in power plant siting. Since fuel cell operation requires little or no water, the displacement of conventional systems with fuel cell power plants can conserve valuable water resources.

In addition to supply shortages, other serious water impacts are associated with the withdrawal and discharge of power plant cooling water. Water withdrawal affects aquatic ecosystems through the entrainment and impingement of aquatic organisms at the intake structures, and water quality degradation from the lowered dilution capacity of the source stream. The return of the cooling water at an elevated temperature is often detrimental to the biota near the point of discharge. To the extent that fuel cells reduce the need for large electric generation facilities, these impacts can be reduced. At the same time, current trends involving the careful planning of water intake strategies and the shift from once-through cooling systems to cooling towers will to some degree offset these potential fuel cell benefits.

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\* Water consumption, which is different from water withdrawal, pertains only to that fraction of the cooling water which is lost from the system (primarily through evaporation) and is no longer available for other uses.

During certain operating conditions, the PAFC power plants will produce more water than they can consume in the reforming process and lose in the exhaust stream. This is especially the case during transients and cold weather. Excess water is collected in the water tank of the coolant system until tank capacity is reached. At tank capacity, additional excess water is removed from the power plant via an overflow drain and transported to the municipal sewage treatment system. This process water is of high quality and its discharge will not create any water quality problems.

Power plant blowdown results in a second wastewater stream from the fuel cell power plant which must be pretreated prior to discharge in a sanitary sewer. In the 4.8 MW units, approximately 450 gallons of this wastewater will be produced each day. In Table 5-5, the quality of this liquid effluent is described. After pretreatment and prior to discharge, the temperature of this wastewater will be reduced to ambient, its iron concentration will be about 1 ppm and the zinc concentration under 5 ppm. The concentration of pollutants in the fuel cell waste stream, although higher than ambient federal standards for receiving streams, are not a concern since: (1) the concentrations will be reduced by pretreatment, (2) they will be quickly diluted upon discharge, and (3) the quantities involved are extremely small.

**Table 5-5. Wastewater Quality from the 4.8 MW Fuel Cell Power Plant and Typical Fossil Fuel Steam Electric Generators (Refs. 5.13, 5.16)**

Pollutant	4.8 MW Fuel Cell (Before Pretreatment)			Typical Steam Electric Generator (kg/MW-hr)		
	Federal NSPS (ppm)	Concen- tration (ppm)	Quantity (kg/MW-hr)	500 MW Coal-Fired	800 MW Oil-Fired	800 MW Gas-Fired
Sulfate	-	200	0.0028	0.813	0.828	0.127
Nitrate	-	200	0.0028	0.0018	0.0019	0.0058
Iron	1.0	200	0.0028	0.0020	0.0020	-
Chloride	0.5	200	0.0028	0.148	0.181	-
TDS	-	1000	0.014	1.05	1.19	2.70
Phosphate	5.0	40	0.00056	0.000071	0.00014	0.00053
Chromium	0.2	4	0.000056	0.000097	0.000097	0.000031
Zinc	1.0	16	0.00022	0.0012	0.00013	0.00015

Water pollution problems associated with the direct discharge of wastewater from power plants are generally of less concern than air emissions or solid waste generation. This is primarily because the wastewater is of relatively pure quality

when compared to other industries, and regulations require its pretreatment prior to discharge. The main sources of wastewater from conventional power plants are cooling tower blowdown, boiler blowdown, metal-cleaning wastes, ash transport water, and low volume wastes (floor drains, miscellaneous cleaning wastes, etc.). A comparison of the wastewater quality of conventional systems with fuel cells is provided in Table 5-5. In addition to the pollutants listed, other water contaminants found in the wastewater stream include polyelectrolyte antiprecipitants, organic-polymer dispersants, insecticides, and herbicides (from agricultural runoff). Coal-fired facilities, which produce ash-handling wastewater, may additionally have elevated levels of heavy metals and other inorganic pollutants which must be treated.

The quality of the wastewater produced by fuel cell systems is not dramatically different than steam electric generators for most of the parameters given in Table 5-5. This is attributable to the similarity in wastewater sources from each system, primarily from water system blowdown. However, greater amounts of wastewater are produced by conventional steam systems, primarily due to the higher cooling water requirements. Chlorides appear to be significantly higher in the steam generators, principally because high levels of chlorination are needed to control biofouling throughout the recirculating cooling system. Total dissolved solids and sulfate concentrations are also significantly higher in the conventional systems.

Fuel cell deployment will inevitably result in surface water improvements since these systems produce and discharge an insignificant amount of wastewater. In addition, since their solid wastes are not as great or hazardous as those produced by conventional power plants (see Section 5.3.3.4), their operation is less of a threat to groundwater supplies. However, electric power plants are not in general major contributors to water quality problems, primarily because federal standards strictly regulate their discharges. For this reason, water quality improvements resulting from the use of fuel cell systems will probably be slight. Perhaps of greater importance is the fact that fuel cells will allow for the reduction of utility wastewater pretreatment costs.

In summary, fuel cell power plants have significant water use benefits and potential water quality advantages over conventional generating stations. The most important of these stem from the reduction in water requirements. In 1975, steam electric power plants used approximately 24,000 gallons of water/MW-hr of electricity produced. The total consumption was greater than that required for either manufacturing or domestic use and was only exceeded by irrigation requirements. Since fuel cells require virtually no water for their operation, they can provide major benefits in water short areas. Potential water quality benefits which will result from the commercialization of fuel cells will probably be less important. The most significant of these, thermal pollution, is virtually eliminated by fuel cell systems. In addition, wastewater pretreatment requirements, which are important considerations in conventional systems, are insignificant in fuel cell power plants.

#### 5.3.3.3 Noise

Energy technologies are noisy operations, which is one reason they are generally located away from population centers. The quiet, electrochemical conversion

process of the fuel cell eliminates many of the noise sources associated with traditional mechanical to electrical energy conversion systems. Since newer central generation facilities are sited in isolated locations, public exposure to their noise levels is generally of little concern; however, occupational exposures to high levels of noise can be a problem if not properly addressed. On the other hand, older fossil-fuel plants are often located close enough to residential and commercial neighborhoods to generate community noise complaints. The comparatively small size, the tendency towards dispersed siting, and the inherently low operational noise levels of fuel cell power plants will greatly reduce the problems associated with noise, both in the workplace and the community.

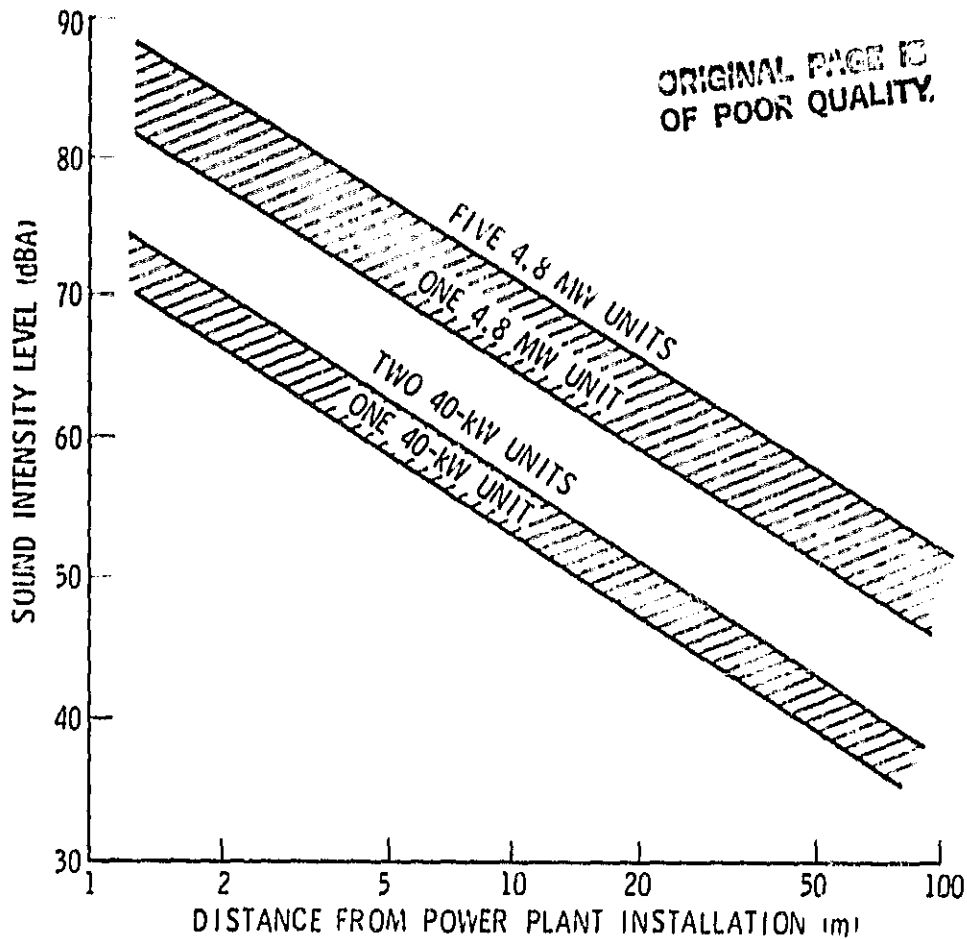
According to performance specifications, the average energy sound level from the operation of the 4.8 MW fuel cell at 30 meters from the power plant perimeter is 55 dBA. The simultaneous operation of five such modules in a 24 MW configuration would increase the noise level to about 62 dBA at this distance (Ref. 5.18). Noise levels will decrease as a function of distance in the manner illustrated in Figure 5-1. This figure also shows the noise emission characteristics of one and two 40 kW units. The free field noise level of these smaller power plants at full power operation has been measured to be 61 dBA at 4.6 m. This noise level was found to vary little over the output range of the power plant.

As would be expected, the multi-kilowatt fuel cell units are much quieter than the larger multi-megawatt systems; nevertheless, concern for noise emissions may be greater for the smaller on-site units since they are to be located immediately adjacent to residential or commercial buildings. As seen in Figure 5-1, the free field noise from on-site power plant installations will exceed the EPA recommended requirements for the protection of public health (see Section 4.1.3) only at distances less than a few meters from the installation. Where necessary, free field noise levels can be easily attenuated by proper siting locations and noise barriers so that noise emissions are within EPA goals at reasonable distances from the installation.

The larger megawatt units will likely have enough of a land buffer zone so that nearby residences will not be affected. At distances very close to the power plant, the free field noise level of the power plant may approach the Federal Occupational Safety and Health Administration (OSHA) noise exposure limit of 90 dBA for an eight-hour day established to protect worker hearing. However, as with the on-site units, noise problems can be easily mitigated.

Lesser reliance on central electric power generation resulting from the deployment of fuel cells will lead to reduced noise effects, particularly those emanating from large cooling towers, forced- and induced-boiler draft fans, transmission lines, and transformers at both the plant and dispersed substations. Noise levels from fuel cell power plants are significantly lower than fossil fuel generating facilities and, even where they are unacceptably high, mitigation measures are easy to implement. The deployment of fuel cells should reduce community complaints about noise from nearby utility stations, and at the same time eliminate the need for expensive noise reduction strategies. Although more people will ultimately be exposed to noise from many dispersed fuel cell power plants than from one central generating station, the noise levels will be much less intense and therefore less of an annoyance.

Figure 5-1. Free Field Sound Pressure Levels for 40 kW and 4.8 MW Fuel Cell Power Plants as a Function of Distance



#### 5.3.3.4 Solid Waste

The solid wastes generated by fuel cell power plants will depend on the technology and fuel used. In current technologies, a zinc oxide (ZnO) reaction bed is utilized in the fuel processor subsystem to remove sulfur from the fuel stream. In the 4.8 MW plant, it is expected that within 3-6 months the ZnO will be 20 percent transformed to zinc sulfide and will have to be disposed (Ref. 5.19). At present, there are no plans to regenerate these reaction beds, and so they must ultimately be removed offsite to sanitary landfills. The volume of reaction bed waste, which is determined by the sulfur content of the fuel used, will be much less than the solid waste discharge of comparable oil- and coal-fired power plants. Because of the low hazard potential of this waste, its proper disposal does not present any significant or unusual problems.

In the 4.8 MW fuel cell, a second solid waste source results from flushing the fuel processor subsystem with nitrogen, an operation required upon plant shutdown. When the plant is not operating, it is necessary to remove the fuel residues from the system to prevent their condensation on, and damage to, the catalyst beds. This fuel residue waste stream is pumped to a holding tank and eventually trucked offsite. Although this waste contains hundreds of hydrocarbons, including potentially dangerous aromatics, the total volumes generated will be exceedingly low and should be easy to dispose of safely.

As discussed in Section 4.1.4, solid wastes from fossil fuel utilities primarily result from air pollution scrubbers, and fly and bottom ash which remains after combustion. By 1990, electric utilities are projected to be the largest single source of both sludge and noncombustible solid wastes, producing approximately 30 and 90 million tons of the wastes, respectively (Ref. 5.20). The greatest contributions will come from coal-fired units. The large central coal-fired facilities which contribute the most to this waste loading are those least likely to be displaced by fuel cells; therefore, the impact of fuel cell commercialization on the production and disposal of solid wastes by electric utilities will not be as significant as the emissions data would suggest is possible. Nevertheless, total national benefits may be noteworthy, in terms of both economics and the reduction of environmental hazards related to solid waste disposal. In regions which are currently having difficulty locating suitable disposal sites, the small amounts of solid wastes generated by fuel cell power plants may make them an attractive energy generation alternative.

The solid wastes which are generated by typical fossil-fuel steam power plants are described in Table 5-6. These figures are based on data from an 800 MW oil- and gas-fired power plant and a 500 MW coal-fired facility. Also included in this table is a rough estimate of the rate at which ZnO reaction bed waste would be produced by a fuel cell using the same technology for sulfur removal as the 4.8 MW power plant. To arrive at this latter figure, several assumptions were made including, (1) a fuel cell heat rate of 9000 Btu, (2) the use of a distillate fuel oil with a sulfur content of 1 percent, and (3) a reaction bed sulfur absorption capability of 25 percent of its weight. This estimate of fuel cell wastes is based on this defined set of circumstances and does not reflect the changes in technology and fuel use which can be expected over time. However, it is, if anything, an overestimate and should be used as a conservative basis for comparison. From this table, it can be seen that the solid wastes from fuel cell power plants are significantly less than oil- and coal-fired facilities, but greater than natural gas-fired units.

Solid wastes from synthetic fuel industries are expected to grow from negligible in 1975 to over one-fourth of the national total in 1990 (Ref. 5.20). If fuel cells become integrally connected with the synthetic fuels industry as expected, the operation of fuel cells will to some degree be responsible for a part of the massive quantities of solid wastes produced by these energy conversion facilities. For this assessment however, it has been assumed that the development of synthetic fuels will proceed independently of fuel cell commercialization and these additional impacts should not be attributable directly to fuel cell operation.

**Table 5-6. A Comparison of the Solid Wastes Generated by Different Energy Technologies (kg/MW-year) (Ref. 5.16)**

<u>Solid Waste</u>	<u>Power Plant Type (with Pollution Controls)</u>			
	<u>Fuel Cell</u>	<u>Gas-Fired</u>	<u>Oil-Fired</u>	<u>Coal-Fired</u>
Scrubber Sludge (dry)	--	neg.	434,000	68,000
Ash	--	neg.	10,000	439,000
ZnO Reaction Bed	93,000	--	--	--
<b>Total</b>	<b>93,000</b>	<b>neg.</b>	<b>444,000</b>	<b>507,000</b>

### 5.3.3.5 Climate

The major concerns involving the impacts of energy generation on climate focus on the global buildup of carbon dioxide from fossil fuel combustion and the regional phenomenon of acid rains. Both of these problems are discussed in Section 4. The buildup of CO<sub>2</sub> in the atmosphere has raised fears of elevated ambient temperatures resulting in ecosystem disruption, shifting precipitation patterns, and/or polar ice melting. The main source of this CO<sub>2</sub> increase is thought to be the combustion of fossil fuels. Since fuel cells will continue to rely on fossil fuels, and CO<sub>2</sub> and H<sub>2</sub>O are the main products of the electrochemical process, the displacement of conventional fossil fueled generators with fuel cell power plants is not expected to change existing CO<sub>2</sub> emission quantities or patterns. However, some decrease in CO<sub>2</sub> emissions may result if the upper limits of fuel cell efficiency and thermal recovery are realized, thus reducing the total amounts of fossil fuels consumed.

Acid rainfall conditions plague certain regions of this country and several other countries as well. It is believed that acid rain results from the combination of NO<sub>x</sub> and SO<sub>x</sub> emissions with atmospheric water. The principal sources of these emissions are stationary combustion facilities, particularly large central electric power plants. The conversion to coal-fired boilers, greater numbers of power plants, and use of taller emission stacks have increased the destructive capacity and areal range of acid rains. Acid rainfall is harmful to fish, crops, and building materials. As seen in Table 5-3, the SO<sub>2</sub> and NO<sub>x</sub> emission rates from both the utility and on-site fuel cell power plants are significantly less than those from fossil fuel-fired steam generators, even when the later systems employ Best Available Control Technologies for sulfur removal. Thus, the deployment of fuel cells can contribute significantly to solving acid rainfall problems.

Fossil fuel combustion products are speculated to contribute to local weather and climate alterations such as changes in temperature and precipitation patterns. Assuming that such impacts are indeed occurring, the low air pollutant emission of fuel cell power plants should serve to mitigate these local phenomena along with any impacts for which they may be responsible.

### 5.3.3.6 Land Use and Aesthetics

The use of dispersed fuel cell power plants for electricity generation will represent a dramatic shift in the way land is currently used for energy generation facilities. Rather than siting a few large power plants in isolated areas of low land value, fuel cells are ideally suited for, and expected to be deployed in, dispersed locations near large urban and suburban centers. This will result in a shifting demand for more land parcels of smaller size but greater value. Because of the comparatively small size and modular configuration of fuel cell power systems, it is reasonable to expect that the urban and suburban areas will be able to meet the land requirements of fuel cell power plants with little or no sacrifice of alternative land uses or problems with siting compatibility.

Although there is no strong correlation between power plant capacity and land requirements, some relationship exists. Land use requirements for central generation facilities are highly variable, depending on type of fuel used, the size of the facility, whether or not disposal of solid waste is on-site, and the type of cooling system employed. In general, natural gas-fired steam generation requires the smallest amounts of land and coal-fired facilities the largest. Economies of scale with regards to land use cannot be fully realized for several small fuel cell power plants in dispersed locations. Thus, although each installation will require only a small area, the total land required for an equivalent amount of power generation may be greater for fuel cells than conventional generation facilities. Conversely, since on-site solid waste disposal areas and extensive cooling facilities are unnecessary for fuel cell power plants, land requirements may also be less.

The 4.8 MW facility in New York required approximately two-thirds of an acre or approximately 0.15 acre/installed MW. UTC has estimated that their planned 11 MW module will require 1.3 acres, or 0.11 acre/MW. In comparison, conventional fossil-fueled power stations require anywhere from 0.01 to 2.0 acres/MW depending on the aforementioned variables. Because of this wide range, it is speculative to estimate the costs or land savings which may result from fuel cell commercialization.

For various economic and environmental reasons, the trend in siting new power plants has been to increase their distance from the load centers. Extensive high voltage transmission systems are the means which allow this siting flexibility. Transmission lines, however, have substantial and often unavoidable impacts. Right-of-way land requirements are generally on the order of 1 acre/mile. Although this land may simultaneously be used for other purposes, it is many times incompatible with surrounding activities. While agriculture may be little affected by transmission lines, corridors through forests may cause a substantial loss to forest product production as well as imposing scenic scars on the landscape. Dispersed, close to the load fuel cell facilities substantially reduce the need for additional transmission lines and the impacts associated with their use.

Aesthetically, dispersed fuel cell power plants displace one set of impacts for another. Although the impacts on visual aesthetics are greater for large central stations than dispersed facilities, they may be of less concern since fewer people are affected. Visual pollution problems related to air emission plumes and power



transmission lines are reduced or eliminated through use of fuel cell generators. On the other hand, fuel cell facilities may be located in areas which expose them to the scrutiny of a great many people. Since some degree of visual degradation will be unavoidable, aesthetic impact mitigation will be an important priority, and power plants will have to be carefully sited so they remain unobtrusive.

#### 5.3.3.7 Health and Safety

Safety codes and standards have been carefully incorporated into the design criteria of the fuel cell power plants under development in order to minimize the occurrence of hazardous events. Most of these construction standards govern electrical systems and interfaces, fuel handling and consumption, and the operation of equipment under pressure. UTC conducts structural analyses and design reviews during the design phase to verify that their power plants are constructed in compliance with the following codes and standards.

- National Electric Code, 1978
- ASME Boiler and Pressure Vessel Code, 1977
- ANSI B31 Code for Pressure Piping, 1977
- UL 795 Commercial-Industrial Gas Heating Equipment
- ANSI Z 21.47 - 1978 (AGA) Gas-Fired Central Furnaces

This is followed by the inspection and testing of the actual components to further verify their compliance. Two nationally recognized testing laboratories, Underwriters Laboratories (UL) and the American Gas Association (AGA) assist UTC in verifying that all subsystems of the power plant are developed to nationally accepted safety specifications.

As a consequence of this concern, fuel cell power plants have been designed with a number of safety features which minimize any potential hazard they may present to both the general public living and working in the vicinity, and service personnel performing maintenance duties. In the 40 kW units for example, a power plant controller includes automatic sensing for equipment protection and automatic shutdown in the event of critical out-of-limits component operation. This sensing system minimizes the potential hazard to personnel or equipment in the event of a single component failure. A certain amount of built-in redundancy also reduces the risk associated with component failure. UTC has conducted tests on the 40 kW system to ensure that it functions according to design.

Additional safety features incorporated into the design of the 40 kW units reduce the potential for accidents. The power plant has no moving components exterior of its cabinet that could cause injury to nearby persons. Special tools are required to open the cabinet, and thus the chance entry of unauthorized persons into the cabinet is extremely unlikely. All air and exhaust vents are screened to prevent the entry of hands, arms, and other objects into the cabinet interior. The components that operate at the highest temperatures (converter, reformer and steam separator) are in a well insulated section of the power plant. This insulation ensures that the temperature of the exterior surface of the cabinet will remain below those

temperatures capable of causing heat injury when contacted. Exhausts from the power plant are controlled so that persons in an interior location will not be exposed to ambient concentrations of power plant exhausts, gases, or fumes that could pose a hazard to their health.

A UTC study examined the failure rates of the 40 kW power plant subsystem components and identified system malfunctions which could result in a series of problems, including nuisance effects, reduced efficiency or reliability, loss of power plant availability, or human hazards (Ref. 5.21). In the context of health and safety, it is only necessary to analyze those malfunctions which can result in a human hazard. UTC identified 24 components whose malfunction could create a situation where the safety system would have to intervene to avert a possible human hazard. These components were estimated to have a combined failure rate of 18 failures for every million hours of operating time. The failure rates of components give probability to a scenario of events which could result in an accident endangering people. Although this probability is undefined, it is much less than the probability of individual component failures would indicate. This is because the built-in, overlapping safety features of the system are such that simultaneous malfunctions of several components, including components of the safety features, would be necessary before an endangering accident would be possible. It is also possible for a power plant accident to result from either a man-made incident and/or natural catastrophe such as sabotage, vandalism, or lightning strikes. The occurrence of such an event is considered improbable, and the safe design of the power plant and the training of operators and service personnel will minimize these potential hazards.

Various federal, state, and local regulations will govern the operation of fuel cell power plants to further ensure their safety. Of major importance are the health and safety standards promulgated by OSHA. The goal of OSHA standards is the protection of the worker in the workplace, and these standards address many facets of the work environment including exposure to noise, radiation, air contaminants, and toxic substances. OSHA standards also set forth requirements for adequate safety equipment, safety color codes for marking physical hazards, and accident prevention signs and tags.

The most common method for evaluating the safety hazards associated with an operation is to review the injury and death statistics resulting from the activity. Unfortunately, no such data are available from fuel cell power plants. Although precommercial fuel cell test units have been operated for several thousand hours, the data base is insufficient to project accident rates that would be associated with the day-to-day operation of this technology. Nevertheless, the equipment and operational/maintenance requirements are similar enough to other industries in general, and other utility systems in particular, to suggest that there will be little difference in worker health and safety statistics (see Section 4.1.7).

The safety features of the fuel cell power plants and the strict adherence to the regulations which govern the operation of these energy facilities eliminate the great majority of sources for possible power plant accidents and safety hazards. Certain features of fuel cell power systems (their comparatively small size, lack of a combustion cycle, state-of-the-art safety systems, and low environmental emissions)

result in the fuel cell being one of the least hazardous methods of energy conversion. Nevertheless, certain hazards are endemic to industrial installations, and it is impossible to totally eliminate the potential for accidents. The storage and use of large volumes of raw and processed fuels in particular increase the potential hazards associated with system operation. Some aspects of fuel cell operation such as their on-site location, their use of phosphoric acid and a wide range of synthetic fuels, and the newness of the technology itself, may create unusual or additional safety problems. Overall, however, the hazard potential of fuel cell power plants are expected to be less than or equal to conventional energy systems and should be well within the acceptable limits for energy generation facilities.

#### 5.3.3.8 Other Environmental Impacts

Other environmental parameters which have been reviewed and found to be minimally affected by the operation of a network of fuel cell power plants include geology, soils, topography, and culture. By reducing the need for transmission lines, fuel cell commercialization may reduce the disturbance to wildlife habitats caused by the construction of corridors in remote locations. In general, fuel cells will be located in areas already disturbed by man's activities and, thus, environment disruption to the wildlife and vegetation in more pristine areas will be reduced. Damage to crops and surrounding vegetation from air pollutants, often a problem with conventional generation facilities, will be mitigated by the use of fuel cells.

Operations and maintenance manpower requirements for conventional generation systems are described in Table 5-7. At this point, it is difficult to determine the manpower requirements for a given fuel cell penetration scenario. However, economies of scale suggest that fuel cell power plants will probably require more personnel per MW of output capacity than fossil-fuel systems since fuel cell power plants will be smaller and more dispersed. Nevertheless, it is hoped that many of the smaller fuel cell plants will be able to operate on a semi-automatic basis and require only a minimal amount of operations and maintenance personnel. Best estimates indicate that around 0.5-1 person will be required to run a 25 MW fuel cell facility. By using this value as an overall fuel cell manpower requirement rate, calculations show that, compared with the manpower requirements for an 800 MW oil-fired power plant, between 625 and 2625 additional workers would be needed at the high fuel cell penetration projection level of 100,000 MW. Thus additional jobs which would be created at the low projection level (20,000 MW) range from 125 to 525. The socioeconomic benefits associated with this increased employment level would be dispersed throughout the nation.

Cumulative economic impacts will be widespread and significant, resulting in secondary and tertiary rippling effects. An economic analysis of the benefits or disadvantages of fuel cell power plants is an integral part of the decision processes of individual utilities, and presumably a significant market penetration of fuel cells would reflect some level of either national economic benefit or enhanced national security (i.e., less dependence on imported energy). However, an evaluation of the scope of economic impacts resulting from the commercialization of fuel cell systems is a complex undertaking beyond the scope of this assessment.

**Table 5-7. Manpower Requirements for the Operation and Maintenance  
of Fossil-Fueled Steam Electric Generating Plants  
(Workers/Year) (Ref 5.16)**

<u>Fuel Used</u>	<u>Nonmanual Technical</u>	<u>Nonmanual Nontechnical</u>	<u>Manual</u>	<u>Total</u>
Gas (800 MW Plant)	1.9	2.0	4.3	8.2
Oil (800 MW Plant)	2.4	2.3	5.8	11.0
Coal (500 MW Plant)	-	-	-	8.5

### 5.3.3.9 Impacts on Energy Consumption and Fuel Use

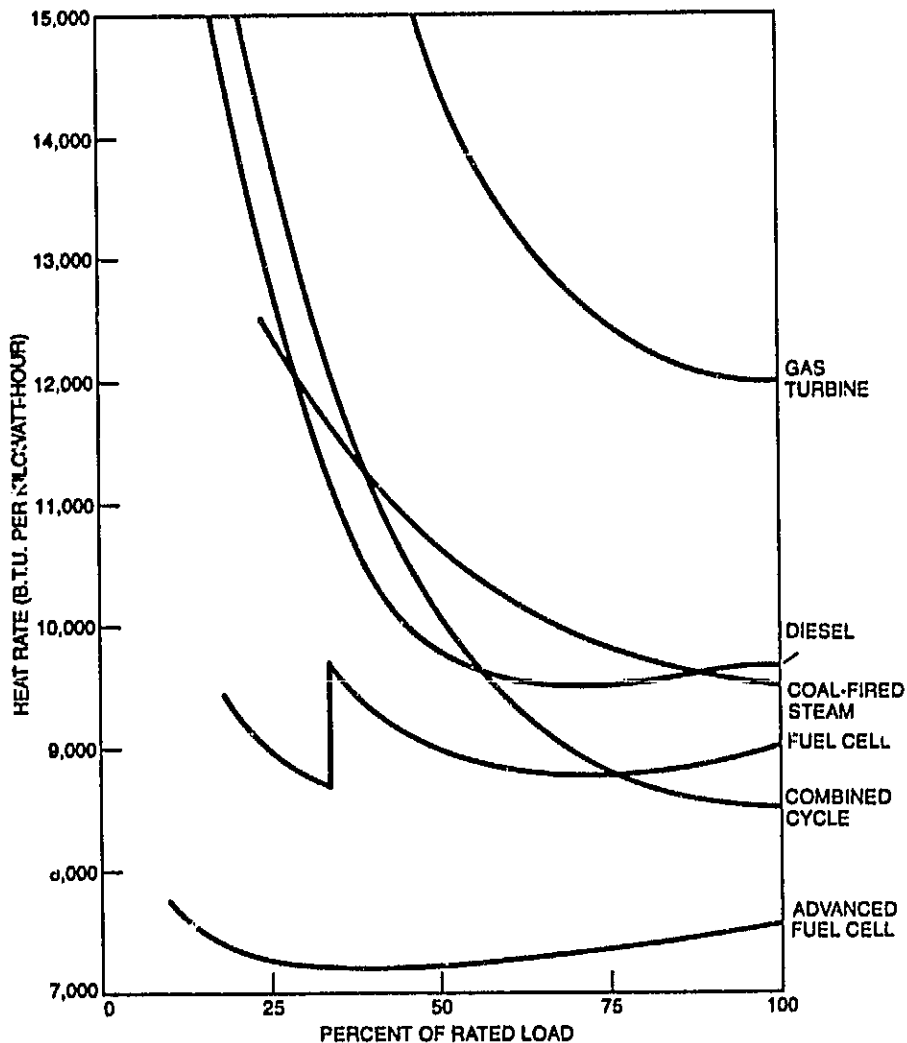
In 1977, electric utilities in the United States consumed 22,515 trillion Btu of energy in the form of petroleum, coal, natural gas, nuclear, and hydroelectric resources. The actual breakdown by fuel use, which is presented in Table 4-8, shows that 17,591 trillion Btu or 78 percent of this energy total was derived from fossil fuels. By far, the greatest amount came from the consumption of coal (46 percent).

The amount of energy resources which are used by any technology to produce a unit of electricity is dependent upon the efficiency of the system. Overall conversion efficiency from chemical (thermal) energy to electrical energy has been limited to 33 to 45 percent when conventional steam-turbine systems are employed. By converting chemical energy directly into electrical energy with a fuel cell, the efficiencies which are theoretically achievable exceed 80 percent. In practice, first generation fuel cells which have been tested are about 40 percent efficient.

The measurement used to describe energy efficiency is termed the "heat rate" of the system and is defined as the number of British thermal units of fuel required to produce one kilowatt-hour of electric energy. The lower the heat rate, the higher the efficiency. A comparison of the heat rates of several energy technologies is presented in Figure 5-2. As seen in this figure, the heat rate of first generation phosphoric acid fuel cells is superior to every fossil-fuel technology except for combined cycle systems, and the heat rate of advanced fuel cells is the lowest. The flat heat rate over the total range of the fuel cell power plant operating capacity reflects the uniformly high fuel cell system efficiency as it is cycled up and down to meet varying load demands.

Because fuel cells have a demonstrably greater efficiency than conventional fossil-fuel systems, they represent a significant energy conservation potential. For example, if fuel cell penetration were to come at the expense of the relatively efficient base load fossil-fuel steam units, approximately 182 trillion kilojoules of energy resources per year could be saved under low fuel cell penetration projections (20,000 MW). At the higher penetration projection (100,000 MW), the annual energy savings would total around 910 trillion kilojoules. These amounts represent approximately 0.7 and 3.6 percent of the total energy consumed in the United States in 1977 for electricity production. Additional energy savings would result, if technology improvements reduce heat rates in advanced PAFC units as expected.

**Figure 5-2. Heat Rate Characteristics of Phosphoric Acid Fuel Cells Compared with Other Types of Power Plants Over a Wide Range of Loads (Ref. 5.22)**



Introduction of fuel cell power plants into the electric utility and on-site markets will displace other types of generating equipment, potentially shifting the types of fuels demanded by these markets. Early entry fuel cells will likely operate on gaseous and light distillate liquid fuels, while later, more advanced phosphoric acid fuel cells may be capable of operating on all distillate and residual liquid fuels. Displacing conventional oil and gas fueled generating equipment with fuel cells is a boost to overall generation efficiency; however, displacement of generators not fueled by gaseous and liquid hydrocarbon fuels (i.e., coal, nuclear, hydro) runs counter to national energy goals by increasing the use of natural gas and petroleum fuels at the expense of coal, nuclear, and hydropower resources. As a result of this concern, fuel cells will be adapted to use synthetic fuels as they become available.

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Electric utilities in the United States had over 190,000 MW of their installed generating capability filled by oil- and gas-fueled steam generators, combustion turbines, and internal combustion generators in 1980. This figure is projected to decrease slightly to approximately 175,000 MW by 1990 (Ref. 5.23). These types of generators appear to be most suitable for displacement by dispersed electric utility fuel cell power plants because of their fuel dependency and lower relative energy efficiency.

The low (18,600 MW) and medium (46,500 MW) electric utility market penetration levels could result in the displacement of large portions of the capability supplied by these generators. The high (93,000 MW) electric utility market penetration could displace more than half of the entire oil and gas based generating capacity. The fraction of generating capability supplied by oil- and gas-fueled generators varies radically from one region of the United States to another, and thus substantial displacement by fuel cells will require corresponding regional variation in fuel cell deployment if fuel shifts toward increased oil and gas use are to be minimized. Displacement of coal-fueled generators by fuel cells operating on synfuels derived from coal will actually reduce overall energy efficiency because of the efficiency loss inherent in synfuel production.

On-site fuel cell power plants can be operated in a variety of modes to meet any or all of site base, intermediate, or peak loads. The mode of operation will determine the loads removed from the utility system and, thus, the generating equipment displaced. The precise type and volume of load displaced will be determined by site load characteristics. The deployment of on-site power plants will, therefore, be less discriminating than electric utility power plant deployment in terms of the generating equipment displaced and hence the fuel type displaced. The maximum shift to oil, gas, and synfuels from other fuels will take place if all on-site penetration occurs in regions lacking oil- and gas-fueled generators available for displacement. In this worst case situation, the high (7,000 MW), medium (3,500 MW), and low (1,400 MW) on-site penetration levels would result in fuel shifts to oil, gas, and synfuels use equal to the full amount of these generating capabilities. The actual fuel shift caused by on-site deployment will be less, however, because (1) deployment will occur in many regions, and (2) the utilities of most regions have a suitable mixture of generating equipment to allow displacement of oil and gas fueled generators.

#### 5.3.3.10 Summary of Operational Impacts

Fuel cell power plants are environmentally attractive when compared with conventional energy generation options. They have lower air and water emissions, consume less water, are quieter, and generate less solid waste. From the analyses in the preceding sections, it appears that, with the exception of land use, the environmental benefits from the operation of thousands of megawatts of fuel cell systems will be considerable. This observation is supported by the environmental comparisons which are summarized in Tables 5-8 and 5-9. In Table 5-8, resource requirements and emission rates are compared for fuel cells and three reference fossil-fueled steam power plants. Individual subsections should be consulted to identify the sources of data and to understand the assumptions which were made in constructing the table. Using these rates, Table 5-9 identifies the net national

**Table 5-8. A Comparison of Fuel Cell Power Plant Emissions/Requirement Rates with Conventional Steam Powered Generators**

<u>Impact Parameter</u>	<u>Power Plant Emissions/Requirements</u>			
	<u>Fuel Cell</u>	<u>800 MW Gas-Fired</u>	<u>800 MW Oil-Fired</u>	<u>500 MW Coal-Fired</u>
Air Pollutants (kg/MW-yr)				
Total Suspended Particulates	0.088	964	964	964
Sulfur Dioxide	0.88	25,404	25,404	37,668
Nitrogen Oxides	560	6,132	9,636	19,272
Water Withdrawal (m <sup>3</sup> /MW-yr)	neg.	8x10 <sup>5</sup>	8x10 <sup>5</sup>	8x10 <sup>5</sup>
Solid Waste Generated (kg/MW-yr)	93x10 <sup>3</sup>	neg.	444x10 <sup>3</sup>	507x10 <sup>3</sup>
Land Requirements (m <sup>2</sup> /MW)	445	32	53	263
Operation and Maintenance Personnel (workers/MW)	0.020-0.040	0.010	0.014	0.017
Energy Consumption (10 <sup>9</sup> kJ/MW-yr)	83.1 (69.3)*	92.4	90.5	92.4

\* Assumes advanced generation fuel cell heat rate of 7912 kJ/kW-hr.

environmental impacts which would result from the displacement of 50,000 MW of electric generation capacity with fuel cell systems (middle penetration scenario). Environmental impacts associated with high (100,000 MW) and low (20,000 MW) penetration values can be similarly calculated from Table 5-8.

Unfortunately, Table 5-9 provides only a superficial picture of the environmental impacts resulting from fuel cell commercialization. National values fail to distinguish the specific impacts on local or regional environments which are the true targets of cleanup efforts. The parameters of noise and aesthetics, which are meaningless on other than a local level, are not presented. Nevertheless, these national comparisons reflect the fact that, since significant environmental improvement are to be realized by the nation as a whole, important inroads will necessarily be made on persistent local and regional problems.

Table 5-9 should be interpreted carefully for another reason. By using data from large steam powered facilities, it is assumed for comparison purposes that fuel cells will displace only these specific technologies. Although this will not be the case, intermediate and base load gas- and oil-fired power plants are expected to be among the initial generation capacity displaced by fuel cell systems. In addition, the influence of advanced energy technologies on fuel cell penetration and vice versa should be considered in order to identify more precisely the amount of displaced environmental impacts which are attributable to the use of fuel cell systems. In

**Table 5-9. Net National Environmental Impacts Resulting from a Fuel Cell Market Penetration of 50,000 MW (Medium Level)**

<u>Environmental Parameter</u>	Impacts Displaced <sup>(1)</sup>		
	<u>800 MW Gas-Fired</u>	<u>800 MW Oil-Fired</u>	<u>500 MW Coal-Fired</u>
Air Pollutants (10 <sup>6</sup> kg/yr)			
Total Suspended Particulates	-48	-48	-48
Sulfur Dioxide	-1,270	-1,270	-1,883
Nitrogen Dioxide	-278	-454	-935
Water Withdrawn (10 <sup>9</sup> m <sup>3</sup> /yr)	-40	-40	-40
Solid Waste Generated (10 <sup>9</sup> /kg/yr)	5	-17	-17
Land Requirements <sup>(2)</sup> (10 <sup>6</sup> m <sup>2</sup> )	21	20	9
Operation & Maintenance Personnel (workers/yr)	500-1500	300-1300	150-1150
Energy Consumption (10 <sup>12</sup> kJ/yr)	-465 (-1,154) <sup>(3)</sup>	-370 (-1,060)	-465 (-1,154)

- (1) Negative values indicate that fuel cells produce/require less of the parameter than the conventional steam powered generator.
- (2) Does not include on-site solid waste disposal.
- (3) Assumes advanced generation PAFC heat rate of 7912 kJ/kW-hr.

spite of these drawbacks, it is clear that the displacement of conventional systems by fuel cells will result in a substantial decrease in the total environmental impacts associated with energy production.

#### 5.3.4 Recycle of Materials

Current fuel cell stack technology requires a stack overhaul for every 40,000 hours of operation. Overhaul necessitates removal of the stack from the power plant and shipment back to the manufacturing plant or other recycling facility. At this facility, the stack is disassembled and reusable components are recovered. Chief among these recovered components is the platinum catalyst. By burning away the graphite and carbon electrode, approximately 90-95 percent of the platinum can be recovered for reuse (Ref. 5.24). Depending on the economics of recovery and reuse,



other stack components may also be recycled. End plates and manifolds may be reused and graphite plates may be ground into powder for reuse (Ref. 5.10). To complete the overhaul, the stack is reassembled with new and reused parts, filled with a new supply of phosphoric acid, and shipped to a fuel cell power plant.

Other fuel cell power plant components that require periodic regeneration include fuel and water filters and purifiers. Ion-exchange columns are regenerated by removing them from the power plant and washing and mixing the resin. Charcoal filters are removed and heated to remove collected impurities. Regenerated ion-exchange columns and charcoal filters are then available for reinstallation. The regeneration of these items will probably be performed locally by the utilities themselves or by local vendors (Ref. 5.25). The proper disposal of liquid and gaseous waste products is required. Fuel and air filters need periodic changing, and they can probably be cleaned by the utilities or local vendors and reused.

Recycling will reduce demand for some power plant materials and, hence, the environmental impacts associated with their acquisition and processing. Disposal impacts will also be lessened. The variety and volumes of recycled material will probably remain low, however, and recovery and reprocessing activities will produce impacts of their own. Recycling will require transportation to and from either the factory or local vendors. Trucks will likely be used for moving these materials. Facilities must also be constructed and operated to handle recycling. The capacity of local vendors may also have to be expanded to handle the added business from utility and on-site fuel cell power plants.

Some power plant materials will likely be disposed rather than recycled. The zinc oxide pellets used to remove sulfur from the fuel flow are converted to zinc sulfide as they absorb sulfur (Ref. 5.26). They will probably be used for treating low sulfur fuels only and have the capacity of removing 20-25 percent of their weight in sulfur (Ref. 5.26). There are currently no plans to recycle this material, and it will likely be dumped in landfills. Four or five pounds will be dumped for every pound of sulfur removed. The acid recovered by the acid condenser and recovery system will probably be treated and disposed. Approximately 90 percent of the acid in the cathode spent air flow is recoverable by this system.

### 5.3.5 Impacts on the Electric and Gas Utility Systems

The U.S. bulk power system presently consists of about 550 GW of installed generation plus 125,000 miles of transmission lines rated 230 kV and above (Ref. 5.27). This system is essentially composed of three distinct (although not isolated) grid networks: (1) the states east of the Rockies have one big interconnected network, with the exception of Texas, (2) most of Texas, and (3) the western states which are interconnected with the eastern states over a few very long transmission ties. Although individual utilities plan their operations to serve the needs of their customers, utility decisions regarding system expansion or capacity mix ultimately affect the stability and reliability of these much larger power networks.

The introduction of fuel cell power plants into utility systems will depend on several important variables including installed cost, operating and maintenance costs, fuel price, heat rate, on-line performance, reliability, capacity factor, emission profiles,

and tax and emission credits. These variables also influence the utility's decision to employ fuel cells in either a base, intermediate, or peak load capacity. As utilities become cognizant of some of the fuel cell characteristics that may provide significant credits or advantage for their systems, fuel cells will begin to compete vigorously for new or replacement generation capacity.

The impacts of a PAFC system on reliability, maintenance schedules, manpower requirements, capacity requirements, and environmental requirements on the utility system are indeterminate at this time. As data become available from various demonstration programs and initial commercial application, it is believed that the benefits of fuel cells for utility systems will become more obvious. At present, the following potential system benefits have been identified.

- Reduced Reserve Requirements. Loss of load probability (LOLP) techniques are used by most utilities to compute generation reserve requirements. Reserve capacities of 20 percent are considered adequate, but some utilities have a reserve margin as low as 10 percent while others have reserves above 50 percent (Ref. 5.28). Forced outage rates, maintenance requirements, unit sizes, response and load characteristics determine the percentage of reserve requirements for a specified LOLP. It is predicted that fuel cells will reduce this percentage through lower forced outage rates, shorter planned maintenance, and smaller unit size.
- Reduced Transmission Requirements on Energy Losses. Since dispersed fuel cell power plants will be located at distribution substations, transmission line requirements and energy losses normally associated with the transmission of power from remote generation stations to load centers will be reduced.
- Rapid-Response Spinning-Reserve Capacity. Since fuel cells are almost as efficient at part-load as they are at full-load, they can be dispatched as load-following units, instead of being "block loaded." The system response of 35 percent to full power in a few seconds underscores the value of fuel cells for rapid-response reserve capacity.
- Area Frequency Regulation. In an electric grid, the imbalance between constantly changing power demands and generated power results in frequency deviations from 60 Hz. The modular nature of fuel cells allows them to be located in various areas of an electric grid and, by operating them in the load-following mode, utilize their rapid power response and tight control features for minimizing frequency deviations.

Other potential benefits of fuel cell deployment for utilities include improved system efficiency, fuel flexibility, environmental compatibility, and reduced lead times and utility capital outlay as a result of modular design and siting versatility.

The first two benefits listed above indicate that fuel cell commercialization will reduce requirements for new generating capacity. Lowering utility capacity

requirements proportionately reduces the environmental impacts associated with the construction, operation, and maintenance of electric generation facilities. The degree to which these impacts can be offset is not easily defined and will depend upon the overall efficiency of fuel cell systems, and the flexibility which utilities have in determining their reserve capacity margins. Given a high fuel cell market penetration level, the environmental benefits should be substantial and may in fact be more important than the other impacts discussed in this assessment.

Because fuel cell power plants will generally be sited at dispersed locations close to the load, utility system transmission requirements will be less. Significant environmental issues are associated with the construction, operation, and maintenance of utility transmission systems. During the construction of a transmission corridor, the heavy influx of workers and machinery can represent a significant short-term disturbance. Large cumulative amounts of land are required (about 1 acre per mile of line) which may interfere with other existing land uses. Aesthetic degradation results when clear-cut corridors contrast sharply with surrounding vegetation, and where steel support towers do not blend in with the existing terrain. Radio and television interference, ozone production, and health effects from electric/magnetic fields have all been blamed on high kilovolt transmission systems. By reducing the need for these systems, fuel cells will reduce these environmental impacts accordingly.

Fuel cell power plants can provide economic benefits to electric utilities because of their modular design and relatively short planning and construction lead times. The modular design permits addition to grid generating capacity in variable increments rather than in the large steps typical of large conventional power plants. The result is a closer alignment of capacity to load and a reduction in the uncertainty traditionally inherent in planning for grid capacity expansion. Shorter planning and construction lead times reduce the duration that capital must be invested in a new power plant project before the plant actually goes on line. Thus capital outlays for expansion of grid capacity can be made in smaller amounts and over shorter lengths of time when fuel cell power plants are employed.

On-site fuel cell power plants, or any on-site generators independent of grid control, have the potential to cause economic impacts on the local electric utility. These impacts are manifestations of at least three changes in utility operation and growth induced by the presence of independently owned and operated electrical generators connected to the utility grid: (1) load factor changes, (2) reduction in utility load growth, and (3) the requirements of the Public Utilities Regulatory Policies Act (PURPA) for electric utilities to buy excess electrical output from small generators or cogenerators. As detailed below, each factor has the potential to produce either an economic benefit or burden for the utility. The sum impact of all economic factors is difficult to estimate, however, in the absence of a thorough economic analysis.

The load factor is the ratio of actual electrical output to potential electrical output by a grid system. The load factor nationwide is about 63 percent, since intermediate and peak generators operate only during portions of the day. On-site fuel cell power plants will be matched to sites to satisfy all or part of their electrical loads. It is probable that most on-site units will be sized to meet at least the base load

demand, with others also sized to meet the intermediate load demand and some sized to satisfy the peak load demand in addition. This combination of operating modes would tend to eliminate a disproportionate amount of base load demand from the grid, thereby lowering the load factor. A reduction in the load factor would impose an economic burden on the utility since it would get a reduced electrical output from its generating facilities and would have to increase the percentage of costlier intermediate and peak generators on the grid. The burden is ultimately passed on to utility customers through rate increases. This situation could be reversed if on-site units were operated to remove only the intermediate and peak load demands from the grid. Although this mode of operation may not be practical because of the capital costs of the units, it would shave intermediate and peak load demands from the grid and result in an increase in the utility load factor and a decrease in the percentage of intermediate and peak generators operated by the grid.

On-site fuel cell power plants may be owned by the local electric utility, but it appears more likely that they will be owned and operated by either the local gas utility or the site owner. Operation of power plants not owned by the electric utility will reduce the growth in electrical load on the utility grid and hence will allow postponement or cancellation of some future power plant projects. This will preserve utility capital by eliminating some need for investments in new facilities. Utilities that already have an excess of generating capability may discover that the demand reduction is an economic liability since it will lengthen the time it takes for demand to catch up with capability. Many on-site units will probably use the utility grid as a backup power supply. Such a use should not significantly increase the load demand on the grid since the small size and large number of on-site units make them very reliable as a group.

PURPA requires public utilities to buy electricity from qualified independent producers at a price roughly equal to the cost utilities would have incurred in producing it. Fuel cell power plants can function as cogenerators and thus will qualify for selling electricity to the utility. Ideally, the utility cost of providing electricity through the grid should be the same regardless of whether the electricity is generated by utility owned facilities or by independent producers. Since the independent producers will be beyond utility control, however, the timing and volume of their input may not be as reliable as utility generated power. The utility will be left to match supply irregularities with grid demands and thus may require a larger and costlier generating reserve.

The deployment of on-site fuel cell power plants may also have an impact on the gas utility industry. Power plants fueled by utility supplied natural or synthetic gas may increase gas consumption in some areas and force expansion or other modifications to the gas distribution system. This could require major capital investments. If the on-site power plants are to be owned by the local gas utility, capital must be expended for the purchase, installation, and maintenance of the power plants. These expenditures could amount to a substantial increase in the utilities' operating budgets. The cost of modifying and expanding the gas delivery system might result in rate increases for gas consumers.

The extremely low levels of air pollutant emissions from fuel cell power plants is an attractive characteristic and contributes to the versatility and siting flexibility of the technology. This characteristic can not only permit electric generation and cogeneration where it might otherwise be prohibited, but can translate into real and tangible economic values under conditions defined by existing federal and state air quality regulations. These regulations, as described in Section 7.2.1, establish ambient air quality and emission standards which govern the siting, operation, and expansion of stationary air emission sources. Under specified conditions, new emission sources are permitted in an area only if they "offset" the emissions of an existing source by a prescribed amount. An existing source can create "offset" credits by reducing air emissions below emission standards. These credits can be traded or sold to other emission sources in the area requiring emission offsets, or they can be saved for future expansion (Ref. 5.29).

Operators of existing air emission sources, such as electric utilities or large industries, can utilize fuel cell power plants to replace their existing polluting energy-generating equipment and thereby create emission reduction credits. They can use these credits as internal offsets, sell them to others as external offsets, or bank them for future internal or external use. Economic benefits can be realized by the sale of credits created by fuel cell installation, or by the use of these credits to offset the need for expensive air pollution equipment on other emission sources in the area (Ref. 5.29).

#### 5.4 Fuel System

PAFC power plants will operate on a variety of gaseous and liquid fuels. PAFC deployment requires a fuel system for producing and delivering these fuels. This section will describe the activities and environmental impacts associated with fuel production and fuel transport, distribution, and storage. Section 6.4 discusses the effects on the fuel system and other fuel cell deployment systems produced by varying the type of fuel used by the fuel cells.

##### 5.4.1 Fuel Production

PAFC power plants will initially be fueled by natural gas, naphtha, and perhaps methanol. Their fuel use capability will eventually widen to include most liquid and gaseous fuels, including synthetic fuel and it can be expected therefore that fuel cells will operate on whatever fuels are economically available. The production of these fuels consists of the extraction of the raw resource (gas, oil, oil shale, tar sands, etc.) and the various processing steps required to convert the resource into a usable fuel (gas cleanup, refining, retorting, gasification, liquefaction, etc.).

Fuel extraction and processing typically have major environmental consequences. All extraction methods consume land and produce aesthetic and habitat disruptions. Strip mines for extracting coal, and possibly oil shale and tar sands, are obvious examples of the magnitude of air, water, and land disruptions possible. Underground mines have unique health and safety impacts, and subsidence from their collapse can affect large surface areas. Mines can alter surface and groundwater systems and increase the acidity of their flows. Huge quantities of solid waste are produced during the processing of coal and oil shale. Oil shale processing may consume large

quantities of water, as do coal gasification and liquefaction. Worker health may be compromised by exposure to synthetic fuels. Production of oil and gas is accompanied by the hazards of blow-outs and spills that can affect worker safety and degrade the environment, especially in marine areas. Fuel refinement techniques generally produce odors, wastewater, and fog plumes as well as sulfur, coke, and other solid and liquid byproducts.

The national fuel production scenario and its resulting environmental impacts should not be significantly expanded or altered by fuel cell deployment since (1) fuel cells should be able to operate on nearly any type of fuel, and (2) fuel cell deployment will replace the fuel demand of displaced power plants rather than creating additional demand. Production of crude hydrocarbon gases and liquids by conventional and synthetic means will continue independent of the types of electric power generators consuming the fuels. Because fuel cells are more energy efficient than the conventional generators they will replace, the quantity of fuel produced domestically or imported for electric power production will probably be less. This energy savings could reduce the environmental impacts of domestic fuel production.

Fuel cell deployment may create a need for expansion of some types of refining facilities and may influence the location of processing and refining facilities. Refineries near fuel cell concentrations may add equipment or otherwise alter their operating procedures to produce additional quantities of naphtha, fuel oil, or whatever types of fuel are being demanded by the local fuel cell power plants. Alteration and expansions of this kind may have an impact on the local environment if total refinery throughput is increased. It is conceivable that gasification plants, or liquefaction plants, could be located near fuel cell concentrations to more economically feed the fuel distribution system serving these power plants. These types of conversion plants sited near urban areas could produce major impacts to local air and water quality, land use, water supply, aesthetics, and solid waste disposal systems.

#### 5.4.2 Fuel Transport, Distribution, and Storage

The transport and storage of fuels for a network of fuel cell power plants is a very important aspect of fuel cell deployment with potentially significant impacts to the environment and public safety. The nature of the fuel delivery system will be determined largely by the types of fuels handled and the size of the power plants served. Both liquid and gaseous fuels are being evaluated for fuel cell use. Possible liquid fuels include naphtha, methanol, fuel oil, other petroleum distillates, and liquid synthetic fuels. Potential gaseous fuels include natural gas, synthetic gas, and even pure hydrogen.

The fuel transport system moves the fuel from its source or generation point to a distribution point near a fuel cell region and then distributes the fuel throughout the region. Possible fuel sources are diverse and include coal mines, oil and gas fields, and oil shale and tar sands developments. The raw fuel may be converted to a synthetic fuel prior to transport (liquefaction or gasification) or shipped in its raw form with only minor processing. Modes of transport employed to move the fuel from the source to a fuel cell region are dependent on fuel type and distance and

may include any of the following: gas pipeline, oil pipeline, coal slurry pipeline, oil tanker, LNG tanker, or coal unit train. Coal supplies would likely arrive at conversion facilities near the fuel cell regions where they would be converted to synthetic gaseous and liquid fuels. Crude oil and other liquid petroleum products would likely require refining by local refineries prior to entering the local distribution systems. Gaseous fuels may also require some local processing before distribution.

The local distribution system is perhaps the more important of fuel transport phases in terms of possible environmental and safety impacts because it will move and store liquid and gaseous fuels within populated areas. Projections on the types of systems that might be used to distribute fuel are usually divided into systems for serving on-site power plants and those for serving utility power plants. Since transport by rail is uneconomical over short distances and barge transport is generally unavailable in a confined regional area, the most likely modes of distribution are pipelines and trucks (Ref. 5.30).

The safety problems posed by fuel storage at on-site power plants suggest the future use of gas pipeline systems for supplying these power plants. The use of a gaseous pipeline fuel is more likely than a liquid fuel delivered by pipeline or truck for several reasons. First, a gaseous fuel inventory can be stored within the pipeline system by "linepacking" or pressurizing the gas. A liquid pipeline fuel would require storage tanks throughout the system to maintain a suitable fuel reserve margin. Liquid fuel delivery by truck would require on-site storage. Secondly, use of a SNG fuel may allow use of the existing, in-place natural gas distribution system. Use of this system would eliminate the need for installing a separate pipeline network for the power plants. Gas consumed out of the natural gas system could be compensated for by a SNG conversion plant supplying the system. This plant would likely be located near the distribution system and would use coal or petroleum as a feedstock.

A fuel distribution system for utility power plants could consist of a pipeline network or a truck delivery system. Operation on SNG fuel may allow use of the in-place natural gas system as described above. Use of other gaseous fuels would require installation of a separate pipeline network having the capability of high pressure storage for providing a fuel reserve. Use of a liquid fuel such as naphtha or fuel oil would allow the option of delivery via pipeline or truck. A liquid pipeline network would require storage tanks for meeting reserve margins. A typical liquid pipeline network might consist of (1) a bulk storage facility near the fuel cell region that is fed by a local refinery, (2) a number of pipelines fanning out from the bulk storage facility to intermediate storage facilities, (3) intermediate storage facilities located throughout the region near clusters of fuel cell power plants, with three-day storage supplies in aboveground tanks, (4) pipelines fanning out from the intermediate storage tanks, with a two day capacity at the power plants. The truck delivery mode would consist of tanker trucks making periodic runs between a bulk supply facility and the power plants. Truck delivery would necessitate a greater fuel storage reserve at the power plant, perhaps as much as a five day reserve (Ref. 5.31).

A liquid pipeline system for utility power plants would likely use 2- and 3-inch-diameter pipelines and would be favored over the truck system when the fuel

volumes are great, the distances are short, and the terrain does not present construction difficulties. Underground tanks would be used at the power plants since the use of aboveground tanks is discouraged in most central urban areas. Sites for intermediate storage facilities would have to be in areas permitting use of aboveground tanks. The movement of tanker trucks through urban areas is usually restricted, but the grid of permitted truck routes should be adequate for fuel delivery.

A given fuel cell region may be serviced by several energy transportation systems supplying different kinds of fuels for fuel cell consumption. For example, gas and coal slurry pipelines may provide the fuel for a network of on-site power plants while oil tankers and oil pipelines provide fuel for the utility power plants in the same region. Each system has its own characteristic environmental impacts. Oil and gas pipelines requires land for right-of-way and excavation for burial. Coal slurry pipelines require right-of-way land and also large quantities of water for moving the coal. LNG tankers require extensive facilities for liquefaction and regasification and are accompanied by their unique safety risks. Oil tankers require loading and off-loading facilities and are a potential source of oil spills and marine pollution. Coal unit trains require land for right-of-way and are a source of noise and aesthetic disruption in the areas through which they pass. Each of the systems requires land for storage and processing of fuels. Its likely that a given system supplying fuel for fuel cell consumption will at the same time provide fuel for other utility and industrial functions in the region. Thus the impacts produced by the energy transportation system may result only in part from the movement of fuel specifically for fuel cell consumption.

The environmental and safety impacts produced by the fuel distribution systems within the fuel cell regions are actually more of a concern than those produced by the bulk energy transportation systems because these impacts are directly attributable to fuel cell deployment and usually occur in residential, commercial, and industrial areas rather than in more isolated areas. Installation of a pipeline distribution system will entail extensive construction work throughout the fuel cell region. The magnitude of the construction impacts will be heightened by their occurrence in populated and congested areas. If "linepacking" gas storage methods are used, the pressured gas pipelines could present an added hazard, especially if accidentally ruptured. A liquid pipeline distribution system will also produce construction impacts (although not as intense if only supplying utility power plants) and will require the construction of intermediate storage tanks throughout the region. Inter-urban storage facilities subject a greater number of persons to the hazards of fire and explosion. They are also a visual blight and a source of hydrocarbon emissions.

A liquid fuel distribution system based on tanker truck transport produces an entirely different set of potential environmental impacts. Increased tanker truck traffic within an urban, suburban, or even rural area increases the risk of serious accident. Rupture of the tanks during a traffic accident could produce explosions and fire anywhere along the truck route. Some fuels, in particular methanol, burn with an invisible flame that makes firefighting more dangerous and difficult. The chemical nature of some fuels restricts the methods that can be employed to control and clean up their spills. The loading and unloading of fuel also has safety risks.



Gasoline and other kinds of liquid hydrocarbons are regularly transported throughout congested urban areas. The added tanker traffic caused by transport of fuel for fuel cell power plants may be small in comparison to the total tanker traffic and thus a significant increase in tanker accidents may not be detectable.

The transport, distribution, and storage of fuels also have many potential health impacts. Many fuels contain organic constituents that are toxic or otherwise harmful to human health. Methanol, for example, is toxic and must be labeled as a poison. Inhalation of high concentrations can produce acute poisoning even during brief exposures. Direct ingestion can produce blindness or may even be fatal. The high polynuclear aromatic content of many synthetic fuels suggests that they may be carcinogenic. Each fuel type will vary in its health impacts characteristics, and future research will shed more light on the precautions that must be taken for some fuels to be used in fuel cell applications. Direct public exposures to these fuels will generally be limited to accidental spills and leaks but because they will be transported, distributed, and stored in populated areas, especially when used in on-site power plants, periodic direct public exposures are unavoidable and must be anticipated.

#### 5.5 Summary of PAFC System Impacts

A national PAFC power plant system will cause environmental impacts from various aspects of its production and operation. This section has presented a simple description of the PAFC system and its probable environmental impacts. It is based on current PAFC technology and numerous assumptions. Technology improvements, further study, and changes in customer requirements could alter the impact conclusions of this section.

The national PAFC system will replace the generating capacity of existing and future conventional power plants rather than producing an increase in overall generating capacity. As such, most of its environmental impacts will be incremental in nature since they will replace the environmental impacts of displaced conventional generators. The production of PAFC power plants on a commercial scale may cause some disruption of competing industries, but other than platinum, it is not expected to cause large percentage increases in raw material demands. The PAFC power plant is cleaner, quieter, more fuel efficient, and uses less water than most conventional generating technologies. Reductions in air emissions, noise, fuel use, water use, and wastewater discharge are expected to result from the deployment of a national PAFC system. The magnitude and importance of these environmental benefits will be functions of market penetration, application, and location.

### SECTION 5 REFERENCES

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## 6. EFFECTS OF ALTERNATIVE FUEL CELL ASSUMPTIONS

The nature of environmental impacts resulting from the deployment of a national system of phosphoric acid fuel cell (PAFC) power plants is dependent on numerous technology, market, and other variables. Each variable can affect one or more parts of the national PAFC system that is described in Section 5. The types and quantities of impacts discussed in Section 5 are based on a set of assumptions regarding the structure and characteristics of the national PAFC system. It is important to recognize that a host of variables are capable of changing the system's structure and characteristics, and hence its impacts. A comprehensive overview of the potential environmental impacts of PAFC deployment is not possible without consideration of the environmental consequences of altering these system variables.

This section describes national PAFC system variables and discusses the effects of altering variable levels and assumptions. The matrix in Figure 6-1 illustrates the system activities that may be affected by the altering of each variable.

### 6.1 Technology Variables

Fuel cell developers can be expected to continually modify their product in order to improve efficiency and reduce costs. Prime candidates for PAFC power plant modification are the fuel cell itself, the fuel processing system, and the cooling system. Improvements in efficiencies and/or reductions in cost should increase market penetration and thereby increase the magnitude and impacts of all parts of the network.

Depending upon economic or competitive advantage, any number of fuel cell components may be modified by fuel cell manufacturers. For example, the operating temperature and pressure of the fuel cell stack could be elevated to achieve a higher fuel use efficiency. The reduction in fuel demand would have obvious environmental and economic benefits, including lower air emission rates. However, the higher operating temperatures and pressures would increase safety hazards, especially at on-site locations where public exposure is greatest, while stimulating acid loss from the stack. Increased acid loss would cause higher acid use and stack maintenance. The capital cost of the power plant might also increase if turbochargers and other equipment have to be added to provide the pressurized environment. The platinum catalyst may be adversely affected by the higher temperatures, thereby increasing maintenance costs. The potential exists to lower fuel cell costs, increase fuel cell endurance, and simplify the fuel processing system by improving the fuel cell catalyst. Development goals are to find substitutes for the platinum catalysts in the anodes and cathodes of the fuel cell while improving catalyst activity, stability, and tolerance to impurities. The search for a substitute for platinum in the fuel cell is focusing on platinum alloys and metallo-organic substances. Tests with platinum alloys have shown them to have better activity, stability, and resistance to impurities, as well as being less expensive (Ref. 6.1). Metallo-organic catalysts are relatively inexpensive, and development efforts are continuing to improve their activity and stability. They too are less sensitive to impurities than platinum (Ref. 6.2).

Figure 6-1. Influence of PAFC System Variables on System Activities

SYSTEM ACTIVITIES	SYSTEM VARIABLES										
	6.1 TECHNOLOGY			6.2 USE OF STANDARD COMPONENTS	6.3 OS/IES CONFIGURATION	6.4 FUEL TYPE	6.5 POWER PLANT LOCATION	6.6 ECONOMIC FACTORS	6.7 GENERATING MODE	6.8 EXPORT MARKET	6.11 MARKET PENETRATION
FUEL CELL	FUEL PROCESSING	WATER TREATMENT									
5.2.1 MATERIAL ACQUISITION	✓									✓	✓
5.2.1 MATERIAL PROCESSING	✓									✓	✓
5.2.2 CONSTRUCTION OF PRIMARY FACILITIES										✓	✓
5.2.3 OPERATION OF PRIMARY FACILITIES	✓	✓	✓	✓						✓	✓
5.2.4 OPERATION OF SECONDARY FACILITIES		✓	✓	✓	✓					✓	✓
5.3.1 SITE PREPARATION						✓			✓		✓
5.3.2 POWER PLANT TRANSPORT										✓	✓
5.3.2 POWER PLANT INSTALLATION											✓
5.3.3 POWER PLANT OPERATION	✓	✓	✓	✓	✓	✓	✓		✓		✓
5.3.3 DISPLACED CAPACITY								✓	✓		✓
5.3.4 RECYCLE OF MATERIALS	✓		✓			✓					✓
5.3.5 UTILITY SYSTEMS					✓		✓	✓	✓		✓
5.4.1 FUEL PRODUCTION		✓				✓					✓
5.4.2 FUEL TRANSPORT		✓				✓					✓

Since the platinum catalyst is so expensive, its use will likely be replaced if and when less expensive substitute catalysts with equal or superior attributes can be developed. This substitution would shift the catalyst production impacts from those associated with platinum to those of the new catalyst. Increased stability could lengthen stack life, thereby reducing the frequency of maintenance and the need for recycling facilities, personnel, and procedures. Increased tolerance of the anode catalyst to carbon monoxide would permit reductions in the shift conversion equipment used in the power plant. All of these factors tend to lower power plant costs, thus expanding its market penetration. Despite the current catalyst research, it appears as though platinum will continue to be used as the fuel cell catalyst for at least another five years (Ref. 6.2).

Catalyst research is also proceeding in the search for reformer and shift converter catalysts that have an improved tolerance to oxygen, sulfur, halogens, and olefins. Such catalysts would permit the simplification of the fuel preprocessing system and would widen fuel flexibility. The fuel cell stack can tolerate a small amount of sulfur in the fuel gas and, if sulfur-tolerant fuel processor catalysts can be developed, the level of sulfur removal can be reduced along with costs and maintenance. The sulfur not removed will be emitted in the reformer burner exhaust as sulfur dioxide (Ref. 6.3). This will increase the power plant emissions of sulfur dioxide above the extremely low levels made possible by the more complete fuel treatment. It will also reduce the amount of liquid and solid sulfur waste requiring disposal. The emission concentrations of other impurities, including halogens, may also increase. The added emissions will impact the ambient air quality surrounding the plant and may affect its siting flexibility.

Fuel cell researchers are attempting to develop new methods of applying the platinum catalyst to the stack electrodes that will reduce the quantity of platinum needed to maintain a suitable reaction rate. Such a reduction in catalyst loading would better optimize platinum use and thereby lower both the fuel cell demand for platinum and the capital costs of the power plant (Ref. 6.2).

Fuel cell development objectives include the reduction of electrolyte loss from the fuel cell and a reduction of electrolyte corrosion to the cell. A reduction in the electrolyte loss rate would not only lengthen stack life and thereby reduce maintenance and recycling frequency and impacts, but would also reduce the volume of recovered acid needing disposal (Ref. 6.3). Development of an electrolyte that is less corrosive to cell components would shift production impacts from those associated with phosphoric acid to those associated with the new acid. Operational hazards may increase from the use of a stronger acid.

The use of zinc oxide beds for sulfur removal is effective for fuels containing up to several hundred ppm sulfur. Fuel oil and other coal liquids have higher sulfur concentrations. For these fuels, the use of zinc oxide is costly and a regenerative removal process is thought necessary. A common regenerative process involving liquid chemical absorption is the Strefford process. The equipment can be packaged in units sized for dispersed utility power plants. Use of this process would replace the handling and disposal impacts of solid zinc oxide with those of a liquid sulfur solution. A regenerative metal oxide process is simpler than the Strefford process and eliminates the handling and disposal problems of removed sulfur. This system

absorbs sulfur on a metal oxide and then regenerates the resulting metal sulfide by oxidizing it with air to form metal oxide while releasing sulfur dioxide to the atmosphere (Ref. 6.4). This system has the obvious potential of greatly increasing sulfur air emissions from the power plant and the human health and property impacts that result from these emissions. Although power plant costs and waste handling problems could be reduced, this type of regenerative system could also cancel a major environmental benefit of fuel cell siting, namely low sulfur emissions.

A possible option for lowering power plant capital costs and maintenance is to limit operation to strict fuel criteria. Designing the power plants to use only fuels that are low in impurities might allow elimination of some fuel preprocessing equipment. This would lower power plant capital costs and reduce maintenance related to fuel preprocessing. Use of fuels low in sulfur and other impurities would also ensure that the content of air emissions is low in these substances.

Water treatment research is striving to lower power plant cost and maintenance by reducing the amount of water treatment required by the system. In order to make this reduction, the system must be able to withstand high concentrations of water impurities and, specifically, the reforming and cooling systems must remain corrosion resistant for a longer period of time and the reformer catalysts must have a higher tolerance to water impurities (Ref. 6.3). Reduction of water treatment components could eliminate the handling and processing of ion exchange columns and charcoal filters, and their associated impacts, but would also significantly increase the concentrations of impurities in the blowdown water. It is possible that this increase could force added wastewater pretreatment procedures at utility power plants and might affect the convenient disposal of excess water from on-site power plants to local wastewater treatment facilities.

Studies have been conducted for air-cooled PAFC systems to compare the costs of suitable quality reformer-boiler feed water from two sources: (1) condensate derived from spent cathode air, and (2) tap water. These studies evaluated the water quality of each source and concluded that the processing of condensate recovered from spent air is more economical than tap water processing in the majority of U.S. cities (Ref. 6.3). Changes in water treatment requirements and costs would alter the bases of these conclusions, however, and make tap water use the preferred alternative. This would increase power plant water consumption by an amount equal to reformer-boiler water requirements.

Improvements in fuel cell technology can be expected to increase fuel cell energy efficiency and reliability. Better fuel efficiency will have the obvious benefit of lowering fuel demand per unit of electrical output. It will also reduce the air emission rate and possibly the rate of other environmental impacts as well. The improved fuel economy will lower operating costs and stimulate market penetration. This additional market penetration would likely boost the total cumulative impacts expected from a national fuel cell system even though the impact rates for individual power plants may decline. The added penetration would also increase the displacement of impacts from conventional generators, however. The lower operating cost may modify the generating mode for which fuel cell power plants are used. Lower cost operation may enhance their penetration into the intermediate

load and base load markets. Increased power plant reliability will reduce both maintenance costs and the margin of capacity reserve required by the utility grid for emergency backup. The reduction in this reserve margin would permit retirement of older, less efficient power plants that are maintained on the grid solely for a reserve function.

## 6.2 Use of Standard Components

In an effort to reduce costs, manufacturers are expected to begin substituting standard or "off-the-shelf" stock components for many power plant parts that were previously custom designed and constructed (Ref. 6.5). Such components include heat exchangers, blowers, and pumps, among others. Besides lowering costs, this substitution will probably slightly lower power plant efficiency and decentralize production activities. Production of these components will shift from the primary manufacturing facility to existing secondary manufacturing facilities specializing in their production. The primary facility will thus become more of an assembly plant than a pure production plant. A result will be the decentralization of environmental and socioeconomic effects related to production.

Manufacturers may also substitute less expensive materials for some materials used in the manufacture of current technology fuel cell power plants. In addition to substituting for expensive catalysts, manufacturers may be able to find less expensive replacements for various other components. For example, metallic tubing may be replaced by plastic or graphite substitutes (Ref. 6.6). This type of cost reducing substitution will lower the capital cost of the power plant and shift material demand and production impacts from the original supply industry to the substitute supply industry. All material substitutions should maintain a high level of operational safety, but some may have a slightly adverse effect on energy efficiency.

## 6.3 OS/IES Configuration

The on-site/integrated energy system (OS/IES) configuration is an important variable because it will determine: (1) the overall energy efficiency of PAFC on-site power plants, (2) the types of existing HVAC equipment to be displaced by on-site power plant penetration, and (3) the increased demand for OS/IES energy components. The inclusion of more energy devices in the system will increase the energy efficiency and capital cost of the system and will stimulate production of these devices. It will also reduce demand for conventional on-site energy devices such as air conditioners and heaters. The thermal/electrical load relationship of the different site classes will probably determine the degree of OS/IES complexity, including the use of thermal energy recovery and storage equipment. The overall effect of increasing the complexity of the OS/IES, in addition to increasing the energy efficiency of the system, is to shift product demand from conventional on-site energy devices to those energy devices that are particularly suited for OS/IES use such as absorption chillers and thermal energy storage devices. This shift will produce socioeconomic changes as production types, levels, and locations change.

#### 6.4 Fuel Type and Flexibility

The type of fuel used by the PAFC power plants depends on two separate factors: (1) the fuel use capability of the power plants, and (2) the availability of different types of fuels for use. Research is advancing fuel processing technology and may eventually enable the power plants to operate on a wide variety of liquid and gaseous fuels (Ref. 6.7). Utility units may have a greater flexibility than on-site units because of their larger economy of scale for fuel processing, fuel storage capacity, and greater isolation from the public. This increased fuel use flexibility will enhance fuel cell market penetration by enabling fuel cells to operate on most available fuels, including synfuels. Results may include a drop in demand for conventional premium fuels and an expanded variety of air emissions and other operational impacts.

The types of fuels available may be the more important variable in determining fuel use. Power plants under current development run on natural gas, naphtha, or methanol. Much of the impact discussion of power plant operation in Section 5 was based on the use of natural gas and naphtha, since these are the only two fuels having any available operational data. The future availability of these and other fuels will depend on oil and gas availability, synfuel developments, competition from other markets, and government policies among other factors.

The synfuels industry is expected to be producing large quantities of synthetic gases and liquids (including methanol) by the end of the century. Should oil and natural gas become unavailable for producing electricity and the synfuel industry produces sufficient quantities of fuels from coal, oil shale, oil sands, biomass, and other sources, then synfuels are the more likely candidates for fueling the PAFC power plants. In such a case, the environmental impacts related to fuel supply would be centered around coal mining, shale mining, retorting, liquefaction, gasification, etc. On the other hand, should oil and gas reserves prove greater than anticipated and synfuel development is stunted, the PAFC power plants would be more likely fueled by natural gas and refined petroleum products. In this case, the impacts related to fuel supply would be caused by the conventional drilling and production of natural gas. The actual mix of fuels for PAFC will probably be a combination of petroleum, natural gas, and synfuels, with a gradual shift toward synfuels as they become more available. Use of some fuels by PAFC power plants may be constrained because of competition from other markets. For example, the plastics industry is a major consumer of naphtha and thus its widespread use as a fuel may not be possible without expansion of production and refining capacity. Although fuel cell deployment will probably influence the types of fuel refined or otherwise produced, it is doubtful if it will exert any significant influence on the overall course of petroleum, natural gas, or synfuel extraction and production.

The types of fuel used by PAFC power plants has an impact on several other segments of the fuel cell network besides fuel production. Some fuels may be transported and distributed through existing liquid and gas pipeline systems, while others may require their own characteristic transport and storage systems. Requirements for gases and liquids will of course differ, but fuels that are especially explosive, flammable, or toxic may also require special transport and storage features. Power plant site preparation activities will have to be modified to



accommodate the storage of different fuel types. Variations in the transport and storage system will produce concurrent variations in the types and magnitudes of environmental and safety impacts expected (construction impacts; safety impacts of transport, storage, and human exposure).

Fuel type will affect power plant operation factors because of differences in processing requirements and air emissions. High sulfur fuels will produce greater solid or liquid waste disposal problems and increase power plant cost. Fuels having other contaminants or unique characteristics may require installation of specific preprocessing equipment. Fuel type will also determine the mix of air emissions from the plant. Synfuels are known to produce different mixtures of chemical constituents during combustion than conventional fuels. These emissions could conceivably have an affect on human health in the vicinity of the power plant if not adequately controlled.

### 6.5 Power Plant Location

Power plant location addresses three separate variables: (1) utility vs. on-site location, (2) intra-regional locations, and (3) geographically preferred regions of the country. Each of these locational variables can have an important influence on the impacts caused by PAFC power plant deployment simply by varying the physical, economic, and human environment impacted.

Currently, the development of both on-site and utility units is proceeding and it does not appear that one is favored over the other, since each is directed at a separate market. The impact assessment in Section 5 assumed an installed capacity split of 7 percent and 93 percent between on-site and utility power plant, respectively. Varying this percentage split will change the number and type of power plants, components, and auxiliary equipment produced, as well as the number and type of conventional energy equipment displaced. It will also affect the magnitude of impacts from power plant installation and operation, since on-site and utility units do have different impact characteristics.

The fuel cell power plants should be sitable anywhere, but the overall environmental benefit from fuel cell deployment will vary depending on where within a region siting occurs. The unique environmental characteristics of fuel cells make them unusually suited for dense urban and suburban areas. These areas are typically plagued by air pollution and wastewater disposal problems that may in part be caused by existing power plants. The benefits to society resulting from the environmental improvements caused by the substitution of fuel cell power plants for dirtier conventional power plants are highest in densely populated areas where human and property exposures are greatest. Location of fuel cell power plants in less critical areas where exposures are not as high or where the marginal environmental improvements obtainable are not as dramatic will lessen the overall environmental benefit of fuel cell deployment. Also, siting in growth areas to meet incremental increases in electric demand will eliminate both the need to build additional transmission capability into these areas and the impacts that accompany the construction and operation of the transmission facilities.

The environmental and energy benefits from fuel cell deployment may be higher in some regions of the country than in others. Regions that have chronic water shortages or air pollution problems will likely accrue more benefits from the low water needs and air emissions of fuel cell power plants. Fuel cells integrated with oil and gas based electric utilities have a greater potential of conserving these fuels than do fuel cells integrated with coal based utilities. Concentrating fuel cell deployment in certain areas thus appears to heighten the environmental and energy benefits obtainable.

## 6.6 Economic Factors

The degree of fuel cell penetration into the electric generating market will ultimately be determined by economic factors. The most important economic factors appear to be the capital, operating, and maintenance costs of the power plants. Other economic factors to be considered are regulatory in nature and include electricity buy-back rates and time-of-day use rates. In addition to determining market penetration levels, these factors will also exert influence on the selection of generating mode and hence the types of conventional generating equipment and environmental impacts displaced.

Capital costs of the power plants are determined by a myriad of material and production costs, some of which have been described in this section. In general, capital costs should decline as mass production techniques are implemented and production experience is acquired. As capital costs decline, fuel cell eligibility for claiming a share of the intermediate and peak load generating markets will improve. These two markets, and particularly the peak market, usually consist of relatively inexpensive generating equipment since the equipment operates only a fraction of the day. Fuel cell expansion into these markets will displace a percentage of the production of conventional intermediate and peak generating equipment and cause some measure of socioeconomic disruption. The environmental impacts that would have resulted from operation of this displaced equipment will also be displaced by fuel cells deployment.

Operating and maintenance costs can be influenced by numerous variables, including operator requirements, fuel and water processing needs, fuel type, and fuel cost. Relatively low operating and maintenance costs are typically prerequisites for base load generating equipment, while higher costs are permissible for intermediate and peak load generators since they operate only a fraction of the day. Reductions in operating and maintenance costs will spur penetration into all load markets, but are perhaps more important in determining penetration into the base load market (on-site and utility base load power plants) than penetration into the intermediate and peak load markets since the latter are more heavily influenced by capital costs. Shifts in fuel cell generating mode penetrations produced by operating and maintenance cost reductions will in turn determine displacements of conventional generating equipment and their impacts.

The proposed decontrol of natural gas pricing will cause natural gas prices to rise towards the decontrolled price of petroleum. Domestic gas prices thereafter will be linked with OPEC pricing decisions and other events in the global petroleum market. The resultant premium prices for natural gas (and petroleum products such as

naphtha and distillate and residual fuel oils) could adversely affect the economics of PAFC system operation. However, since price increase will also affect conventional generation and cogeneration technologies that use natural gas or petroleum fuels, a central issue for PAFC commercialization will be the relative impacts of price developments on fuel cells vis-a-vis competing fossil-fueled options (Ref. 6.8).

The Public Utilities Regulatory Policies Act (PURPA) encourages on-site power generation by requiring electric utilities to purchase electricity from qualified independent generators at a price equal to the utility marginal cost of generation. This buy-back provision will stimulate deployment of on-site fuel cell power plants since fuel cell operators may find it profitable to sell power to the utilities. Modifying the buy-back price will alter the profitability of power sales to the utilities and thus effect on-site fuel cell power plant market penetration. The profitable nature of selling electricity to the utilities may also encourage full power operation of on-site fuel cells over extended periods of time (Ref. 6.8). This will increase the quantity and alter the timing of power purchases and thereby change the type of utility generators required to fulfill the remaining power demand on the grid. This will subsequently influence equipment and impact displacements and could promote the use of premium fuel cell fuels at the expense of other utility fuels such as coal. Increasing PURPA buy-back rates will increase power purchases and utility load, equipment, fuel, and impact displacements while decreasing the buy-back rate will tend to have the opposite effects.

In order to discourage peak demand, electric utilities are permitted to vary power prices according to the time of day. These time-of-day use rates are highest during periods of peak demand and lowest during periods of minimum demand. The popularity, and hence market penetration, of on-site generators should increase as utility rates climb. Time-of-day rates should have a leveling effect on the overall demand curve and consequently will change the type of utility generating equipment required to fulfill the power demand. Less peak demand will result in a decreased need for peak generators on the grid and perhaps an increased need for base and intermediate load generators. This may be a boon for fuel cell market penetration if fuel cell costs are such that base and intermediate load generating modes are favored. On the other hand, time-of-day use rates may stunt fuel cell penetration if fuel cell costs favor peaking generating modes by fuel cell power plants.

#### 6.7 Generating Mode

PAFC power plants can be operated to meet base, intermediate, or peak load demands on the utility grid. The mode in which they are operated will be a factor in determining power plant size and will have a major impact on the operation of other grid generators, with possible results including fuel and equipment displacements.

Utility PAFC power plants appear particularly suited for fulfilling intermediate and peak load demand, although the relatively high capital costs of first generation PAFC power plants may hinder their use for peaking power. Their use for base load generation does not seem particularly desirable in most instances since base demand is probably better met by large hydro, nuclear, coal, and other power plants not fueled by gas or oil. Some locations, such as Southern California, that currently use oil and gas as base load fuels and have environmental constraints against the use of

other fuel types, may be sites for base load PAFC power plants. These power plants would probably have sizes in the neighborhood of 500 MW and thus their construction and operational impacts would be substantially greater than 30 MW dispersed PAFC power plants but also substantially less than those of a conventional oil, gas, or coal fueled 500 MW power plant.

It is likely that on-site PAFC power plants will be operated continuously to meet all but perhaps the highest peak demands of the site, with the possibility that excess production during off-peak hours could be added to the grid. The net result would be a reduction in total peak, intermediate, and base demand, with the percentage reduction in each dependent on the load profile of the sites as a whole. This could cause an important change in the load profile left to the grid to fulfill. Alternatively, on-site PAFC power plants could be operated only during peak demand hours or in a variety of other peak, intermediate, or base load modes. Each particular mode of operation will change the load profile of the grid as a whole and thus the types of equipment and fuel used to satisfy the load.

As described in Section 4.2, utilities use an assortment of generating equipment and fuels to produce their peak, intermediate, and base power. The mode of PAFC operation will determine the type of conventional generating equipment that is displaced as well as the type of fuel displaced. The most likely candidates for displacement are turbines, reciprocating internal combustion engines, and smaller oil and gas-fueled steam generating plants because they: (1) generate peak and intermediate power, (2) use premium hydrocarbon fuels, and (3) are less energy efficient than fuel cells. The exact mix of equipment displaced depends on several variables, including the region of fuel cell deployment, the size of the utility, regional load factors, and power plant size, age, and fuel type. Displacement of generating equipment will have impacts not only on fuel use but will also affect the industries and work force producing the equipment as well as the materials consumed and environmental impacts caused by their production. The turbine industry, for example, depends heavily on electric utilities for sales. A reduction in turbine production would decrease material, fuel, and manpower requirements. These reductions would be compensated for to some extent by increased fuel cell production, however.

#### 6.8 Export of PAFC Power Plants

PAFC power plant manufacturers predict a sizable foreign market for on-site and utility PAFC power plants. Export of power plants and parts would provide an economic benefit to the nation, while their production would cause the environmental impacts associated with material acquisition, processing, final production, and transportation. The market penetration assumptions of Section 5.1 do not account for foreign market penetration, since the level of the penetration is very speculative, and the environmental impacts are restricted to the production phases of fuel cell deployment. Japanese and European manufacturers are expected to try to gain control of a part of the worldwide fuel cell market and thus the actual number of power plants that might be produced and exported from the United States is much in doubt. The environmental impacts related to export production will intensify the impacts caused by the manufacture of fuel cells for domestic use.

## 6.9 Advanced Fuel Cell Power Plants

Fuel cell designs more advanced than the PAFC design are under development and may be ready for commercialization by 1990. These designs are more energy efficient and appear particularly suited for utility size applications. The influence of these advanced designs on PAFC penetration is uncertain. Their rapid development and deployment could substantially stunt the penetration of PAFC power plants, particularly at utility locations. It is likely that advanced fuel cell power plants will have better energy efficiency, but their environmental and safety characteristics may be better or worse than those of PAFC power plants.

## 6.10 Alternative Energy Systems

The effect of alternative energy systems development, other than fuel cells, on PAFC penetration is also an unknown at this time. The development of efficient and economical photovoltaic or other energy systems could render the fuel cell obsolete for some applications because of its reliance on hydrocarbon and alcohol fuels or other reasons. The net result would be a decrease in PAFC penetration of the electric generation market. The energy efficiency and environmental impact traits of alternative energy systems could differ substantially from those of fuel cell systems.

## 6.11 Market Penetration

As discussed in Section 5.1, a variety of assumptions must be made when projecting fuel cell market penetration levels. The level of penetration achieved is dependent on a number of economic, energy, environmental, and policy factors. The penetration level is important because it ultimately determines the scale of every facet of fuel cell production and operation and thus the magnitudes of their environmental impacts.

In general, increased fuel cell penetration into the electric utility market will lessen the national environmental impacts resulting from electrical generation. Impacts from the production and operation of fuel cells will increase with heightened penetration but should be more than offset by the displaced impacts of conventional generators. Conservation of premium oil and natural gas fuels should increase as a function of penetration, assuming that fuel cells do not displace a substantial quantity of current and planned generating capacity fueled by coal, hydro, nuclear, and other non-premium fuels. The production of conventional generating equipment will decline as a function of penetration, but the socioeconomic impacts resulting from this decline should be offset to some extent by the increased production of fuel cell power plants.

## 6.12 Possible Impact Trends of Alternatives

Possible fuel cell environmental impact trends are discernible from the alternatives discussed in this section. Alternatives and impact trends are summarized in Table 6-1. Each technical, system, and economic alternative will alter the nature and magnitude of environmental impacts projected in Section 5. On balance, technology advancement, mass production, and operational experience will probably lower the

Table 6-1. Summary of Possible PAFC Alternatives and Their Resulting Impact Trends

Possible Alternatives	Impact Trends	
	Beneficial	Adverse
<b>1. Technology Variables</b>		
• Higher Operating Temperature and Pressure	Δ Fuel Efficiency ▽ Air Emission Rates	Δ Acid Loss Δ Safety Risk Δ Capital Cost
• Change of Fuel Cell Catalyst	Δ Tolerance of Impurities Δ Stack Endurance ▽ Fuel Processing Complexity ▽ Capital Cost	
• Change of Fuel Processor Catalyst	Δ Tolerance of Impurities ▽ Fuel Preprocessing Δ Fuel Flexibility ▽ Sulfur Disposal	Δ Air Emission Rates
• Reduction in Catalyst Loading	▽ Platinum Demand ▽ Capital Cost	
• Reduction of Electrolyte Loss	▽ Acid Use ▽ Stack Maintenance	
• Use of Regenerable Sulfur Removal Systems	▽ Solid Waste Production ▽ Maintenance Cost	Δ Air Emission Rates Δ Liquid Waste Production
• Strict Fuel Use Criteria	▽ Air Emission Rates ▽ Capital Cost ▽ Maintenance Cost	▽ Fuel Flexibility
• Improvement of Reforming and Cooling System Corrosion Resistance	▽ Waste Handling ▽ Capital Cost ▽ Maintenance Cost	▽ Discharge Water Quality
• Improvement of Energy Efficiency	▽ Fuel Use Rate ▽ Impact Rate ▽ Operating Cost	
• Reliability Improvement	▽ Backup Reserve Rate ▽ Maintenance Cost	
<b>2. Use of Standard Components</b>		
• Increased Use of Standard Components	Δ Decentralization of Production Impacts ▽ Capital Cost	▽ Energy Efficiency
• Use of Substitute Materials	▽ Capital Cost	▽ Fuel Efficiency
<b>3. OS/IES Configuration</b>		
• Increased OS/IES Complexity	Δ Energy Efficiency Δ Production of OS/IES Equipment	Δ Capital Cost ▽ Production of Conventional Equipment
<b>4. Fuel Type and Flexibility</b>		
• Increased Fuel Use Flexibility	▽ Use of Premium Fuels Δ Market Penetration	Δ Variety of Air, Safety, and Other Impacts
• Use of Premium Oil and Gas Fuels	Δ Premium Fuel Use Efficiency	Δ Fuel Production Impacts Δ Reliance on Imported Fuels
• Use of Syntuels	▽ Use of Premium Fuels	Δ Syntuel Production Impacts
• Use of Hazardous Fuels	Δ Fuel Flexibility	Δ Health Hazards Δ Safety Hazards Δ Power Plant Costs
• Use of Fuels High in Sulfur and Other Impurities	Δ Fuel Flexibility	Δ Air Emission Rates Δ Power Plant Costs
Δ Increase ▽ Decrease		

Table 6-1. Summary of Possible PAFC Alternatives and Their Resulting Impact Trends (Continued)

Possible Alternatives	Impact Trends	
	Beneficial	Adverse
5. Location of PAFC Capacity		
• Location in Densely Populated Areas	∇ Public Exposure to Air, Water, and Noise Pollution	Δ Public Safety Hazard
• Location in Areas of Demand Growth	∇ Transmission Facilities and Impacts Δ Matching of Capacity and Load	
• Location in Environmental Quality Problem Regions	∇ Regional Air Emissions ∇ Regional Water Demand and Quality Impacts	
• Location in High Premium Fuel Use Regions	Δ Regional Conservation of Premium Fuels	
6. Economic Factors		
• Reduction of Capital Operating, and Maintenance Costs	Δ Market Penetration Δ Displacement of Impacts	Δ Displacement of Conventional Energy Equipment
• Increase of PURPA Buyback Rates	Δ On-Site Market Penetration Δ Displacement of Impacts ∇ Δ Premium Fuel Use	Δ Equipment Displacement Possible Mode Changes
• Change of Time-of-Day Use Rates	Δ On-Site Market Penetration	Possible Mode Changes
7. Generating Mode		
• Use of Large Baseload PAFC Power Plants	Δ Conservation of Premium Fuels in Some Areas ∇ Environmental Impacts Relative to Conventional Power Plants	Δ Displacement of Non-Premium Fuels in Some Areas
• Operation of On-Site Power Plants in Base Load Mode	∇ Overall Environmental Impacts ∇ Local Environmental Impacts Δ ∇ Use of Premium Fuels	∇ Utility Base Load
• Operation of On-Site Power Plants in Peak Load Mode	∇ Utility Peak Demand Δ Conservation of Premium Fuels ∇ Environmental Impacts	
8. PAFC Export		
• Export of PAFC Power Plants	∇ National Trade Deficit	Δ Production Impacts
9. Advanced Fuel Cell Power Plants		
• Commercialization of Advanced Fuel Cell Power Plants	Δ Fuel Conservation ∇ Δ Environmental and Safety Impacts	∇ PAFC Market
10. Alternative Energy Systems		
• Commercialization of Alternative Utility and On-Site Systems	∇ Δ Fuel Conservation ∇ Δ Environmental and Safety Impacts	∇ PAFC Market
11. PAFC Market Penetration		
• Increased Market Penetration	Δ Premium Fuel Conservation ∇ Overall Environmental Impacts	Δ PAFC Environment Impacts Δ Production Impacts Δ Equipment Displacement

Δ Increase  
∇ Decrease

capital, operating, and maintenance costs of fuel cell power plants. Lower costs will encourage additional penetration into all markets; but in particular, lower capital costs will spur peak and intermediate market penetration, and lower operating and maintenance costs will boost base and intermediate market penetration.

Technology alternatives may have a bearing on several individual impact parameters of concern. Catalyst research is attempting to develop methods for reducing platinum loading and may succeed in replacing the use of platinum entirely. Fuel cell platinum demand would drop below the values projected in Section 5.2.1.1 as a result of these catalyst innovations. Catalyst, equipment, and fuel changes will alter the type and rate of fuel cell air emissions. The use of sulfur tolerant catalysts, regenerative sulfur removal equipment, and higher sulfur fuels will increase sulfur emissions above the values projected in Section 5.3.3.1. Higher reformer temperatures may also increase the emission of oxides of nitrogen. Projected emission rates for both of these constituents are so miniscule, however, that sizable rate increases would be required to produce environmental impacts of concern. The combustion of some fuels, including synfuels, may produce unusual organic constituents not produced during combustion of natural gas and naphtha. This trend towards increased air emission rates will reduce the fuel cell reputation as a clean power generator but should not measurably affect its siting suitability in most cases.

Technological innovations may also affect fuel cell water use, water discharge, and solid waste characteristics. Catalyst and material improvements may reduce power plant water quality criteria and eliminate the need for some or all of the water processing equipment. In the interest of lowering power plant costs, water may be supplied to and discharged from the power plant at increased rates rather than being recycled within the power plant. This trend may be particularly evident in on-site power plants. Elimination of water processing equipment would degrade the quality of discharge water. The use of fuels with high sulfur content will increase the quantity of sulfur waste requiring disposal. The nature of this waste may change, however, if regenerable sulfur removal systems are employed.

The fuel efficiency of PAFC power plants should improve to a degree as fuel cell technology advances and matures. The level of improvement may be tempered somewhat by equipment and operational modifications meant to reduce capital and operating costs. Fuel use flexibility will increase and should eventually include different types of synthetic fuels. Hazards associated with fuel transport and storage may increase with the use of some synfuels.

The preferential siting of PAFC power plants in areas of poor air quality or high premium fuel use should ease these problems. Credits accrued by utilities for lowering their air emissions and premium fuel use should encourage siting in these areas. The operation of numerous independent PAFC power plants on a utility grid will alter the utility load and may force changes in equipment and fuel used by the utility and hence its environmental impacts.

Development of a sizable foreign market for fuel cells will stimulate domestic production for export. This increase in production will elevate environmental



Impacts associated with fuel cell production but will also boost domestic employment and improve the nation's balance of payments with fuel cell importers.

### 6.13 Alternatives Summary

This section describes technical, system, and economic variables that could individually or collectively alter the environmental impact traits of a national PAFC system. Each variable presents an alternative that affects some or all system activities. Technical variables alter power plant features such as materials, design, operation, and fuel use. System variables determine the structure of the PAFC system and the location and operating modes of the power plants within the system. Economic variables account for changes in power plant costs and the effects of several external economic factors.

An analysis of PAFC variables indicates possible alternatives to the environmental impact conclusion of Section 5. Technology advancements and cost reductions could result in higher air emissions and water use by PAFC power plants. The character of air emissions, water discharges, and solid wastes may change because of equipment modifications and fuel use shifts. Although these trends would tarnish the environmentally-benign reputation of PAFC power plants and reduce the environmental benefits of PAFC deployment, they should not have a major effect on power plant siting suitability. Improvements in fuel efficiency and fuel use flexibility would boost premium fuel savings, but increased public exposure to some fuels could be health and safety hazards. The deployment of power plants in areas of air quality, water quality, and fuel use problems would likely multiply the importance of PAFC environmental benefits. Shifts in power plants costs could affect PAFC application and generating mode and therefore the quantity and value of environmental improvements.

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## 7. GOVERNMENT POLICIES AND REGULATIONS

A variety of federal, state, and local policies and regulations apply to the deployment of fuel cell power plants. For the most part, these regulations have been promulgated to achieve the goals established by energy and environmental legislation during the past decade. This section provides a discussion of the applicable energy and environmental management policies and regulations. It also evaluates the policy consistency and regulatory compliance of fuel cell power plant siting and operation. Federal legislation discussed in this section includes:

- National Energy Act
- Federal Nonnuclear Energy Research and Development Act
- Clean Air Act
- Federal Water Pollution Control and Clean Water Acts
- Marine Protection, Research, and Sanctuaries Act
- Endangered Species Preservation Act
- Wild and Scenic Rivers Act
- Coastal Zone Management Act
- National Historic Preservation Act
- Noise Control and Quiet Communities Acts
- Resource Conservation and Recovery Act
- Occupational Safety and Health Act
- Hazardous Materials Transportation Act
- Toxic Substances Control Act
- Communications Act

### 7.1 Energy Legislation

Energy legislation in this country since 1973 has been directed toward decreasing national dependence on foreign energy supplies through conservation measures, development of renewable and synthetic fuel technologies, and increased domestic production of conventional resources. The fuel cell power plant is recognized as a valuable asset for achieving this objective. These power systems promote energy conservation by the efficient use of fossil fuel supplies, deriving more useful work per unit of energy consumed than conventional systems. Their flexibility and reliability make them especially effective for satisfying intermediate and peak load requirements. As a consequence of these potential benefits, energy legislation has directly or indirectly encouraged fuel cell technology development through program funding, research, and the selective exemption from regulatory requirements.

### 7.1.1 National Energy Act

Provisions of the National Energy Act (NEA) of 1975 are designed to reduce United States oil import needs by the year 1985, increase the use of fuels other than oil and gas, and increase energy efficiency. The NEA is composed of five separate pieces of legislation:

- The Public Utilities Regulatory Policies Act (PL 95-617), which provides methods for encouraging public utility rate structure revisions to move energy pricing to reflect actual costs.
- The Energy Tax Act (PL 95-618), which contains a range of tax credits for conservation and solar energy as well as other tax measures designed to reduce the nation's dependence on imported oil.
- The National Energy Conservation Policy Act (PL 95-619), which established a variety of regulatory, grant, and loan programs to enhance conservation.
- The Powerplant and Industrial Fuel Use Act (PL 95-620), which is designed to increase the use of coal.
- The Natural Gas Policy Act (PL 95-621), which essentially decontrols the price of new natural gas and establishes other measures designed in part to encourage production of natural gas.

The Public Utilities Regulatory Policies Act addresses the topic of rate design standards for utilities. This Act proposes that utilities structure their retail rates in a way that would encourage conservation of energy, efficient use of facilities and resources, and equitable rates to electric consumers. Cogeneration and small power production facilities are encouraged by Federal Energy Regulatory Commission rules which exempt them from certain state and federal regulations pertaining to electric utility rates. The fuel cell units, as cogenerators, qualify for these exemptions. In addition, the Act requires electric utilities to purchase excess electrical production from grid-connected cogenerators, such as fuel cell power plants, as long as they are not owned by the utility.

The National Energy Conservation Policy Act requires utilities to develop energy conservation programs for residential and commercial buildings. These programs are to identify and promote appropriate energy conservation measures. Included among residential energy conservation measures are devices associated with load management techniques that reduce the maximum kilowatt demand on an electric utility. The on-site fuel cell power plant can be considered a load management device since it is located on site and can reduce peak demand by satisfying the site demand and supplying electricity into the utility grid. Commercial energy conservation measures specified by the Act include cogeneration systems which produce electricity as well as steam or other forms of thermal or mechanical energy. The fuel cell power plant can be used as a cogeneration device and thus should qualify as such a measure. Therefore, promotion of the development and use of fuel cell power plants by utilities is consistent with the objectives of the Act.

The National Energy Act directly affects the use of petroleum and natural gas. Under the Powerplant and Industrial Fuel Use Act, petroleum and natural gas may not be used as a primary energy source in new electric generating plants, unless DOE specifically grants an exemption for its use. These restrictions apply only to very large power plants with fuel heat input rates of 100 million Btu per hour or greater, but more importantly, they apply only to power plants employing boilers or turbines. Since fuel cell power plants employ neither boilers nor turbines, the fuel restrictions are not applicable.

#### 7.1.2 Federal Nonnuclear Energy Research and Development Act

The Federal Nonnuclear Energy Research and Development Act of 1974 (PL 93-577) established a national program for research, development, and demonstration of potentially beneficial energy sources and utilization technologies. Energy conservation, meaning both improvement in the efficiency of energy production and use, and reduction in energy waste, is a primary consideration in program implementation. Included among the specific program elements is the commercial demonstration of fuel cells for central station electric power generation. While the research, development, and demonstration of on-site fuel cell power plants is not specifically mentioned in the text of the Act, these activities are also consistent with the Act's purpose and objectives because of the beneficial energy and environmental attributes of fuel cell technology.

The federal government is authorized by the Act to provide assistance for or participation in demonstration projects, including field demonstrations of prototype energy utilization applications. It may also enter into cooperative agreements with non-federal entities to demonstrate the technical feasibility and economic potential of prototype energy technologies. DOE and NASA-Lewis Research Center participation in the fuel cell power plant development and demonstration projects is consistent with both this authorization and the policy and objectives of the Act.

#### 7.2 Environmental Legislation

As with all law, environmental law is a composite of legislation, judicial interpretation, and regulatory statute. Although three levels of government - federal, state, and local - interact to create and enforce environmental policy, it is the federal government which assumes the leadership role in environmental protection. The activities of a commercial fuel cell industry will require compliance with national environmental policies as well as state and local laws where applicable. Since these fuel cell activities will be national in scope, it is difficult to evaluate the impact of specific state and local regulations on individual facilities. Therefore, the following subsection primarily discusses the influence of national environmental legislation on fuel cell commercialization.

The literature on fuel cell power systems universally agrees that fuel cells can provide significant environmental benefits relative to conventional energy conversion technologies. As discussed in Section 5, the displacement of conventional technologies with up to several hundred thousand megawatts of fuel cell capacity can help to reduce environmental problems related to air emissions, water use and discharge, noise, and solid waste disposal. For this reason, the commercialization of

fuel cell systems is seen to be consistent with the goals embodied in our national environmental policy. Although several environmental laws will provide guidelines and restrictions for a developing fuel cell industry, no regulations are foreseen which would inhibit the successful dissemination of fuel cell technology.

### 7.2.1 Air Quality Management

The provisions of the Clean Air Act of 1963 (PL 88-206), as amended to the present, encourage cooperative activities and uniform legislation by state and local governments for the prevention and control of air pollution. While the Clean Air Act directs EPA to set ambient air quality standards and to establish emission limitations for new pollutant sources, the task of developing strategies for attaining the ambient air quality standards is given to the states. Accordingly, states are required to have State Implementation Plans that spell out in specific detail how federal ambient air quality goals will be met.

Each state is required as part of their State Implementation Plan to have a permit program governing new stationary sources of pollutants. New sources located in areas that already meet national ambient air quality standards (NAAQS) are regulated by the prevention of significant deterioration (PSD) program, which limits the cumulative amount of pollutants that can be added to the area by new sources. Under PSD requirements, no major emitting facility may be constructed unless the owner demonstrates that emissions from the construction or operation of such facility will not contribute to the degradation of air quality past an allowed level for that region. This ensures, to the maximum extent practicable, the continued maintenance of the ambient air quality of a region and discourages practices which would degrade pristine areas to the minimal federal ambient air quality levels. The term "major emitting facility" is defined in the Act as any stationary source of air pollutants which has the potential to emit 250 tons per year or more of any air pollutant (100 tons for specified categories). In addition, the Act explicitly states that a PSD permit is required for any steam electric power plant of more than 250 million Btu per hour heat input (approximately the size of a 25 MW power plant) that emits more than 100 tons per year of any pollutant. For comparison, a 25 MW fuel cell power plant based on current technology emits only about 15 tons per year of all air pollutants combined.

The siting of new major stationary sources in PSD areas is also controlled by visibility regulations designed to protect and enhance visibility in certain Class I federal areas (national wilderness areas and parks). Major facilities, defined as above, are required to demonstrate that their air emissions will not impair the visibility or visual aesthetics of these areas.

In areas that do not meet all of the NAAQS requirements (non-attainment areas), emission offset regulations govern the siting of a new source. Emission offset rules permit new "major emitting facilities" (emitting more than 100 tons annually) to be located in non-attainment areas provided that (1) emissions from the new source, other new sources that are not "major emitting facilities," and existing emissions will be sufficiently less than total emissions from existing sources, and (2) the new facility complies with the lowest achievable emission rate (LAER) defined as the most stringent emission limitation achievable for that facility.

In general, the PSD and emission offset programs apply only to new sources of pollution which are expected to interfere with the attainment or maintenance of national standards. The likelihood that there will be such interference will vary with local conditions, such as current air quality, meteorology, topography, and growth rates. For this reason, regional air quality management districts are allowed to set standards more stringent than those required by the Clean Air Act. The determination whether an air emission permit or emission offsets are required for the operation of a fuel cell power plant will be an individual and subjective decision by the regional air quality management district which has jurisdiction. Because the total quantities of air pollutants emitted from fuel cell power plants are relatively low (about 3 tons/year from the 4.8 MW demonstration plant), it is unlikely that they would be considered a significant or "major" pollution source in any locality. Siting should therefore not be a problem. The air emission characteristics of fuel cell production factories will have to be evaluated as information becomes available to determine potential siting restrictions on these facilities.

Another section of the Clean Air Act requires the Administrator of the EPA to publish (and periodically revise) federal standards of performance for emissions from new sources. These standards are defined for stationary source categories which cause or contribute significantly to air pollution. Because federal coverage is limited to major new sources, fuel cell power systems are not included in any of the categories. Federal new source performance standards have been defined for three types of fossil-fuel fired steam generating units having heat inputs of more than 250 million Btu per hour. These standards, which were presented in Section 5 (Table 5-2), are not applicable to non-steam fuel cell power plants but can be utilized to illustrate the low emission character of fuel cell power plants. As seen in Table 5-2, fuel cell power plants can comply with these standards by a large margin.

## 7.2.2 Water Quality Management

The basic federal legislation dealing with water pollution is the Federal Water Pollution Control Act (FWPCA) (PL 92-500), which was shaped into its present form by extensive amendments of earlier legislation. The Act was again amended in 1977 by the Clean Water Act (PL 95-217). Like the Clean Air Act, the FWPCA is the product of incremental legislation over a considerable period, resulting in an increasingly dominant federal role. There are a number of other federal statutes bearing on water pollution, the most important of which are the Safe Drinking Water Act of 1974 (PL 93-523) and the Marine Protection, Research and Sanctuaries Act of 1972 (PL 91-522) (the Ocean Dumping Act).

The sections of the FWPCA which are relevant to fuel cell commercialization concern the discharge of wastewaters. The Act establishes separate regulatory schemes for two classes of point source dischargers: discharges directly into the navigable waters and discharges into publicly owned treatment works.

Direct discharges are subject to a dual set of requirements: effluent standards and water quality standards. Effluent standards are limitations by particular types of dischargers on the amounts of pollutants that may be discharged. These limitations are based primarily on the availability of pollution control technology. Effluent standards for new sources are based on the "best available demonstrated control

technology, processes, operating methods, or other alternatives" including, where practicable, a standard permitting no discharge of pollutants. These new source performance standards (NSPS) are required for several categories of sources (27 industries are specified in the original Act), none of which include fuel cell power plants. However, due to the similarity in function, a comparison of fuel cell wastewater quality with the performance standards for steam electric power plants is appropriate. To this end, the reader is referred to section 5 (Table 5-4).

Water quality standards consist of a set of rules defining a required quality for the ambient water based on technical information as to the minimum requirements necessary to sustain various uses of the water. Water quality standards are initially adopted by the states and submitted to EPA for approval; if EPA fails to approve, it may promulgate federal standards for the particular state. The standards for different waters may vary, depending on the uses assigned to the water and the preferences of the individual state, although EPA has made an attempt through its approval authority to impose some degree of uniformity in this area.

Direct discharges are required to conform to both the effluent standards and the water quality standards, whichever is stricter. The basic enforcement mechanism for both sets of standards is the National Pollutant Discharge Elimination System (NPDES). Under this system, EPA may issue permits to direct dischargers which define maximum levels of discharge, if any, permissible for compliance with all applicable standards. States with permit programs meeting federal requirements may assume authority to issue federal permits, in which case the state-issued permits are subject to an EPA veto.

The FWPCA governs point source discharges from pipelines into coastal waters while the Marine Protection, Research, and Sanctuaries Act (MPRSA) governs dumping of wastes into ocean waters from vessels. The MPRSA requires a federal permit from EPA for any transportation from the United States of any material for the purpose of dumping into ocean waters. The substantive criteria for issuance of permits under the two acts are similar.

An NPDES permit will be required for any fuel cell power plant or fuel cell manufacturing facility which discharges wastewater directly into a navigable waterway. The quality of the blowdown from the UTC 4.8 MW demonstration facility (see Section 5.3.3.2) indicates that some pretreatment would probably be required by the NPDES permit controlling the discharges from this plant. On-site units that are currently being developed have self contained water purification units; therefore, wastewater discharges should not require pretreatment. Because of the relative purity of the fuel cell wastewater stream, NPDES permits should not be difficult to obtain.

Federal control over dischargers into publicly owned treatment works follows a different procedure. Under the FWPCA, EPA is required to promulgate pretreatment standards designed to prevent the discharge of any pollutant through publicly owned treatment works which "interferes with, passes through, or otherwise is incompatible with such works." Until these standards are promulgated (probably in 1983), local interim water quality standards apply to the discharge of wastewaters into treatment systems and storm drains.



A discharger into a publicly owned treatment system is not currently required to obtain a permit under the FWPCA, although a permit may be required by municipal law. However, the treatment works themselves must receive a permit for discharges into navigable waters, and each such permit must provide for notice to EPA or the state (depending on which issued the permit) of any substantial change in the volume or character of pollutants introduced into the works. Finally, users of publicly owned treatment works approved for federal financing after 1 March 1973, are required to pay a "proportionate share" of the cost of operation and maintenance, and industrial users will be required to pay a portion of the cost of construction.

Fuel cell wastewater discharges into a publicly owned treatment facility, therefore, will not require an NPDES permit, but a permit may be required by the local sanitation district. The decision to issue a discharge permit is made on a case by case basis with reference to water emissions data for typical industrial processes. In the absence of appropriate data, as is the case with fuel cells, discharge into local treatment systems or storm drains will generally require a permit unless the water is of equal or better quality than typical residential sewage. Using this criterion, the larger utility power plants may require a local discharge permit; however, on-site units, by virtue of their self contained water purification system, probably will not.

### 7.2.3 Federal Land Use Policies

Several major pieces of federal legislation have been enacted to protect and preserve specified areas of the country. As would be expected, development in these regions, when not totally prohibited, is strictly controlled. Any activities of a commercial fuel cell industry which require access to these lands will be governed by the appropriate legislation and regulations. These protected areas include:

- National Parks In 1916, the National Park Service Act established the National Park System, with administrative authority delegated to the Department of the Interior. The units of the National Park System carry a variety of statutory and administrative designations, but fall into three broad categories: natural areas, historical areas, and recreational areas. Although a variety of economic uses are permitted in recreational areas which are not allowed in the natural or historic areas, Congress has generally authorized such other uses only to the extent consistent with the basic recreational purpose of the area.
- National Wilderness The National Wilderness Preservation System was established by Congress under the Wilderness Act of 1964. The Act provides that it is the policy of Congress "to secure for the American people of present and future generations the benefits of an enduring resource of wilderness," to which end the national wilderness areas are to be "administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness."

- National Wildlife Refuge The National Wildlife Refuge System is administered by the Fish and Wildlife Service within the Department of Interior, under a general directive to administer the system for the "conservation and protection" of fish and wildlife.
- National Forests The Forest Service Organic Administration Act of 1897 established national forests "to regulate their occupancy and use and to preserve the forests thereon from destruction." In assuming the administrative role, the Forest Service has traditionally permitted a wide variety of compatible uses in the national forests. That administrative practice was confirmed by Congress in the Multiple-Use and Sustained-Yield Act of 1966 which declared that the national forests "shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes."
- Wild and Scenic Rivers Under the Wild and Scenic Rivers Act of 1968 (PL 90-542), certain rivers are designated to have their natural environmental qualities preserved. The Act provides for the protection of the environmental qualities of both the water and the land area adjacent to the river, the boundaries of which are unspecified. A stream classification system, providing for three river categories, was designed to regulate the degree and intensity of shoreline development. While both residential and public service facilities may be developed in two of the river categories, such development is subject to approval of the management agency of the particular river involved. The management plans govern improvements to existing buildings and structures as well as new construction projects.
- Coastal Zones The Coastal Zone Management Act of 1972 (PL 93-583) requires state and local authorities to establish management programs, subject to federal approval, for environmentally sensitive coastal areas.
- Historic Landmarks The National Historic Preservation Act of 1966 (PL 89-665) authorizes the Secretary of the Interior to maintain the National Register of historic landmarks. In addition to individual buildings and sites, the National Register includes some historic regions in their entirety. Siting of a fuel cell power plant at any location, building or structure included in the National Register requires prior coordination with the Advisory Council on Historic Preservation.
- Endangered Species Under the Endangered Species Preservation Act of 1966 (PL 89-669), as amended in 1969 and 1973, the Secretary of the Interior is authorized to acquire lands in order to conserve, protect, restore and propagate species of fish and wildlife that are threatened with extinction.

Since most of these protected lands are relatively isolated from population centers, it is unlikely that utilities will find them suitable sites for the dispersed multi-megawatt fuel cell power plants, which gain their advantage from close location to populated areas. Similarly, there appears to be no reason why fuel cell manu-

facturing, assembly, and fuel support facilities will require access to these sensitive areas. On the other hand, the remoteness and environmental sensitivity of protected lands makes them ideal candidates for the installation of on-site multi-kilowatt fuel cell systems, which provide clean power while eliminating the need for environmentally disruptive electrical transmission systems. Fuel cell units installed in this capacity will need to observe the more stringent land use regulations of the federally protected areas.

#### 7.2.4 Noise

Noise control regulations are enforced at the federal, state, and local level. Authorization for federal laws stem from the Noise Control Act of 1972 (PL 92-574), which directs EPA "to promote an environment for all Americans free from noise that jeopardizes their health or welfare." Under this Act, EPA is required to regulate new products that are "major sources of noise" and to establish noise labeling requirements for noisy products as well as for products designed to reduce noise. Specifically, regulations should be proposed for these products if they fall in the categories of construction equipment, transportation equipment, motor engines, or electrical/electronic equipment.

In 1970, the Noise Control Act was modified by the Quiet Communities Act (PL 95-609), the purpose of which was to encourage the development of noise control programs on the community and state level. State ordinances in general deal primarily with ground transportation systems. Local ordinances, on the other hand, deal with several different aspects of the noise problem, such as restricting noise from transportation systems and construction equipment, and limiting the noise transmitted across property lines. Specific noise level requirements are contained in local zoning laws and building codes and often differentiate between day- and night-time noise levels. Typical noise ordinances limit construction noise to around 80 dBA (at 50 feet) and residential noise (lawn mowers, garden tools, etc.) to 65 dBA, also measured at 50 feet.

EPA has also identified noise levels which if not exceeded should protect against some of the worst affects of noise. These levels include a margin of safety and were derived without considering the technical or economic feasibility of achieving them. They should therefore be viewed as long range environmental goals rather than EPA-recommended regulatory goals. As described in Section 4 (Table 4-5), EPA recommends a 24-hour average exposure of 70 dBA or less to protect against hearing loss, and yearly average values of 55 dBA for outdoors and 45 dBA for indoors to protect against activity interference and annoyance.

The installation of fuel cell power plants will temporarily generate elevated noise levels associated with construction activities. This noise, typical of other construction activities of similar size, will be controlled by applicable local regulations. Noise restrictions on power plant operation will differ by locality and land use (residential, commercial, and industrial). Since fuel cell power plants are noted for their quiet operation, careful siting should eliminate most, if not all, noise concerns. On-site units located in or adjacent to noise sensitive areas may require noise attenuation by proper positioning or shielding.

Occupational Safety and Health Administration (OSHA) noise regulations will apply to power plant construction, assembly, and installation activities. Standards promulgated by this agency under the Occupational Safety and Health Act of 1970 (PL 91-596) are outlined in Table 7-1. Under authority of the Noise Control Act, EPA recommended that OSHA adopt a more stringent standard of 85 dBA for 8-hour noise exposures.

**Table 7-1. Department of Labor, Occupational Noise Exposure Standards**

<u>Permissible Noise Exposures</u>	
<u>Duration Per Day (Hrs)</u>	<u>Sound Level dBA</u>
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
1/2	110
1/4 or less	115

### 7.2.5 Solid Waste Disposal

Federal legislation guidelines governing the disposal of solid wastes can be found in the Solid Waste Disposal Act of 1965 (PL 89-272) as amended by the Resource Recovery Act of 1970 (PL 91-512) and the Resource Conservation and Recovery Act of 1976 (PL 94-580). These acts provide guidelines for the proper disposal of solid wastes generated by residential, commercial or industrial activities. Reflecting concerns for the special dangers posed by hazardous substances, the acts require EPA to identify solid wastes which are hazardous or toxic, and develop standards and guidelines to ensure that generators and transporters of such wastes undertake the necessary precautions for their safe disposal. Other sections address the issues of resource conservation by encouraging the practice of recovering energy and other resources from discarded materials. Technical and financial assistance is provided for the development of management plans and facilities for resource recovery.

The composition and quantities of solid wastes that will be generated during the manufacture, assembly, and operation of fuel cell power plants have not been adequately defined and are expected to change as different source fuels and technologies evolve. Fuel cell manufacturers and power plant operators will be responsible for identifying the appropriate disposal procedures for the specific solid wastes generated.

The high value of platinum will undoubtedly encourage the recovery of this element from decommissioned fuel cell power stacks. Subject to economic considerations, other materials of construction and operation may also be recovered under the guidelines of the Resource Conservation and Recovery Act.

#### 7.2.6 Safety and Health

A variety of federal, state, and local safety regulations, as well as national association safety codes, will affect the construction and operation of a fuel cell power plant deployment system. The purpose of these regulations and codes is to minimize the danger to life and property incident to the activities addressed. Although national association codes do not have the force of law, compliance is often required since they are many times used by federal, state, and local authorities for regulatory purposes. An understanding of safety regulations and codes is important in the development of a deployment system since it's possible that they may constrain some system options.

The working environment within and surrounding the fuel cell power plants, manufacturing facilities, recycling facilities, and fuel production and conversion facilities is regulated by safety and health standards authorized by the Occupational Safety and Health Act of 1970 (PL 91-596) and promulgated by the Occupational Safety and Health Administration (OSHA). The goal of OSHA standards is the protection of the worker in the work place, and these standards address many facets of the work environment including, among others, facilities, machinery, fire protection, personal protection, and work hazards. Specific standards protect the worker from exposure to harmful levels of noise, radiation, air contaminants, and toxic substances. There does not appear to be any environmental emissions from fuel cell deployment activities which would present a unique hazard to workers; however, the environmental impact characteristics of fuel cell and synthetic fuel production activities are not yet firmly established.

Federal regulations and national association codes govern the intra-urban transportation and storage of flammable and combustible fuels to ensure worker and public safety. The Department of Transportation's Materials Transportation Bureau regulates the procedures and equipment for storing fuels and transporting fuels by truck, rail, pipeline, and barge under the authority of legislation such as the Hazardous Materials Transportation Act of 1974 (PL 93-633) and the Natural Gas Pipeline Safety Act of 1968 (PL 90-481). The Hazardous Materials Transportation Act classifies numerous chemicals as hazardous thereby requiring special labeling and handling during their transport. Naphtha, fuel oil, methanol, and other potential fuel cell power plant fuels are listed among the hazardous chemicals by the Act.

Specifically, federal regulations and national association codes affect the fuel delivery systems for fuel cell deployment by imposing limits on:

- Tank Trunk Operations - (loading/unloading, capacity, use of streets and highways, operation)
- Site Fuel Storage - (total quantity, tank size, venting, in-plant transfer, fire protection)

- Fuel Oil and Gas Pipelines - (materials, design, construction, operation, maintenance)
- Rail Shipments - (loading/unloading, capacity, operation)
- Barge Traffic - (loading/unloading, specifications, pollution control, operation)

The fuel delivery systems for multi-kilowatt and multi-megawatt fuel cell power plants will include on- and off-site storage and various combinations of truck, rail, pipeline, and possibly barge transportation. All fuel delivery systems will have to be designed and operated in full compliance with all applicable federal regulations, national association codes, and additional requirements imposed by state and local jurisdiction.

#### 7.2.7 Toxic Substances

The philosophy of the Toxic Substances Control Act of 1976 (TSCA) (PL 94-469) is that chemicals should not enter the marketplace and be dispersed into the environment without adequate testing, and that the effects of existing chemicals should be reviewed so that unreasonable risks to human health or the environment may be removed. It subjects the entire chemical industry to comprehensive federal regulation for the first time and extends EPA's authority into virtually every facet of the chemical industry including product development, testing, manufacturing, processing, distribution, use and disposal. TSCA requires EPA to publish an inventory of existing chemical substances and requires industry to develop data on the health and environmental effects of the chemicals they manufacture. Development of chemicals and fuels for fuel cell manufacture and operation will require compliance with all applicable TSCA regulations.

#### 7.2.8 Electromagnetic Interference

In accordance with Section 301 of the Communications Act of 1934, as amended, the Federal Communications Commission (FCC) prohibits the operation of an incidental radiation device that causes harmful interference. Harmful radiation is defined as any emission, radiation, or induction which endangers the functioning of a radio navigation service or other safety service, or seriously degrades, obstructs, or repeatedly interrupts a radio communication service. An incidental radiation device is any device that radiates radio frequency energy during the course of its operation although not intentionally designed to do so. In the event that harmful interference is caused, the operator of the device must take prompt action to eliminate the harmful interferences.

Fuel cell power plants are considered incidental radiation devices because the inverters are sources of emitted and conducted radio frequency radiation. The power plants will be equipped with electromagnetic interference (EMI) filters to remove conducted radiation at the source. Initial testing has not indicated the production of harmful interference by fuel cell inverters, and NASA-Lewis is taking steps to ensure that all necessary EMI testing is conducted to guarantee, as much as possible, that the power plants will be in full compliance with FCC regulations prior to deployment in the field.

### 7.2.9 DOE International Responsibilities

On January 4, 1979, President Carter signed Executive Order 12114 in order to further the purposes of the National Environmental Policy Act (NEPA) with respect to the environment outside the United States, its territories and possessions. The Order requires that federal agencies conduct environmental review procedures for major actions significantly affecting the environment of the global commons or any foreign nation which may or may not be involved in the action. Actions not having a significant effect on the environment outside the United States, as determined by the responsible agency, are specifically exempted. If so required, environmental review activities may entail generic, programmatic or specific environmental impact statements; bilateral or multilateral environmental studies; or concise reviews of the environmental issues involved, including environmental assessments, summary environmental analyses or other appropriate documents.

DOE recently adopted final implementing guidelines for Executive Order 12114, in large measure reiterating the provisions of this Presidential document (46 FR 1007, January 5, 1981). These guidelines supplement the procedures set forth in DOE's final guidelines for compliance with NEPA, published on March 28, 1980 (45 FR 20694). Since the DOE-sponsored phosphoric acid fuel cell development program is scheduled to include field testing in foreign countries and since the developed technology may eventually be exported to foreign countries, DOE will likely be required to evaluate the significance of the foreign environmental impacts resulting from the development program with respect to these new department guidelines.

### 7.2.10 Local Environmental Regulations

Local environmental regulations governing fuel cell power plant deployment are primarily associated with building and construction standards, and zoning laws designed to segregate land uses and minimize activity conflicts. Specific local regulations include building, zoning, fire, electrical, pressure vessel, plumbing, noise, and installation codes. Additionally, some local codes may require special installation procedures and component certification by national safety associations. Due to the small degree of environmental impacts associated with the on-site fuel cell power plants, there is expected to be little difficulty in achieving their compliance with all local regulations. However, siting of dispersed fuel cell power plants may be constrained by local regulations, particularly zoning regulations, because of their larger size and elevated impacts.

### 7.3 Conclusion

Based on this limited review, it appears that with proper siting, construction, and operation, a fuel cell power plant deployment network will not be in conflict with any of the legislation or regulations considered. Special permit conditions may apply, however, if facilities are to be sited in restricted land use areas or certain wastewater discharge options are selected.

## 8. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This document presents the assessment of the environmental and energy impacts expected to result from the commercialization of phosphoric acid fuel cell (PAFC) power plants. This section summarizes those impacts, develops conclusions concerning their severity, and presents recommendations appropriate to commercialization. Areas requiring further research are identified and discussed.

No severe environmental impacts resulting from PAFC commercialization are identified by this environmental assessment. Most of the identified impacts are incremental in nature; i.e., they replace to a degree the impacts of energy technologies displaced by fuel cell market penetration. Overall, the incremental environmental improvements of commercialization outnumber and outweigh incremental environmental degradations. Despite the continuing evolution of PAFC technology, it appears that major differences in environmental impact characteristics should not exist between power plant systems produced by competing manufacturers. Impacts may vary, however, depending on power plant application and location. This assessment has not identified any environmental impact factor that would inhibit commercialization of PAFC technology.

### 8.1 Summary

DOE is supporting the development of PAFC power plant systems through its Phosphoric Acid Fuel Cell Program. The program is administered through the NASA-Lewis Research Center Lead Center Office. Program objectives are to develop reliable prototype PAFC power plant systems in both multi-kilowatt and multi-megawatt power sizes that will meet national goals to conserve energy, reduce energy costs, and preserve the environment. In addition, nongovernment program participants have the objective of evaluating the commercial potential of PAFC technology. The program seeks to achieve these objectives through support of competitive PAFC technology development in the private sector. Two competing private development projects are being supported for both multi-kilowatt and multi-megawatt power sizes. Although these four projects employ the same basic power plant design, considerable variation exists in the design of such subsystems as the fuel cell stack, fuel processor, and thermal management.

The commercialization of PAFC systems is a major activity which will result in numerous impacts on the national environment and economy. These impacts will occur through a wide range of direct and peripheral commercialization activities involving the production, installation and operation of the PAFC power plants and the extraction and processing of various fuel and material resources. The fuel cell power plant is one of a variety of energy generation alternatives. Commercialization of this technology will influence the quantity of fuel consumed for electrical generation and the manner in which the fuel is supplied. Therefore, the impacts of fuel cell commercialization have been evaluated in the context of the entire electrical power generation system.



A well defined fuel cell commercialization scenario has not been constructed due to a number of uncertainties and variables. Nevertheless, a commercialization framework based on several explicit assumptions has been created to facilitate the assessment of potential environmental impacts. Three different levels of PAFC penetration into the electric power production market were adopted from previous PAFC market penetration studies. These levels provide the basis for quantifying overall commercialization impacts. It is also assumed that commercialization of PAFC power plants will not significantly affect the total national demand for electric power, but will rather replace some existing and planned conventional generating capacity with PAFC power plants. Consequently, the environmental impacts of PAFC manufacture and operation will, in general, replace the manufacturing and operational impacts of other energy technologies and should therefore cause only incremental changes in affected environmental parameters. The cogeneration use of PAFC power plants would provide an exception, however, since it would permit an even greater displacement of conventional energy equipment.

This assessment has attempted to identify potential impacts where possible within the constraints of study assumptions and commercialization variables. In Section 6, the impacts identified in Section 5 were further qualified in the context of these commercialization variables. A summary of the major impacts which can be expected from PAFC commercialization is provided below. For clarity and convenience, commercialization impacts have been addressed in the following activity groups: (1) PAFC Power Plant Production, (2) PAFC Power Plant Installation and Operation, (3) Fuel Use Issues, and (4) Utility, Regulation, and Legislation Issues.

#### 8.1.1 PAFC Power Plant Production

The production of PAFC power plants on a commercial scale will impact the environment either directly through primary manufacturing activities, or indirectly by influencing other market sector production activities. Actual power plant production will take place in primary production facilities which will manufacture the fuel cell stack and various power plant components and assemble the components into complete power plant systems and subsystems. Secondary production facilities will supply raw and finished products such as heat exchangers, blowers, pumps, valves, and electrical devices to the primary production facilities for additional processing or assembly. Other industries manufacturing on-site energy equipment or conventional energy generation equipment such as turbines or diesel engines will experience a change in demand for their products. The acquisition of raw materials for power plant fabrication will require the mining, extraction, and processing of ores and fossil fuel feedstocks. These production activity impacts are summarized below.

Raw Material Acquisition and Processing. Fuel cell power plants will be constructed of a variety of materials including steel, copper, nickel, platinum, plastic, graphite, and phosphoric acid. The production and processing of ores, petroleum, and natural gas are major industries with sizable impacts to the environment. It appears that, for all materials but platinum, the net changes in volumes of materials required for fuel cell production are small enough so that only minor environmental or supply market effects will occur. Fuel cell requirements for platinum, estimated at 6.2

million troy ounces at medium penetration levels (50,000 MW), may impact market supplies, and result in possible production shortages and higher prices. Since platinum is considered important enough to warrant classification as a strategic mineral, national security concerns may arise. Although increased platinum production will increase environmental impacts associated with mining and processing, relatively few persons are engaged in producing platinum domestically; thus national environmental impacts will be negligible.

Primary Production Facilities. To be economically feasible, fuel cell power plants and components must be mass produced. This will require the construction of several primary production facilities. Construction of these facilities will produce impacts associated with typical construction projects including dust emissions, noise, water runoff, erosion, traffic increases, and general aesthetic disruption. Once operational, a primary production facility will likely consist of separate areas for manufacturing components, assembling components, and storage for the materials, chemicals, and subcomponents shipped in from secondary production facilities. The possible noteworthy environmental impacts expected from the operation of primary facilities are air emissions, waste water effluents, and worker health and safety problems. These would arise during the storage and handling of metals, plastics, and other materials. Environmental impacts resulting from the production of the power plants appear to be comparable to many types of industrial production activities. The relatively large use of plastics and resins may distinguish fuel cell impacts from those of other energy technologies.

Secondary Production Facilities. Depending on production economics, some pre-made subcomponents and components (off-the-shelf parts) will be purchased by the primary fuel cell production plant from other manufacturers. Components which may be acquired in this manner are diverse, and their production requires the handling of such materials as chemical feedstocks, metals, plastics and resins. Increased production of secondary facilities to meet fuel cell requirements will proportionately increase the environmental impacts characteristic of the particular industries. On-site fuel cell units will influence the choice of heating and air conditioning equipment employed by making thermal energy-based systems economically attractive. Thus, greater numbers of thermal energy-based equipment such as absorption chillers and radiation and convection heating equipment may be manufactured at the expense of traditional heating and air conditioning systems (e.g., fossil fueled furnaces and electric air conditioners). Deployment of fuel cell power plants will displace existing or planned conventional generators such as internal combustion generators and steam, oil, and gas turbines. The degree to which the industries manufacturing this equipment are adversely affected will be a function of the fuel cell operational modes and market penetration level. It does not appear likely that a severe economic impact would occur under the assumed market penetration levels, however.

#### 8.1.2 PAFC Power Plant Installation and Operation

The construction activities required at the sites of utility PAFC power plants are basically typical of those expected during the erection of most similarly sized industrial facilities. These activities are expected to last from one to two years; considerably shorter than the four to five years required for construction of a gas-or

oil-fired steam power plant. Site preparation activities for the smaller multi-kilowatt power plants will not require any major construction. Transportation of the power plants and components to the sites for installation may cause a slight increase in highway truck traffic but the PAFC equipment will not be a hazardous cargo.

Phosphoric acid fuel cell systems will produce fewer total environmental impacts than conventional energy generation alternatives while simultaneously conserving energy resources. The importance of the environmental benefits resulting from fuel cell commercialization will vary by location, depending on the areal pattern of fuel cell penetration and the specific environmental problems of the locale. On a national scale, the environmental benefit will be substantial.

Air Quality. The generation of electricity is responsible for the production of more particulates, sulfur oxides, and nitrogen oxides than all other stationary sources combined. In addition, about one-third of the hydrocarbon and carbon monoxide emissions from stationary sources originate from power generation systems. Even with the installation of the most advanced pollution abatement equipment on new fossil-fueled power plants (particularly coal-fired), air pollutant emissions remain three to four orders of magnitude greater than those projected for similarly sized fuel cell systems. Therefore, sizable improvements in national air quality can be expected when fuel cells penetrate the energy supply market in substantial quantities. Since it is highly probable that fuel cell utilization will initially occur in areas of poor air quality (close to the load in urban areas), the air quality benefits of fuel cell systems are more likely to be focused where most needed.

Water Quality and Supply. Because the electrochemical reaction of the fuel cell produces water as a byproduct, little, if any, external water is required for power plant operation. This is in marked contrast to large steam electric power plants which require massive quantities of water for system cooling (approximately 800,000 m<sup>3</sup>/MW-yr). Serious environmental problems are associated with this water demand, including impacts on aquatic ecosystems from organism impingement and entrainment in the intake structures, and removal of valuable water supplies from the resource base in water-short areas. Wastewater discharges from fuel cell systems are lower and the quality is generally superior to conventional fossil-fueled power plants, lowering utility pretreatment requirements and costs. Wastewater from on-site systems requires no pretreatment prior to disposal. In addition, fuel cells eliminate or reduce water quality problems associated with thermal discharges, power plant site runoff, and the disposal of air emission control equipment residues. Even though legislation and regulations addressing water quality and supply problems from conventional power plants will serve to reduce the magnitude of these problems over the next few decades, the commercialization of fuel cells will still provide significant water quality benefits.

Noise. The quiet, electrochemical conversion process of fuel cells eliminates many of the noise sources associated with conventional steam powered systems. This translates into fewer community complaints and lower investments for noise control equipment by the utilities. It also allows for power plant siting close to the load. Site specific noise attenuation strategies may be required for on-site fuel cell units located adjacent to noise sensitive users, but these should be easily implemented. The exposure of fuel cell operations and maintenance personnel to elevated noise

levels will be less of a hazard than in large conventional power plants, and fuel cell noise emissions will easily conform to OSHA standards.

Solid Waste. The quantities and types of solid wastes generated by fuel cell power plants depend upon the individual technology. For example, present technologies produce spent zinc oxide/sulfide reaction beds which must be disposed of in sanitary landfills. However, this may not be the case in future, sulfur-tolerant fuel cell systems. As another example, although intermittent flushing of the fuel processor subsystem of UTC's 4.8 MW plant will produce a small amount of potentially hazardous liquid hydrocarbon wastes, no comparable wastes are produced by the smaller 40 kW units. It is, therefore, difficult to identify the specific solid waste streams of fuel cell systems at this time; however, the wastes produced by PAFC systems, including fuel production, are expected to be similar in terms of both quantity and hazard potential to the solid wastes generated by fossil-fueled power plants.

Climate. Air emissions from fossil-fueled power plants are believed to contribute to changes in local, national and international climate. Of primary concern are CO<sub>2</sub> emissions, which are believed responsible for the so-called "greenhouse" effect, and SO<sub>x</sub> and NO<sub>x</sub> emissions which have been linked to the phenomenon of acid rains. Despite their higher fuel efficiency, the displacement of fossil-fueled generators with fuel cell power plants is expected to produce only a minimal change in existing CO<sub>2</sub> emission quantities or patterns. However, since substantial reductions in SO<sub>x</sub> and NO<sub>x</sub> emissions can be expected, the deployment of fuel cells should contribute to the improvement of acid rainfall conditions.

Land Use and Aesthetics. In contrast to the large isolated parcels of land required for conventional central generation facilities, the land required for fuel cell power plants will be smaller individual units of higher value because of their probable location within developed, urban areas. It is difficult to determine whether more or less land will be cumulatively required since land requirements vary by type of fuel used, whether solid waste is disposed on site, and the type of cooling system used. Aesthetic problems related to emission plumes and power transmission lines are reduced or eliminated through the use of fuel cell power systems. On the other hand, fuel cell power plants will be located close to large numbers of people, and thus have a greater visual exposure. On-site units in particular will most likely require some aesthetic impact mitigation.

Health and Safety. Due to their comparatively small size, lack of a combustion cycle, state-of-the-art safety systems, and low environmental emissions, fuel cells are among the least hazardous methods of energy conversion. The low environmental emissions from fuel cells dramatically reduces the exposure of workers and surrounding populations to air, water, and noise induced health effects when compared with conventional facilities. A series of safety features and backup safety systems in the fuel cell plant minimizes the likelihood of accidents. Nevertheless, certain hazards endemic to industrial installations, such as the storage and use of various fuels, cannot be totally eliminated. Since there are no injury or death statistics available for fuel cell power plants, accurate comparisons cannot be made. However, there do not appear to be any features of the fuel cell power plant which would suggest that worker health and safety statistics would be unusually high or low.

Other Environmental Impacts. Geology, soils, topography, and culture and other environmental and social parameters sometimes affected by industrial development will be minimally affected by fuel cell commercialization. Increased employment will result from the greater number of operation/maintenance personnel required for fuel cell power plants as compared with conventional power plants (up to 2,625 additional jobs for high penetration predictions). Economic benefits, primarily due to the greater energy efficiency of fuel cells, will probably be important, but this area requires a more thorough analysis.

### 8.1.3 Fuel Use Issues

The deployment of fuel cells will affect both the amount and types of fuels used for energy production. By converting chemical energy directly into electrical energy, the fuel cell is able to obtain greater conversion efficiencies than conventional generation technologies. This will result in the conservation of fuel resources. Although PAFC power plants will initially be fueled by natural gas, naphtha, and probably methanol, their fuel use capability will eventually widen to include most liquid and gaseous fuels, including synthetic fuels. Environmental and economic impacts will be associated with the production, transport, distribution, and storage of these various fuels.

Fuel Conservation. Because fuel cells have a demonstrably greater efficiency than conventional fossil fuel systems, they represent a significant energy conservation potential. Although exact energy savings are impossible to derive in the absence of displacement scenarios, potential savings can be estimated by comparing fuel cells with base load fossil fuel steam generators. On the basis of this comparison, approximately 220 trillion kilojoules of energy resources per year (36 million barrels of distillate oil or 10 million tons of bituminous coal) could be conserved under low fuel cell penetration projections (20,000 MW). Displacing conventional oil and gas fueled generating equipment with fuel cells will conserve this amount of energy in premium fuels. Fuel cells presently require oil and gas fuels and this is contrary to national energy goals. As a result, fuel cells will likely be adapted to use synthetic fuels as they become available. The use of synfuels derived from coal will reduce overall fuel efficiency because of the efficiency loss inherent in current synfuel production processes.

Fuel Production. The production of fuels for fuel cells will require the extraction of raw resources (gas, oil, coal, oil shale, tar sands, etc.) and their conversion into usable fuels through refining, retorting, gasification, liquefaction, etc. Fuel extraction and processing typically have major environmental consequences. These impacts should not be significantly expanded or altered by fuel cell deployment, however, since (1) fuel cells should be able to operate on nearly any type of fuel, and (2) fuel cell deployment will result in a redistribution of the fuel required by the displaced power plants rather than creating additional demand. Although fuel cells will eventually be adapted for synfuels use, the growth of synfuels industries is expected to proceed independent of fuel cell commercialization.

Fuel Transport, Distribution, and Storage. The transport and storage of fuels for a network of fuel cell power plants is a very important aspect of fuel cell deployment with potentially significant impacts to the environment and public safety. The mode

of fuel transportation will depend on fuel type and distance and may include pipelines, tankers, or trains. A fuel distribution system may consist of a pipeline network or a truck delivery system. The environmental and safety impacts produced by the fuel distribution systems are more of a concern than those produced by the bulk transportation systems because these impacts are directly attributable to fuel cell deployment and will likely occur in populated residential, commercial, and industrial areas. Transporting fuels by truck poses inherent risks for the communities and other motorists en route. However, gasoline and other liquid and compressed gaseous fuels are regularly transported throughout congested urban areas and it is unclear whether the added tanker truck traffic serving fuel cell power plants would significantly increase tanker accidents. It is clear, however, that the transport of fuels creates a greater safety risk than the transport of energy in the form of electricity. Storage of fuels will require numerous on-site, intermediate, and bulk storage facilities, increasing the likelihood of public exposure to accidental explosions, spills, or leaks. Because fuel cell systems will be intentionally located in or near populated areas, periodic direct public exposures are unavoidable and must be anticipated.

#### 8.1.4 Utility, Regulation and Legislation Issues

The manner in which utilities deploy fuel cells will depend upon several variables including installed cost, operating and maintenance costs, fuel price, heat rate, on-line performance, reliability, capacity factor emission profiles, and tax and emission credits. By themselves, fuel cells offer utilities many environmental and load management benefits which will be unique to each utility. These benefits have been supplemented by the National Energy Act of 1978, which provided economic incentives for fuel cell use while increasing regulatory constraints on conventional fossil fueled technologies. Utilities may find that fuel cells present an attractive alternative which will help them meet their responsibilities under the myriad of national, state and local environmental regulations.

Impacts on Electric Utility Systems. Fuel cells can help utilities lower reserve requirements, decrease transmission requirements, provide efficient spinning-reserve capacity, and increase system stability. Other potential benefits include improved system efficiency, fuel flexibility, environmental compatibility, and reduced lead times and utility capital outlay as a result of modular design and siting versatility. Lowering reserve and transmission requirements will proportionately reduce the environmental impacts associated with the construction, operation and maintenance of electric generation and transmission facilities. On-site fuel cell power plants, or any on-site generators independent of grid control, have the potential to cause economic impacts on the local electric utility. It is possible that on-site units may be sized to primarily meet the base load demand, acquiring most of the peak and intermediate demand electricity from the utility. This would tend to increase the percentage of costlier intermediate and peak generators on the grid and result in electric utility rate increases. Many on-site units will probably use the utility grid as a backup power supply. Such a use should not significantly increase the load demand on the grid since the small size and large number of on-site units make them very reliable as a group.

Impacts on Gas Utility Systems. Fuel cell deployment may affect the capital requirements and business orientation of the gas utility industry. Widespread use of gas-fueled PAFC power plants could require expansion of other modifications to gas distribution systems. The ownership of numerous on-site PAFC power plants by gas utilities would shift their business orientation from fuel supplier toward energy equipment owner and operator. In each case, PAFC commercialization would require new capital investments on the part of gas utilities.

Energy Legislation. Energy legislation, primarily the National Energy Act (NEA) of 1978, has directly or indirectly encouraged fuel cell technology development through economic incentives, program funding, research, and the selective exemption from regulatory requirements. Perhaps the most important incentive for fuel cell commercialization involved the regulatory and rate benefits allowed cogeneration systems in the Public Utilities Regulatory Policies Act (PURPA) of the NEA. Since fuel cells can be deployed as cogenerators, this law should serve to spur commercialization. Under PURPA, electric utilities are required to purchase excess electrical production from grid connected cogenerators. The acquisition of small amounts of electricity from many disparate independent producers (i.e., fuel cell cogenerators) may impact the reliability and economic strength of the electric utility operator. The National Energy Act also defines a phase-out plan for the use of natural gas to produce electricity. Although natural gas fueled fuel cell plants are exempt from this legislation, the operation of large numbers of these systems may precipitate similar fuel restrictions and encourage a shift to other fuels.

Environmental Legislation. National, state, and local environmental regulations will provide guidelines and restrictions for a developing fuel cell industry; however, no regulations are foreseen which would inhibit the successful dissemination of fuel cell technology. On the contrary, fuel cells represent an alternative for utilities seeking to comply with environmental cleanup requirements and new source restrictions. Because of their dispersed nature, and low environmental emission levels, the environmental review process for siting a fuel cell power plant will be less extensive and controversial than with other conventional power systems.

## 8.2 Environmental Impact Conclusions

The siting of numerous PAFC power plants throughout the nation will have important energy use and environmental impact ramifications. Table 8-1 summarizes the important beneficial and adverse impacts expected to result from PAFC commercialization. The magnitude of these impacts will be a function of fuel cell penetration into the electric utility market and the environmental traits of PAFC technology. While it is unlikely that the environmental traits of mature PAFC technology will vary significantly from one manufacturer to another, it is probable that variation of such parameters as energy efficiency, fuel type, platinum requirement, and public exposure will occur between large multi-megawatt power plants and smaller multi-kilowatt power plants. These variations will result from differences in power plant location and operating conditions.

Fuel cells are significantly more energy efficient than conventional fossil-fueled generating equipment and, even at low market penetration levels, their operation could result in the saving of sizable energy resources. The types of fuels conserved,

Table 8-1. Impacts of PAFC Commercialization

<u>Beneficial Impacts</u>	<u>Adverse Impacts</u>
● Fuel Conservation	● Higher Platinum Demand
● Lower Air Emissions	● Public Exposure to Fuels
● Lower Water Use & Discharge	● Limited Socioeconomic Disruption
● Less Noise	
● Possible Land Use Savings	

and hence the benefits accrued, are dependent on the fuel use capability of fuel cells and the fuel type of displaced generators.

PAFC power plants have low air emissions, require little or no water, and are relatively quiet. The replacement of conventional power plants having higher air emission rates by fuel cells will improve ambient air quality levels. This improvement will be particularly beneficial when replacement occurs in heavily populated, polluted urban areas. The low fuel cell water demand and wastewater discharge rate will lessen electric utility impacts on the nation's freshwater and ocean resources. The quieter operation will reduce utility personnel exposure to elevated noise levels and will improve the ambient noise environment in the vicinity of electric utility power plants.

It is difficult to compare the cumulative land requirement for numerous on-site and dispersed PAFC power plants to that of a large conventional power plant of equivalent capacity because of numerous variables. The land requirement will probably be similar in many instances. PAFC power plant land will generally be of higher value, however, since it will more commonly be located in urban and suburban areas. Land savings may accrue from the reduced need for additional power transmission corridors. The solid and liquid waste disposal characteristics of fuel cells and conventional fossil-fueled generators are highly dependent on fuel type and on the whole should not be substantially different from one another. PAFC power plants will be designed and constructed according to applicable safety codes and their operation should not present an increased safety hazard to utility personnel and the general public.

Except for possible impacts on the platinum market, the production of large quantities of PAFC power plants should not create any unusual or abnormally large impacts. The impacts resulting from the construction and operation of manufacturing facilities will be typical of many industrial facilities. Raw material needs for power plant and system infrastructure construction will be small percentages of total raw material output and should cause only marginal increases in environmental impacts associated with mining, refining, and processing of the raw materials. Demand for some materials may decrease as a result of the production displacement of conventional energy equipment. Some socioeconomic impacts may result from the displacement of workers employed in the manufacture of conventional energy



equipment but these impacts will be mitigated to a degree by employee increases in the fuel cell related industries. The fuel cell demand for platinum catalyst does not appear to have the potential to outstrip global supplies of platinum. Fuel cell research is actively attempting to find substitute catalysts for platinum and methods of reducing platinum requirements.

The transportation and installation of PAFC power plants and components will cause relatively minor impacts that are similar in magnitude to transport and construction projects of comparable size. Since site preparation and construction activities for PAFC power plants have a shorter duration than for conventional power plants, the site impacts associated with these activities will be greatly reduced.

Since PAFC power plants will have a wide fuel use capability, major shifts in the national fuel production infrastructure and its environmental impacts should not result from commercialization. Fuel cell energy conservation may permit a reduction in planned domestic energy production or the importation of foreign energy supplies. Transportation and distribution of fuel cell fuels within urban and suburban areas will increase public exposure to the safety risks of a variety of fuel types.

The foregoing environmental impact conclusions are based on the environmental traits of existing and near term PAFC technology. Future changes in these traits could drastically alter commercialization impacts and hence the conclusions of this assessment. However, based on current and reasonably foreseeable PAFC characteristics and the assumptions made within this assessment, the widespread commercialization of PAFC power plants should produce major national environmental benefits in terms of improved air quality, increased energy conservation, and reduced water consumption and wastewater discharge. Benefits may also accrue from reductions in exposure to high noise levels and reduced land requirements for long distance transmission lines. Liquid and solid waste disposal problems will probably be only minimally changed by PAFC commercialization. The manufacture, transportation, and installation of PAFC power plants are typical operations and will produce no unusually large impacts. The primary environmental issue of concern posed by commercialization is the possible safety hazards of transporting various fuel cell fuels through populated areas. These hazards should be minimized however by proper attention to construction and operation safety codes and regulations.

Caution is advised in the unqualified acceptance and use of these environmental impact conclusions because of the uncertainties and assumptions inherent in the evaluation of a developing technology. Uncertainties surrounding mature PAFC technology characteristics, PAFC power plant application, and PAFC market penetration create the need for assumptions that dilute the value of assessment conclusions.

### 8.3 Development and Siting Recommendations

PAFC commercialization will produce numerous national environmental benefits. These environmental benefits can be enhanced by attention to the following recommendations during PAFC development and siting.

**Sulfur Emissions.** Current PAFC technology is sensitive to sulfur impurities in fuel. Removal of the sulfur by the power plant traps the sulfur in a solid or liquid form and greatly reduces sulfur air emissions. It has been proposed that power plant costs can be reduced by either improving the level of power plant sulfur tolerance or developing regenerable sulfur removal systems for power plant use. Both of these options could result in sizable increases in power plant sulfur air emission rates. It is recommended that due consideration be given to the cost of sacrificing environmental compatibility that will accompany these sulfur-related innovations. Increased sulfur air emission rates could degrade PAFC siting flexibility.

**Synfuel Air Emissions.** PAFC fuel use capability is projected to include a variety of synthetic fuels. Tests with synfuels have revealed combustion products different from those associated with common fossil fuels. Some of these are complex organic products suspected of causing deleterious health effects. PAFC development should be cognizant of the human health findings of synfuel research and develop commensurate technology alternatives which will avoid or minimize proven and suspected synfuel-related health impacts.

**Water Use.** Fuel cells produce water as a byproduct and, through recovery and treatment of this water, can operate continuously with little or no water from an outside source. Elimination of the water recovery and treatment subsystems of the power plant would reduce capital costs while increasing power plant water consumption and discharge. Should this option be contemplated, due consideration should be given to the water consumption and discharge environmental benefits which would be forfeited.

**Fuel Use Flexibility.** PAFC developers should continue activities to widen the fuel use capability of fuel cells. This would enhance their ability to utilize available fuels and could speed their shift from premium oil and natural gas fuels to synthetic and other alternative fuels.

**Hazardous Fuels.** Some gaseous and liquid fuels that are potentially usable by PAFC power plants have characteristics that could elevate the health and safety concerns of fuel transport, handling, and storage. Fuel toxicity, flammability, explosiveness, carcinogenicity, and other common and unique traits could pose hazards to the health and safety of the public and utility personnel. It is recommended that fuel cells not use fuels that pose unreasonable health and safety risks and that extreme care be taken in the design of transport and storage systems for selected fuels to ensure adequate safety margins.

**Power Plant Location.** The environmental benefits of PAFC commercialization can be increased by siting power plants in specific types of locations. For example, siting in areas of high population density with environmental problems caused in part by power generation will maximize the benefits realized from improved air quality, reduced water use, etc. Similarly, siting in areas of high premium fuel use may increase the amount of premium fuels conserved by fuel cells, while siting in areas of new growth may eliminate some need for new power transmission systems. It is recommended that PAFC commercialization be concentrated in these types of areas, and other similar areas revealed by analysis, so that the maximum level of benefits can be realized.

Displacement of Power Plants Not Fueled by Oil or Natural Gas. A primary fuel cell benefit is the more efficient use of premium oil and natural gas fuels. When PAFC power plants displace power plants fueled by oil and natural gas, sizable quantities of these fuels can be conserved. However, when PAFC power plants displace power plants that are not fueled by oil or natural gas, whether such displacement is intended or inadvertent, consumption of premium fuels could actually increase at the expense of coal-fired, nuclear, and other forms of power generation. The siting and operation of PAFC power plants should be sufficiently planned for integration with each utility grid system to provide the maximum practicable avoidance of these unwanted displacements.

#### 8.4 Recommendations for Additional Study

The indepth coverage of a topic as broad as fuel cell commercialization is not possible in a single document and indeed is not the aim of this assessment. A number of environmental and economic aspects of fuel cell commercialization have been identified which are considered important enough to require further research and evaluation. These areas are described below.

Regional Impacts of Fuel Cell Commercialization. National impacts shed little insight into the impacts of fuel cells on local or regional environments. Several regions of the country suffer from environmental problems concerning one or more of the following: air quality, solid waste disposal, water quality, and water availability. The electric utilities which service these areas are under continuous pressure to reduce contaminant levels originating from their power plants. Because they are environmentally superior, fuel cells can be presented to these utilities as an economically attractive alternative to conventional generation technologies. Regional impact assessments are needed which evaluate the capacity profiles, plant retirement projections, and regulatory responsibilities of electric utility systems serving regions with significant environmental problems. Traditional utility options for new or replacement capacity additions should be compared with the option of using fuel cells. Comparative environmental and energy impacts can then be translated to an economic base to identify the best energy generation system for the utility and the region.

Generating Mode Effects on Benefit Maximization. Penetration of fuel cell power plants into the electric power generation market will displace competing generators which are primarily fossil fueled. The types of generators displaced, and hence the fuel and environmental impacts displaced, will depend on the generating mode which fuel cells fill. The following subjects should be examined: (1) the influence of power plant capital and operating costs in determining fuel cell generating mode, and (2) the generating mode that maximizes fuel and impact displacements. These two subjects could then be synthesized to determine the most cost effective generating mode in terms of capital costs, operating costs, and fuel and impact displacements.

Utility Shifts in Equipment and Fuel Use. The presence of numerous fuel cell power plants and other on-site generators feeding into an electric power grid will produce a myriad of grid management problems for the electric utility. PURPA regulations requiring utility purchase of this power could shift the size and type of load left to utility generators. The equipment and fuel use changes that would result from the utility load shift and the environmental consequences of these changes should be investigated. Other management problems such as the need for a greater percentage of utility reserve should also be investigated.

Fuel Cell Cogeneration and Electric Utilities. Since the use of byproduct thermal energy can double the efficiency of the fuel cell, fuel cell cogeneration systems will likely be deployed in great numbers. A significant penetration of fuel cells therefore implies a significant increase in the use of cogeneration systems. A rapid growth in cogeneration, a trend which has been encouraged by the National Energy Act of 1978, poses some problems for electric utilities. Requirements to buy back electricity at marginal costs may undermine the load management strategy, service rates, and reliability of individual utilities. These potential problems should be analyzed.

Environmental and Safety Impacts of Fuel Delivery. On-site and dispersed fuel cell power plants will operate on a variety of available gaseous and liquid fuels. These fuels will require transportation to the power plant sites as well as storage at the sites and within the transportation system. Each fuel type has characteristic safety and environmental hazards connected with its transport and storage, and each may require a specialized fuel delivery system designed to mitigate these hazards. Although PAFC power plants will operate on many common fuels, the unique exposure factors of on-site power plant use may require that fuel safety and environmental investigations be conducted on candidate fuels to determine their hazardous qualities, exposure pathways, and mitigating safety equipment and procedures.

Fuel Cell Environmental Data Base and Assessment Update. The PAFC environmental data base is relatively sparse, especially for the systems under development by Westinghouse/ERC and Engelhard. The environmental characteristics of all PAFC systems should be periodically tested and reviewed as the technology matures in order to build a suitable data base for evaluating environmental compatibility and ensuring compliance with environmental regulations. Likewise, this Environmental Assessment should be periodically reviewed and updated to keep it current with developing technology and trends in PAFC application and market penetration.

## APPENDIX

### TECHNOLOGIES FOR ENERGY GENERATION AND STORAGE

The technology mix which will comprise any national energy supply network of the future is unpredictable. Without this knowledge, it is impossible to quantitatively assess the environmental impacts of fuel cell commercialization since it cannot be discerned which technologies would be used in place of on-site and utility fuel cell systems. To give meaning to the projected environmental impacts of a commercial fuel cell industry, fuel cell power plants have been compared with base load fossil fuel steam generation systems throughout this assessment. Although a certain amount of this type of capacity will be displaced, other conventional intermediate and peaking generation technologies such as gas turbines, internal combustion engines, and smaller fossil fuel steam generators, are more likely targets. In addition, the development of advanced energy technologies will influence the impacts of fuel cell commercialization. Although advanced energy technologies such as solar, wind and geothermal will not actually be displaced by fuel cell power plants, the fact that they will often compete for the same market can result in a technology substitution, which is in effect a displacement.

To accurately evaluate impacts of fuel cell commercialization, the reader must be familiar with alternative energy generation technologies. Although desirable, a thorough quantitative evaluation of these technologies is a formidable undertaking beyond the scope of this assessment. However, a certain amount of background information on the technological status and environmental impacts of the major alternative generation technologies will allow the reader to qualify the environmental impact conclusions of this assessment. To this end, the following technologies are briefly reviewed:

#### Conventional Technologies

- Surface pumped hydroelectric storage
- Gas turbine
- Reciprocating internal combustion
- Small fossil-fuel steam generators

#### Advanced Technologies - Storage

- Underground pumped hydroelectric storage
- Compressed air energy storage
- Batteries

#### Advanced Technologies - Generation

- Geothermal
- Wind
- Photovoltaic
- Solar thermal

## A.1 Conventional Technologies

As can be seen in Figure 4-10 (or Table 4-12), the bulk of the nation's electrical generating capacity is in the form of fossil-fueled steam units. These units vary in size from a few to a couple of thousand megawatts and serve different functions within each utility. In general, the older, smaller units are used to provide for intermediate loads. These facilities are usually located near population centers and rely on petroleum or gas fuels. In addition, because of their advanced age, they are often the first in line to be retired. Unless pollution control equipment has been retrofitted, these facilities generally produce greater amounts of environmentally degrading emissions per megawatt than their newer counterparts. Base load power is often provided by very large, newer, coal-fired or nuclear facilities located in isolated areas of the country. Base load plants represent approximately one-quarter of the total installed generating capacity.

Although some doubt has been expressed as to the value of fuel cells for peak power production (primarily because of the comparatively higher capital costs of these systems), many attributes of the fuel cell technology make it particularly attractive for this application. Today, electrical peak load capacity is met primarily by combustion turbines and internal combustion peaking generators and surface pumped hydroelectric storage. Together, these technologies constitute about 11 percent of the national generating capacity. This picture is not expected to change significantly over the next 20 years, although the accelerated emergence of the advanced technologies described in Section 4.2.4 may challenge this projection.

Surface pumped hydroelectric storage (SPHS) has been used in the United States since 1953 and many systems are in operation today. An SPHS system requires a suitable site for the upper-level reservoir to be located at sufficient elevation in the vicinity of the lower reservoir and also at a reasonable distance from the load center concerned. Since sites with such characteristics are being rapidly depleted today, the potential for future growth of these systems is limited. Internal combustion sources, for peak-load periods, are fast responding and easy to maintain and operate. They have historically been used for this purpose because of their low capital costs and cycling flexibility. However, because they have relatively low efficiency and burn premium fuel (oil or natural gas), alternative energy technologies for peaking application are presently being sought.

Stationary internal combustion sources are grouped into two categories: gas turbines and reciprocating engines. Gas turbines can be either simple open cycle, regenerative open cycle, or combined cycle. Regenerative-type gas turbines constitute only a very small fraction of the total gas turbine population. Reciprocating internal combustion engines are classified as either spark or compression ignition (diesel) engines. All diesel oil reciprocating engines are compression ignited, and all gasoline reciprocating engines are spark ignited. Spark ignition gasoline engines have very limited use for electricity generation because of their poor part-load economy and cost of fuel.

On the basis of total installed horsepower, electricity generation is the predominate user of gas turbines (Ref. A.1). For this technology, the total 1978 installed capacity was 50,800 MW, of which approximately 82 percent were oil-fueled

(distillate oil and kerosene), 7 percent were gas-fueled combustion turbines, and 11 percent were combined cycle plants. This represented 8.7 percent of the national installed electricity generation capacity. The average size of gas turbines in 1978 was approximately 31 MW and, as of December 31, 1976, the capacity average age was approximately 5 years (Ref. A.1). Units between 15 and 100 MW are generally used for peak load electricity generation, and units greater than 100 MW are often incorporated into combined cycle systems to increase base load production efficiency. It is predicted that utilities will continue to dominate the gas turbine market in the future. The National Electric Reliability Council projects a 23 percent increase over the 1978 installed capacity by 1985, or a short term annual growth rate of about 3 percent (Ref. A.1). In terms of geographical distribution, the states with the highest installed capacity of utility gas turbines include New Jersey, Florida, New York, Pennsylvania, and Illinois.

For 1976, the Federal Power Commission reported a generation capacity of 5,300 MW for internal combustion reciprocating engine plants owned by utilities. This was approximately 1.0 percent of the national installed generation capacity. As of December 1974, the average unit size was 1.9 MW and the average age was approximately 10 years. Although these engines are useful as peaking units for large power facilities, their major use is for base load electricity generation by municipal power companies, often in areas where demand does not justify the construction of large steam power plants. For the nine-year period from 1976 to 1985, the FPC estimated that the net installed capacity for utility reciprocating engines would only increase by approximately 100 MW, or less than 2 percent (Ref. A.1). The states with the highest installed capacity of these engines include Kansas, Iowa, Missouri, Michigan, and Minnesota.

## A.2 Advanced Technologies

As petroleum and natural gas resources become scarce and prices for these energy resources increase, alternative means of electricity generation become increasingly competitive. While a few of these advanced technologies such as the fuel cell and compressed air energy storage emphasize greater fossil fuel efficiency, most rely completely on renewable energy services, including solar, wind, hydroelectric, ocean thermal, and geothermal. These technologies can be scaled to meet any fraction of the energy demand, including base, intermediate or peak loads, although storage technologies are installed particularly for their peaking capabilities. To some degree, all of the advanced energy conversion technologies discussed in this section will compete with fuel cells for future markets. For the most part, these markets will consist of the replacement of aging fossil fuel generators and the growth of new energy markets, primarily to satisfy intermediate and peak demands. The following sections will evaluate the commercialization potential and environmental characteristics of several advanced energy technologies to enable the environmental assessment of fuel cell commercialization in light of anticipated energy development trends.

### A.2.1 Energy Storage Technologies

Energy storage systems can allow utilities to reduce fuel consumption by accumulating the more highly efficient base load energy during periods of low demand for

use during peak demand periods. Presently, there is only one well established method of energy storage for electric utilities--pumped hydroelectric storage. Future applications appear limited both because of the shortage of suitable bodies of water and topographic sites and because of objections from people who perceive such plants as being a major threat to the natural environment. Less than 2 percent of all U.S. electric energy is obtained from these facilities, and it is doubtful that this will increase much in the future. The three most promising alternatives to this conventional storage technology are underground pumped hydroelectric storage, compressed air energy storage, and batteries.

Underground pumped hydroelectric storage (UPHS) is less limited by topographic and environmental constraints than its conventional counterpart. The lower reservoir is constructed underground in hard rock, without any connection to a natural body of water. The upper body of water can also be artificially created and can be much smaller since the distance between the lower reservoir and the upper one can be several thousand feet, compared with less than 1,000 feet for a typical surface pumped-storage system (Ref. A.2). The prospects for UPHS are appealing, both because the engineering experience exists and suitable sites are widely available. Nevertheless, the costs, risks, benefits and potential for improvement are not yet well defined for this technology.

The proposed specifications for a typical UPHS plant call for a capacity of 1000-2000 MW, with 8-10 hours of storage and an overall efficiency of close to 70 percent. The time required for construction is 6-8 years and total time in excess of 10 years may result if planning and lead time are considered (Ref. A.3). Commercialization milestones are as yet not identified and it appears that UPHS facilities will not begin to operate until the 1990s at the earliest. The principal environmental concerns include groundwater impacts, surface reservoir impacts, and worker health and safety during construction.

Compressed air energy storage (CAES) is a technique which incorporates a modified state-of-the-art gas turbine and an underground reservoir to produce peak power electricity. CAES systems are similar to some forms of pumped-hydroelectric storage in their use of underground caverns. This method, however, offers several advantages: a wider choice of geological formations, compactness, and a smaller minimum size for an economically attractive installation. In 1979, a German utility initiated the demonstration of a commercial CAES storage installation in Huntorf, West Germany. By burning a certain amount of natural gas, this system is able to generate 290,000 kW for about two hours. The Department of Energy currently has a fairly comprehensive program for CAES development, with a goal of determining the economic and technical feasibility of deploying a demonstration plant in a utility system in the 1980s.

The major components of a CAES system are the underground air storage chambers and the gas turbine compressor/generator system located above ground. During periods of low electricity demand, the excess capacity of a remote baseload generating plant would be used to power an air compressor train at the facility and store it underground. During daily peakload periods, when electricity demands exceed the capacity of baseload plants, the compressed air would be extracted from underground storage, mixed with fuel, ignited in a combustion chamber, and



expanded through a turbine for power. The major difference between the CAES turbine and a simple cycle turbine is that the compression and expansion portions of the cycle are performed at different times. By using more of the efficient baseload energy and down-sizing the peaking turbine (made possible by the removal of the compressor), the consumption of premium fuels can be reduced by more than 60 percent with a CAES system (Ref. A.4). In fact, some advanced CAES technologies may not require premium fuels at all.

A well designed CAES plant is expected to have a smaller adverse impact on the environment when compared to a conventional gas turbine peaking plant. Most of the environmental problems encountered in the deployment of CAES systems are site specific and can generally be mitigated by appropriate site selection. Specific concerns relate to the potential hazards of solid waste and water degradation resulting from the mining of cavities, the potential for groundwater contamination, and the possibility of induced seismic activity.

EPRI and DOE recently established the Battery Energy Storage Test (BEST) Facility to assess the most promising advanced batteries under development for utility storage application. The first prototype to be tested after initial checkout with lead-acid batteries will be a 4.8 MW zinc-chlorine battery followed soon after by a 5 MW sodium sulfur battery. A test-bed demonstration of utility energy storage is scheduled for 1984 at the Wolverine Power Cooperative in northern Michigan which will connect a 30 MW lead-acid battery storage system to the utility grid. The availability and cost of battery materials are perceived as the major constraints to market penetration.

Like other storage options, batteries will require a higher utilization of base load capacities, increasing the environmental impacts of these technologies. Additional impacts can be expected from their manufacture, use, and final disposal. Of special concern is the potential for worker exposure to toxic chemicals during the production and operation of battery systems. Several components of near-term battery manufacturing and disposal cycles are classified as hazardous waste generators under Section 2001 of the Resource Conservation and Recovery Act.

#### A.2.2 Generation Technologies

During the next 20 years, the United States will begin to use new technologies that rely on renewable forms of energy, including geothermal, solar, wind, biomass and ocean thermal. Of these energy sources, the first three are currently viewed to have the greatest potential for augmenting the nation's electric energy supplies. These technologies will compete with fuel cells for future markets; however, since their efficient operation relies on such geographically dependent variables as insolation, wind speed, water resources, and geology, the location of the technology will likely determine its competitive advantage. The efficiency of fuel cell electricity production is location independent, and thus a greater number of potential markets will be accessible. This advantage is partially offset by the reliance of fuel cells, at least initially, on fossil fuels.

With regard to these new technologies, it is important to distinguish capacity displacement from energy displacement. Capacity displacement refers to the

extent which conventional generating plants may be entirely replaced by a new technology, while energy displacement considers only the amount of new energy which is available to substitute for conventional fuels. Because demand varies predictably, but energy sources such as solar and wind are inconsistent, it is doubtful that these technologies will provide much capacity displacement. However, they are expected to provide a significant amount of overall energy displacement and corresponding savings in fossil fuels. Fuel cells, because of their reliability, will provide both capacity and energy displacement.

There are currently three categories of geothermal resources: hydrothermal, geopressured, and hot dry rock. The currently exploited geothermal resources are of the hydrothermal type and may be liquid or vapor dominated. Within the United States, about 10 major development projects have been established by joint government and industry effort, or by industry alone. They range from pilot plants to full scale commercial facilities (Ref. A.5). In 1980, the total installed geothermal capacity was slightly over 800 MW, mostly at the Geysers field in Northern California. By the year 2000, an aggressive national program could expand this capacity to 35,000 MW (Ref. A.5). The DOE has an established Geothermal Energy Program to assist in the commercialization, demonstration and technical research requirements of this technology. There are also numerous other federal, state, and local government geothermal activities, including a federal loan-guarantee program to encourage and assist the financing of geothermal energy development by the private sector.

Nine potential environmental problems in geothermal power production are identified in the Geothermal Energy Systems Environmental Development Plan published by DOE. Those that appear to be most important are airborne emissions, solid wastes, brine disposal, induced seismicity, subsidence, water use, and hydrological alterations. These impacts are highly site dependent (Ref. A.5).

Wind energy can be extracted by either horizontal- or vertical-axis windmills in a wide variety of configurations. Most of the major small- and large-scale devices in advanced stages of development or commercialization are of the horizontal-axis type. The federal program, led by the DOE, has as its goal the generation of 1.7 Quads of wind energy by the year 2000 (Ref. A.5). Small-scale devices for individual household use are presently available from a growing number of sources at reasonable prices. Large-scale devices generating several megawatts are in the demonstration phase. The Wind Energy Systems Act of 1980 (PL 96-345) provides incentives for the commercialization of wind energy systems through grants and loans. In general, the environmental issues associated with wind energy conversion are relatively minor when compared with other major energy technologies. Four environmental issues which are of greatest concern include safety, electromagnetic interference, noise and aesthetics.

In a conservative scenario, projections show that solar technologies (excluding biomass, hydro, wind, and ocean thermal energy conversion) could displace as much as 2.3 Quads of the energy expected to be required by the U.S. in the year 2000 (Ref. A.6). If the federal government were to aggressively pursue solar development programs, as much as 7.0 Quads of conventional energy could be displaced. To accomplish this goal, the priority will be on individual dispersed solar thermal units,

which through active or passive design, can provide thermal heating and cooling for industrial, agricultural, and residential needs. In addition, several approaches are under development for the conversion of solar energy to electricity, either directly with photovoltaic arrays or indirectly with solar thermal power systems.

The principle behind solar thermal power systems involves heating a working fluid to a temperature high enough to drive a turbine. The turbine's mechanical output is then used to drive an electric power generator which produces electricity. Because of the high temperatures needed for electricity generation in this manner, the solar radiation must be concentrated. This is generally accomplished through the use of any of three types of solar collectors - parabolic trough, parabolic dish, or central receiver. There are two applications envisaged, (1) relatively large capacity solar plants (20 MW or greater) would be designed for use in utility networks, and probably be sited in remote locations, and (2) dispersed power system employing solar plants of lesser capacity would supply individual consumers at the point of energy use. Projections of the potential demand for solar thermal energy for the year 2000 range from 1 to 7 Quads (Ref. A.7).

Early application concepts limited solar thermal power systems to electric power production. However, they may also be used to obtain process heat, or in total energy systems to produce both power and useful heat. While thermal applications are appropriate for industries, integration of solar power plants into existing urban settings to provide heat for low temperature applications (e.g., space heating and cooling) will be difficult and probably uneconomical. Thus these systems by nature appear best suited for centralized applications by industries (including agribusiness) and small utility systems amenable to community ownership (Ref. A.7).

Photovoltaic cells are modular by nature, and little is to be gained by grouping large masses of cells at a single collection site. On the contrary, it is more sensible to apply the technology in a decentralized fashion--perhaps incorporated in the roofs of buildings--so that transmission and storage problems can be minimized. With a decentralized use, the 80 percent or more of the sunlight that such cells do not convert into electricity can be harnessed to provide energy for space heating and cooling, water heating and refrigeration. Because of their modular design, photovoltaic systems are probably more suitable for on-site uses, although solar thermal power plants may be attractive for certain industrial or agricultural operations. Commercial acceptance for either system is several years off and it is likely that only one of the two systems will eventually emerge to capture a share of the energy market.

Many of the environmental effects associated with operating photovoltaic and solar thermal central receiver plants are similar. The coverage of large areas of land by heliostats and photovoltaic arrays will modify local terrain, species composition, and microclimate. At the present state of development, large scale centralized solar thermal power systems are land, water, and capital intensive. Leakage of working fluids or storage media create environmental concerns for worker safety and the protection of local water quality. Smaller scale dispersed systems are likely to be located near areas already developed for agriculture or industry. The primary environmental concern will be public safety and protection of property. Although the operation of photovoltaic systems is environmentally benign, the construction of

photovoltaic cells requires processes and materials which raise concerns for worker health and safety.

### A.3 Environmental Comparison of Energy Technologies

Fuel cell power plants generally produce fewer environmental impacts than other fossil fuel power systems; however, when compared with other advanced energy technologies, this is not necessarily the case. Table A-1 compares the environmental impacts of fuel cell power plants with selected alternative energy generation technologies. A ranking of relative impact is assigned to each technology to help the reader make meaningful interpretations.

The ranking system is necessarily judgmental, and attempts to balance widely disparate impact characteristics. The magnitude is relative rather than absolute and thus the degree of difference between two sequential technologies may be very great or very small. Nevertheless, this table is a useful gauge for estimating relative environmental tradeoffs involving future energy scenarios in the absence of accurate projections.

From the table, it can be seen that fuel cells offer overall environmental benefits when compared with the two conventional fossil-fueled peaking units (gas turbines and internal combustion engines) and several of the advanced energy technologies. If fuel cells were to be used in place of these technologies, net national environmental benefits would result. For the most part, these benefits would be less significant than those which were derived in comparing fuel cells with fossil-fueled steam generators (Sections 5.3.3) since advanced technologies are generally more environmentally "clean" than conventional systems.

The impacts resulting from the displacement of conventional peaking unit capacity (representing 11 percent of the total) with fuel cells is important since the characteristics of fuel cells make them well suited for peak power production. The potential influence of advanced energy technology substitution is less important, since these systems are not projected to significantly penetrate the energy network in the foreseeable future. In addition, the initial market penetration of advanced technologies will undoubtedly come at the expense of conventional fossil fuel systems rather than fuel cells. Nevertheless, the quantitative impact analysis provided in this assessment should be tempered with qualitative observations derived from the information in this table.

**Table A-1. Comparison of the Environmental Impacts of Fuel Cell Systems with Selected Alternative Energy Generation Technologies**

AIR

<u>Technology</u>	<u>Ranking<sup>(1)</sup></u>	<u>Environmental Impacts</u>
Fuel Cell	5	Fuel cells have very low levels of conventional air pollutants. Production of fuel cell fuels from coal gasification and liquefaction in the future will result in additional emissions characteristic of these synthetic fuel technologies. This is not necessarily unique to fuel cell systems, however, since other fossil fuel-dependent technologies will also increasingly rely on synthetic fuels.
Gas Turbines	8	Air emissions from gas turbine utilization result from the combustion process and the on-site storage of oil or gasoline. Air pollution equipment is generally not installed; however, water and steam injection techniques are being evaluated for NO <sub>x</sub> emissions control and fuel additives are often employed to reduce visible smoke emissions. Trace elements which occur in the fuel oil are generally released in the particulate matter. For oil-fired gas turbines, nickel, copper and phosphorus have been identified as potential problems. Other emissions include NO <sub>x</sub> , SO <sub>x</sub> , CO, hydrocarbons, and trace elements such as arsenic, barium, manganese and th.
Reciprocating Internal Combustion	9	Unlike the large baseload equipment, air pollution control equipment is generally not installed on reciprocating engines. Air emissions result from the combustion process and the on-site storage of oil or gasoline. Aside from NO <sub>x</sub> , SO <sub>x</sub> , CO, particulates, and hydrocarbons, oil-fueled engines may emit nickel, copper, and phosphorus in concentrations high enough to present a problem. Hydrocarbons (especially from storage evaporation losses) and NO <sub>x</sub> emissions contribute significantly to the national emissions burden.
Pumped Hydroelectric Storage	4	There are no air emissions during the electricity generating phase of these systems; however, the use of a coal baseload power plant during the storage phase results in emissions characteristic of this technology. On the other hand, nuclear or hydroelectric baseload energy plants produce no combustion air pollutants. Even with the use of coal, pumped hydroelectric storage systems have less emissions than comparable conventional petroleum-based peaking units.
Compressed Air Energy Storage	6	A CAES turbine consumes only about one-third as much oil or gas as a simple cycle turbine. Air emission from the CAES turbine will therefore be proportionately less. Emissions from baseload energy production to provide the compression energy will partially offset this reduction. If a nuclear plant is used, there will be no additional combustion emissions. The net air quality, even with coal baseload production, is expected to be superior to conventional gas turbine systems. The compressed air will pick up contaminants from the cavity which may be transported to the surface through minor cavity leaks or upon exit from the turbine.
Geothermal	7	Incoming geothermal steam may be vented directly to the atmosphere during plant shutdown, initial well drilling and testing. During these times, air emissions are at their peak. Pollutants in the plume include hydrogen sulfide, ammonia, methane, and traces of arsenic, boron, mercury, and radon-222. The emission of greatest concern, hydrogen sulfide, is generally 80% removed during normal plant operation by an installed abatement system. The other pollutants do not present hazards at the concentration levels released. Water vapor is released by the cooling towers and may result in local fogging, icing on adjacent roads and structures, and potential interactions with other pollutants to form acid mists.
Wind Energy Conversion	1	None
Photovoltaic	2	System operation will have little or no impact on local air quality since an array will emit no gaseous or particulate pollutants.
Solar Thermal	3	Compared to conventional power generating systems, effects on air quality should be minimal. Some degradation could occur from the evaporation of working, storage, cooling, and cleaning fluids. There is a possibility that the high temperatures and light intensities produced at the receivers may initiate chemical reactions in the atmosphere to generate harmful pollutants such as nitrogen oxides from oxygen and nitrogen.

Table A-1. Comparison of the Environmental Impacts of Fuel Cell Systems with Selected Alternative Energy Generation Technologies (Continued)

WATER

<u>Technology</u>	<u>Ranking</u>	<u>Environmental Impacts</u>
Fuel Cells	3	Small amounts of high quality water are produced which must be discharged. Small amounts of wastewater from power plant blowdown must also be pretreated and disposed. The larger units may require a minimal water supply.
Gas Turbines	4-5	The overall water quality in the area near the plant should not be degraded during normal plant operations. This is due mainly to the small amount of water required to operate the plant. Runoffs due to storms and compressor water washing which contain oil residues can be routed to a central collection point where oil is removed before the water evaporates.
Reciprocating Internal Combustion	4-5	Similar to Gas Turbines.
Pumped Hydroelectric Storage	9	Above ground storage systems may present unique problems, particularly for fish protection. Depending on the amount of use and size of the upper reservoir, maintenance of natural circulation patterns and acceptable water quality (temperature and dissolved oxygen) may be a problem. Aquatic organisms may become impinged or entrapped during the cycle. Fluctuations in the reservoir water level may create a biologically impoverished zone. In underground storage, the mineralization, solids suspension, and increased temperature of the upper reservoir due to water cycling may present additional problems.
Compressed Air Energy Storage	6	For constant pressure systems, the surface reservoir may become contaminated. Subsurface water impacts include the potential contamination of underground drinking water supplies due to improper casing which allows communication between aquifers. Air leaking from the reservoir may collect in potable aquifers and impact the flow rates of wells in the area.
Geothermal	8	In the Geysers field, the amount of steam from the wells exceeds the amount of cooling water required, the amount of water in the cooling system increases during plant operations. In most cases, the excess spent fluids are reinjected into the geothermal wells, minimizing the contamination of surface and ground water in the vicinity of the plant. This is not always possible, however, and alternative disposal practices may impact surface reservoirs and groundwater aquifers. Discharges of toxic wastewater to local streams could possibly result from rainwater runoff in the absence of appropriate plant containment barriers.
Wind Energy Conversion	1	None
Photovoltaic	2	System operation will have little or no impact on local water quality since an array will emit no liquid or solid wastes under normal operating conditions. Arrays which require water to cool panel frames (concentrating Fresnel lenses) will probably recirculate water, thereby minimizing water inputs and release potential.
Solar Thermal	7	Solar thermal power plants may require more water than conventional systems because of their lower thermal energy conversion efficiency. These requirements may increase if a once through cooling system is required because of poor water quality. Open Brayton cycle heat engines require essentially no cooling water, but the engine is still under development. The accidental release of working fluids, many of which are very toxic, may result in subsequent water contamination.

**URBAN AND SUBURBAN  
OF POOR QUALITY**

**Table A-1. Comparison of the Environmental Impacts of Fuel Cell Systems with Selected Alternative Energy Generation Technologies (Continued)**

<u>LAND USE</u>		
<u>Technology</u>	<u>Ranking</u>	<u>Environmental Impacts</u>
Fuel Cells	1	Dispersed fuel cell systems will likely be sited near urban/suburban areas which is land of comparatively high value. The land required to generate 1 MW with fuel cells is approximately 0.15 acres. The modular nature of fuel cell units will allow for flexibility in meeting the land use requirements for individual sites.
Gas Turbines	2	A 60 MW plant would occupy about 15 acres of land, or about 0.25 acres/MW.
Pumped Hydroelectric Storage	5	The present method of this technology requires an upper and lower reservoir, each of which may be natural or artificially created. Large areas of land are therefore required; however, this land can simultaneously be used for other activities. Issues associated with reservoir creation and maintenance involving recreational opportunities and the loss of alternative land uses are applicable. Since available sites for this technology are limited, future uses of pumped hydroelectric storage will for the most part rely on underground storage which requires much less land than a surface system of the same energy-storage capacity. A 1000 MW pumped storage plant would require 514 acres.
Compressed Air Energy System	3	For constant volume systems, there is no reason that a CAES system should require more land than a conventional peaking turbine. A constant pressure system will require a water reservoir, which is subject to large variations in surface level could be an aesthetic and hazardous nuisance.
Geothermal	4	A 110 MW unit such as is found at the Geysers field in California, may require from 31-62 acres of land.
Wind Energy Conversion	6	The land required for wind energy generation is considered a major impediment for the commercialization of this technology. The Department of the Interior's 2.5 MW MOD-2 wind turbine generators would require in excess of 34 acres for a field of four units (10 MW). In many instances, however, this land may be used for other activities such as grazing or agriculture.
Photovoltaic	7	Land use is significant. Installation of photovoltaic arrays over large areas will modify the local terrain, species composition, and meteorology. Depending on the technology employed, approximately 2-6 acres of land will be required for each MW of installed capacity. On-site applications will not require additional land since they will probably make use of rooftop locations.
Solar Thermal	8	As with photovoltaic systems, the early commercialization of central-dispersed generation solar thermal systems will likely occur in the desert regions of the southwestern U.S. This will serve to either mitigate or exacerbate certain environmental impacts of energy production. Depending on the design and concentrating ability of the system, 6-12 acres of land will be required for each MW of installed capacity. On-site systems can make use of compatible locations, primarily on rooftops, and will thus require minimal amounts of land.

NOISE

Fuel Cells	1	Fuel cell power plant operations are characterized by very low noise levels due mainly to the absence of forced-draft fans, boiler feed pumps, and turbine generators. The 40 kW units have been tested at 61 dBA at 4.6 meters at full power. UTC's larger 4.8 MW unit is expected to have a sound level of 55 dBA at 30 meters, acceptable for residential applications.
Gas Turbines	4	Noise is an unavoidable impact from the operation of a combustion turbine. Silencers are generally installed on the turbine inlet and outlet lines and acoustical insulation is also used. For a 60 MW unit, the noise level is about 55 dBA at 121 meters.
Compressed Air Energy Storage	3	Because the compressor and turbine do not operate at the same time, the noise level of a CAES facility should be lower than a conventional turbine-generator set. However, noise emissions will be more continuous since the plant will operate most of the day in either a compression or generation mode.
Geothermal	5	The major sources of noise are the cooling towers, turbine-generator, steam vents, and steam ejectors. Mufflers are used on the steam vents and ejectors to decrease the noise level. For a 110 MW unit, noise levels during normal operations are approximately 65 dBA at 30 meters and 55 dBA at 457 meters.
Wind Energy Conversion	2	Some noise has been reported from almost all wind generators, particularly the "swishing" noise associated with the rotor blade tips. Other sounds, which may be heard over long distances (one mile from the site) include a periodic low-frequency "thumping" that is particularly annoying because of its low beat about once per second.

Table A-1. Comparison of the Environmental Impacts of Fuel Cell Systems with Selected Alternative Energy Generation Technologies (Continued)

HEALTH AND SAFETY

<u>Technology</u>	<u>Ranking</u>	<u>Environmental Impacts</u>
Fuel Cells	4	Fuel cell units are designed according to selected safety codes and standards and equipped with built-in safety systems. The primary area of concern is in fuel usage and in the case of liquid fuels, fuel storage. These practices however are strictly regulated by industry safety standards. On-site locations will expose larger populations to any potential safety hazards.
Gas Turbines	5-6	The major hazard of the plant is fire with the sources being the fuel oil (gasoline) system, turbine generator and electrical system. In the fuel oil system, the major fire hazard is the fuel oil storage tanks. Storage requirements will probably be greater at a gas turbine plant than at a similarly sized fuel cell installation.
Reciprocating Internal Combustion	5-6	Similar to Gas Turbines.
Pumped Hydroelectric Storage	2	Flooding of the powerhouse is a concern which could endanger operating personnel. The main issue associated with above ground systems concerns dam safety and the potential effects of dam failure. The major safety advantage of these systems is that combustible fuels are not required.
Compressed Air Energy Storage	3	First generation facilities will require the use of natural gas with its associated risks. The catastrophic failure of the integrity of the cavity, although extremely unlikely, presents a safety hazard.
Geothermal	7	The principal hazard to the general public is an increase in air pollutants, especially H <sub>2</sub> S, mainly due to the steam venting resulting from plant shutdown. There is also an increase in noise during venting to levels approximately 90 dBA at 250 feet. Fires are less prevalent at geothermal plants than at other types of power plants due to the lack of combustibles.
Wind Energy Conversion	9	Safety is a serious concern of this energy technology. The dangers associated with structural failures of the tower, rotor, or generator threaten both on-site personnel and nearby residents. Problems in this area have led some authorities to predict that wind devices may have one of the highest occupational man-days lost (per megawatt-year) records of any energy technology. The height of these systems also may present a hazard to aircraft in the area.
Photovoltaic	1	Accidents such as fire could cause the release of toxic fumes from combustion of the CdS and GaAs cells, encapsulation materials, and/or concentrating lense materials.
Solar Thermal	8	The release of candidate working/storage fluids such as liquid sodium, sodium hydroxide, hydrocarbon oils, and eutectic salts could pose a serious threat through fires, explosions or water contamination. Because of their proximity to large populations, on-site systems are of added concern. Misdirected solar radiation may present a hazard to workers in a centralized solar thermal power plant.

(1) Technologies are ranked in order of increasingly negative environmental impact with respect to the specific environmental parameter in question.



## APPENDIX REFERENCES

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## ACRONYMS AND ABBREVIATIONS

AC, ac	Alternating Current
AGA	American Gas Association
BTU	British Thermal Unit
CAES	Compressed Air Energy Storage
dBA	Decibels (A Scale)
DC, dc	Direct Current
DOE	Department of Energy
EIS	Environmental Impact Statement
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERC	Energy Research Corporation
FCC	Federal Communications Commission
FPC	Federal Power Commission
FTSC	Field Test Steering Committee
FWPCA	Federal Water Pollution Control Act
GRI	Gas Research Institute
HVAC	Heating, Ventilating, and Air Conditioning
kW	Kilowatt
LAER	Lowest Achievable Emission Rate
LNG	Liquefied Natural Gas
LOLP	Loss of Load Probability
MW	Megawatt
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NEA	National Energy Act
NEPA	National Environmental Policy Act
NERC	National Electric Reliability Council
NO <sub>x</sub>	Nitrogen Oxides
NPDES	National Pollution Discharge Elimination System
NSPS	New Source Performance Standards

OSHA	Occupational Safety and Health Administration
OS/IES	On-Site, Integrated Energy System
OTEC	Ocean Thermal Energy Conversion
PAFC	Phosphoric Acid Fuel Cells
PSD	Prevention of Significant Deterioration
PUC	Public Utilities Commission
PURPA	Public Utilities Regulatory Policies Act
RCRA	Resource Conservation and Recovery Act
SCE	Southern California Edison Company
SNG	Synthetic Natural Gas
SO <sub>2</sub>	Sulfur Dioxide
SPHS	Surface Pumped Hydroelectric Storage
TDS	Total Dissolved Solids
THC	Total Hydrocarbons
TSCA	Toxic Substances Control Act
UL	Underwriters' Laboratories
UPHS	Underground Pumped Hydroelectric Storage
UTC	United Technologies Corporation
W/ERC	Westinghouse Electric Corporation/Energy Research Corporation