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National Benefits Associated with Commercial Application of Fuel Cell Powerplants

Prepared for the Energy Research & Development Administration

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NATIONAL BENEFITS ASSOCIATED WITH COMMERCIAL APPLICATION OF FUEL CELL POWERPLANTS

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PREFACE

During the past several years, a jointly funded fuel cell research and development program has been conducted by United Technologies Corporation with a consortium of electric and gas utilities.

As part of this work, more than 60 man-years of effort have been expended by both utilities and UTC to define the role and benefits of the fuel cell in the nation's utility systems. These studies have recently been expanded to include parameters of special interest to the public sector. The purpose of this document is to make this latter information available to the public for its consideration and discussion. Comments from interested parties are encouraged and should be addressed to the undersigned.

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I. SUMMARY

The fuel cell is a device that converts fuel to electrical energy in a highly efficient and environmentally acceptable manner regardless of the unit size. Because of their unique features, fuel cell powerplants can be located close to the point of electricity demand, reducing energy losses associated with transmission and distribution and permitting effective use of waste heat. When used to complement other types of generation equipment within a utility system, the fuel cell permits the entire system to be operated in a more fuel effective manner. Viewed on a national scale, these wide-ranging fuel conservation opportunities can provide substantial savings.

Major privately sponsored research and technology efforts, now in progress, are aimed at developing the fuel cell for utility industry applications. These efforts, supported by both electric industry and gas industry elements, are developing the fuel cells for two major areas of application. In the first application, multi-megawatt fuel cell powerplants would be dispersed within electric utility networks to complement large-scale systems and provide for the generation needs of small private and public utilities. In the second mode, smaller size fuel cells would be sited at building locations to provide integrated electric and thermal service for commercial and industrial complexes. With continued funding of planned programs, utility application of the fuel cell could result within this decade.

Joint application studies conducted by both utility companies and manufacturing representatives as part of these development programs have indicated both areas of application could provide economic and operational utility service benefits. Furthermore, successful deployment of the first generation fuel cell units could provide significant near-term benefits to society.

The objective of this report is to outline and discuss the application opportunities for first generation fuel cell powerplants, quantify improvements that these systems can offer in comparison with conventional electric generation techniques, and, in the context of a range of potential deployment scenarios, quantify the benefits to the Nation as a result of these improvements. This study has assumed that continued support of existing development programs will result in the commercial application of fuel cells in 1980.

The potential benefits associated with commercial deployment of fuel cell powerplants during the 1980 to 1990 time period include fuel conservation, energy cost savings, pollution damage reduction, capital investment reduction, and improvement in balance-of-payments. The magnitude of these benefits are summarized below:

Fuel Conservation – Figure 1 illustrates the range of fuel conservation potential associated with three fuel cell deployment scenarios. Conservation potential ranges from 0.4 to 1.0 million barrels of oil equivalent per day in 1985 to between 0.8 and 1.9 million barrels per day in 1990. Cases I, II and III are based on annual electric capacity and energy demand growth rates of 6.7%, 6.0% and 5.0% and high, moderate and low fuel cell market penetration levels respectively.

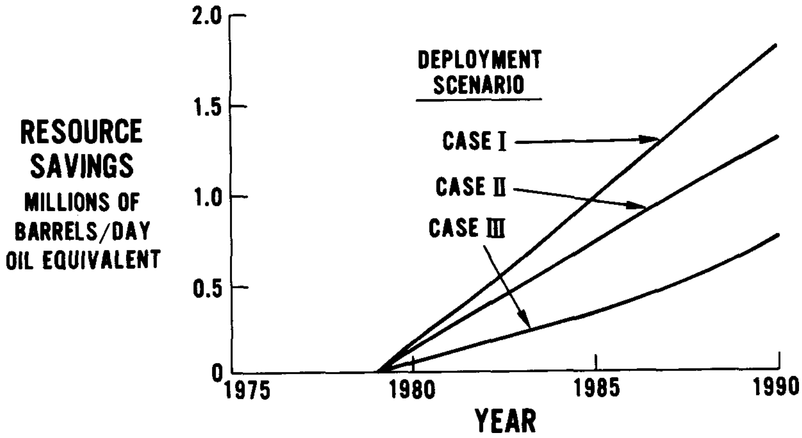


Figure 1 – Fuel Resource Conservation

Energy Cost Savings – The energy cost savings associated with the total cost of capital, fuel, operation and maintenance for fuel cell powerplants are shown in the table below for the period 1980 to 1990. Savings are in the form of 1976 present value for two discount rates.

Deployment Scenario	Energy Cost Savings, Billions of Dollars	
	10% Discount Rate	15% Discount Rate
Case I	10.5	6.8
Case II	7.2	4.7
Case III	3.5	2.3

Pollution Damage Reduction – On the basis of pollution damage costs defined by an independent source, the damage **reduction** resulting from the use of fuel cell powerplants could result in savings that range from $250 to $680 million in 1990 alone.

Capital Investment Reduction – The fuel cell powerplant's siting flexibility feature provides the opportunity for reducing the utility industry's requirement for investment capital by $2.3 to $11.5 billion during the 1980 to 1990 period.

Improvement In Balance-of-Payments – The export potential of the fuel cell powerplant, coupled with the potential for reducing fuel imports, could result in a net reduction in U. S. balance-of-payments of from $6.9 to $16.0 billion in 1990 alone.

II. FUEL CELL CONCEPT AND CHARACTERISTICS

The fuel cell is an electrochemical device which directly combines fuel and air to produce electricity. First generation commercial fuel cell powerplants will incorporate subsystems which permit operation on common liquid and gaseous fuels and produce electricity in a form which is compatible with the needs of utility systems. These powerplants will have many characteristics which favor their use in power generation applications.

Description of Concept

The fuel cell powerplant is a device for generating electricity from a wide range of fuels such as liquid petroleum distillates, natural gas, and synthetic fuels such as coal-derived products. Fuel cell powerplants perform the same function as a diesel engine electric generator set or as the steam turbine electric generators used in central power stations. However, the manner in which electricity is generated in a fuel cell is substantially different than for these familar systems.

In the fuel cell energy conversion process, a hydrogen-rich fuel is electrochemically combined directly with oxygen from the air to produce electricity and water, as shown in Figure 2. Waste heat produced by the reaction process is removed with the exhausted air. The basic process is highly efficient, and pollution-free and these characteristics are independent of output power. Single fuel cells can be assembled in stacks of varying sizes to produce a wide range of output levels.

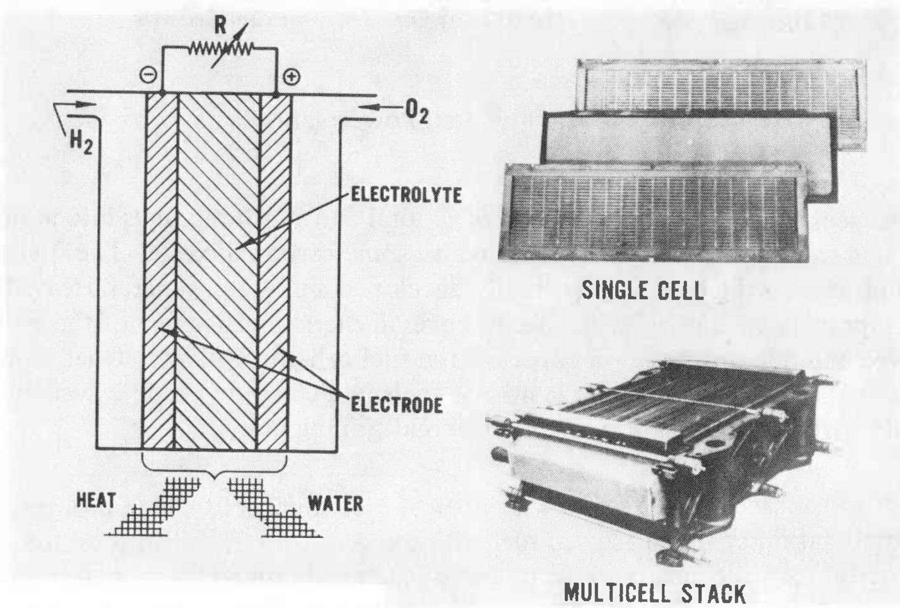


Figure 2 – The Fuel Cell Concept

Fuel cell powerplants have been built and operated for a range of space and military applications, and experimental demonstrators have been built for commercial applications. The specific arrangement of a fuel cell powerplant is dependent upon the fuel and oxidant used and the application requirements. For the U. S. Apollo space program, which included the manned voyages to the moon, the fuel cell operated on hydrogen and oxygen and supplied direct current (d.c.) power for the spacecraft electrical needs. This was a very simple powerplant consisting of a cell stack and a few controls.

Commercial fuel cell powerplants operating on fossil fuel and air will comprise three main units as shown schematically in Figure 3: the reformer section, the fuel cell power section, and the inverter.

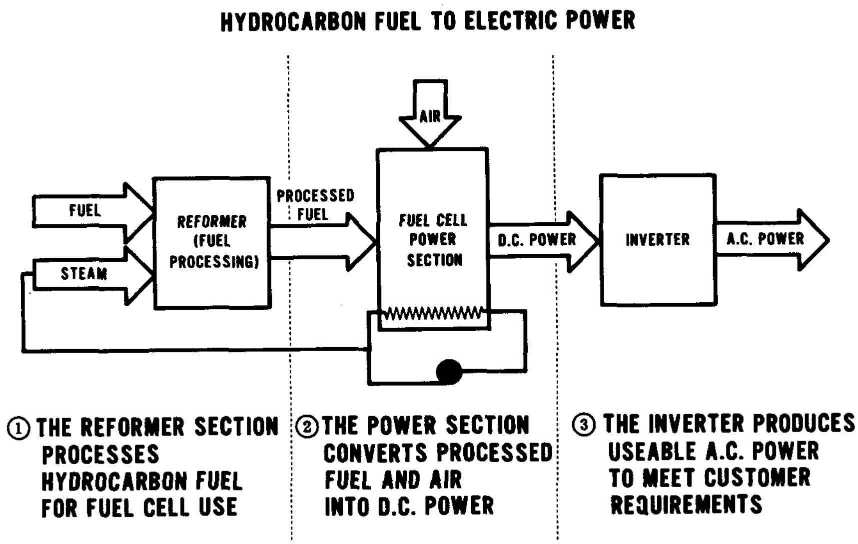


Figure 3 – The Fuel Cell Powerplant

The reformer section converts a wide range of natural and synthetic fuels into a more reactive form, usually a gaseous mixture of hydrogen with some carbon dioxide. The fuel conditioner is based on processes which are commercially developed and are in general use by the chemical industry. Improvements in the packaging and overall thermal efficiency of these units have been achieved and demonstrated on experimental fuel cell powerplants. Operation on the products of coal gasification or other synthetic fuels, which could become available in the future, could permit simplification of the fuel conditioning unit.

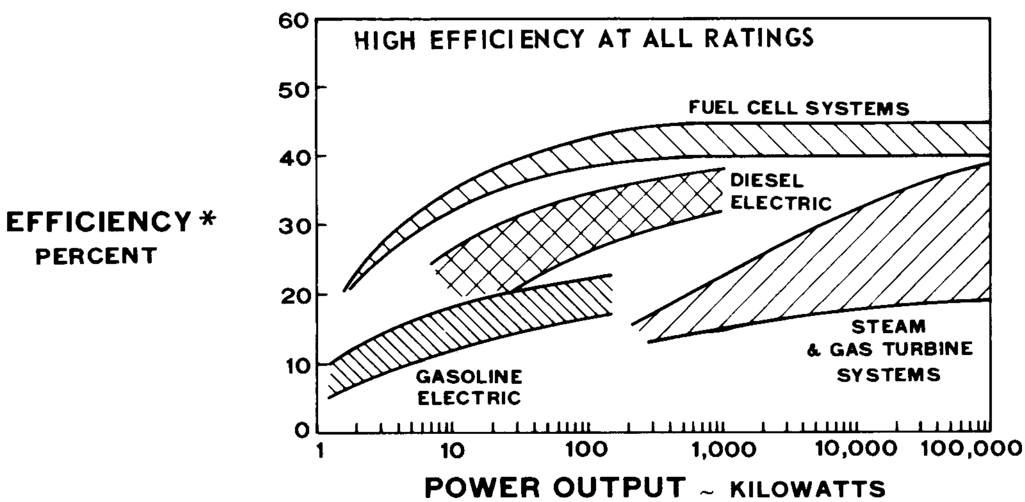
The fuel cell power section consists of a number of individual cells which promote the electrochemical combination of the processed fuel with oxygen from the air to produce direct current (d.c.) electricity. In a fuel cell stack a number of such cells are connected electrically in series to permit generation at hundreds or thousands of volts d.c. Connecting a number of cell stack assemblies in parallel permits generation of any power level from kilowatts to multi-megawatts.

The inverter converts direct current electricity from the cell section into alternating current electricity suitable for commercial applications. Inverters are presently in commercial and industrial use in many applications ranging from small consumer devices to large-scale electric utility equipment. The development of inverters for fuel cell powerplants has been directed toward reductions in unit cost and size.

Characteristics of Fuel Cells

Fuel cell powerplants have many general characteristics which favor their use in a wide range of power generation applications. In use, they will offer both the utility and the consumer advantages over other forms of electric generation while providing competitive costs.

Fuel cell powerplants ranging in power output from less than one hundred kilowatts to thousands of kilowatts have an efficiency which is comparable to the best large central steam plants. Figure 4 compares the full-load efficiency of fuel cells with that of conventional generation equipment.



***BASED ON LOWER HEATING VALUE**

Figure 4 – Fuel Economy/Efficiency for All Sizes

In addition to high efficiency at full load, the fuel cell is also highly efficient over a range of output levels from 25 to 100 percent of rating. Unlike conventional generation equipment, fuel cell efficiency increases as load is reduced from rated power, as shown in Figure 5.

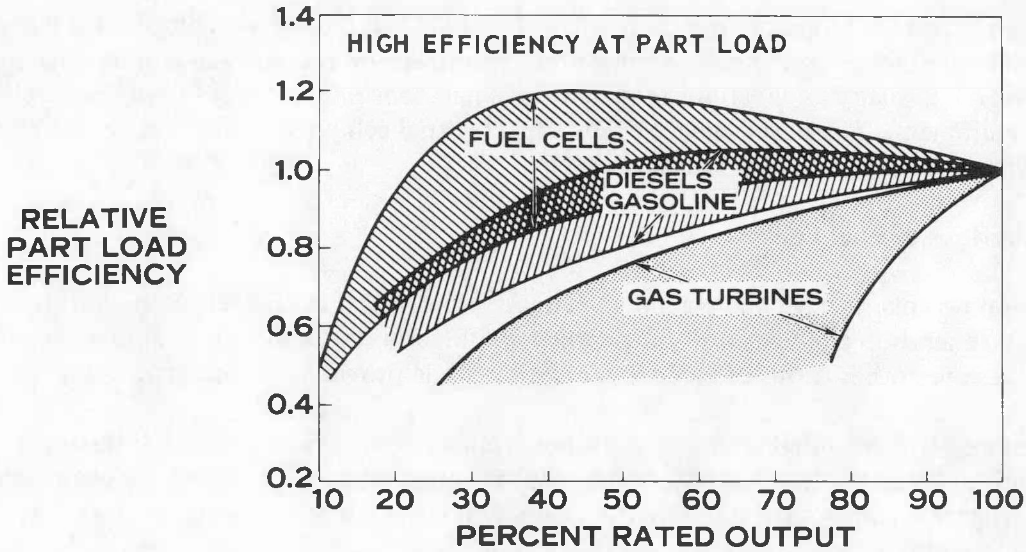


Figure 5 – Fuel Economy/Efficiency at Part Load

Fuel cell powerplants can be constructed of standardized components, with modules of the three main units grouped to provide the appropriate power rating. This modular construction permits factory assembly and checkout of the powerplant system resulting in vastly reduced installation lead times. Multiple units installed within a utility system may be easily paralleled electrically to provide a single output source.

Fuel cell powerplants operate effectively on gaseous fuels such as natural gas, synthetic natural gas (SNG), or propane, as well as on low sulfur content light distillates. Operation on fuels such as diesel or kerosene type fuels with high sulfur content has been demonstrated, and this capability is a practical goal for second generation powerplants. This fuel flexibility provides utilities with an adaptable power source both in the context of present and future energy formats.

Measured emissions from experimental powerplants have shown that the fuel cell exhaust contains less than one-tenth the pollutants per unit of energy delivered, compared to the EPA standards for modern conventional fossil fueled central station generators. Emissions of sulfur oxide, nitrogen oxides, hydrocarbons and particulates are significantly lower than the fuel cell powerplant, as indicated in Figure 6, resulting in favorable environmental impact.

The nature of the fuel cell process and the system operating temperature levels permit the powerplant waste heat to be rejected to ambient air or recovered for use in a variety of thermal energy applications, including industrial processes or space heating. Figure 7 illustrates the relative amount and type of waste heat available from a fuel cell powerplant.

POUNDS OF POLLUTANTS PER MILLION BTU HEAT INPUT

	FEDERAL STANDARDS*			
	GAS-FIRED CENTRAL STATION	OIL-FIRED CENTRAL STATION	COAL-FIRED CENTRAL STATION	EXPERIMENTAL FUEL CELLS**
PARTICULATES	0.1	0.1	0.1	0.0000029
NO_X	0.2	0.3	0.7	0.013-0.018
SO_2	NO REQUIREMENT	0.8	1.2	0.000023
SMOKE	20% OPACITY	20% OPACITY	20% OPACITY	NEGLIGIBLE

*FEDERAL STANDARDS EFFECTIVE 8-17-71
**YORK RESEARCH CORP., Y-7309 APRIL 1970

Figure 6 – Environmental Impact

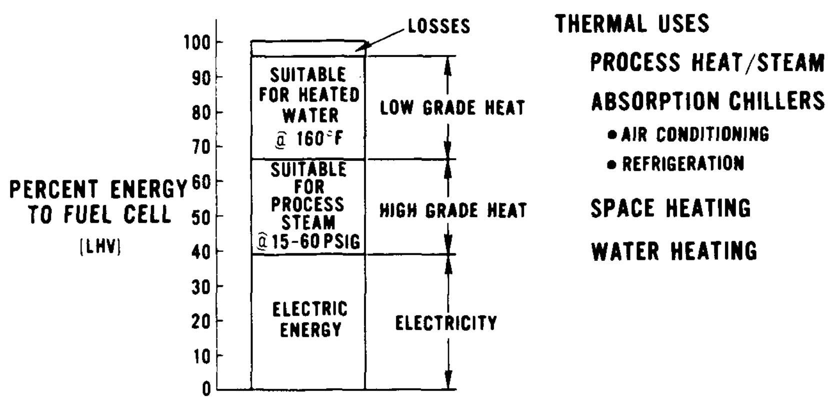


Figure 7 – Waste Heat Recovery Potential

No external source of water is required for cooling of the conversion process. The static nature of the conversion process minimizes noise generated by the fuel cell powerplants. The electrochemical conversion process automatically responds to rapid changes in load demand, and control systems automatically compensate for changes in ambient conditions, permitting automatic, unattended operation. Scheduled and unscheduled maintenance requirements are low in frequency, cost and complexity since the only moving parts are the air and fuel supply systems. Fuel cell powerplants achieve the same high levels of efficiency and the same competitive capital and operating costs for small capacities, as for large capacity, multi-unit fuel cell systems.

From the viewpoint of electric and gas utilities, power generation equipment with these generic characteristics offer several application features which are not presently available from any other single conventional generation device.

III UTILITY FUEL CELL POWERPLANTS

In contrast with conventional generation equipment, fuel cell powerplants offer several unique application features which make them attractive to utility system planners. Technology programs in progress are aimed at the development of commercially viable fuel cell powerplants which can be dispersed within electric utility networks or sited at the ultimate point of electricity demand. Continuation of these planned efforts could lead to the practical use of fuel cells within this decade.

Powerplant Application Features

Commercial fuel cell powerplants will provide gas and electric utility companies with new options for meeting both the growing energy demands and the increasing conservation and environmental constraints that their systems must meet. These expanded options stem primarily from the application features of this new class of generation equipment which are discussed below.

Siting Flexibility (Figure 8) – This application feature results from the environmental and operational characteristics of fuel cell powerplants. Their low exhaust emissions and low noise level permit them to be placed in areas of the utility's system hitherto inaccessible as generation sites because of their proximity to existing or planned residential or commercial areas.

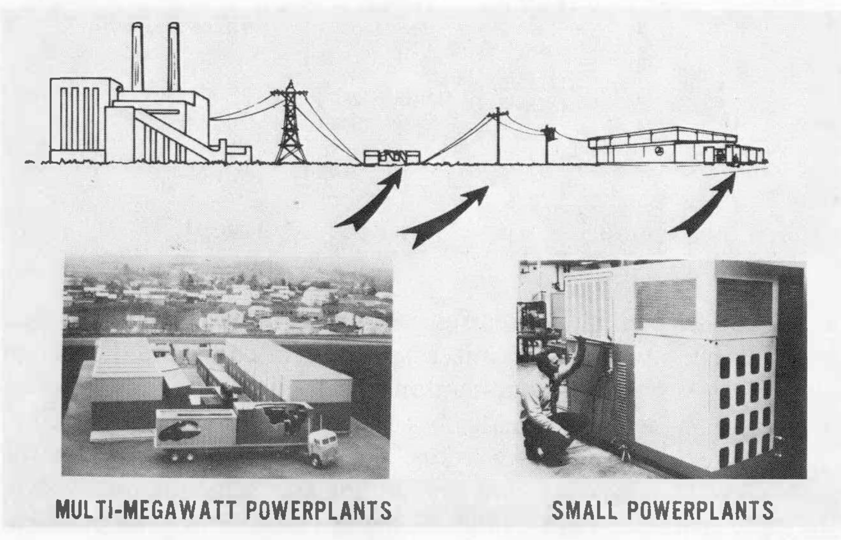


Figure 8 – Siting Flexibility

Since the powerplant does not require an external water supply for cooling or energy processing, siting is not limited by water availability or cooling water thermal restrictions.

The modular construction of large-scale fuel cell powerplants enhances their transportability making available any site which is accessible by conventional transport methods. Small-scale on-site powerplants may be sited within existing buildings or as roof top installations further expanding siting options.

Adaptability to Load Growth (Figure 9) – The modular nature of the fuel cell powerplant results in a highly flexible and effective concept capable of providing generation capacity in phase with growth in the demand for electric power. Power may be added in small blocks at the time and point in the system where it is needed. As the demand for power increases, units may be added in parallel to meet the new requirements. Load paralleling, unit synchronization, and load sharing are accomplished simply and quickly. Because of the short installation lead time, unexpectedly rapid system growth can be effectively met.

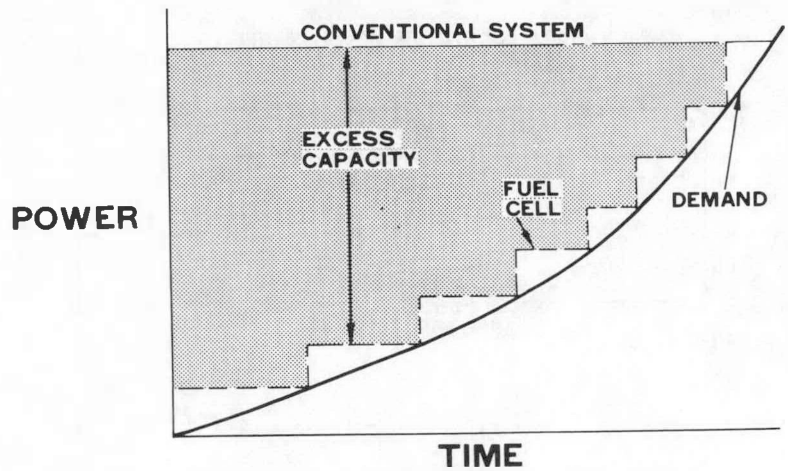


Figure 9 – Matching Load Growth

Duty Cycle Flexibility – Large-scale utility systems presently use a mix in type of generation equipment in providing baseload, intermediate and peaking energy demands. Individual units are dispatched to meet the varying load requirement and are generally operated at full-load whenever possible in order to minimize fuel use. Because of their high efficiency at both rated and part-load and because of their ability to respond automatically and rapidly to load changes, fuel cells are not limited in the manner in which they may be used. Thus they may be dispatched in the conventional manner or used as a load-following device to provide cycling load demands. For small-scale systems such as municipal and rural utilities, which have traditionally relied upon cycling generators to meet their system demands, the fuel cell powerplant would provide a more fuel-effective option.

Potential applications for on-site generation range from industrial site to commercial and multifamily residential buildings, where the loads tend to fluctuate considerably. Unlike conventional small-scale generation devices, fuel cells can be efficiently used in all of these applications.

High Energy Availability (Figure 10) – The high availability of fuel cell powerplant systems stems from three factors: (1) reliable operation, (2) the parallel operation of modular components, and (3) low scheduled maintenance requirements. Because of the high system reliability and low scheduled maintenance requirements, each modular fuel cell component is available for energy production during much of the year. Since powerplant systems are composed of modular subsystems operated in parallel, the unavailability of any one of these subsystems would limit the output capability of the system but would still permit power to be generated. Thus, maintenance and repairs could be performed on a subsystem without requiring the shutdown of the whole system. The results of an experimental test involving three 12.5 MW fuel cell powerplants supplying power to an electric utility substation are illustrated in Figure 10. Over the entire test period, over 95 percent of the system's energy generation capability was available on demand.

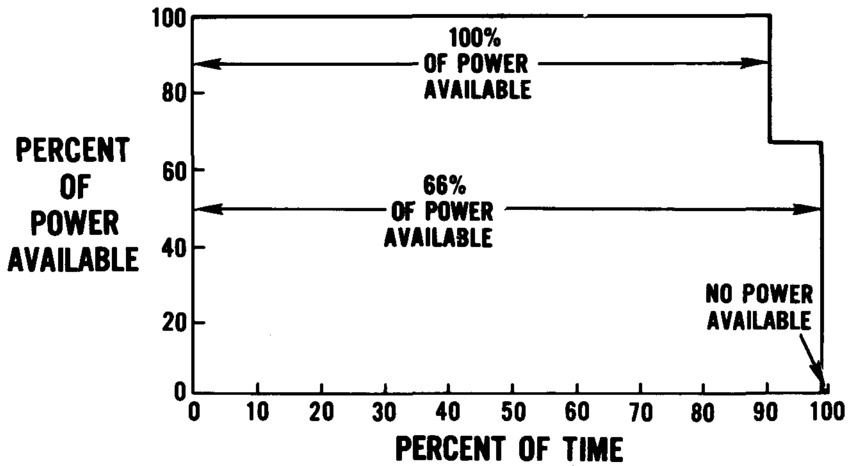


Figure 10 – High Energy Availability

Waste Heat Availability (Figure 11) – Like conventional generation devices, the fuel cell produces waste heat because it is not 100 percent efficient. However, since fuel cells convert energy electrochemically, waste heat can be recovered with no generation efficiency penalty. Because fuel cell powerplants can be located close to the load, this recovered waste heat can be put to practical use.

Of the sensible waste heat produced by the fuel cell powerplant, approximately 40 percent is suitable for high grade heat (process steam at 15 to 60 psig), 50 percent is low grade heat suitable for heated water at 160°F, and 10 percent is lost to the surroundings and therefore unrecoverable. Since waste heat is a byproduct of the energy conversion process, the amount of heat energy available from the fuel cell is in direct proportion to the amount of electricity produced. As illustrated in the office building example in Figure 11, the coincidental occurrence of both the required energy for space heating and the heat energy available from the fuel cell powerplant permits the practical use of waste heat (indicated by the shaded area of the graph). This coincidence of supply and demand can be improved by using the waste heat for other applications such as water heating and air conditioning or through the integration of the fuel cell with a heat pump.

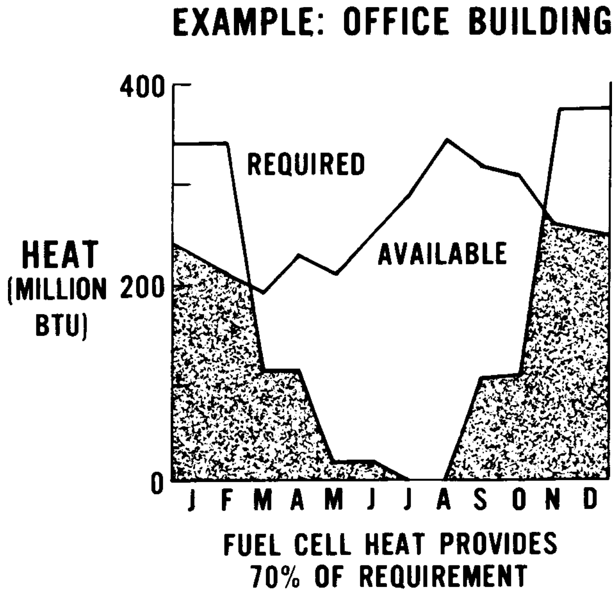


Figure 11 – Practical Use of Waste Heat

Waste heat recovered and used in this manner can serve a wide range of applications including industrial process heat or steam, absorption chillers for air conditioning and refrigeration, and space or water heating in municipal or agricultural (crop drying, feedlots, etc.) areas.

Economic Energy Production – The cost of providing electricity to the ultimate user includes the capital costs associated with owning the electric generation transmission and distribution facilities, the cost of the fuel required to power the generation device, the operating and maintenance costs associated with the facilities, and the cost of the energy lost in transmission and distribution. Compared on the basis of user cost, the fuel cell powerplant offers the potential for energy cost savings in many electric utility applications in comparison with conventional options. In applications where the fuel cell's waste heat can be utilized, additional cost savings can be made possible.

Fuel cell powerplants have an additional feature which will impact on utility problems of the future. With their adaptability to a range of fuels, they compliment future energy supply formats. Central coal processing techniques under development for example, could provide a range of synthetic gases and liquid fuels highly suitable for dispersed or on-site fuel cell powerplants.

Future fuel cell powerplants could also supplement nuclear or solar based energy systems. In one approach to future energy needs, nuclear or solar power, and a more extensive electrical transmission and distribution system, would become the source of bulk power. These systems however, must operate as baseload generators to achieve maximum efficiency and minimum system costs. Fuel cell powerplants operating either as energy storage systems, or a mix of intermediate and peaking plants, could provide an energy efficient and cost-effective means of supplying the necessary supplemental energy.

Because the above application features are relatively independent of the size (capacity) of the powerplant, it provides an attractive option for many sectors of the energy supply industry: large-scale private electric utilities as well as small-scale municipal and rural electric utilities, and gas distribution companies.

Fuel Cell Application Formats

Broadly speaking, early fuel cell application opportunities can be classified into two formats. The first is as a dispersed generator for the electric utilities; i.e., multi-megawatt powerplants placed within an electric utility transmission-distribution system at substation or intertie locations. A second is an on-site converter of fuel to electricity at the load center or point of energy use. Figure 12 illustrates these energy formats.

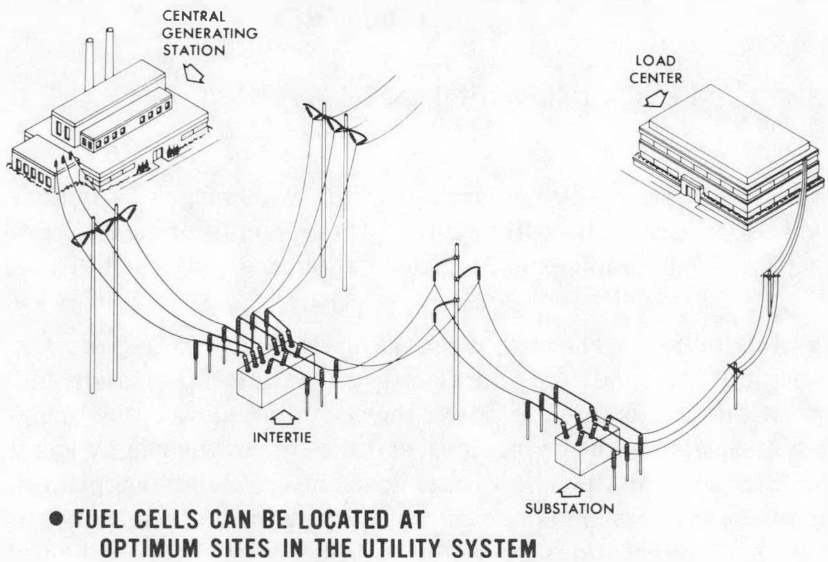


Figure 12 – Fuel Cell Application Formats

The electric utility industry must supply the demand for electric energy in the face of restrictions on air pollution, thermal and water quality pollution, the difficulties of obtaining sites and rights-of-way for powerplants and transmission lines and the increasing cost of investment capital required for transmission, distribution, and generation equipment. The fuel cell powerplant with its utility-oriented application features can be dispersed throughout the electric service area near load centers. Used in this manner, the fuel cell powerplant permits utilities to add capacity in many critical areas within their system, utilize hitherto unavailable site locations and improve the fuel utilization and economic characteristics of the overall system.

An extension of the dispersed generation is an on-site powerplant generating electric power from fuel delivered to the site. Electrical distribution as well as transmission energy losses and costs are eliminated, generating efficiencies are improved, and the maximum benefits realized. Further fuel economy is attained through integration of the fuel cell with a thermal energy supply system. This integrated fuel cell energy system, for example, could use less energy for providing both electrical and thermal needs than a conventional system would use for providing thermal energy only.

Fuel Cell Development Status

Two fuel cell powerplants are presently under development for use as dispersed and on-site generators. The first, a 26-megawatt (26,000 kilowatts) powerplant is being developed for use throughout electric utility systems and it offers the potential for attacking many of the different problems of that industry. A model of this powerplant is shown in Figure 13.

Figure 13 – 26-Megawatt Powerplant Installation

Nine electric utility companies are supporting this development effort and have placed provisional orders for 56 of these powerplants, pending a successful outcome of the development program. The specification goals for this powerplant include:

- Rating 26 MW
- Heat Rate 9300 Btu/kWh @ 26 MW
- Cooling Air (Dry) or Water
- Emissions Below NYC and Federal Stds.
- Noise Acceptable in Residential Area
- Fuels Clean Liquid and Gaseous
- Water Required None

The second powerplant under development is a 40-kilowatt unit designed for on-site power generation in buildings and at industrial locations. The development of this powerplant is being supported by a group of gas utility companies, and a successful program outcome could lead to significant fuel conservation. A photograph of a prototype 40-kW unit is shown in Figure 14.

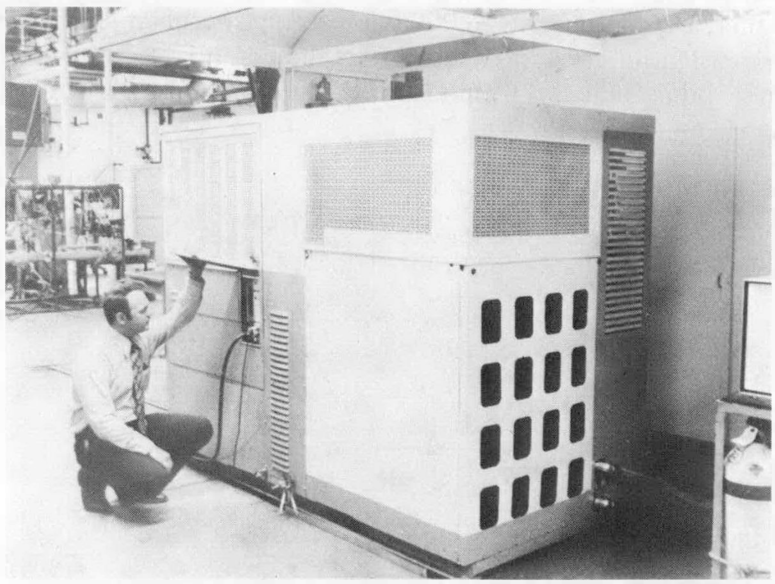


Figure 14 – 40-KW Powerplant Prototype

The goals of the 40-kilowatt powerplant development program include:

- Rating 40 kW
- Efficiency (LHV) 40% (part-load)
- Operating Range 0 - 40 KW
- Power Output 3 Phase
- Water Required None
- Startup Automatic or Semi-Automatic
- Fuel Pipeline Gas

Both of these development programs are now at a critical stage. Commercial fuel cell technology has advanced dramatically, but it is not yet to the point where fuel cells have demonstrated adequate endurance and competitive cost. New forms of construction materials, catalysts and components are being developed to reach the cost goals. In all areas, alternative candidates have been established which could provide the efficiency, cost and life necessary for commercially viable systems. Extensive engineering development and demonstration remains to be done before overall economics, operating reliability and durability are established, however if the planned efforts in these areas are successfully completed, fuel cell powerplants could be commercially available by 1980.

IV FUEL CELL APPLICATIONS WITHIN UTILITY SYSTEMS

Studies conducted by the utilities and UTC as part of present fuel cell development programs have concluded that the fuel cell powerplant's unique application features could provide utilities with new options for meeting their system's growing energy demands. When used in these applications, fuel cell powerplants could provide significant fuel conservation, economic, and environmental benefits.

General

Specific applications which have been identified as attractive early opportunities for dispersed multi-megawatt powerplants include (1) the generation of intermediate and peaking-duty energy (either as intermittent or cycling duty generators), (2) as environmentally compatible options for generating power in critical locations and (3) for generating power in small municipal and rural systems. In addition, the on-site generation application employing fuel cell powerplants in the multi-kilowatt range is an attractive option from the standpoint of fuel and cost savings for a broad range of commercial, residential and industrial energy users. The characteristics of these dispersed and on-site applications and the potential benefits associated with the use of first generation fuel cell powerplants in these applications are discussed in this section. Advanced fuel cell technology leading to the development of second-generation units is part of presently planned development efforts and could result in broader application opportunity as well as improved conservation and cost savings in the future.

Intermittent Duty Generation Within Large-Scale Utilties

The demand for electric power varies on a seasonal, weekly and daily basis as shown in Figure 15. These variations result in the requirement that approximately 40 - 50 percent of the total generating capacity of a utility system (power as measured in kilowatts) be operated throughout the year as "baseload" generation. This generating capacity, usually in the form of nuclear, oil and coat-fired steam, and hydro-electric power plants, provides the system's baseload energy representing approximately 75 percent of the system's total annual energy output (as measured in kilowatt-hours).

The remaining 50-60 percent of the system's power demand (referred to as intermediate and peaking power) is provided by various types of specialized generating equipment. Liquid and gaseous fueled equipment such as gas turbines, combined cycle plants and cycling steam systems as well as pumped storage hydro plants are typically used to generate intermediate and peaking energy (usually representing 25 percent of the utility system's annual energy output). Because of the capability of these types of generators for being easily turned on and off, they can be utilized on an intermittent basis to provide the daily load cycles. Like coal and nuclear plants conventional peaking and intermediate plants also operate most efficiently at rated load and are therefore used in this manner whenever possible.

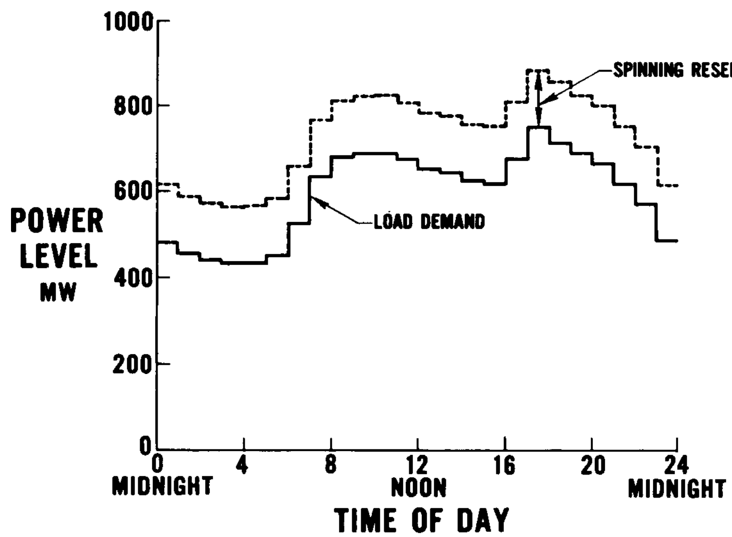


Figure 15 – Typical Daily Load Variation

In order to insure service continuity and provide for practical contingencies such as scheduled maintenance, operating failures and demand forecast errors, all utility systems must maintain a generating reserve margin. This reserve margin normally includes (1) a non-operating or "standby" reserve of generating equipment which can be brought on-line within a few hours and (2) an operating or "spinning" reserve which could be available instantaneously. "Spinning" reserve requirements are typically provided by conventional baseload or intermediate duty equipment operated at less then full load or by pumped storage capacity.

Viewed from the standpoint of the total utility system power supply requirements, the role of baseload, intermediate peaking and reserve generating capacity is illustrated in Figure 16.

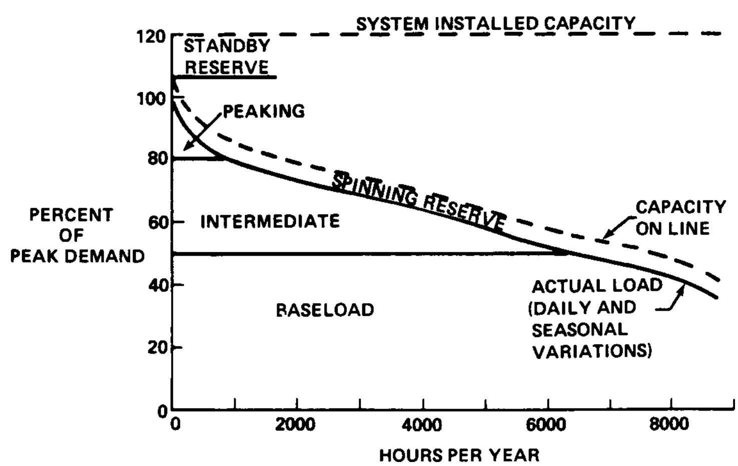


Figure 16 – Utility Power Requirements

The siting flexibility, high energy availability and economic energy production features of fuel cell powerplants make them an attractive option for use as intermittent generators in providing a utility system's intermediate and peaking energy. The siting flexibility feature permits the powerplant to be located close to the load (at the distribution substation for example), eliminating transmission energy losses and resulting in a reduction in transmission system costs and need for transmission system rights-of-way. As discussed in Appendix A1, the reduction in transmission costs associated with intermediate and peaking generation applications can range from about $60/kW to $180/kW (in 1980 dollars). Transmission losses, normally amounting to 5% of the energy generated, can be eliminated.

The fuel cell's high energy availability in comparison with conventional powerplants reduces the need for system reserve generation requirements and leads to both an economic advantage (reduction in capital requirements and energy cost) and the advantage of reducing the siting requirements for this reserve capacity. As discussed in Appendix A2, this represents a capital cost savings of $28/kW (in 1980 dollars).

Because of the fuel cell powerplant's efficiency and other operating characteristics, fuel resource utilization and overall energy costs may be reduced when compared with conventional options for intermittent operation. The assumptions and methodology used in determining these savings are detailed in Appendix A5 and indicate that for every 1000 MW of installed fuel cell capacity used in this manner, up to 966 barrels per day of fuel resources and from $1.7 to $9.5 million per year in energy costs may be saved.

The benign air pollution characteristics of fuel cell powerplants will result in a net reduction in air pollution and a corresponding reduction in pollution-related costs. The savings associated with the reduced pollution from fuel cell powerplants is developed in Appendix A12 based on a comparison with equipment meeting Federal air pollution standards. For every 1000 MW of fuel cells used as intermittent generators, these savings range from $2.0 to $5.3 million per year.

Continuous Duty Cycling Generation in Large-Scale Systems

The preceding section described the utility advantages and fuel and cost savings associated with dispatching fuel cell powerplants in the same manner as conventional equipment (i.e., intermittent operation at full-load). Because of the duty cycle flexibility of fuel cell powerplants, however, they may be used in a slightly different manner for providing peaking and intermediate duty energy and result in even greater conservation benefits.

In this application the fuel cell powerplant is operated continuously at varying load levels to permit maximum overall system efficiency. Operating reserve requirements, often provided by running central station generators at less than full load (operating reserves must be available instantanesouly), could be efficiently provided by the fuel cell, permitting the larger central stations to be operated continuously at their most efficient point as illustrated in Figure 17.

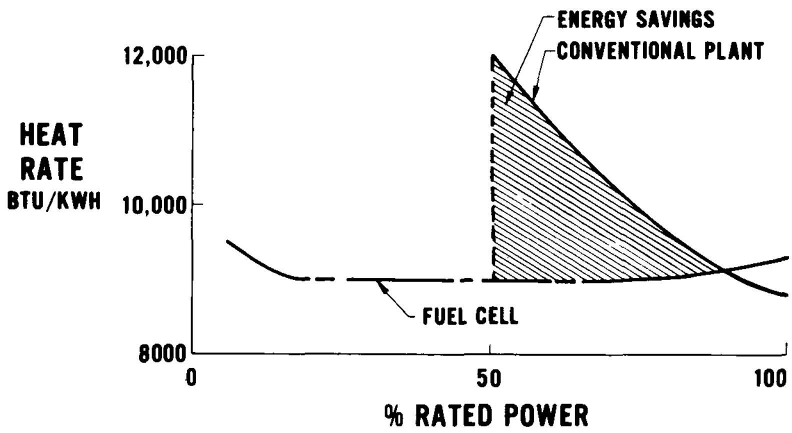


Figure 17 – Fuel Cells Provide Cycling Loads Efficiently

As with the intermittent duty application, the fuel cell offers a reduction in transmission requirements and improves siting option with resulting fuel and cost benefits. Appendix A6 discusses the fuel resource savings which result from both the high fuel cell conversion efficiency and the overall system operating improvements that they make possible. For every 1000 MW of fuel cell powerplants used in the continuous duty cycling mode, fuel resource savings of 5,222 barrels per day could be achieved. Energy cost savings which result from lower capital and fuel costs could amount to $30.8 million per year and reduced air pollution could provide an additional $3.6 million per year savings.

Appendix A13 compares the capital cost of fuel cells with the capital costs of conventional options for providing cycling duty generation. The capital savings offered by fuel cells ranges from $130/kW to $220/kW. Thus for every 1000 MW of installed fuel cell capacity, utility investment requirements could be reduced by at least $130 million.

Replacement of Plants in Environmentally Critical Areas

Considerable liquid and gaseous fueled generating plant capacity exists in areas which are critical from the standpoint of environmental regulations, land availability, and power reliability requirements. These areas, principally in urban locations, require stringent air and water quality standards for generating plants. Limited land availability for siting modern equipment, adding environmental control equipment, or siting electric transmission towers and switchgear equipment to carry remotely generated power, reduces replacement options for these plants. In addition, the potentially severe consequences of power failure in these areas enhances the need for the high system reliability associated with local generating plants. Many of the generating plants located in these areas are now more than thirty years old and exhibit high heat rates (low efficiency), high levels of air and thermal pollution, and high operating costs.

Plants using high-sulfur fuels could be retrofitted with stack gas cleanup and cooling water treatment systems to meet regulations, but penalties of lower efficiency and higher operating costs would result. In may cases even these options are not possible because of the lack of available nearby land. On the other hand, conversion to clean fuels would result in very high fuel costs.

Replacement of these plants on the same site with new liquid fueled generating plants having improved heat rates would entail substantial increase in capital investment and would result in higher consumer energy costs. Replacement with coal-burning equipment would not be possible because of the vast siting area requirements associated with coal handling, storage, and exhaust gas cleanup.

Eliminating these outdated plants and bringing power into these areas via underground electricity transmission lines (where right-of-way availability makes this possible) would also impose a very high financial burden on consumers due to the high cost of underground transmission

Because of its siting flexibility, economic energy production and duty cycle flexibility, the fuel cell would offer a new option to utilities facing the dilemma of supplying these areas with sufficient reliable electric energy while meeting stringent environmental standards. Replacing critical urban generating plants with fuel cells would provide an environmentally sound option for these utilities and, at the same time, permit a considerable savings of fuel resources and reduction in operating costs as discussed in Appendix A7. For every 1000 MW of fuel cell used in this manner, fuel resource savings of 11,050 barrels per day and energy cost savings of $28 million per year could be achieved. In comparison with plants meeting Federal air pollution standards, fuel cells offer an additional savings of $3.9 million per year due to reduced air pollution damage.

Municipal and Rural Generation

A municipal utility provides electric power for a small city. Rural utility systems, generally cooperative companies, are responsible for supplying electric power to large areas characterized by very low population and therefore low power density. In both cases, system power demands are low in comparison with the larger-scale utility companies discussed in the preceding paragraphs. Thus, municipal and rural systems combine all of the requirements of large utility systems, but at much lower system capacity levels.

At present, municipal and rural systems purchase approximately 60 percent of their energy needs from the larger private utility companies and generate the remaining 40 percent with their own equipment. One of the major reasons for this tendancy for municipals and rurals to purchase a high percentage of energy is that the larger utilities benefit from an economy of scale (lower capital costs and higher efficiencies) due to utilization of large capacity equipment and can produce and sell energy at a lower cost. Because of the smaller system size of municipal and rural utilities, the equipment that is used to produce the self-generated portion of this energy is used in an all-purpose manner including baseload, intermediate load-following, and peaking duty cycles. Small steam plants or diesel-generators are generally used in these systems with high energy costs resulting from utilization at other than optimum operating points. Even with conventional equipment, the large utility systems can operate at higher efficiencies due to the overall system equipment diversity.

Because of their small generating capacity requirement and equipment availability, rural and municipal systems often must install conventional equipment in large increments which cannot be fully utilized until a future period. This contributes further towards high energy costs due to low efficiency operation and low capacity factor. In addition, municipal and rural systems tend to have a higher level of reserve margin than larger utilities.

The fuel cell's duty-cycle flexibility, high energy availability, adaptability to load growth, and economic energy production features provide small municipal and rural utilities with both a new option for production of that part of their system energy needs that are traditionally met by self-generation, as well as the potential for producing electricity within their own system at a cost that is competitive with energy purchased from larger systems. Since the fuel cell's features are independent of size, the high efficiency and favorable cost characteristic which make it attractive to the large-scale utilities also benefit the smaller utility system.

Municipal and rural systems, which tend to have a higher level of reserve margin than larger utilities, benefit greatly by the fuel cell's high energy availability. In addition, these reserve requirements can be substantially reduced at no penalty to system reliability. This can result in decreased investment requirements and further improvements in energy cost.

Appendix A8 discusses the fuel resource and energy cost savings associated with using fuel cell powerplants for municipal and rural generation. For each 1000 MW used in this manner, savings of 4,235 barrels per day of fuel resources and $16.6 million per year in energy cost could be achieved. As described in Appendix A12, the reduction in air pollution costs associated with using 1000 MW of fuel cells in this application could provide an additonal $5.8 million per year savings.

Generation with Waste Heat Utilization

A major portion of the United States energy resources are utilized to provide the thermal energy requirements of all segments of society. In addition, the energy resources which provide this need are primarily liquid and gaseous fuels with an extensive, existing distribution system. Conservation efforts aimed at reduction in the use of these fuels have taken the form of:

- Conservation at the point of use
- Replacement of liquid and gaseous fuels with coal
- Replacement of liquid and gaseous fuels with electricity

All of these steps have been successful to some extent, however, the number of applications that can convert to direct use of coal are limited, and the use of electricity reduces the overall efficiency of energy supply significantly since the waste heat associated with the generation process generally cannot be used.

The concept of electrical generation close to both the electrical and thermal load (where the waste heat from the generation process can be used) is attractive. The favorable waste heat characteristics of the fuel cell powerplant coupled with its siting flexibility allow the consideration of many integrated electrical/thermal energy supply concepts. Some of these concepts include:

- Integrated utility service for urban and suburban areas to supply thermal energy for space and water heating and absorption cooling purposes.
- Integrated service at industrial sites to supply thermal energy for process heat/ steam needs as well as space and hot water heating requirements.
- Integrated service in agricultural areas to provide thermal energy for crop drying or processing.
- Use of thermal energy to repower existing steam turbines to produce additional electric energy.

The use of integrated fuel cell service can provide significant resource conservation as indicated in Appendix A9. When fuel cell thermal energy applications are compared with conventional thermal supply system efficiencies the amount of fuel resource savings associated with the utilization of fuel cell waste heat is 1330 barrels per day of oil equivalent per 10^9 kWh generated.

On-Site Integrated Energy Systems

Fuel cell powerplants dispersed throughout a service area, rather than sited in central locations, have been discussed in previous sections. It has been shown that use of the fuel cell in this manner can conserve fuel and provide new and important degrees of flexibility with favorable impact on transmission needs, siting ease, and system reliability and security. As the fuel cell is brought closer to the point of electrical use, electrical transmission and distribution losses and costs are eliminated and much of the heat normally wasted is available to meet the thermal needs of the building application.

On-site application of fuel cell energy systems combines all the advantageous features of fuel cells. The siting flexibility of the fuel cell allows consideration of location at the building site. The modularity of the fuel cell allows a close match between building requirements and the powerplant size. Its duty cycle flexibility allows the variation in building requirements to be met. The fuel cell also has the high energy availability characteristic required for on-site duty. The relatively simple recovery of waste heat from the fuel cell allows the heat to be used for space and water heating, air conditioning or other building uses. In addition, on-site location of the fuel cell allows further equipment integration (i.e., with an electric heat pump), optimizing energy system efficiency.

On-site fuel cell systems can have many variations depending on such factors as building type, geographic location, and thermal and electrical energy requirements. In all applications energy resource savings are realized. Savings tend to be large in applications where integration with other energy supply equipment can be accomplished. A fuel cell system representative of many applications is a multi-family residential complex in a northern location. In this case, the electrical energy requirements of the complex are supplied by the fuel cell and the thermal energy requirements are supplied by a combination of waste heat from the fuel cell and the output of an electric heat pump. This fuel cell system configuration results in the energy requirements of the complex being satisfied with less than one-half of the energy resources previously required. In addition, the fuel cell system can accomplish this energy resource savings in an economical manner.

The specific resource and economic savings with on-site generation are detailed in Appendix A10. For each 1000 MW of installed fuel cell capacity, fuel resource savings of 42,158 barrels per day and energy cost savings of $17.5 million per year may be achieved. As indicated in Appendix A12, an additional savings of $6.4 million per year results from the fuel cell's lower air pollution levels.

International Applications

The U.S., with about 6 percent of the world's population, consumes over 30 percent of the electricity generated in the world. The sense of urgency created in the U.S. by the dichotomy of high energy usage on the one hand and rising energy cost, increased pollution and dwindling natural resources on the other hand is largely responsible for the present interest in fuel cell powerplants. Other developed countries of the world comprise 22 percent of the world's population and consume almost 60 percent of the electricity generated in the world. For many of these countries the energy dilemma is more urgent than it is in the U.S. Dispersed fuel cell applications such as those described in the preceding sections of this report, could have a major impact on the energy problems of these countries.

The developing nations of the world include the majority of the world's population, over 70 percent. Transformation of the economies of these countries into the industrial-agricultural structures of the developed nations is somewhat dependent on their capacity to generate and use electrical energy. Since their per capita GNP is about one-tenth that of developed countries, any solution aimed at economic development must be both capital and cost efficient.

Several other characteristics however, which are relatively common to developing countries detract from the capital and cost effectiveness of using conventional methods. For example, the scattering of population into widely dispersed villages or village clusters means that the average capital requirement for transmitting and distributing electricity from a central generating plant to a given population size is much greater than for developed countries.

The alternative of using conventional internal combustion engine-driven systems for on-site generation (thereby eliminating the transmission system requirements) also has a number of disadvantages:

- The specific cost of the generating equipment is higher because of the smaller unit size.

- Redundant units and accompanying higher costs would be required to achieve satisfactory reliability.

- The fuel efficiencies are much lower than those of larger central plants, thus raising fuel costs.

- A greater number of skilled personnel would be required to maintain on-site generating equipment.

In addition, the load growth characteristics of developing areas typically feature very low initial load requirements accompanied by a high growth rate. Since conventional on-site systems can be incrementally expanded only at the substantial expense of adding the necessary synchronizing equipment, the systems are generally designed for considerable excess capacity in the early years to provide for load growth. This places an additional strain on an already capital-poor economy.

The availability of commercially viable fuel cells for developing countries would permit the elimination of many of the problems now associated with using conventional equipment for on-site generation. For example, on-site fuel cell powerplants would offer the following advantages:

- Modular construction providing low capital cost and high performance essentially independent of scale.

- Can be easily paralleled and thus match load growth on a step-by-step basis permitting efficient use of capital.

- Unattended operation.

- Simplicity of fuel cell systems means high reliability and minimal maintenance which can be performed by semi-skilled personnel.

- Efficient use of both liquid and gaseous fuel resources.

- Reduction in capital costs associated with electric transmission and distribution.

On-site fuel cell powerplants with these characteristics could play a major role in establishing the capacity for generating and using electricity in developing countries. Later, as electrical loads become established, dispersed generators could be substituted for groups of on-site systems and offer additional economies associated with greater electrical diversity.

The need for electric energy is basic both to maintaining the growth rate of economically advanced countries and to expanding the economies and standard of living of developing countries. The emergence of fuel cell technology into commercially viable energy conversion systems would produce a significant impact on the economic and environmental consequences of supplying these energy requirements.

Other Applications

In addition to the applications discussed in the preceding sections, several other opportunities are being investigated but the benefits have not been included in this analysis. For example, second generation fuel cell powerplants may be thermally integrated with coal-based fuel processing systems to provide a highly efficient conversion system. Preliminary studies indicate that such a system, incorporating a steam turbine bottoming cycle, could convert solid coal to electricity at an overall efficiency of 50%.

Another possibility is a heating system based on coupling the fuel cell powerplant with the heat pump. Essentially a variation of the integrated energy system described earlier, the fuel cell heating system would provide only thermal energy. Applied to a commercial or industrial heating application, this system could provide the same thermal output as a conventional furnace with only one-half of the fuel input requirement.

A third additional application of fuel cell powerplants would involve the integration with other utility services to provide the electrical energy, environmental conditioning and other related requirements to residential or industrial complexes. Integration with waste treatment facilities would produce a synthetic fuel which could be used in the powerplant to generate electricity. Thermal byproduct energy could be used for environmental conditioning in the form of space heating or air conditioning and for water or process heat. Such an integrated utility system offers the promise for further improvements in economics and energy conservation.

V. NATIONAL IMPACT OF FUEL CELL APPLICATION BENEFITS

The commercial application of fuel cell powerplants during the 1980 to 1990 time period could provide a total fuel savings of from 0.4 to 1.0 million barrels per day by 1985 to between 0.8 and 1.9 million barrels per day by 1990. The present value of estimated energy cost savings for the period ranges between $2.3 and $10.5 billion. Other benefits include pollution cost reduction, capital investment reduction and improvement in balance-of-payments.

Fuel Cell Deployment Estimate

The national impact of fuel and cost savings associated with fuel cell deployment is primarily dependent on two factors: (1) the level of savings for each of the various potential applications and (2) the degree to which each application is utilized. The methodology used in determining national impact in this section of the report will therefore be to develop a range of estimates for fuel cell applications associated with all fuel cell manufacturers during the period 1980 to 1990, and then apply the per-unit benefits discussed in the preceding section to these application scenarios. National fuel and cost savings will thus be expressed as a range of values.

Appendix B develops an estimate of the market for liquid and gaseous fueled electric generation equipment based on three possible annual capacity and energy growth rates: 5.0%, 6.0% and 6.7%. For the two major utility segments, these market estimates are summarized below:

MARKET FOR LIQUID AND GASEOUS FUELED CAPACITY ADDITIONS
1000's MW

	1980 to 1985	1985 to 1990	Total 1980 to 1990
Private Utilities			
5.0% Growth	61.6	81.2	142.8
6.0% Growth	81.6	113.1	194.7
6.7% Growth	97.6	138.6	236.2
Municipal & Rural Utilities			
5.0% Growth	6.4	8.2	14.6
6.0% Growth	8.2	11.2	19.4
6.7% Growth	9.6	13.4	23.0

Within the private utility sector, new capacity additions for liquid and gaseous fueled equipment will be used for providing intermediate and peaking energy. While the fuel cell powerplant may be used as either an intermittent or cycling duty system, the greater fuel and cost savings associated with the latter will favor its use in that mode. A nominal penetration of 25% of the intermediate and peaking market has been assumed (25% of additions to liquid and gaseous fueled capacity).

In addition to the requirement for new additions to generating capacity, the utility industry must replace units which are retired either due to economic or technological obsolescence. Past trends indicate that the annual retirement rate is approximately 0.5 percent of installed capacity. For the 1980 to 1990 period, this represents a total retirement of 44,000 MW.

Studies have been conducted which indicate that 28,000 MW of retirement generating capacity is located in areas where environmental and transmission constraints are critical. In assessing the market for fuel cells, it has been assumed that 100 percent of this capacity would be replaced by fuel cell powerplants. This is equivalent to a 64% penetration of the replacement market for the 1980 to 1990 period. Because of the high conservation and economic benefits attainable, it was further assumed that the 28,000 MW would be replaced by 1985.

Within the municipal and rural utility sector, the fuel cell is assumed to nominally penetrate 50% of liquid and gaseous fueled capacity additions on the basis of the high fuel and cost savings associated with its deployment.

Fuel cell powerplants providing power for the municipal applications and the plant retirements in urban areas will likely be located in areas which would permit the utilization of waste heat for industrial processes and district heating and cooling. (Municipal generation represents 70% of the energy of the municipal and rural segments). It has therefore been been assumed that nominally 50% of these applications will be used in conjunction with waste heat utilization.

The most attractive market application for on-site, integrated energy systems from the standpoint of fuel conservation and cost savings is in commercial and apartment buildings. While the potential exists for utilization in both new buildings and existing buildings, only the former will be considered in this study.

The potential market for on-site integrated energy systems is shown in the table below:

POTENTIAL MARKET FOR ON-SITE GENERATION

	Commercial and Apartment Building Additions, 1,000 MW Equivalent		
	1980 - 1985	1985 - 1990	Total 1980 - 1990
Commercial Buildings	18	28	46
Apartment Buildings	17	19	36
Total U.S. Addition	35	47	82

Of this total potential market for capacity additions, the fuel cell integrated energy system is assumed to penetrate nominally 20%.

Figure 18 compares the nominal fuel cell market penetration estimates discussed in the preceding paragraphs with the total market for new generating capacity during the 1980 to 1990 period. The fuel cell market represents 19% of the total market for new generating capacity.

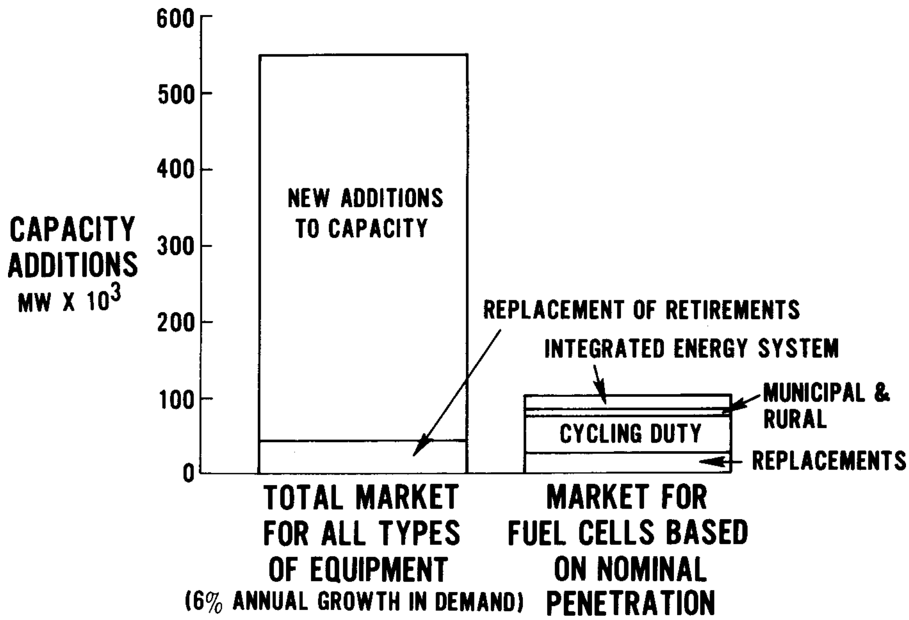
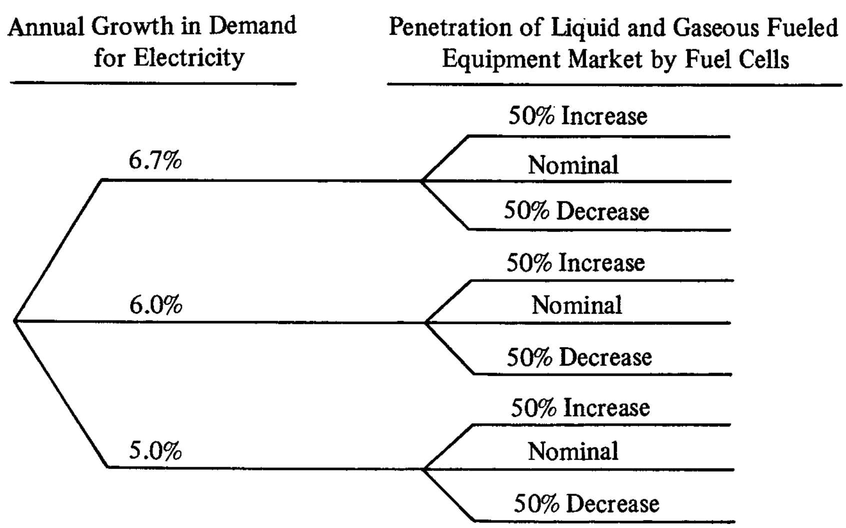


Figure 18 – Nominal Fuel Cell Market for 1980 – 1990

Because of the uncertainity associated with both the growth rate in demand for electricity and the penetration of fuel cells into the market for liquid and gaseous fueled generation equipment, both of these parameters were treated as part of a decision-tree network as shown below. Variations of ±50% around the nominal market penetration estimates were considered.



In order to analyze the full range of impact potential associated with fuel cell applications, three bracketing cases were defined on the basis of the above decision-tree. These three cases, outlined below, represent the full spectrum of fuel cell deployment potential:

Market Scenario	Annual Growth In Electricity	Fuel Cell, Penetration
Case I	6.7%	50% greater than nominal
Case II	6.0%	Nominal
Case III	5.0%	50% less than nominal

The range of fuel cell application estimates resulting from the preceding assumptions and the three market scenarios are summarized in the table below.

Fuel Cell Application	Additions to Capacity, 1000's MW					
	1980 - 1985			1985 - 1990		
	Case I	Case II	Case III	Case I	Case II	Case III
Private Utilities						
Cycling Duty	36.6	20.4	7.7	52.0	28.3	10.2
Replacement	28.0	28.0	14.0	0	0	14.0
Municipal & Rural Utilities	7.2	4.1	1.6	10.1	5.6	2.1
On-Site Integrated Energy Systems	10.5	7.0	3.5	14.1	9.4	4.7
Total Fuel Cell	82.3	59.5	26.8	76.2	43.3	31.0

In comparison with the total market for new generating capacity, the preceding fuel cell capacity additions for the 1980 to 1990 period represent a share of from 14% (Case III) to 25% (Case I). Viewing Cases I, II, and III from the standpoint of cumulative installed fuel cell capacity, the three scenarios represent 14%, 10% and 7% of total U. S. capacity respectively by 1990.

Fuel Conservation Impact

Applying the per-unit fuel conservation benefits for each application discussed in Section IV to the three market scenarios, results in the fuel savings shown in the table below and in Figure 1 of Section I.

Fuel Cell Application	Fuel Savings, Millions of Barrels per Day					
	1985			1990		
	Case I	Case II	Case III	Case I	Case II	Case III
Private Utilities						
Cycling Duty	0.190	0.106	0.040	0.401	0.253	0.093
Replacement	0.312	0.312	0.156	0.312	0.312	0.312
Municipal and Rural Utilities	0.031	0.017	0.007	0.074	0.041	0.016
Waste Heat Utilization in Municipal and Urban areas	0.052	0.047	0.023	0.068	0.056	0.047
On-Site Integrated Energy System	0.433	0.289	0.144	1.015	0.677	0.339
Total Fuel Cell	1.018	0.771	0.370	1.870	1.339	0.807

Energy Cost Savings

Applying the per-unit cost savings for each application discussed in Section IV to the three market scenarios results in the cost savings shown in the table below:

Application	Energy Cost Savings, Billions of Dollars 1980 - 1990 Case I	Case II	Case III
Private Utility			
Cycling Duty	14.4	8.0	3.0
Replacement	6.7	6.7	4.5
Municipal and Rural Utilities	1.5	0.9	0.3
On-Site Integrated Energy Systems	11.1	7.3	3.7
Total	33.7	22.5	11.5

The energy cost savings shown in the table above is based on a linear buildup of capacity and results in a total potential savings from 1980 to 1990 of from $11.5 billion to $33.7 billion (stated in 1980 Dollars). However, because of the time-value of money, the value of these savings in terms of 1976 dollars will be less than this.

Assuming a 4.5% inflation rate from 1976 to 1980 and a discount rate of from 10% to 15%, the present value of these energy cost savings (derived in Appendix A11) is from $2.3 billion to $10.5 billion as shown in the table below. Note that this is the present value in 1976 dollars of energy cost savings only and does not include other benefits such as pollution damage cost reduction and capital cost reductions discussed in the next paragraphs of this section.

Deployment Scenario	Present Value of Energy Cost Savings for the 1980-1990 Period, Billions of Dollars 10% Discount Rate	15% Discount Rate
Case I	10.5	6.8
Case II	7.2	4.7
Case III	3.5	2.3

The cost of attaining the above benefits is determined by the magnitude of the effort required to develop commercial fuel cell powerplants. Figure 19 illustrates the relationship between benefit and cost for a range of fuel cell development program costs. For example, a nominal program cost of $250 million (in 1976 dollars) would result in a benefit-to-cost ratio of from 9 to 42.

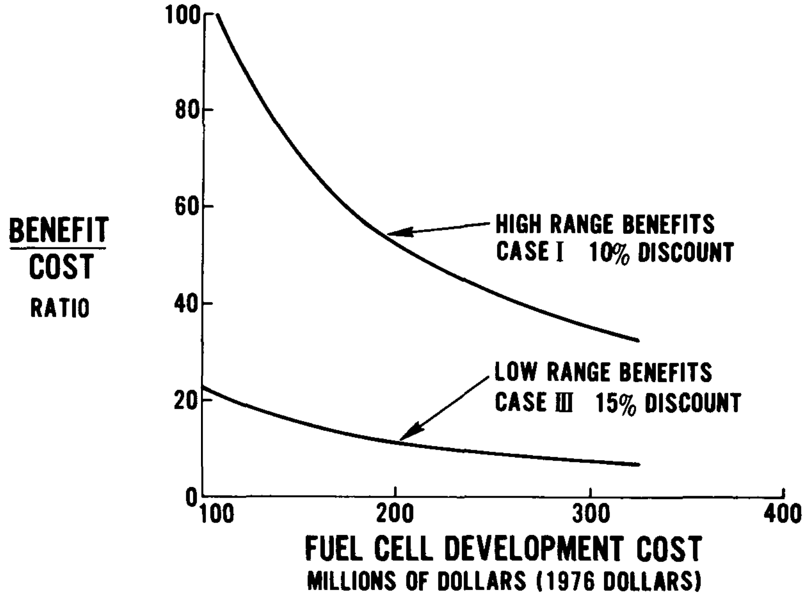


Figure 19 – Benefit-to-Cost Ratio of Fuel Cell Development

Pollution Damage Cost Reduction

The additional economic benefits associated with reduced pollution levels for fuel cell powerplants are summarized for each application in Section IV. In the context of the three deployment scenarios, these cost savings for the year 1990 range from about $250 to $680 million per year as summarized in the table below:

Application	Pollution Damage Cost Reduction, $Millions/Year		
	Case I	Case II	Case III
Private Utility Generation	429	286	175
Public & Cooperative Municipal and Rural Generation	101	56	21
On-Site Generation	154	103	51
Total	684	445	247

Capital Cost Reduction

Both the gas and electric utility industries are concerned with increasing capital requirements. The fuel cell with its lower capital cost can make a significant contribution towards easing these requirements for all of the applications discussed in Section IV. The following example quantifies this benefit for the cycling duty application only.

As discussed in Section IV, the capital cost savings associated with the cycling duty fuel cell application is between $130/kW and $220/kW. Based on the lower value of savings and the 1990 installed capacity for this application, the total capital cost savings are shown in the table below:

	Capital Cost Savings, Billions of Dollars
Case I	$11.52
Case II	6.33
Case III	2.33

These savings represent the reduction in the amount of generation and transmission equipment which utilities must purchase for the period 1980 - 1990 as a result of using fuel cell powerplants in the continuous duty cycling mode.

Balance of Payments Reduction

The problems of fuel scarcity and high energy cost are international in scope. This situation, coupled with a rising world-wide concern for environmental quality, points to a significant international market for fuel cell powerplants. The U.S. presently maintains a leadership position in the development of fuel cells. The early availability of a commercially viable fuel cell would place the U.S. in a dominant position for the export of finished products or technology. Also, use of fuel cells to save gas and oil will reduce the amount of fuel that must be imported into this country beginning in 1980. The overall effect of exports of fuel cell powerplants combined with reduced oil imports will be an improvement in this country's balance-of-payments.

In 1971, the U.S. trade balance was negative for the first time in the twentieth century. This was largely a result of a slight decrease in manufactured goods exported and a large increase in the cost of oil imported. Since the early seventies, a positive balance of trade has been maintained by an increase of manufactured goods to developing countries and a large increase in agricultural exports. Since agricultural exports and oil imports are expected to balance in the future, the sales of manufactured goods will be the deciding factor in the U.S. balance of payments.

The domestic oil savings resulting from using efficient fuel cells will have significant impact on reducing oil imports. If all of the fuel saved by using fuel cells were applied to reducing foreign oil imports, a decrease of from 4 to 10 billion dollars would result as outlined below:

	Case I	Case II	Case III
Total 1990 Fuel Savings, 10^6 B/D	1.870	1.339	0.807
Potential Import Reductions, $ X 10^6 (1)	$9,952	$7,126	$4,295

(1) Based on $\$2.43/10^6$ BTU crude oil cost from A. D. Little Study; $14.58 per barrel.

In addition, the foreign market for fuel cells in both developing and developed countries could represent a significant portion of the U.S. exported manufactured goods. The table below provides an estimate of the foreign market for electric generation equipment in 1990 corresponding to a U.S. growth rate of 6%. Developing and developed countries are treated separately because of the vastly different growth rates associated with each.

Market Type	Annual Growth Rate	1990 Additions to Capacity, 1000's MW
Developed Non-Communist Countries	6%/Yr.	78.9
Developing Non-Communist Countries	9%/Yr.	41.5
		120.4

In comparison with the annual U.S. market for generation equipment in 1990 (6% growth case) the foreign market is greater by a factor of approximately 2.0.

Conservatively assuming the foreign market for fuel cells to be the same as the domestic market would result in the 1990 export market shown in the table below:

	Case I	Case II	Case III
1990 Fuel Cell Export Market, 1000's MW	13.85	7.87	5.64
1990 Export Market, $ Millions	$3,047	$1,731	$1,241

(Based on $220/KW selling price)

The combined effect of fuel import reduction and product export increase establishes the impact on U.S. balance of payments. This impact, outlined below, results in an improvement of from $7 billion to $17 billion for 1990.

	Case I	Case II	Case III
Fuel Import Reduction, $ Billions	$13.85	$7.87	$5.64
Increase in Product Exports, $ Billions	3.05	1.73	1.24
Total Impact on Balance of payments, $ Billions	$16.90	$9.60	$6.88

APPENDIX A – ASSUMPTIONS AND CALCULATIONS

1. Transmission System Costs

The capital investment in electric transmission facilities is determined by transmission voltage levels, transmission distances, rights-of-way costs and installation difficulty (largely a function of terrain). These costs in the U. S. vary from about $65 per KW of installed generating capacity to over $260 per KW of generating capacity. Using fuel cells in those new applications offering the most advantageous cost saving would result in a reduction in transmission capital of $97 to $194 per KW (1980 dollars) system installed capacity.

Baseload, intermediate and peaking generating equipment typically represents 50%, 30% and 20% of installed system generating capacity respectively. A weighted average transmission cost associated with each type of generating equipment would be:

Equipment Duty Cycle	High Range Transmission Cost, $/KW of Equipment	Low Range Transmission Cost, $/KW Equipment
Baseload	228	114
Intermediate	180	89
Peaking	130	64
Weighted Average System	194	97

Energy losses resulting from electricity transmission are approximately 5% of generation.

2. System Generating Reserve Costs

Large-scale private utility generation systems require reserve generating capacity to provide for the following contingencies:

- Daily and annual load factor forecasting error
- Scheduled maintenance
- Backup for unit failure in operation or startup
- Regulation of voltage and frequency

While U. S. reserve capacity is presently about 36%, it is felt that by 1980 an optimum reserve level of 20% will be reached and will adequately provide the necessary reserve requirements. This means that to each kilowatt of generating capacity added to meet load demand, 0.2 KW of reserve capacity must be added. If this reserve capacity is added as the lowest cost alternative (gas turbines at $140/KW in 1980 dollars), the added cost of this reserve is $28/KW.

Public utility systems tend to have a higher reserve capacity requirement. A conservative estimate would place the requirement for these systems at 25% of system capacity.

Because of the high energy availability of fuel cell powerplants, minimal reserve capacity will be required for fuel cell installed capacity. The following table compares fuel cell unabailability with fossil and nuclear plants.

	$\frac{\text{Hours Unavailable}}{8760} \times 100$
Fuel Cell	4%
Fossil Plants*	
200-389 MW	14%
600 MW and above	27%
Nuclear *	21%

* Source: "Electrical Generating Plant Availability", Federal Power Commission Bureau of Power Staff Report, May 1975

3. Characteristics of Electric Generation Equipment

The table below defines the economic and efficiency characteristics of alternative electric generation equipment assumed to be available for the applications discussed in Section IV for the 1980 to 1990 time period. These characteristics are essentially consensus values developed in conjunction with utility industry representatives. Fuel cell characteristics are based on first generation technology. Costs are expressed in terms of 1980 dollars.

Equipment	Generating Equipment Installed Cost, $/KW	Full Load Heat Rate, BTU/KWH	O & M Cost, Mills/KWH	Fuel Type	Fuel Cost,(1) $/10^6 BTU
Large-Scale Intermediate and Peaking					
Simple Cycle Gas Turbine	140	10,000	1.50	Low Sulphur Distillate	3.36
Cycling Steam	280	10,500	1.30	Residual Oil	2.73
Combined Cycle	250	8,500	2.00	Low Sulphur Distillate	3.36
Fuel Cell	250-350	9,300	1.40 - 2.10	Light Distillate	3.55
Large-Scale Baseload					
Nuclear	700	10,300	1.35	Nuclear	0.30
Coal	600	9,500	1.80	Coal	1.76
Residual Oil	400	9,000	0.90	Residual Oil	2.73
Small-Scale Generation					
Cycling Steam	400	10,500(2)	1.90	Residual Oil	2.73
Diesel	225	10,500(2)	4.00	Low Sulphur Distillate	3.36
Fuel Cell	250-350	8,700(2)	3.00	Light Distillate	3.46

(1) Fuel costs are from "Assessment of Fuels for Power Generation in Electric Utility Fuel Cells", A. D. Little, Inc., EPRI 381 Final Report, October 1975. Values used were an arithmetic average of the four regions studied. Fuel cell cost includes $0.09/10^6 BTU for transport to a dispersed location and storage (intermediate and peaking application).

(2) Part-load heat rates.

4. Definition of Energy Costs

Annual capital costs for each piece of equipment are calculated by applying a financial factor of 17% to the generating, transmission and reserve capital costs associated with each. Allowance is made for the fact that where transmission energy losses are involved, 5% additional generating capacity will be required. The 17% annual capital charge factor results from the following assumptions:

Depreciation	Straight Line
Debt/Equity	0.5
Interest on Debt	7%
Return on Equity	12%
Income Tax Rate	50%
Fixed Expense Rate	2%
Economic Life	20 Years

Fuel costs include both generation losses and 5% transmission losses for equipment not sited near the substation.

The equation below defines the total cost of energy at the substation including all capital, fuel and operating charges.

$$\frac{¢}{\text{KW-HR}} = \text{CAPITAL} + \text{FUEL} + \text{OPERATIONS AND MAINTENANCE}$$

$$\frac{¢}{\text{KW-HR}} = \underbrace{\frac{(\$/\text{KW}) \times \text{A.C.C.}}{(\text{HRS/YR})\ \text{op}}}_{\substack{\text{Generation Cost} \\ \text{Transmission Cost} \\ \text{Allocation for Reserve} \\ \text{Financial Factors}}} + \underbrace{\text{FUEL COST} \times \text{H.R.}}_{\substack{\text{Fuel Price} \\ \text{Line Losses} \\ \text{Heat Rate}}} + \underbrace{\text{O \& M COSTS}}_{\substack{\text{Scheduled Maintenance} \\ \text{Operation Expense} \\ \text{Overhaul Cost}}}$$

5. Comparison of Fuel Cells and Conventional Equipment for Intermittent Duty Application

Fuel cell powerplants used in this application would be competing with conventional liquid and gaseous fueled equipment for provision of peaking, intermediate or baseload energy. The table below summarizes the annual cost components for the two duty classifications in which the fuel cell provides the greatest advantage. The fuel cell is compared with only the lowest cost option in each case.

	Annual Costs (1980 Dollars), $/KW/Yr.				
	Capital Cost				
	Generation	Transmission	O&M	Fuel	Total
Peaking (1500 hrs/yr)					
Simple Cycle Gas Turbine	29.8	10.9-22.1	2.3	52.9	95.8-107.1
Fuel Cell	42.5-59.5	0	2.1	49.5	94.1-111.5
Intermediate (4000 hrs/yr)					
Combined Cycle	49.5	15.1-30.6	8.0	119.9	192.4-208.0
Fuel Cell	42.4-59.5	0	10.1	132	181.2-202.6

In determining the energy cost savings summarized in Section IV, the lower range of transmission costs were assumed for the conventional systems and an installed cost of $250/kW was assumed for the fuel cell.

Fuel savings were based on a comparison of the full-load heat rates. To account for the processing and transport losses associated with converting resources to primary fuels, a conversion efficiency of 85% was assumed. A factor of 6 million BTU's per barrel of oil equivalent was used to convert heating value to barrels per day.

Using 1000 MW of fuel cells to provide peaking and intermediate energy in this manner would provide the following cost and fuel savings:

Fuel Resource Savings	up to 966 barrels per day
Cost Savings	$1.7 to 9.5 million/year

6. Fuel Cells in Continuous Duty Cycling Applications

Because of the vagaries of load demand and equipment availability and the need for an operating reserve margin, generation equipment cannot always be run at its most effective operating point (i.e., full load). Because of the duty cycle flexibility of the fuel cell, however, utilities can use it to cover these varying load requirements in a fuel and cost efficient manner, thereby allowing the conventional equipment to be operated at its optimum level.

Analysis of this mode of operation does not lend itself to a one-for-one comparison as in the previous application example. This problem has therefore been analyzed by developing a computer simulation model of a typical large utility system. The overall characteristics of this utility system are listed below:

System installed capacity	10,000 MW
Annual load factor	62 percent
Installed reserve	17.5 percent annual peaking
Operating reserve	Equivalent to largest unit on-line
Spinning	50 percent of operating reserve
5 minute	50 percent of operating reserve

Generation equipment within the system is assumed to be a typical mix of gas turbines for peaking, cycling steam and combined cycle equipment for intermediate loads and nuclear, hydro and steam equipment for baseload. The type, amount and characteristics of this equipment are shown in the table below.

Type	Percent Of System	Rated Unit Size, MW's	Maintenance, Weeks/Year	Rated Heat Rate, BTU/KWH
Steam - 1945	6.0	50	3	13000
Steam - 1955	13.0	100	3	11000
Steam - 1965	15.0	300	4	10000
Steam - 1975	18.0	600	5	9000
Nuclear	22.0	1100	8	10500
Combined Cycles	2.2	220	3	8500
Pre '75 Combustion Turbines	9.8	70	2	12000
Post '75 Combustion Turbines	3.0	100	2	10500
Hydro	5.0	500	1	N/A
Cycling Steam - 1975 (1)	6.0	600	4	10500
Fuel Cells (1)	6.0	50	1	9300

(1) Competitive Expansion Alternates

The utility option for system expansion (6% of system) was assumed to be either fuel cells or cycling steam equipment.

Using dispatching procedures aimed at minimizing system production cost, the annual cost and fuel consumption was calculated first for the system using cycling steam equipment, and next for the system using fuel cells operating in the continuous duty cycling mode. This analysis was repeated for systems containing from 3% to 12% fuel cells. While the production cost savings continued to increase over the entire range of fuel cell installed capacity, this parameter optimized at the 6% level.

Based on a 31% capacity factor for the cycling duty fuel cell powerplant, the fuel and cost savings associated with 1000 MW of installed capacity are:

Fuel Resource Savings	5,222 barrels/day
Cost Savings	$30.8 million per year

7. Replacement of Plants in Critical Areas

Approximately 28,000 MW of liquid and gaseous fueled generating plant capacity located in environmentally restrictive areas are attractive candidates for replacement. These plants typically provide cycling-duty energy and operate at an average annual capacity factor of 25% to 70%. Heat rates range from 13,000 to 22,800 BTU/KWH and operation and maintenance cost varies between 0.20 and 0.846 ¢/KWH. Average equipment characteristics are assumed to be:

Capacity factor	34%
Heat rate	15,600 BTU/KWH
Operation & maintenance cost	0.38 ¢/KWH

The most viable options open to utilities for providing this capacity requirement consistent with environmental constraints are:

- Operate on low-sulphur fuels and add water treatment systems.
- Operate on high-sulphur fuels and add water treatment and stack gas cleanup systems.
- Replace in-situ with modern liquid-fuel plant burning clean fuel.
- Replace with remotely located generation capacity and bring power to area via underground transmission.
- Replace in-situ with cycling duty fuel cell.

The following table compares the economic characteristics of the five options:

	Option 1	Option 2	Option 3	Option 4	Option 5
	Clean Fuel	High Sulphur Fuel	Use Clean Fuel	Remote Generation	Cycling Fuel Cell
Generation Equipment Capital Cost	0	0	$400/KW(1)	$216/KW(2)	$250-350/KW
Transmission Equipment Capital Cost	0	0	0	$395/KW(4)	0
Water Treatment Equipment	$25/KW	$25/KW	$25/KW	0	0
Stack Gas Pollution Control Equipment	0	$150/KW	0	0	0
Total Capital Cost	$25/KW	$175/KW	$425/KW	$610/KW	$250-350/KW
Heat Rate, BTU/KWH	15,600	16,200(3)	10,500	9,240(5)	8700(6)
Fuel Cost, $\$/10^6$ BTU	3.36	2.73	3.36	3.36	3.46
O & M Cost, Mills/KWH	3.8	3.8	1.9	1.9	3.9

(1) Capital cost of 100 MW cycling duty plant.
(2) Weighted average for intermediate and peaking equipment; ($140/KW) (0.4) + ($250/KW) (0.6) = $206/KW; 5% additional capacity to cover transmission loss brings cost to $216/KW.
(3) Includes 4% increase in heat rate due to added pollution control equipment.
(4) Weighted average for intermediate and peaking equipment; ($64/KW) (0.4) + ($89/KW) (0.6) = $79/KW; undergrounding will cost an average of five times overhead transmission bring capital cost to $395/KW.
(5) Weighted average for intermediate and peaking equipment energy; (10,000 BTU/KWH) (0.20) + (8500 BTU/KWH) (0.80) = 8800 BTU/KWH; 5% transmission loss brings heat rate to 9240 BTU/KWH.
(6) Part-load heat rate between 30% and 60% load is 8700 BTU/KWH.

With an annual carrying charge of 17% and assuming a 34% capacity factor, the energy costs for these systems are:

	Option 1	Option 2	Option 3	Option 4	Option 5 Fuel Cell
Capital, ¢/KWH	0.15	1.00	2.42	3.48	1.43-2.00
Fuel Cost, ¢/KWH	5.24	4.42	3.53	3.10	3.01
O & M Cost, ¢/KWH	0.38	0.38	0.19	0.19	0.39
Total Energy Cost	5.77	5.80	6.14	6.77	4.83-5.40

Comparing the energy cost of the fuel cell system with the lowest cost alternative option (option 1 continuing to operate existing plant on clean fuel), the fuel cell offers both fuel and cost savings benefits. For each 1000 MW of fuel cells used in this manner, the savings are:

Fuel Resource Savings	11,050 barrels/day
Cost Savings	$28 million/year

8. Fuel Cells for Municipal and Rural Generation Applications

The availability of fuel cell powerplants for use in municipal and rural generation systems would provide these utilities with both a new equipment option for self-generated energy and a cost-effective alternative to purchasing energy from the larger private utility companies. Because of the wide range in the cost of purchased energy (heavily influenced by the amount of low-cost nuclear and hydro energy produced in the system), only the self-generation comparison has been evaluated here.

Low-capacity, cost-effective generation equipment available to municipal and rural utilities for cycling duty is presently limited mainly to liquid and gaseous fueled systems such as diesel engine-driven generators and cycling steam plants. The characteristics of these systems in comparison with fuel cells are shown in the table in Section 3 of this Appendix.

The annual capital charge for municipal and rural systems is lower than for private utilities because of the lower interest on debt capital; an annual charge of 11% has been assumed.

Because of the high energy availability of fuel cell powerplants, minimal reserve capacity will be required in contrast with at least a 25% reserve requirement for the conventional equipment.

Assuming an annual capacity factor of 50% for all of the above equipment, the costs associated with each are listed in the table below:

ANNUAL COST OF ENERGY, ¢/KWH

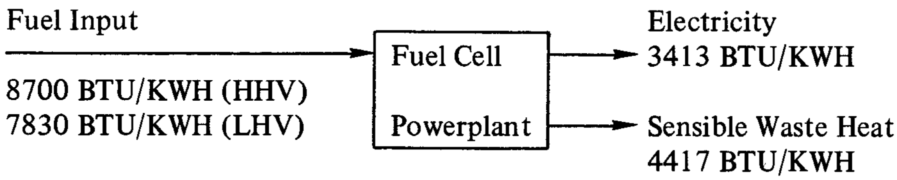
Equipment	Capital	Fuel	O & M	Total
Diesel Plant	0.71	3.53	0.4	4.64
Cycling Steam	1.26	2.87	0.19	4.32
Fuel Cell	0.63-0.88	3.01	0.3	3.94-4.19

In comparison with the most cost-effective alternative, the use of 1000 MW of fuel cells would provide the following energy cost and fuel savings:

Fuel Resource Savings	4,235 barrels/day
Cost Savings	$16.64 million/year

9. Waste Heat Utilization

Since waste heat results from powerplant inefficiencies, the amount of waste heat produced is inversely proportional to operating efficiency. Thus, in the fuel cell powerplant, more waste heat is produced when operated at full-load than at part-load. Assuming part-load operation for the fuel cell (and therefore less waste heat available), the waste heat production is illustrated in the diagram below:



Assuming a 60% recovery efficiency for the waste heat including heat exchanger efficiency and losses, 2650 BTU/KWH of useable waste heat could be provided for use. The demand for this heat may not always coincide with the amount of heat available from the powerplant. Thus, a coincidence factor of 70% would mean that 1855 BTU of heat would be used for each KWH of electric energy produced by the fuel cell powerplant.

The production of heat or steam by conventional, large-scale heating equipment is about 75% efficient. Thus, to produce 1855 BTU of useable energy by conventional means would require 2473 BTU of fossil fuel. Using the fuel cell waste heat instead of conventional heating techniques would therefore provide a savings of 2473 BTU of primary fuel for each KWH generated in the fuel cell.

The recovery of fuel cell waste heat would of course, require additional equipment. This analysis therefore assumes that the cost savings associated with the reduction in fuel use would be balanced off by the additional cost of recovery equipment. Fuel savings for this application are summarized below:

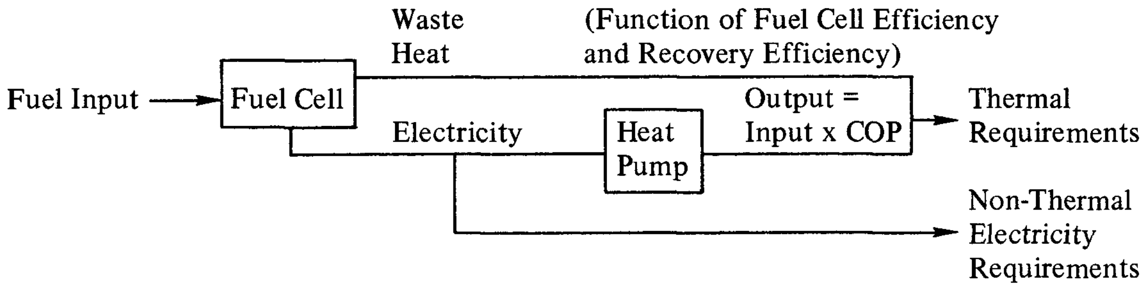
Primary Fuel Savings	2473 BTU/KWH or 1.13 x 10^3 B/DOE per 10^9 KWH generated
Resource Savings	1.33 x 10^3 B/DOE per 10^9 KWH generated

10. On-Site Integrated Energy Systems

Locating fuel cell powerplants at the point of energy use such as industrial sites and commercial and apartment buildings combines the fuel economy advantages of high generating efficiency, and elimination of electric transmission and distribution losses with the opportunity for recovering and using waste heat for space and water heating. The incorporation of an electric heat pump[(1)] into the system, permits the highly efficient use of electricity for supplementary heating and for cooling. Such a system is shown schematically below:

[(1)] A heat pump is essentially an air conditioning system which, when operated in reverse, efficiently transforms electricity into heat.

FUEL CELL INTEGRATED ENERGY SYSTEM



The fuel input requirements (and therefore the system efficiency) is dependent on:

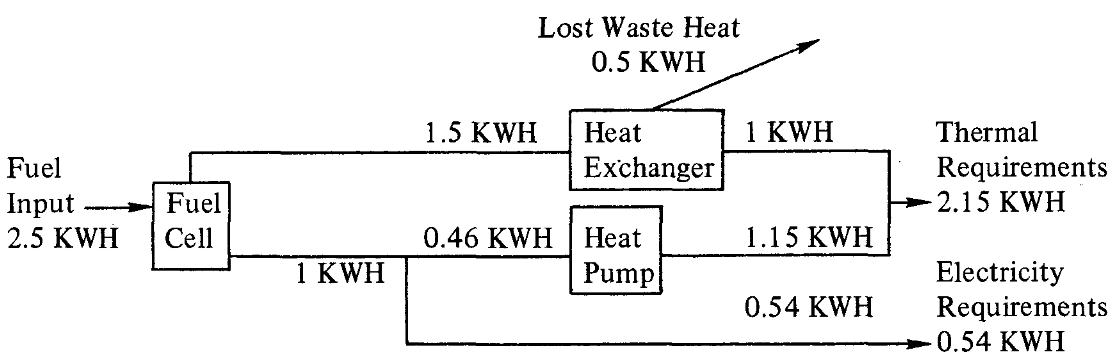
- Fuel Cell Efficiency
- Heat Pump Coefficient of Performance
- Waste Heat Availability and Recovery Efficiency
- Ratio of Thermal-to-Electric Load Requirements

Providing the cycling load demands of commercial, apartment and industrial buildings at a part-load efficiency of 40% (LHV), the fuel cell would produce 5120 BTU of waste heat per KWH generated. Assuming a 75% recovery efficiency and a 90% coincidence factor for this waste heat results in 3456 BTU of useable waste heat, per KWH generated.

The ratio of thermal energy demand to electricity demand is generally a characteristic of a particular building type or industrial process. For example, this ratio ranges from 0.5 to 4.0 for office buildings, from 0.5 to 8.0 for hotels and motels and from 3.0 to 11.0 for apartment buildings. For this analysis a ratio of 4.0 was assumed to be representative for an integrated system application (a higher ratio results in greater fuel savings).

The heat pump coefficient of performance is determined by its mode of operation (heating or cooling), ambient temperature, and the type and size of the equipment. A C.O.P. of 2.5 is representative for this type of application.

For the fuel cell integrated energy system described, the energy balance on an annual basis is shown schematically below. Values shown are to 1 KWH of electricity production.



The fuel cell integrated system provides the electric energy normally generated and transmitted by an electric utility system and the thermal energy converted by a gas or oil furnace. The characteristics of a highly efficient conventional electric and thermal system are listed below:

Electric System

Generation System heat rate (typical of the best available marginal capacity additions)	8500 btu/kWh
Transmission and Distribution	10%

Thermal System

Heating conversion efficiency	60%

The primary fuel requirements necessary to produce 1 KWH of electricity and 4 KWH equivalent of thermal energy at the site from each system are listed below:

FUEL INPUT REQUIREMENTS, KWH EQUIVALENT

System	For Thermal Energy	For Electric Energy	Total
Conventional System	6.70 KWH (60% eff.)	2.74 KWH 36.5% eff.)	9.44 KWH
Fuel Cell Integrated Energy System	← 4.63 KWH	→	4.63 KWH

Thus, the net savings with the fuel cell system is 4.81 KWH of fuel energy or 16,417 BTU per KWH of electricity demanded.

To determine the cost savings associated with the fuel cell integrated energy system, a 16-unit apartment complex was used as a model. This building, in a Northern location, had a thermal-to-electric energy demand ratio of 6 to 1. Natural gas provides the supplemental thermal requirements of the fuel cell system, is used for powering the fuel cell and provides thermal energy for the conventional system. The costs of the fuel cell and conventional systems are developed in the table below:

ANNUAL COSTS (1980 DOLLARS)

	Conventional System	Fuel Cell Integrated Energy
Annual Energy Requirement		
Thermal Gas, MCF	2450 MCF	521 MCF (supplementary heating)
Fuel Cell Gas, MCF	0	1524 MCF
Electricity, KWH	119,300 KWH	0
Energy Cost		
Gas @ $1.59/MCF	$3896/Year	$3252/Year
Electricity @ 5.17¢/KWH	$6168/Year	0
Equipment Cost Increase Over Convention System		
Fuel Cell(1)	0	$4136/Year to $5165/Year
Fuel Cell Thermal System(2)	0	$585/Year
Total Annual Cost	$10,064/Year	$7973/Year to $9003/Year

(1) Owning, operating and maintenance cost for installed fuel cell cost of $400/KW to $500/KW.
(2) $3,594 written off over 10 years, 10% interest charge.

Note that the total gas utilization of the fuel cell system providing both electric and thermal energy is less than the conventional system providing thermal energy alone.

The fuel and cost saving benefits associated with the fuel cell integrated energy system are summarized below:

Range of Energy Cost Savings	1.75¢/KWH to 0.89¢/KWH
Savings Used in National Impact Statement (based on Cost Goal of $400/KW installed)	1.75¢/KWH
Primary Fuel Savings	16.417 BTU per KWH or 7.44 x 10^3 B/DOE per 10^9 KWH
Resource Savings	8.75 x 10^3 B/DOE per 10^9 KWH

Based on a 55% capacity factor for on-site fuel cell powerplants, the fuel and cost savings associated with 1000 MW of installed capacity are:

Fuel Resource Savings	42,158 barrels/day
Energy Cost Savings	$1.75 million/year

11. Present Worth of Cost Savings

The calculation of the present worth (total present value of a stream of future savings) of the energy cost savings is based on the per-unit benefits and estimated market levels presented earlier in Appendix A and summarized in the National Impact statement. The table below summarizes these accumulated savings.

ENERGY COST SAVINGS
(Millions of 1980 Dollars per Year)

	1980-1985			1985-1990		
	I	II	III	I	III	III
Private Utility						
Cycling	3386	1887	711	11019	6078	2250
Replacement	2352	2352	1176	4312	4312	3332
Municipal and Rural Utilities	359	204	80	1163	655	251
Waste Heat Utilization in Municipal & Urban areas.	0	0	0	0	0	0
On-Site Integrated Energy System	2669	17701	881	8436	5570	2812
Total	8766	6214	2848	24930	16615	8645

The calculations for cost savings have been based on cumulative installed capacities for the intervals 1980-1985 and 1985-1990. In order to calculate present worth, these values were translated from cumulative to annual statistics. A straight line interpolation of installed capacity was used for all market segments. To those annual savings, discount or present worth factors of 10% and 15% were applied in order to find the 1976 present value of these future savings. These rates are felt to be a typical range of discounting rates for public sector investments. The table below illustrates this operation using Case I as an illustrative example.

ANNUAL COST SAVINGS
(Millions of Dollars)

Year	Annual Cost Savings	10% Present Worth Factor	10% Discounted Cost Savings	15% Present Worth Factor	15% Discounted Cost Savings
1980	491.5	0.683	335.7	0.572	281.1
1981	971.6	0.621	603.4	0.497	432.9
1982	1463.2	0.565	826.7	0.432	632.1
1983	1946.2	0.513	998.4	0.376	731.8
1984	2434.8	0.467	1137.1	0.327	796.2
1985	2917.9	0.424	1237.2	0.284	828.7
1986	3508.1	0.386	1354.1	0.247	866.5
1987	4098.2	0.351	1438.5	0.215	881.1
1988	4698.4	0.319	1498.8	0.187	878.6
1989	5288.5	0.290	1533.7	0.163	862.0
1990	5878.6	0.263	1546.1	0.141	828.9
1976 Total Present Worth in 1980 Dollars.			12509.7		8069.9

At this point, the present value is represented as a sum in year 1976 in terms of 1980 dollars.

In order to convert 1980 dollars into 1976 dollars, an annual inflation rate of 4.5% was assumed.

The following table summarizes the 1976 present worth of energy cost savings for the three deployment cases in terms of 1976 dollars.

ENERGY COST SAVINGS 1976 PRESENT WORTH
(Millions of 1976 Dollars)

	Energy Cost Savings		Millions of Dollars
	Case I	Case II	Case III
10% Discount Rate	10,491	7,184	3,546
15% Discount Rate	6,767	4,652	2,278

12. Pollution Damage Cost Reduction

Air pollution in the form of sulphur dioxide, nitrogen oxides and particulates causes significant damage to health, property and vegetation. Introduction of fuel cells into the U.S. electric generation system will significantly reduce the pollution damage to the environment and subsequently, the costs of these damages.

Using present day pollution standards for liquid fueled steam generators, pollution caused by sulphur dioxide, nitrogen oxides and particulates may be estimated for both conventional generators and fuel cells. This comparison is presented in the table below:

POLLUTION DAMAGE REDUCTION

	Tons/MW/Year		
	Fossil Steam Fired[1] (Liquid Fuel) Meeting U. S. Standards	Fuel Cell	Reduction Using Fuel Cell
Sulphur Dioxide	14.4	0	14.4
Nitrogen Oxides	5.4	0.5	4.9
Particulates	3.6	0	3.6

[1] **Based on 4000 hours/year operation, 9500 BTU/KWH hr. source is Federal Register, Vol. 36, No. 159, Tuesday, August 17, 1971 (Part II)**

An estimate of the damage cost associated with the various types of air pollution was made in a report by the U. S. Department of Health, Education and Welfare entitled "The Cost of Air Pollution Damages: A Status Report", July 1970. The table below compares these costs for the three major types of electrical powerplant pollution.

Pollutant	Typical Damage Cost, $/Year Per Ton/Year
Particulates	225
SO_X	294
NO_X	47

The table below summarizes the pollution damage cost savings resulting from using fuel cell powerplants and assuming the alternative is a liquid fossil fueled steam generator meeting U. S. standards.

POLLUTION DAMAGE COST REDUCTION EXAMPLE

Pollutant	Tons/MW/Year Reduction Using F/C	Damage Cost, \$/Year Per Ton/Year	Annual Savings, \$/MW of Fuel Cell/Year
Sulphur Dioxide	14.4	294	\$4234
Nitrogen Oxides	4.9	47	230
Particulates	3.6	225	810
			\$5274/MW/Year

In terms of energy production, this results in a savings of \$1.319 million per year per 10^9 KWH generated. Consistent with the capacity factors assumed in previous sections of this Appendix, the pollution damage cost reduction associated with 1000 MW of fuel cells is summarized in the table below for each applicaton.

Fuel Cell Application	Savings per 1000 MW, \$ Million Per Year
Intermittent Duty Peaking	\$1.98
Intermittent Duty Intermediate	5.28
Cycling Duty	3.59
Urban Plant Replacement	3.93
Municipal and Rural	5.77
Integrated Energy Systems	6.36

13. Capital Cost Savings

Fuel cell powerplants offer the potential for capital cost savings in all of the applications discussed. This example defines the savings associated with the cycling duty application only.

When the fuel cell is used as a cycling duty generator, it competes predominantly with cycling steam and combined cycle plants. The comparative capital costs for these generators and their associated transmission and reserve requirements are discussed in Sections 1, 2 and 3 of this Appendix and summarized in the table below. Comparing the low range of capital cost for the fuel cell with that of the lowest capital cost alternative yields a capital savings of from \$130/KW to \$220/KW.

Equipment	Total Cost of Generation and Transmission, $/KW
Combined Cycle Plant	380 - 471
Cycling Steam Plant	411 - 502
Dispersed Fuel Cell	250 - 350

APPENDIX B

THE MARKET FOR LIQUID AND GASEOUS FUELED UTILITY GENERATION EQUIPMENT

The market for electric generation equipment is determined primarily by the rate of growth in total demand for electricity. Until the energy crisis in 1973, this annual growth rate for the U. S. was almost 7.5%. The table below illustrates the divergence in recent forecasts of future growth.

ELECTRICITY DEMAND
RECENT FORECASTS OF ELECTRICITY DEMAND

Source	Date	Average Annual Growth Forecast 1975-1985
National Electric Reliability Council	August 1975	6.7%
Electrical World	September 15, 1975	6.0%
Edison Electric Institute	October 1975	5.3% - 5.8%
Federal Energy Administration	February 1976	5.7%
Petroleum Industry Research Foundation	May 1975	5.0%

Since the objective of this analysis is to study the effects of growth rate upon the market, rather than to predict the rate itself, a range of values were considered: 5%, 6%, and 6.7%. These were applied to both growth in generation (KWH) and total installed capacity (MW). The following table summarizes the total electrical production for years 1975 through 1990 using the assumed growth rates.

ELECTRICITY PRODUCTION DEMAND

	Total Production (KWH x 10^9)		
Year	5.0% Annual Growth 1975-1990	6.0% Annual Growth 1975-1990	6.7% Annual Growth 1975-1990
1975 (1)	1900	1900	1900
1980	2424	2542	2628
1985	3093	3401	3634
1990	3947	4551	5026

(1) Electrical World, September 15, 1975

The preceding table summarizes the total electricity demand which must be supplied by all utilities. This demand must be supplied by: (1) municipal and rural systems, and (2) the larger, privately owned utilities.

Low capacity, cost effective generation equipment available to municipal and rural utilities for cycling duty is limited to liquid and gaseous fueled systems such as diesel engine driven generators and cycling steam plants. Unlike the larger private utilities, which have an alternative to the use of liquid and gaseous fuels for their baseload energy generation, the small municipal and rural systems will be forced to maintain their present equipment mix and the same percentage of liquid and gaseous fueled equipment. If the relative mix remains constant, the table below shows the generation by fuel type for the three growth rates.

ENERGY NEEDS FOR MUNICIPAL AND RURAL GENERATION
KWH x 10^9

	1975			1980			1985			1990		
	Liquid & Gaseous Fuels	Hydro	Coal	Liquid & Gaseous Fuels	Hydro	Coal	Liquid & Gaseous Fuels	Hydro	Coal	Liquid & Gaseous Fuels	Hydro	Coal
5% Growth Case III	80	13	26	102	17	33	130	21	42	166	27	54
6% Growth Case II	80	13	26	107	17	35	143	23	47	192	31	62
6.7% Growth Case I	80	13	26	111	18	36	153	25	50	212	34	69

Based on 1974 Generation from EEI statistics of 112.3 x 10^9 KWH and 6% growth 1974-1975 (119.0 x 10^9 KWH in 1975) x (67% oil and gas generation) = 80 x 10^9 KWH

Unlike municipal and rural utilities, the larger private utilities have a wide range of equipment options and therefore a broader fuel choice. However, because of their duty cycle and economic characteristics conventional equipment is normally used by utilities in the following manner:

Equipment	Fuel	Duty Cycle
Steam Generators	coal	baseload
	nuclear	baseload
	liquid and gaseous fuels	baseload or intermediate
Hydro-Electric	—	baseload
Combined Cycles	liquid and gaseous fuels	intermediate
Cycling Steam	liquid and gaseous fuels	intermediate
Gas Turbines	liquid and gaseous fuels	peaking
Pumped Hydro	energy from nuclear or coal plants	peaking and intermediate

Coal, nuclear, hydro-electric and liquid and gaseous fuels thus provide baseload energy. Energy in the intermediate and peaking range is provided by pumped storage equipment and generators powered by liquid and gaseous fuels.

An estimate of the market for liquid and gaseous fueled equipment capacity additions in the private utility sector was therefore based on the following assumptions:

- Nuclear, hydro and solid coal will be used for baseload generation (75% of total electrical production).
- Based on optimistic projections of nuclear, hydro and coal supplies, liquid and gaseous fuels will be used for baseload only in a shortfall situation.
- The remaining 25% intermediate and peaking energy, must continue to be supplied by pumped storage and liquid and gaseous fuels (primarily oil and processed coal).

The table below shows the calculated values of energy demand requirements for baseload and intermediate and peaking categories for the private utility sector.

PRIVATE UTILITY ENERGY DEMAND
(KWH x 10^9)

	5%			6%			6.7%		
Year	Total	Baseload	Intermediate & Peaking	Total	Baseload	Intermediate & Peaking	Total	Baseload	Intermediate & Peaking
1975	1781	1336	445	1781	1336	445	1781	1336	445
1980	2272	1704	568	2383	1787	596	2463	1847	616
1985	2899	2174	725	3188	2391	797	3406	2555	852
1990	3700	2775	925	4266	3200	1067	4711	3533	1178

The intermediate and peaking energy requirements defined in the above table will be supplied by pumped storage (energized by nuclear powerplants for lowest energy costs) and liquid and gaseous fueled powerplants. An estimate of pumped storage energy capability is shown in the table below:

Year	Pumped Storage Capacity, 1000's MW	Intermediate and Peaking Energy Provided, KWH x 10^9
1975	10.4	16
1980	16.0	24
1985	30.7	46
1990	45.0	68

Source: Electrical World, September 15, 1974 for installed capacity. Facilities assumed to be operated an average of 1500 hours/year.

The remaining intermediate and peaking energy which must be supplied by liquid and gaseous fueled powerplants is:

DEMAND FOR INTERMEDIATE AND PEAKING ENERGY FROM LIQUID AND GASEOUS FUELS, 10^9 KWH

Year	5.0% Growth	6.0% Growth	6.7% Growth
1975	429	429	429
1980	544	572	592
1985	679	751	806
1990	857	999	1110

Optimistic projections of electrical production by nuclear, hydro, and coal fired equipment are:

PROJECTED BASELOAD ELECTRICITY PRODUCTION (KWH x 10^9)

Year	Nuclear Baseload[1]	Coal[2]	Hydro, Geotherm[2] and Other
1975	159	875	304
1980	443	1160	332
1985	950	1550	365
1990	1367	2070 (proj.)	400

(1)Electrical World, September 15, 1975. (Total Nuclear less Pumped Storage) Capacity factor assumed to improve from 45% in 1975 to 70% in 1990.

(2) Petroleum Industry Research Foundation, Inc. optimistic estimate.

Comparing the above forecasts of baseload energy supply with the range of baseload energy demand defined for the three growth cases, leads to the conclusion that liquid and gaseous fuels will not be needed for baseload energy from 1980 and beyond. Note that this analysis was conducted on the basis of optimistic forecasts for nuclear, coal, and hydro energy and that less optimistic supply estimates for these fuels could alter the conclusion.

The table below summarizes the total U.S. demand for electric energy from liquid and gaseous fuels for both private utilities and municipal and rural systems.

U.S. DEMAND FOR ELECTRIC ENERGY FROM LIQUID/GASEOUS FUELS
10^9 KWH

	1975	1980	1985	1990
Municipal & Rural				
5.0	80	102	130	166
6.0	80	107	143	192
6.7	80	111	153	212
Private				
5.0	482	544	679	857
6.0	482	572	751	999
6.7	482	592	806	1110

The following table converts these annual energy requirements into increases required during two periods: 1980 to 1985 and 1985 to 1990. Assuming capacity factors(1) of 50% and 25% for municipal and rural systems and private utilities respectively, this table also shows the required liquid and gaseous fueled additions to capacity during the interval between 1980 and 1990.

	Increased Energy Requirements (10^9 KWH)		Additions to Capacity (1000's MW)		
	1980-1985	1985-1990	1980-1985	1985-1990	Total 1980-1990
Municipal & Rural					
5.0	28	35	6.4	8.2	14.6
6.0	36	49	8.2	11.2	19.4
6.7	42	59	9.6	13.4	23.0
Private					
5.0	135	178	61.6	81.2	142.8
6.0	179	248	81.6	113.1	194.7
6.7	214	304	97.6	138.6	236.2

(1)Rated Power (Kw) x Capacity Factor x 8760 (Hrs/Year) = Annual Energy Production (KwH/Year)

The table below summarizes the total market for new generating capacity in the United States. Additions to capacity are based on a peak capability of 492 thousand megawatts in 1975 and a reduction of reserve capacity from 38% in 1975 to 20% in 1980. Annual retirements are assumed to be 0.5% of installed capacity.

U.S. CAPACITY ADDITIONS
(MW x 10^3)

Annual Growth	Additions to Total Capacity 1980-1985	Additions to Total Capacity 1985-1990	Retirements 1980-1985	Retirements 1985-1990	Total Market For New Capacity 1980-1985	Total Market For New Capacity 1985-1990
5.0%	164	216	19	25	183	241
6.0%	216	291	19	25	235	316
6.7%	247	351	19	25	266	376

In comparison with the total market for generating capacity additions, liquid and gaseous fueled generating capacity represents 37% to 40% of the total as shown in the table below.

TOTAL UTILITY MARKET FOR NEW EQUIPMENT 1980-1990
(MW x 10^3)

Annual Growth	Total Retirements[(1)] and Additions	Liquid and Gaseous Fuels	Percent of Total
5.0%	424	157.4	37%
6.0%	551	214.1	39%
6.7%	642	259.2	40%

(1) Includes 44,000 megawatts of potential retirements.