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ON-SITE FUEL CELL ENERGY SYSTEMS: THE U.S. AIR FORCE FIELD TEST DEMONSTRATION PLAN

University of Wisconsin-Extension
Energy Technology Center
Madison, Wisconsin 53706

December 1980
TECHNICAL REPORT AFWAL-TR-80-2118
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This technical report has been reviewed and is approved for publication.

Richard Honneywell

RICHARD G. HONNEYWELL, 1Lt, USAF
Project Engineer

Robert R Barthelemy

ROBERT R. BARTHELEMY
Chief, Energy Conversion Branch

FOR THE COMMANDER

Jim D Reams

JAMES D. REAMS
Chief, Aerospace Power Division
Aero Propulsion Laboratory

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The large scale application of fuel cell energy systems, electrochemical energy conversion devices, to facility operations, could result in significant benefits to the public and to the U.S. Air Force. This report summarizes the advantages and potential applications of fuel cells on an Air Force base, highlights the pertinent operational characteristics of a fuel cell, identifies the ongoing governmental and industrial programs that are aimed at commercializing this technology as early as the mid 1980's, and recommends and outlines a U.S. Air Force On-Site Fuel Cell Field Test Demonstration Program Plan.

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FOREWORD

This report prepared for the Aerospace Power Division, Aero Propulsion Laboratory, Wright-Patterson AFB, describes the ongoing effort by government and the private sector to commercialize on-site fuel cell energy systems. Additionally, this report recommends that the U.S. Air Force become involved in demonstrating the operational feasibility of these energy conservative systems.

The work reported herein was performed under project/task/work unit 3145/24/09, during the period 30 March to 30 September 1980, under the direction of Lt. Richard Honneywell, (AFWAL/POOC), as project engineer. The report was authored by Mr. Michael A. Aimone, University of Wisconsin-Extension, Madison, Wisconsin and was submitted in September, 1980.

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EXECUTIVE SUMMARY

INTRODUCTION

The large scale terrestrial application of fuel cells, an electrochemical energy conversion device, could result in a significant energy savings for this nation. Specifically, the Department of Energy (DOE) estimates that fuel cell technology could, in the near term, save this nation 270,000 barrels of oil equivalents per day and over $1 billion in foreign imports per year. The fuel cell is an efficient and environmentally benign energy conversion technology which converts stored chemical energy directly into electricity and heat.

This report summarizes the advantages and potential applications of fuel cells on an Air Force base, identifies the ongoing governmental and industrial programs that are aimed at commercializing this technology as early as the mid 1980's, evaluates the economic consequences of fuel cell energy systems to the U.S. Air Force, and recommends a U.S. Air Force On-Site Fuel Cell Field Test Demonstration Program Plan.

ELECTROCHEMICAL ENERGY CONVERSION SYSTEMS

Fuel cells are not new devices; in fact, Sir Humphrey Davy demonstrated a crude type of fuel cell in 1801. Sir William Grove; however, is credited with developing the first practical fuel cell device in 1839.

A fuel cell is similar in operation to a battery. These electrochemical devices convert stored chemical energy directly into electric energy. No intermediate energy conversion process occurs. When chemical reactants are fed into a fuel cell, energy in the form of electricity and heat is developed. The unique difference between a fuel cell and a battery is that the fuel cell allows for a continuous energy conversion process; as long as chemical reactants are fed into the fuel cell, energy conversion takes place.

The fuel cell is energy efficient; over 80 percent of the stored chemical energy can be recovered as electricity or heat. Also, the fuel cell maintains this high level of energy conversion efficiency with part load operation. The fuel cell does not contribute significant quantities of air, water, or noise pollution and the cell is modular and thus can be efficiently arranged in many versatile electric power output configurations.

Fuel cell energy systems could be sized to operate within utility grid or distributed at the points of utilization. The U.S. Air Force should be interested in both sizes of fuel cell energy systems. This report; however, is only interested in identifying the opportunities of small (kilowatt) sized on-site (distributed) fuel cell energy systems.

U.S. AIR FORCE APPLICATIONS FOR FUEL CELL ENERGY SYSTEMS

The fuel cell energy system could provide an energy conservative means of supplying energy-intensive facilities on a U.S. Air Force base. Additionally, these systems could replace Air Force-owned standby generator systems. Fuel cells are comparatively lightweight and air transportable and could operate on conventional distillate or residual fuel stocks or synthetic fuels. They could replace emergency generators on Civil Engineering contingency pallets and could be installed within Aerospace Ground Equipment (AGE) to support military aircraft ground operations. Larger fuel cell energy systems could replace (or supplement) the electrical power transformer and electric distribution systems for single buildings or large areas of an Air Force base and provide for remote applications. Table 1 lists the potential fuel cell applications on an Air Force base.

THE COMMERCIALIZATION OF FUEL CELL ENERGY SYSTEMS

The government and the private sector are interested in commercializing fuel cell energy systems. Both the large multi-megawatt utility-based systems and the smaller on-site systems are under advanced research, development, and proof-of-concept testing. Recently, the National Fuel Cell Coordinating Group, an official coordinating body of fuel cell funding entities, has been formed to assure the comprehensive and logical development of fuel cell subcomponents and technologies.

The phosphoric acid fuel cell system is presently the most advanced technology available. The phosphoric acid on-site system should reach the initial phases of commercialization by 1985. This technology is also being utilized for developing the multi-megawatt utility-based fuel cell energy system.

Molten carbonate fuel cell energy systems operate at higher temperatures and are intended for use within a utility grid or large industrial complex where the high temperature waste heat can be utilized. Molten carbonate technology does have an application for replacement of U.S. Air Force central heating plants. Unfortunately, this technology will not be ready for commercialization until after 1990.

Several advanced concepts are undergoing research and development. These solid polymer and solid inorganic electrolyte systems are unique in construction and should provide excellent reliability and efficiency. Several solid polymer electrolyte systems are under investigation for military-unique low power, long duration applications.

TABLE 1

POTENTIAL USAF USES FOR FUEL CELLS

ENERGY-INTENSIVE FACILITIES WITH HIGH COINCIDENT ELECTRICAL/THERMAL LOADS	
-Industrial	-AAFES facilities
-Military Family Housing	-Hospital
-Enlisted dormitory complexes	-Computer facilities
-Enlisted dining halls	-Sewage treatment plant
EMERGENCY AND STANDBY SYSTEMS	
-Hospital	-Navigational Aids
-Security police, civil engineering, and operations and maintenance command posts	-Airfield lighting system
-Sewage treatment plant	
MOBILE APPLICATIONS	
-Aerospace ground equipment	
-Shuttle buses and maintenance vehicles	
-Industrial forklifts and other warehouse vehicles	
REMOTE APPLICATIONS	
-Radar stations	-Navigational equipment
-Communication sites	-BARE BASE facilities

THE NATIONAL ON SITE/INTEGRATED ENERGY SYSTEM FUEL CELL OPERATIONAL FEASIBILITY PROGRAM

The objective of the National On-Site/Integrated Energy Fuel Cell Operational Feasibility Program is to establish national acceptance of and the commitment to fuel cell energy systems. Both tecnnical feasibility studies and non-technical customer acceptance studies are to be completed. To achieve this objective, the following goals have been developed:

- o Establish operational feasibility and measure reliability of power plants as a key element of on-site energy systems,
- o Verify the fuel cell conservation and environmental characteristics of on-site fuel cell energy systems,
- o Evaluate institutional, regulatory (PUC involvement), code and legal issues under various simulated ownership arrangements,
- o Verify the practicality of different on-site fuel cell energy system configurations in a variety of applications and conditions,
- o Verify the overall viability of attractive early entry market candidates,
- o Assess system economic performance including capital cost, installation costs, and operating and maintenance costs,
- o Inform the public of the concept in order to prepare for broader acceptance by society, and
- o As a result of in-service operation, identify power plant improvements requiring design iteration.

The program begins with a preliminary site survey to identify candidate sites. These sites are analyzed to determine facilities with an acceptable thermal-to-electric load ratio. Sites are to be selected so that all regions of the country and all early market sectors of the economy are evaluated.

Selected sites are fully instrumented and data are collected for one year. Fuel cell energy systems are then installed and evaluated for one year. It is envisioned that this program would be a major effort for the participating utility companies; whereas, the individual customers demonstrating the system would have little technical involvement in the demonstration program. Figure 1 highlights the milestones established for this program.

Recently, the Congress passed legislation recommending that six fuel cell energy systems be purchased and installed with 1981 Military Construction Program minor construction funds. The projects recommended include Army, Navy and Air Force barracks and administrative complexes and remote locations.

FUEL CELL ECONOMICS

Fuel cells have been shown to be economically competitive in certain market areas. Payback periods of 5 years or less are anticipated. DOE has analyzed numerous applications of fuel cells and has shown that:

- The fuel cell on-site energy system saved gross energy resources in all building types studied. Savings ranged from 50 to 10 percent,
- On a national aggregate basis, the resource requirements for present commercial buildings could be reduced by 30 percent with the fuel cell system,
- In buildings where thermal energy use was high relative to electric use, the fuel cell on-site energy system provided both the thermal and electric energy requirements for less resources than were required to supply the thermal requirements alone, and
- Resource conservation, and to a greater degree life-cycle costs, were greatly influenced by the building's thermal-to-electric load ratio.

Specifically, a study has recently been completed that shows that in buildings with large coincident thermal-to-electric load ratios, significant resource

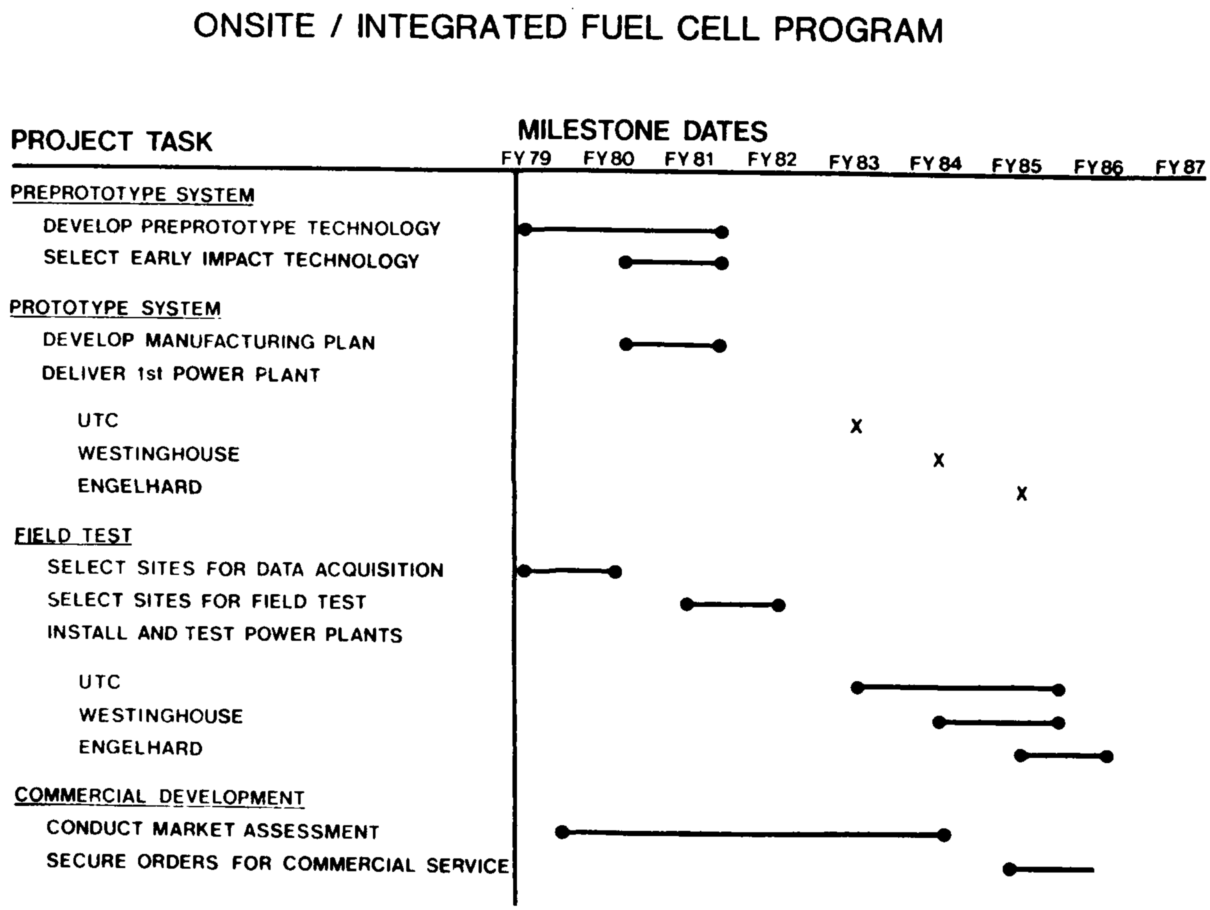


Figure 1. Program Milestones for the On-Site/Integrated Energy System Program.

(electrical and recoverable thermal energy) savings can be anticipated, but that the absolute level of savings is diminished at low thermal-to-electric ratios. Figure 2 demonstrates this relationship.

An aggressive U.S. Air Force Fuel Cell Program could payback in less than 2 years. This aggressive program could result in a 45 percent reduction in petroleum fuels by FY 2000 compared to a FY 75 baseline and would enable the U.S. Air Force to meet and exceed other of its FY 2000 facility energy goals. This multi-year program would cost $650 million. However, prior to a large scale investment in fuel cell energy systems, it is recommended that the U.S. Air Force demonstrate and develop experience with this novel energy conversion technology.

THE U.S. AIR FORCE FIELD TEST DEMONSTRATION PROGRAM

The U.S. Air Force demonstration program is organized to closely parallel the National Fuel Cell Operational Feasibility Program. U.S. Air Force participation in the program will result in a savings in facility energy. Further, U.S. Air Force is a good candidate for this program because of its significant quantity of industrial, commercial, and institutional facilities which exhibit a large coincident thermal-to-electric load factor. Additionally, the U.S. Air Force has been designated the lead DOD agency for fuel cell energy systems; and therefore, should be activately participating in the ongoing fuel cell field demonstration and proof-of-concept Operational Feasibility Program.

The main objectives of the Air Force on-site fuel cell demonstration program are: (1) to provide U.S. Air Force personnel the first hand opportunity to evaluate the technological reliability, associated regulatory constraints, and energy savings potential of an on-site fuel cell energy

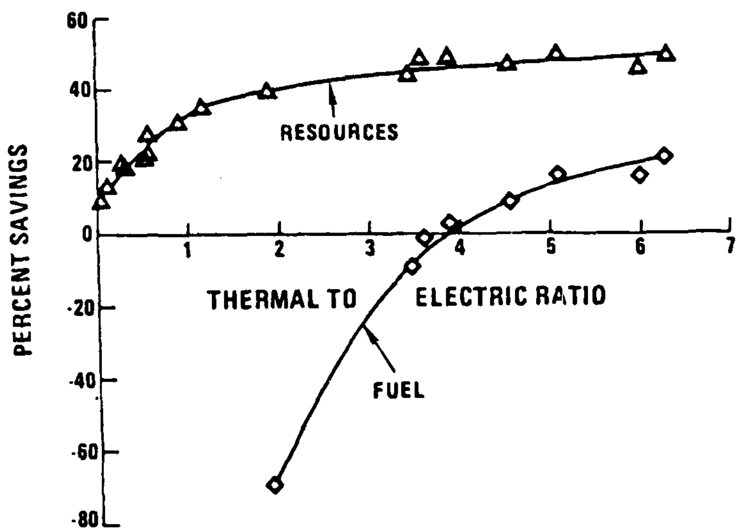


Figure 2. Conservation Potential of Fuel Cell-Heat Pump Systems Versus Building Thermal-to-Electric Load Ratio. Recoverable resources include generated electricity and thermal energy; whereas fuel input excludes the recoverable heat content available to do work.

system; and (2) to allow U.S. Air Force personnel to gain important technological training and experience operating and maintaining the system under typical operational conditions. Table 2 summarizes the advantages for an active U.S. Air Force involvement in the National Fuel Cell Operational Feasibility Program.

THE U.S. AIR FORCE FIELD TEST DEMONSTRATION PROGRAM PLAN

The National Operational Feasibility Program Plan has two major phases: a field test phase and a business assessment phase. The outcome of this program is the field testing and demonstration of three fuel cell units on Air Force bases in the continential United States. This program plan recommends that the U.S. Air Force jointly participate in demonstrating the feasibility of on-site fuel cell energy systems with demonstrating local utility companies. The U.S. Air Force will take the lead during the field test phase and the participating utility company will be responsible for completing the business assessment phase of the program. A follow-on phase is suggested and is intended to further test these power plants.Additionally, the U.S. Air Force should purchase the congressionally-directed fuel cell energy systems and operate these systems using the same program guidelines outlined above.

The major milestones of this program are shown on Figure 3. Table 3 itemizes the anticipated manpower and fiscal requirements per installation for this field demonstration phase.

TABLE 2

REASONS FOR A U.S. AIR FORCE INVOLVEMENT IN

THE NATIONAL FUEL CELL PROGRAM

Saves facility energy; meets DOD established FY 2000 facility energy goals

Provides technology familiarization

Develops technician training and hands-on experience

Demonstrates unique-military related on-site fuel cell applications

Allows for government evaluation of regulatory and technical constraints

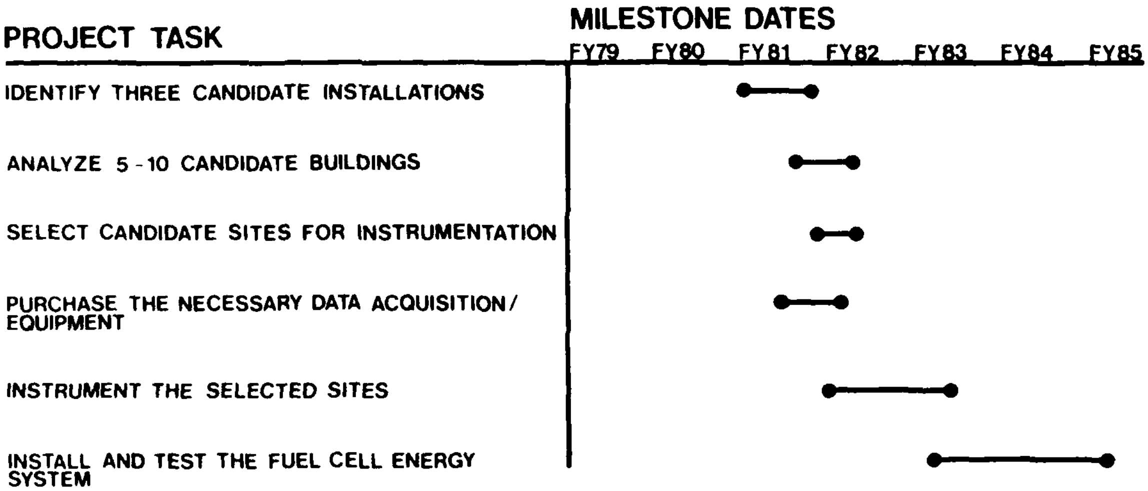


Figure 3. U.S. Air Force Field Test Demonstration Program Plan Milestones.

TABLE 3

U.S. AIR FORCE FIELD TEST DEMONSTRATION PROGRAM

MANPOWER AND FISCAL REQUIREMENTS

(Per Installation)

	PROGRAM ADMINISTRATION (Man-Yr)	TRAVEL FUNDS ($000)	EQUIPMENT PURCHASE ($000)	SITE PREPARATION ($000)
FY 81	.25	2.0	20.0	
FY 82	.125	2.0		
FY 83	.125	2.0		10.0
FY 84	.25	3.0		
FY 85	.25	3.0		3.3
PROGRAM TOTALS	1.0	12.0	20.0	13.3

SUMMARY

This report is in five sections. The next section defines the advantages and potential applications on an Air Force base of the fuel cell energy system and fully describes the operational characteristics of the fuel cell energy system. Section III summarizes the goals, objectives, and major players in the National Fuel Cell Program. Section IV investigates the anticipated economics of fuel cell energy systems. Finally, Section V outlines the U.S. Air Force Field Test Demonstration Program Plan.

SECTION II

ON-SITE FUEL CELL ENERGY SYSTEMS

INTRODUCTION

The Department of Energy (DOE) estimates that fuel cell technology could, in the near term, save this nation 270,000 barrels of oil equivalents per day and over $1 billion in foreign imports per year (1). United Technologies Corporation (UTC), under contract to DOE, has further investigated the market potential of fuel cells and estimates significant long-term public benefits (2). These long term benefits include a $6.2 billion reduction in individual consumer energy bills and an additional $3.4 billion increase in indirect societal benefits. Figure 4 highlights the fuel cell associated public benefits predicted by UTC.

This section explains the basic electrochemical energy conversion process, defines the conservative fuel cell; identifies the potential applications of fuel cells on an Air Force base; and finally, highlights pertinent fuel cell fundamentals. The following section describes the governmental and industrial programs ongoing to achieve these long-term public benefits indicated in Figure 4.

ELECTROCHEMICAL ENERGY CONVERSION SYSTEMS

Energy, the ability to do useful work, is neither created or destroyed. Effective use of energy depends on efficiently converting energy from one form to another. Indeed, our industrial growth as a nation has partially resulted from our flexibility and technological know now to convert abundant energy sources from one energy form to another. For example, for centuries, solar energy has been slowly converted into biomass energy, and in turn; wood and other forms of biomass have been converted into steam--and other forms of

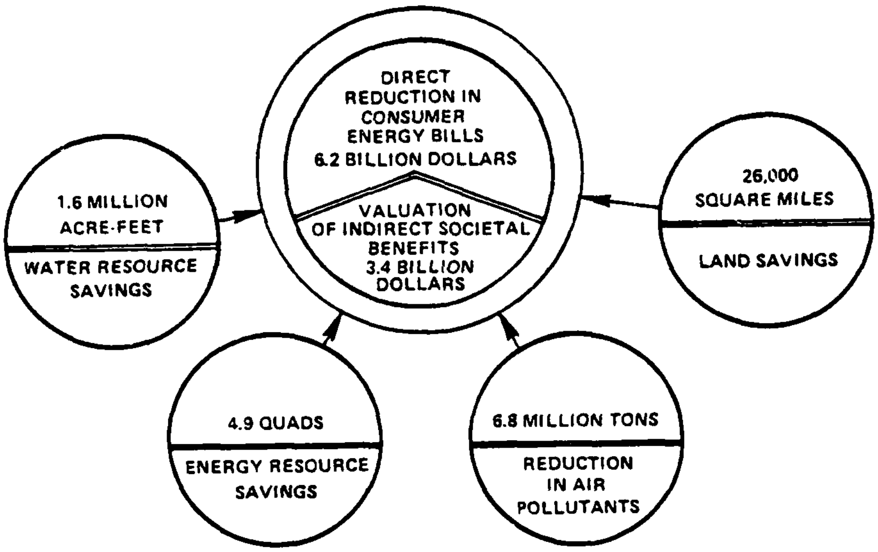


Figure 4. Cummulative Fuel Cell Energy System Public Benefits By the Year 2000. (2) Note: 1 Quad is equal to 10^{15} Btu and these results were obtained by assuming a 1983 commercialization market entry with 25 million kw of fuel cell energy systems by FY 2000.

energy. To further this example, the discovery of domestic sources of fossil fuels in the 1850's resulted in our development of many new chemical-mecnanical energy conversion technologies which help support tne industrial revolution. Figure 5 shows the myriad of energy conversion alternatives not available to the energy engineer (3).

Electromechanical energy conversion devices have dominated the scene throughout the 20th century. Indeed, electric machines are compact, powerful, flexible, and a very versatile means of converting energy. However, a new breed of energy conversion technologies are reaching the initial stages of commercialization. These electrochemical energy conversion technologies could significantly augument conventional electromechanical devices by the year 2000!

Electrochemical energy conversion processes include the familiar storage battery and the fuel cell. These devices are characterized by the fact that they convert chemical energy directly into electric energy. No intermediate energy conversion process occurs. Because of this direct energy conversion, electrochemical devices are a very efficient means of energy conversion.

Fuel cells are similar to batteries. Fuel cells and batteries are constructed with a cathode, an anode, an electrolyte, and some type of external electrical circuit. The common lead-acid storage battery, typical of the automobile ignition system, is a secondary type storage battery; that is, the intermittent chemical energy conversion process can be continued only by recharging the cell. During the recharging process, energy is utilized to reconstitute the chemical reactants. On the other hand, the common dry cell battery, a primary cell, cannot be recharged. When the chemical reactants are fully consumed, the electrochemical energy conversion process is exhausted. The unique difference between the storage cell and the fuel cell is that the

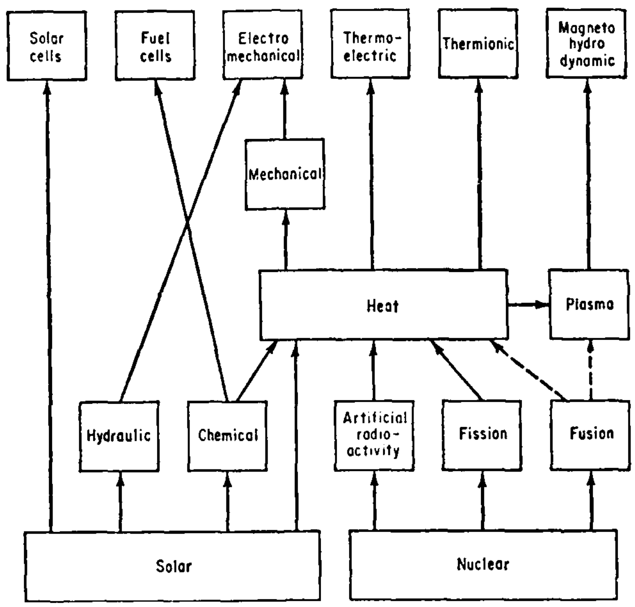


Figure 5. Energy Conversion Alternatives from Basic Resources to End-Product Technologies. (3)

fuel cell allows for a continuous energy conversion process; electrodes are not consumed. As long as the chemical reactants are fed into the cell, energy in the form of heat and electricity is produced.

ON-SITE FUEL CELL ENERGY SYSTEMS

The fuel cell, an electrochemical energy conversion device, directly converts chemical energy stored in two reactants into electric and thermal energy. Ultimately, the two reactants combine and form a chemical compound of lower internal energy.

Fuel cells are not new devices. Sir Humphrey Davy built a type of fuel cell in 1801 using zinc and oxygen as reactants in an electrolyte which resulted in the direct conversion of chemical energy into electricity (4). Efforts in developing a practical fuel cell resulted when Sir William Grove, in 1839, demonstrated that gaseous reactants could be combined to produce electric energy. In Grove's classic experiment, platinum catalyst electrodes were utilized to combine hydrogen and oxygen gases in an alkaline electolyte (5).

The fuel cell energy conversion process takes place in a single chamber or cell, as shown in Figure 6. As depicted in this figure, the fuel and oxydizer are combined in the medium of an electrolyte at the boundary of the electrodes and a voltage potential is developed externally between the electrodes. When an electric circuit is completed between the electrodes, direct current flows. The stored chemical energy available within the reactants is released upon reactant combination and results in an electric and thermal energy release from the cell.

Fuel cells can be classified based on the chemical characteristics of their electrolyte. For example, the initial Grove's cell combined hydrogen

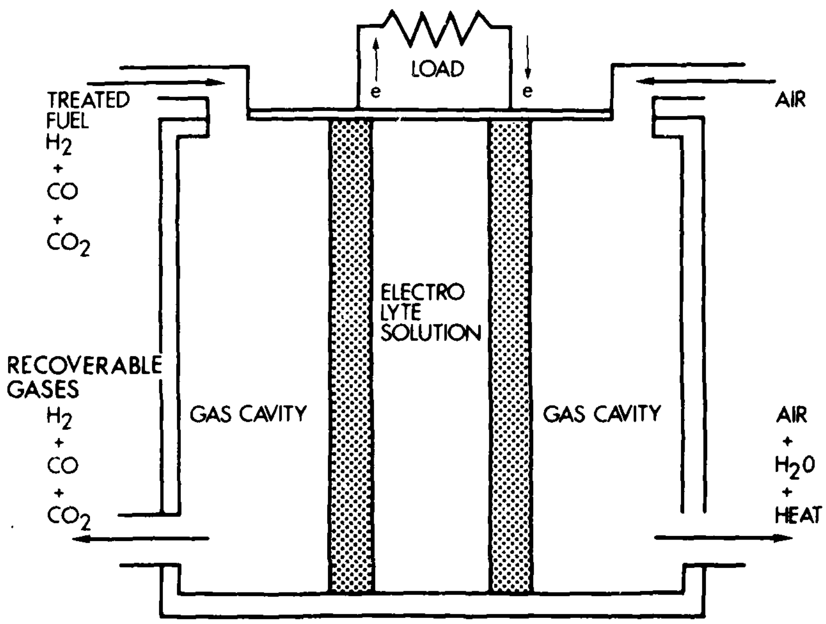


Figure 6. The Basic Fuel Cell Energy Conversion Process.

and oxygen reactants in an alkaline (potassium hydroxide) electrolyte. Currently, engineering development is ongoing with hydrogen-oxygen fuel cells using both alkaline and acid electrolytes. Additionally, high temperature molten carbonate and solid-type electrolytes are undergoing advanced research and development. Fuel cells can further be classified based on the fuel type. Generally, fuels within the fuel cell power section are limited to pure hydrogen; however, a fuel preprocessor, called a reformer, can accept liquid and gaseous hydrocarbons or carbon-based fuels (most notably coal and carbon monoxide). Figure 7 shows the versatile fuel options available for new generation fuel cell energy systems. Finally, fuel cells can be classified based on physical dimensions, weight, and electric power output.

As discussed, the fuel cell converts chemical energy into electric and thermal (both low temperature and higher temperature) energy. Figure 8 diagrams the auxiliary equipment required to support the fuel cell power section. As shown in Figure 8, a hydrocarbon-based fuel flows into the reformer section. Additionally, steam is required during the fuel reforming process. The reformer processes the high molecular weight hydrocarbon fuel and cracks it into its component parts. The hydrogen from the reformer is then combined with oxygen (air) within the fuel cell power section. Electric power, in the form of direct current, is produced and inverted in the power conditioning section. Alternating current at 115 volts (or any other desired voltage level) is the output. Some of the thermal energy available (steam) is utilized to support the reformer process. Excess thermal energy can be utilized to meet industrial process and space heating needs. Figure 9 diagrams the component layout of a pre-prototype fuel cell energy system, as manufactured by the United Technologies Corporation (6).

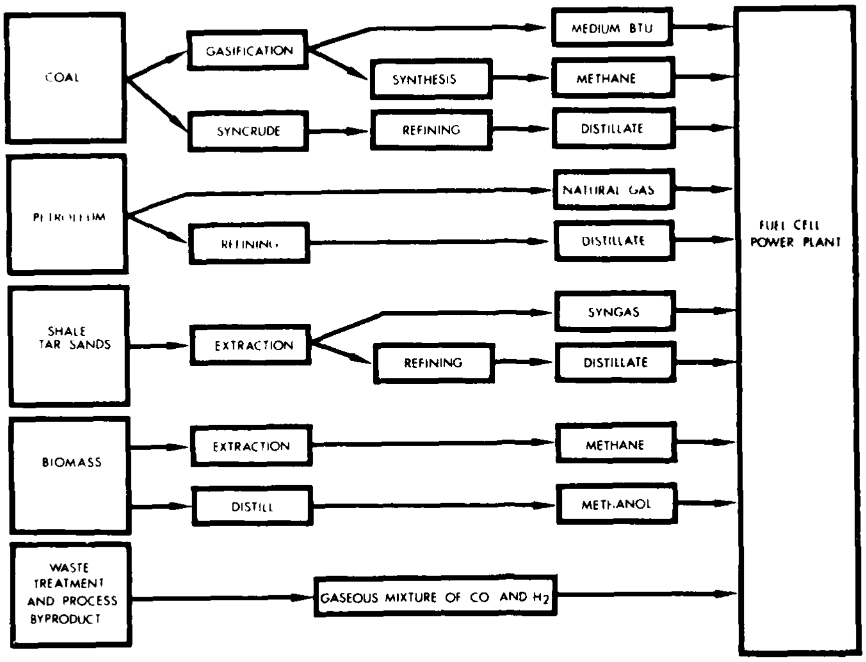


Figure 7. Fuel Cell Energy Systems Fuel Resources.

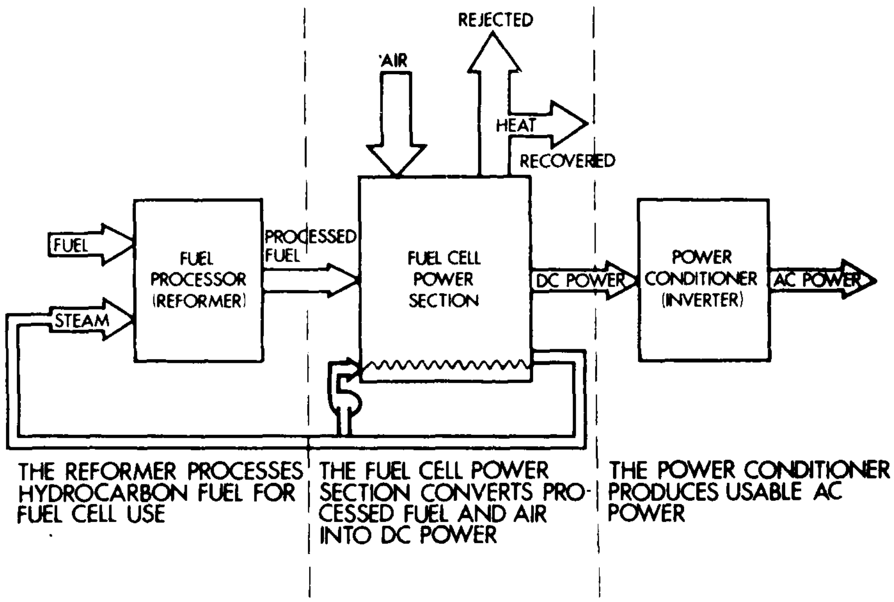


Figure 8. Block Diagram of a Fuel Cell Energy System. (6)

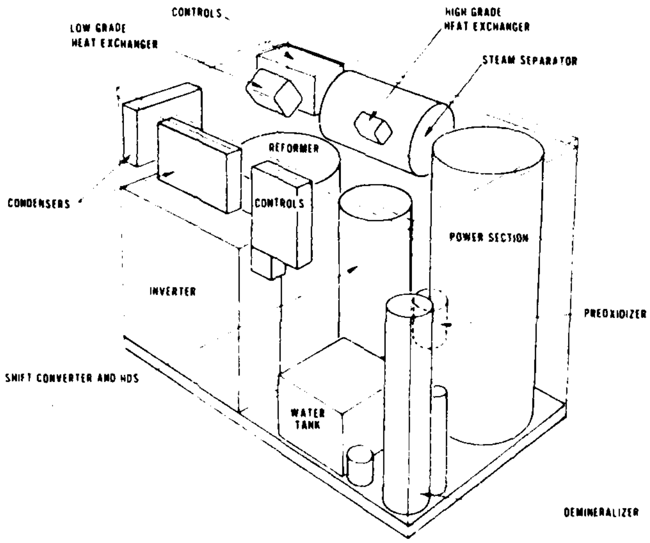


Figure 9. Component Layout of the UTC Preprototype 40 kw Fuel Cell Energy System. (6)

One advantage of the fuel cell as an energy conversion device is its high chemical to electric energy conversion efficiency. Further advantages of the fuel cell are that it maintains this high level of energy conversion efficiency with part load operation. The fuel cell can be used in a cogeneration configuration; that is, where both electric and thermal grade energy can be recovered. Under cogeneration operation, the fuel cell has an overall chemical to thermal efficiency of 80 percent.

Other advantages of the fuel cell include the fact that the cell does not contribute significant quantities of air, water or noise pollution and the cell is modular and thus can be efficiently arranged in many versatile electric power output configurations. Further, the cell requires a minimum of maintenance and can operate unattended for long periods of time. Table 4 summarizes the numerous advantages of fuel cell as an industrial power source.

The fuel cell energy system could provide an energy conservative means of supplying energy-intensive facilities on a U.S. Air Force base. Additionally, the fuel cell energy system could replace Air Force-owned standby generator systems at hospitals, computer centers, operational and security buildings, and airfield navigational aids and lighting systems. The reliability and economics associated with these standby or emergency fuel cell cogeneration systems may, in time, result in these "standby" units being utilized as "prime" units with commercial power backup. Fuel cells are comparitively lightweight and air transportable and could operate on conventional distillate or residual fuel stocks. They could replace emergency generators on Civil Engineering continuency pallets and could be installed within Aerospace Ground Equipment (AGE) to support military aircraft ground operations. Larger fuel cell systems could replace (or supplement) the electrical power transformer

TABLE 4

ADVANTAGES OF FUEL CELL

- High efficiency across all loading characteristics
- Quiet
- Low Pollutant emissions
- Compact and modular
- A cogeneration technology
- Instant load response
- Multiple fuel capability
- Unattended operation
- No vibrations

and electric distribution systems for single buildings or large areas of an Air Force base and provide power for remote applications. Table 5 lists the potential fuel cell applications on an Air Force base.

Although there are several different types of fuel cells, their principles of operation are similar; the simple hydrogen-oxygen-alkaline electrolyte model, as described in the next section, adequately depicts the internal electrochemical processes involved. The following section describes the technical characteristics of the elementary fuel cell energy system.

FUEL CELL FUNDAMENTALS

The fuel cell is composed of four parts: the hydrogen electrode (cathode), the oxygen electrode (anode), the electrlyte and the external electrical load. This material has been abstracted from reference (7).

The Hydrogen Electrode Process

Figure 10 shows schematic diagram of the processes in a hydrogen-oxygen fuel cell. At the fuel electrode, hydrogen gas is transported into the cell from an external fuel supply and then through the pores of the electrode to the reaction site. In its natural state, hydrogen consists of diatomic molecules represented by H_2; however, immediately prior to the electrochemical reaction, the hydrogen molecules are chemisorbed (become attached via a catalyst) on the surface of the electrode catalyst, and the molecule then splits into two separate chemisorbed hydrogen atoms. After the chemisorption step, the individual atoms migrate a short distance through the electrode pores to the reaction zone. At the same time, hydroxyl (OH^-) ions, which are part of the electrolyte solution, are transported through the electrolyte within the electrode pores to the reaction zone. In the presence of a catalyst, the chemisorbed hydrogen atoms and the hydroxyl ions combine,

TABLE 5

POTENTIAL USAF USES FOR FUEL CELLS

ENERGY-INTENSIVE FACILITIES WITH HIGH COINCIDENT ELECTRICAL/THERMAL LOADS

-Industrial	-AAFES facilities
-Military Family Housing	-Hospital
-Enlisted dormitory complexes	-Computer facilities
-Enlisted dining halls	-Sewage treatment plant

EMERGENCY AND STANDBY SYSTEMS

-Hospital	-Navigational Aids
-Security police, civil engineering, and operations and maintenance command posts	-Airfield lighting system
-Sewage treatment plant	

MOBILE APPLICATIONS

-Aerospace ground equipment

-Shuttle buses and maintenance vehicles

-Industrial forklifts and other warehouse vehicles

REMOTE APPLICATIONS

-Radar stations	-Navigational equipment
-Communication sites	-BARE BASE facilities

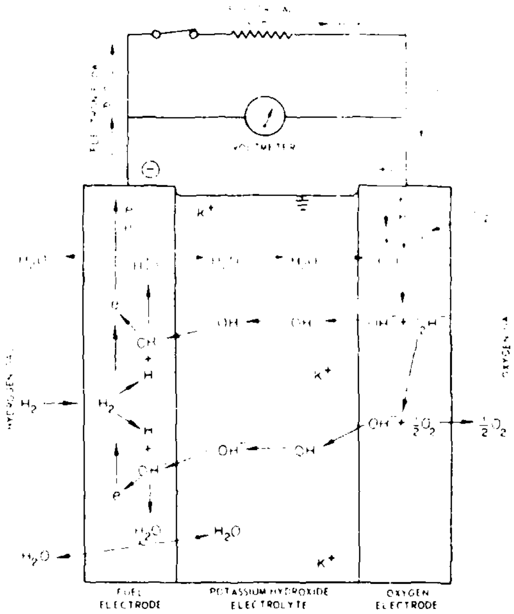


Figure 10. Schematic Diagram of a Hydrogen-Oxygen Fuel Cell Energy System. (7)

forming water (H_2O) and releasing an electron to the electrode. The water is either dissolved into the electrolyte or passed out through the fuel pores in a gaseous form, depending upon the relative water vapor pressure in the fuel gas and the vapor pressure of the liquid electrolyte. In summary, the following reactions occur at the fuel electrode:

Step 1. H_2 (free) $\longrightarrow$ H_2 (chemisorbed)

Step 2. H_2 (chemisorbed) $\longrightarrow$ H (chemisorbed) + H (chemisorbed)

Step 3. 2H (chemisorbed) + $2OH^-$ $\longrightarrow$ $2H_2O + 2e^-$, and the

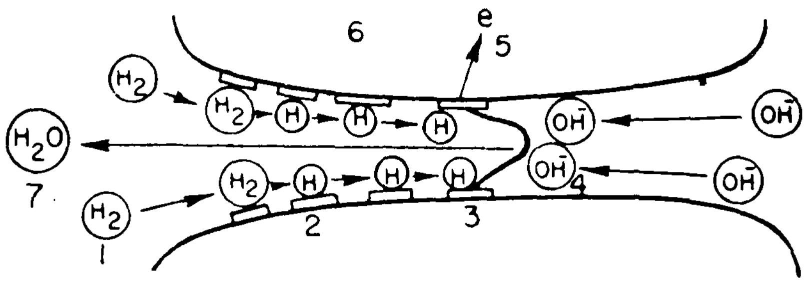
net fuel electrode reaction is:

$$H_2 + 2OH^- \longrightarrow 2H_2O + 2e^-$$

At the hydrogen fuel electrode, the catalyst plays a dual role. Besides acting to decrease the activation energy necessary to commence the reaction, it also serves as a bonding surface upon which the hydrogen molecule chemisorbs, splits, and migrates to the reaction zone.

Figure 11 shows the porous electrode reaction zone where the electrochemical reaction process occurs. On the right of the figure the liquid electrolyte containing hydroxyl (OH^-) ions flows into the porous electrode. On the left is the gaseous fuel. At this reaction zone, the porous electrode must contain the point of electrochemical reaction consisting of chemisorbed particles, electrolyte, catalyst, and the electrode.

The location of the reaction zone interface is controlled by the relative gas and electrolyte pressures, pore sizes, and the surface tension between the electrode pore and the electrolyte. In an operating cell, if the differential gas pressure becomes too high, fuel gas will flow through the electrode into the electrolyte without reacting. In some porous electrodes, if the fuel gas pressure becomes too low, the electrolyte solution will flood the pores and cover all the active reaction surfaces.



1. Hydrogen Molecule
2. Adsorption Catalyst & Hydrogen Atoms
3. Reaction Zone & Reaction Catalyst
4. Hydroxyl Ions
5. Released Electron
6. Electrode
7. Water Molecule

Figure 11. Fuel Cell Electrode Catalyst Reaction Zone. (7)

The Oxygen Electrode Process

After the electron is released at the fuel electrode, it is conducted through an external electrical circuit where the electron flow (an electrical current) can perform useful work. As in the case of two dissimilar metals, when the circuit is completed, electrons will flow from the fuel electrode through the external circuit and into the oxygen electrode.

Oxygen atoms are found in nature bonded into oxygen molecules containing two atoms. However, while these oxygen molecules (O_2) are also chemisorbed on a catalyst surface prior to the reaction, they do not split into individual oxygen atoms as do the hydrogen atoms. After chemisorption, the oxygen atoms migrate a small distance to the oxygen reaction zone. Here, with the presence of a catalyst, they combine with two electrons from the electrode, and one water molecule from the electrolyte, to form a perhydroxyl (O_2H^-) and a hydroxyl (OH^-) ion. The reaction is:

$$O_2 \text{ (chemisorbed)} + H_2O + 2e^- \longrightarrow O_2H^- + OH^-$$

The hydroxyl ion then passes into solution to replace one of the two hydroxyl ions consumed concurrently at the hydrogen electrode.

The perhydroxyl ion (O_2H^-) is more of a problem. The accumulation of these ions at the oxygen electrode reaction zone will substantially reduce the oxygen half cell voltage. Therefore, it is desirable to minimize the concentration of perhydroxyl ions.

In summary, the following reactions occur at the oxygen electrode:

Step 1. $O_2 \text{ (free)} \longrightarrow O_2 \text{ (chemisorbed)}$

Step 2. $O_2 \text{ (chemisorbed)} + H_2O + 2e^- \longrightarrow O_2H^- + OH^-$

Step 3. $O_2H^- \longrightarrow OH^- + O$

and the net oxygen electrode reaction is:

$$1/2\ (O_2) + H_2O + 2e^- \longrightarrow 2OH^-$$

The role of the catalyst in the oxygen electrode is threefold. It plays its usual part in reducing the activation energy required to cause the reaction. In addition, it chemisorbs the oxygen molecules at the reaction zone. And finally, the catalyst breaks down the perhydroxyl ions allowing the cell to remain in chemical balance and allowing the oxygen electrode to maintain a voltage nearer its true electrochemical potential.

Function of the Electrolyte

During the operation of the cell, it was shown that hydroxyl (OH^-) ions were consumed at the hydrogen electrode, and that some water was rejected into the electrolyte. It was also shown that at the oxygen electrode, water was consumed from the electrolyte, and the hydroxyl ions (OH^-) were formed. The function of the electrolyte is simply to supply the ions at the fuel electrode, water at the oxygen electrode, and to act as a mechanical barrier between the two gases to prevent mixing and direct combustion.

When the reaction is in progress, the electrolyte acts as an ion and water transfer medium. Since the water content of the cell is high (70 percent), this water molecule transfer is accomplished easily by normal internal molecular diffusion and convection. The concentration of (OH^-) ions is considerably smaller, and represents a much greater problem at high reaction and transfer rates. Ions are transported by a combination of diffusion, convection, and electrostatic attraction.

A convenient way of looking at the electrolyte function is as an electron charge transport by means of ions. Reviewing the electrochemical circuit, as shown in Figure 11, electrons are released at the fuel electrode, conducted through the external circuit, and received by the oxygen electrode. In order to complete the electrical circuit, they must be transported from the oxygen electrode to the fuel electrode. Through a reaction at the oxygen electrode, the electron becomes part of an ionic charge which carries this additional electron across the electrolyte. When reaching the fuel electrode, the OH^- particle deionizes and releases the electron. Thus, the electron has completed the electrical circuit.

Over-all Fuel Cell Process

In the model fuel cell, hydrogen enters the porous fuel electrode and reacts with hydroxyl ions from the electrolyte, forming water and giving off electrons in the process. These electrons then flow through the external electrical circuit to the oxygen electrode. Oxygen then reacts with water and these electrons to form hydroxyl ions. These hydroxyl ions then flow through the electrolyte back to the fuel electrode. The internal reactions are:

Fuel Electrode: $H_2 + 2OH^- \longrightarrow 2H_2O + 2e^-$

Oxygen Electrode: $1/2\ O_2 + H_2O + 2e^- \longrightarrow 2OH^-$

Net Reaction: $H_2 + 1/2\ O_2 \longrightarrow H_2O$

Acid electrolyte cells are of greater interest than alkaline electrolyte cells for terrestrial application because the acid electrolyte cells result in higher long-term performance when hydrocarbon or carbon dioxide fuels are utilized. This is true because when the potassium hydroxide electrolyte is used with a hydrocarbon or carbon-based fuel source, the electrolyte gradually becomes inoperative as the concentration of hydroxyl ions is greatly reduced by the presence of bicarbonate. The reaction at the anode is:

$$2CO + 4OH^- \longrightarrow 2H_2O + 2CO_2 + 4e^-$$

Unfortunately, as the carbon dioxide is released, it is absorbed by the electrolyte:

$$KOH + CO_2 \longrightarrow KHCO_3$$

Thus, the alkaline cell is not only unsuitable for operation with CO as a fuel, it can be contaminated by the presence of a trace impurities of CO_2 in H_2 or O_2.

Research is currently ongoing in three future generations of fuel cells. First, phosphoric acid electrolyte fuel cells are nearing commercialization. Optimum catalyst materials, used for fuel reforming and cracking, are currently under investigation. Second, the molten carbonate system, which could use gasified coal, fuel oils or waste materials, is under investigation. Third, the high temperature cell using a solid-type electrolyte is being considered as a viable utility-based power source.

FUEL CELL EFFICIENCY

Fuel cells convert chemical energy directly into electrical energy without undergoing as intermediary (thermal energy) conversion process; and hence, eliminate a step which is always associated with a marked increase in entropy. This direct energy conversion process allows for the possibility of more effective utilization of hydrocarbon fuels, especially when compared with the alternative heat engine combustion technologies. Figure 12 shows the thermal energy conversion efficiencies and associated energy losses for a conventional electromechanical conversion process. Figure 12 shows a similar comparison of conversion efficiencies for the fuel cell process.

The Carnot limitation involved with the heat engine depends on the temperature difference between the source and sink reservoirs associated with the heat engine:

$$\eta = \frac{T1-T2}{T_2} \tag{1}$$

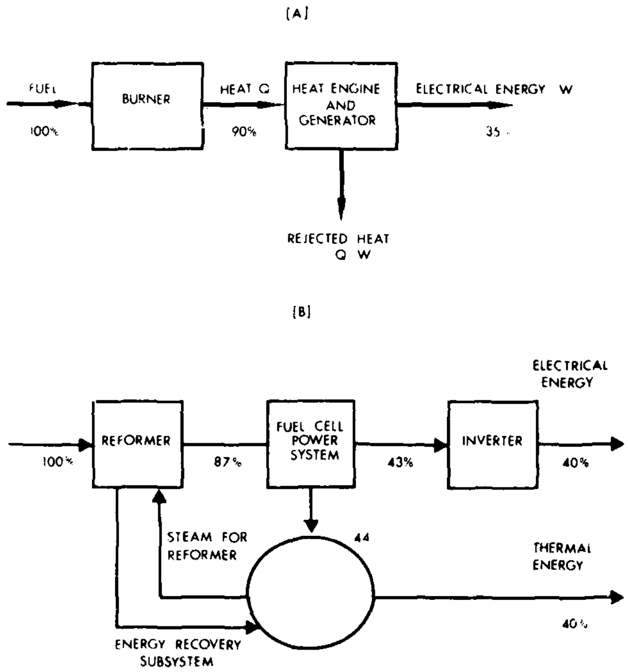


Figure 12. (a) Conventional Thermal Electric Conversion Efficiency and Associated Energy Losses. (b) Fuel Cell Conversion Efficiency and Associated Losses.

where T_1 is the temperature of the heat source, and T_2 is the temperature of the rejected heat reservoir. All temperatures are expressed in the absolute scale. This Carnot limitation, based on the second law of thermodynamics, severely limits the maximum practical conversion efficiency whenever a thermochemical energy conversion process occurs. As shown in Figure 12, the practical maximum conversion efficiency for conventional heat engine-to-electric energy conversion system is 35 percent

The fuel cell is not a heat engine and therefore is not controlled by the Carnot limitation. Chemical energy is converted directly into electrical energy; heat is not an intermediary form of energy conversion between the chemical reaction and the electrical output. Since heat is not intermediary, the Carnot limitation does not apply to the fuel cell. This is the reason for the overall high efficiency of fuel cell devices.

Although the fuel cell is not subject to the Carnot limitation, it is still not without heat losses and inefficiencies. While the heat of reaction (ΔH) represents the total heat energy (thermochemical) available in a fuel, only ΔF, the free energy of reaction, is available to do useful work during the electrochemical conversion process. Where ΔH is available for thermochemical work and $T \Delta S$ is the inherent heat generated in th reaction, the amount of energy available for electrochemical work, ΔF, is:

$$\Delta F = \Delta H - T \Delta S \qquad (2)$$

The maximum thermal efficiency is therefore,

$$\eta = \frac{\Delta F}{\Delta H}, \qquad (3)$$

$$= \frac{\Delta H - T \Delta S}{\Delta H} \qquad (4)$$

or

where: ΔH is the overall heat of the reaction,

ΔF is the Gibbs free energy of the reaction,

T is the absolute temperature,

ΔS is the change in entropy of the system.

The overall fuel cell efficiency relationship is related to temperature, as is the Carnot limited heat engine; however, fuel cell efficiency rises as the temperature of the cell decreases. Figure 13 shows this efficiency relationship for both the heat engine and the fuel cell.

There are further losses associated with the fuel cell. Besides the temperature realted $T \Delta S$ losses, the fuel cell is limited by electrode polarization effects. These polarization losses result from the internal chemical reaction of the reactants that result in electrode corrosion and undesirable heat. Polarization losses are related to the electrical loading at the electrode surfaces. Figure 14 shows a plot of cell electrode voltage potential versus current density in amperes per square foot of electrode surface area.

Activiation polarization occurs initially and is an irreversible effect. Ohmic polarization is the dominate effect through the normal operating range of the cell. Beyond point B in Figure 14, concentration polarization effects take over and will ultimately result in an internal short circuit of the fuel cell. Chang believes that these concentration polarization effects are a result of electrostatic effects due to concentration gradient in the electrolyte (3). This electrostatic effect of the ions in the electrolyte

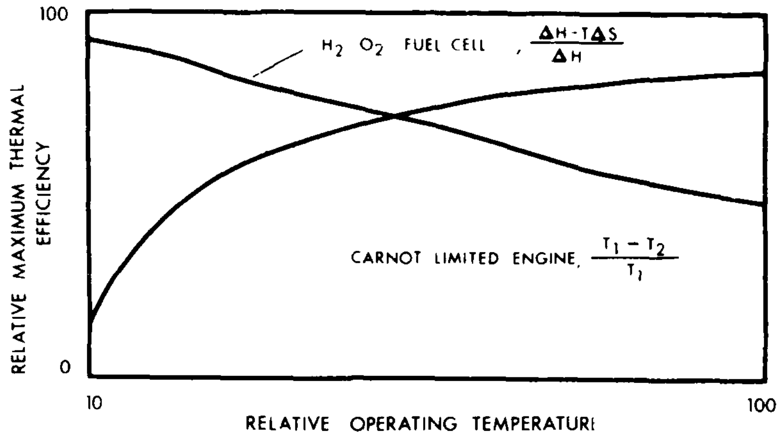


Figure 13. Comparison of Full and Part Loading on Conventional Thermal and Fuel Cell Conversion Technologies.

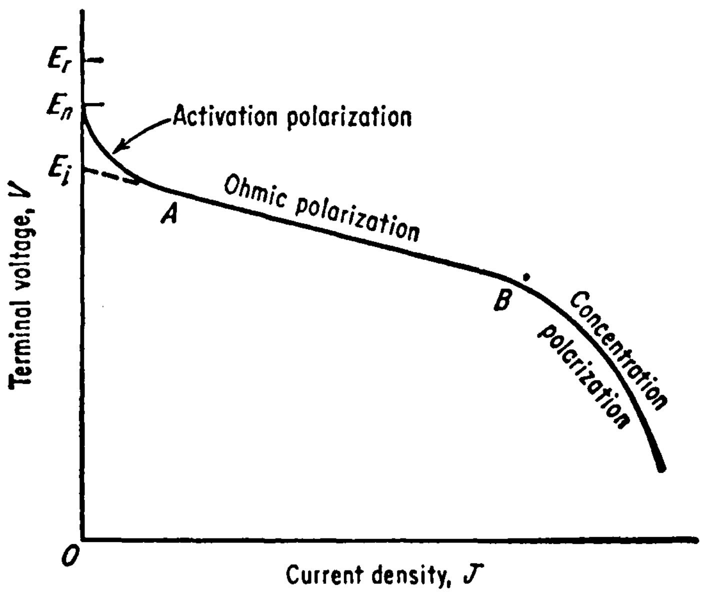


Figure 14. Fuel Cell Electrode Voltage Difference Versus Current Density. (3)

gives rise to local charge concentrations near the electrodes and limit in exchange across the bulk electrolyte.

There are several other ways that the efficiency relationship of fuel cells should be evaluated. First, Figure 15 plots the overall electric and useable thermal output of a fuel based on rated electric power out. This plot shows that the overall cogneration process, using fuel cells could approacn 80 percent, utilizing the optimum electric/thermal mix conditions. Figure 15 also demonstrates the very excellent part loading characteristics associated with fuel cells.

Second, Figure 16 shows a plot of the economical ranges of output electric power and efficiencies for conventional electromechanical devices and the fuel cell. This plot compares the versatile loading and efficiency characteristics of fuel cells from the smallest to the largest sizes.

SUMMARY

The basic concept of a fuel cell energy system is not new. Technical advances in material science and electrochemistry in the past one hundred years has resulted in fuel cell efficiencies which approach 80 percent. Furtner advances, however, are required in order to make these systems commercially viable in the market place.

Currently, research and development efforts are ongoing to improve the molten carbonate and solid-type electrolyte systems. Also, a significant effort is ongoing to demonstrate the market potential of the smaller size phosphoric acid electrolyte type fuel cell system. This system could be installed as a compact and efficient on-site fuel cell energy system that could provide both electric and thermal energy for residences and small industrial, commercial, and institutional customers.

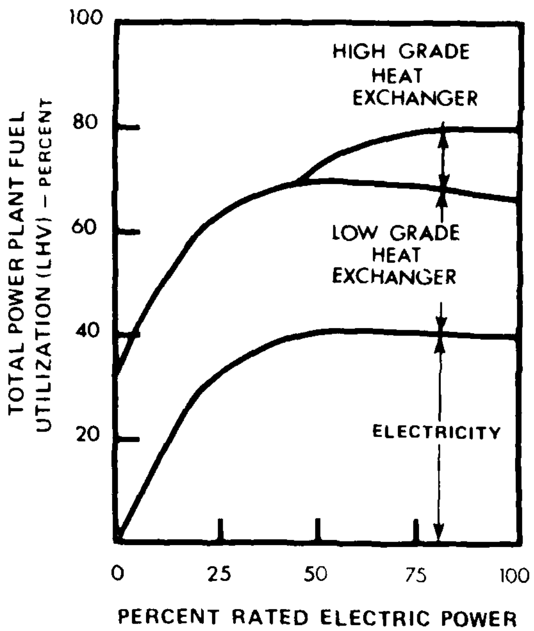


Figure 15. Overall Electric and Thermal Output of a Fuel Cell Based on Rated Electric Power Out. (6)

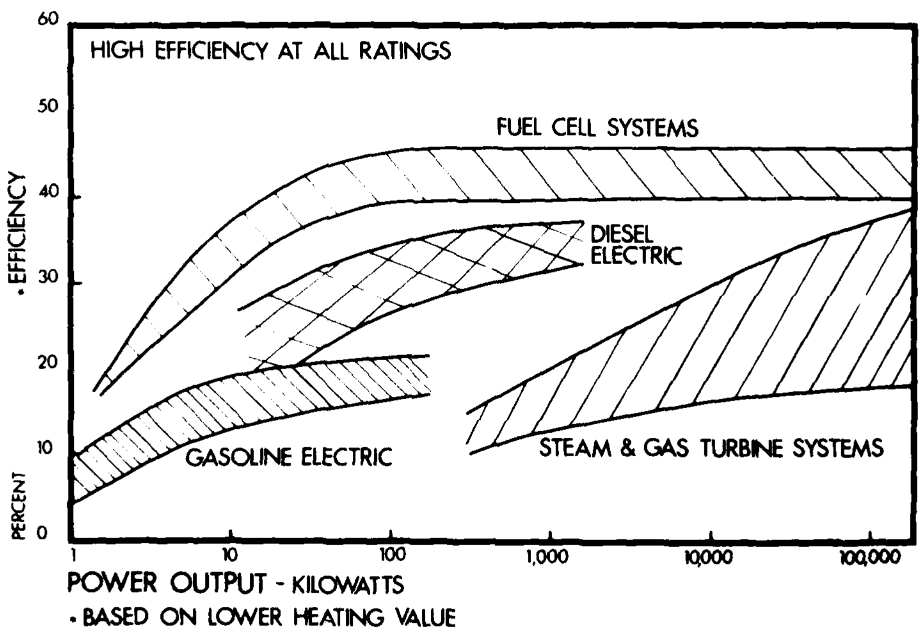


Figure 16. Economic Ranges of Output Electric Power and Efficiency for Conventional Thermal Devices and Fuel Cells.

owned by the utility that provides the system fuel supply, e.g., the gas utility supplying a hydrocarbon based fuel; or owned by the building owner.

The next section summarizes the governmental and industrial sponsored fuel cell research and development programs and specifically highlights the goals of the On-Site Fuel Cell Operational Feasibility Program.

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SECTION III

FUEL CELL ENERGY SYSTEM DEVELOPMENT PROGRAMS

INTRODUCTION

The fuel cell is an efficient and environmentally benign energy conversion technology which could supplement; or, in time replace, present energy conversion devices. The fuel cell, an electrochemical conversion process, directly converts energy stored in two chemical reactants into electric and thermal energy. Continued fuel cell research and development, including prototype and full scale system demonstration is required. Government incentives, to cover high-risk initial capital investments are also required in order for fuel cell energy systems to provide the substantial public benefits mentioned in Section II.

This section identifies the long-term technological and commercialization efforts ongoing by governmental and private organizations. Specifically, fuel cell energy system research and development is being conducted by ten major organizations, as listed in Table 6. These organizations are aggressively developing advanced technological systems and commercialization strategies for marketing fuel cell systems. This section summarizes the work of these major organizations and highlights the specific program plan to commercialize an on-site fuel cell energy system.

THE COMMERCIALIZATION OF FUEL CELL ENERGY SYSTEMS

A comprehensive National Fuel Cell Program has been recently established via the formation of the National Fuel Cell Coordinating Group. This group

TABLE 6

MAJOR ORGANIZATIONS CONCERNED WITH FUEL CELL DEVELOPMENT

Major Funding Organizations

- Department of Energy
- National Aeronautics and Space Administration
- Gas Research Institute
- Electric Power Research Institute
- Department of Defense

Major Developers

- Energy Research Corporation
- Engelhard Industries
- General Electric Company
- United Technologies Corporation
- Westinghouse Electric Corporation

allows for the continued dialogue between governmental and non-governmental funding organizations and is directed by the Department of Energy (DOE). The National Fuel Cell Coordinating Group recently has met and drafted a comprehensive program plan using the Critical Path Management (CPM) process (1). This CPM process involved identifying the program milestones in the form of an activity network having an explicitly defined set of objectives and expenditures. This process has helped identify and eliminate overlaps and the CPM process will indicate the impact of future resource constraints.

TECHNOLOGICAL SYSTEMS UNDER STUDY

Figure 17 displays the three major fuel cell energy systems currently under advanced research, development, and proof-of-concept testing. Prototype development and limited commercial production phases follow proof-of-concept testing. Phosphoric acid electrolyte fuel cell systems are receiving a major portion of advanced development funds and this technology could reach the initial phases of commercialization during the mid 1980's. Molten carbonate and solid electrolyte systems, both of which require further advanced research and development, unfortunately will not reach the initial phases of commercialization until after 1990. Table 7 summarizes the past and projected DOE funding for these three major types of fuel cell energy systems (2).

Phosphoric Acid Fuel Cell Energy Systems

The phosphoric acid fuel cell energy system could reach the initial phase of prototype commercialization by 1985. Preprototype development and proof-of-concept testing is ongoing in two competing program areas: (1) Multi-Megawatt utility-based systems, and (2) Multi-Kilowatt On-Site/Integrated Energy Systems. These two competing programs are described in further detail below.

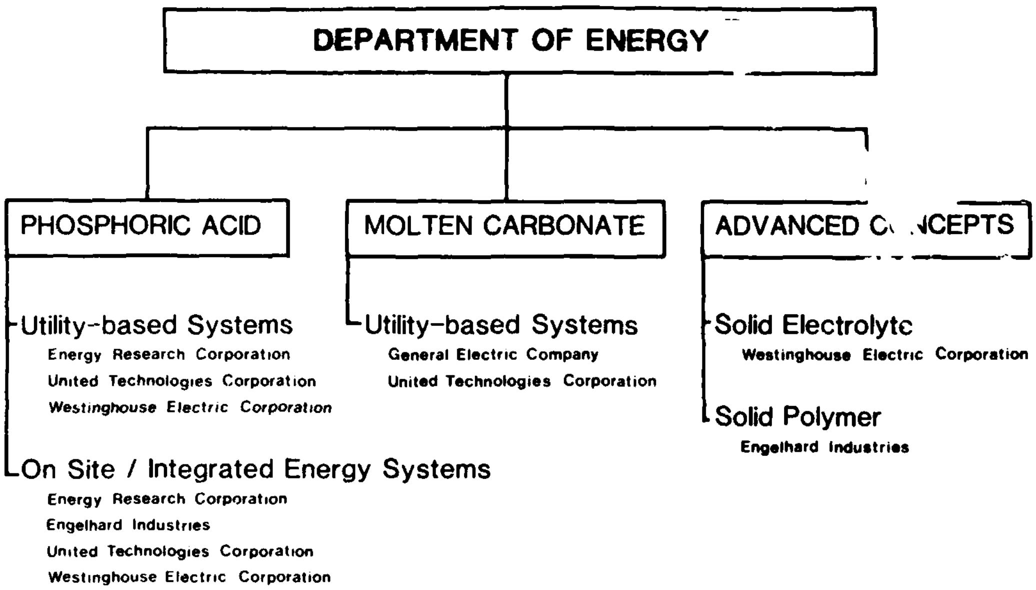

Figure 17. Types of Fuel Cell Energy Systems Undergoing Research, Development, and Proof-of-Concept Testing.

TABLE 7

DEPARTMENT OF ENERGY FUNDING STRATEGIES
THE NATIONAL FUEL CELL PROGRAM

DEPARTMENT OF ENERGY FUEL CELL TECHNOLOGY APPROPRIATIONS* ($million)

PROGRAM YEAR (FY)	TECHNOLOGY AREA		
	PHOSPHORIC ACID DEVELOPMENT	MOLTEN CARBONATE DEVELOPMENT	ADVANCED CONCEPTS
78	29.5	2.2	2.7
79	21.5	17.0	2.35
80	23.5	12.0	0
81 (est)	19.0	8.0	0

*These figures include the cost of supporting contracts, technology development, laboratory support and program management.

Westinghouse Electric Corporation and Energy Research Corporation are jointly developing a 7.5 Mw commercial utility-based fuel cell system (3). Currently, small preprototype subsystems are under investigation; emphasis in this program is placed on developing an air-cooled fuel cell stack assembly. DOE and Electric Power Research Institute (EPRI) are the major funding organizations for this program element, and the Tennessee Valley Authority and Southern California Edison are the two participating utilities involved in this program.

Alternatively, EPRI and DOE has requested that United Technologies Corporation (UTC) develop the Fuel Cell Generator (FCG-1) program (4). The ultimate goal of the program is to manufacture a 10 Mw modular phosphoric acid fuel cell for utility-base applications. The UTC system is water cooled and uses natural gas and naptna as a fuel stock. In 1971, the FCG-1 program demonstrated a 1 Mw experimental feasibility plant (5). This naptha fueled power plant successfully demonstrated the feasibility of a large utility-based fuel cell system. The next objective of the project is to design, build, and test in a utility, a 4.8 Mw power plant module. The Consolidated Edison Company of New York has been chosen as the host utility for this operational feasibility demonstration and the 4.8 Mw power plant is being erected in New York City and preliminary testing will begin this year.

Three phosphoric acid fuel cell on-site/integrated energy systems are under study and preprototype assembly. Engelhard Industries is developing a 100 kw system consisting of 25 kw modules that will reform methanol for use in a fuel cell energy system (6). It is anticipated that methanol will be abundantly available from coal in many locations that presently do not nave natural gas. The system will be water cooled. The program calls for a subscale 5 kw power plant to be operational by the end of this year. The design of the major components of the breadboard system will begin in 1981 with prototype construction starting in 1982. Proof-ot-concept testing is planned for 1983 through 1985.

The Westinghouse and the Energy Research Corporation on-site system program will parallel their utility-based fuel cell energy system program (7). Subsystem requirements will be refined while work progresses towards integrating the component parts which include the fuel cell power plant, the HVAC subsystem and energy storage. Like their utility-based system, this 60 kw (2 each, 30 kw modules) on-site system will be air cooled. System proof-of-concept tests are planned for 1985.

United Technologies Corporation is also involved in the development of an on-site/integrated energy system (8). This program is a follow-on of the TARGET (Team to Advance Research for Gas Energy Transportation) program which had successfully demonstrated sixty 12.5 kw fuel cell energy systems at 27 locations from 1972 through 1973. The UTC 40 kw on-site fuel cell energy system program plan calls for the manufacture and site demonstration of 45 power plants at 25 locations by 1985.

Both the Westinghouse/Energy Reserch Corporation and Engelhard on-site/integrated energy system programs will capitalize, to a certain extent, on the extensive field test phase of the UTC prototype power plants. All three manufactures will attempt to have operational on-site phosphoric acid systems by 1985. The ultimate goal of the phosphoric acid fuel cell program is to develop several qualified manufacturers and demonstrate the energy-efficient advantages of on-site/integrated energy fuel cell systems in the near term. This will inturn result in the commercialization of this unique energy conversion technology. Figure 18 highlights the major

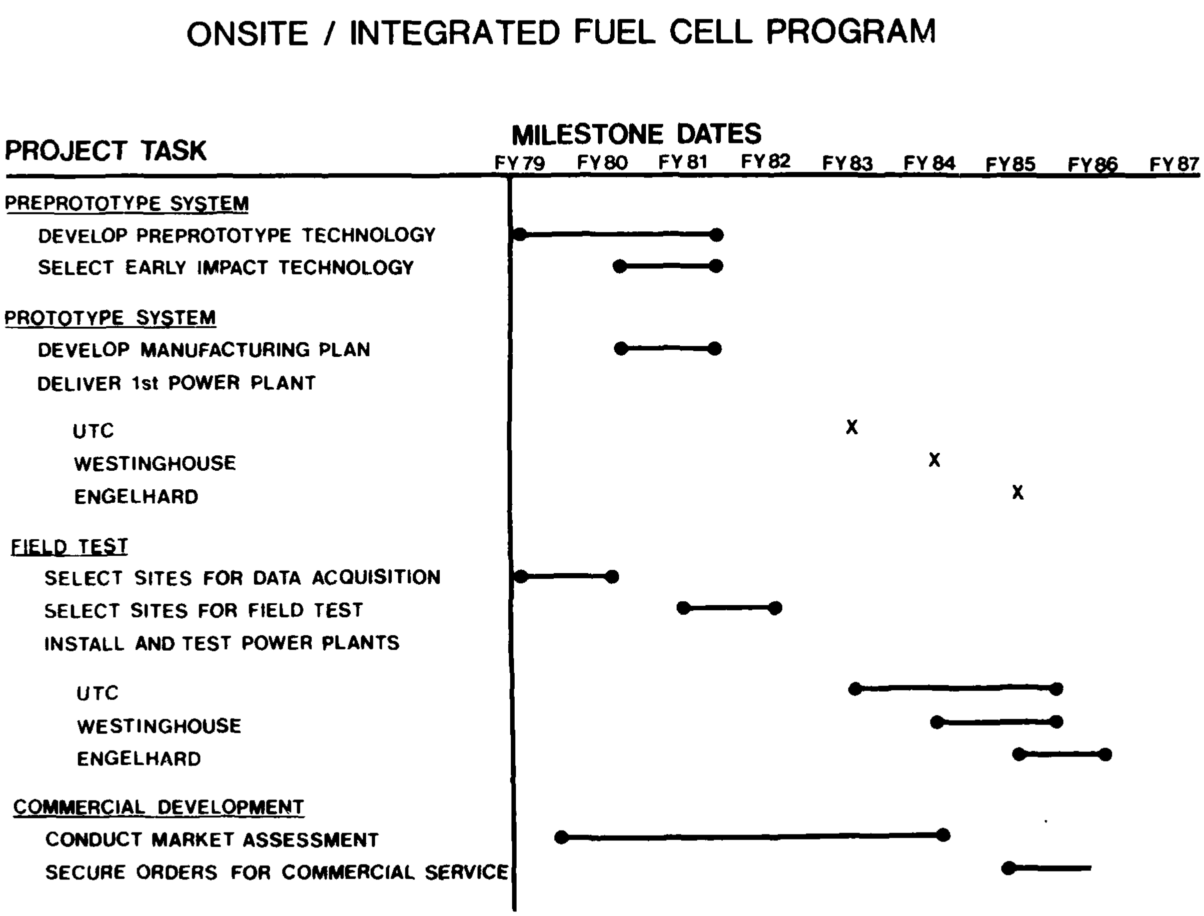

Figure 18. Program Milestones for the On-Site/Integrated Energy System Program. (1)

milestones of the On-Site/Integrated Energy System Fuel Cell Program, as identified by the National Fuel Cell Coordinating Group.

Molten Carbonate Fuel Cell Energy Systems

Molten Carbonate Fuel Cell systems utilize light petroleum or coal as a fuel stock and operate at high temperatures (1000° C). It is intended that these fuel cell energy systems would be installed within the utility grid; however, a cogeneration application would provide the most energy-efficient mode of operation. Therefore, the most efficient operation of the molten carbonate fuel cell system would be within a base-loaded utility system in a urban/commercial area where the byproduct thermal energy can be easily distributed and used for process or space heating/cooling. Once these systems become commercialized, they could be used to replace U.S. Air Force central heating plants and generate both steam and electricity.

DOE has established a $30 million program to develop molten carbonate fuel cell energy systems (3). Both the General Electric Company (GE) and UTC are involved in a program to: (1) develop a reference coal-fueled power plant design, (2) develop fuel cell stack components and verify component life; (3) initiate development of full-scale stack testing; and, (4) determine the tolerance to contaminants in coal-derived gas (9).

Advanced Fuel Cell Energy Systems

Advanced systems include solid electrolyte and solid polymer fuel cell energy systems.

Zirconia-based solid electrolytes are under investigation at the Brookhaven National Laboratory (10). Further, Westinghouse Electric Corporation is also investigating the advantages and limitations of yttria-stabilized-zirconia solid electrolytes (11). In general, these high temperature solid electrolyte fuel cell energy systems are composed of a thin layer of calcium stabilized zirconia supports, a nickel or cobalt-zirconia cermet as the fuel electrode, yttrium-stabilized-zirconia as the electrolyte tin-doped idium oxide or strontium/calcium substituted lanthanum manganite as the air electrode current carrier, and magnesium and aluminum-doped lanthanum chromite as the cell interconnection. These systems are intended for use in utility-based electric systems where a cogeneration application is available.

The solid polymer electrolyte fuel cell systems are under investigation by the U.S. Army and Engelhard Industries. These hydrogen/oxygen fuel cell systems would be fueled from a calcium hydride and water fuel canister and could provide a silent, lightweight electric energy system for lower power, long duration operations (12).

DEPARTMENT OF DEFENSE ACTIVITIES

The U.S. Air Force is the lead service organization for fuel cells. Due to the developing nature of fuel cell energy systems, the Aero Propulsion Laboratory (APL) is deeply involved in evaluating the efficient use of fuel cells. APL acts as a DOD focal point for information transfer and interagency and interdepartmental coordination. The major thrusts of the APL program are to adapt DOE fuel cell technology and to develop military unique fuel cell subcomponents. Figure 19 highlights the APL program elements (13).

The Aero Propulsion Laboratory has identified several application studies that must be undertaken prior to the military testing and demonstration of fuel cell energy system. The On-Site Fuel Cell Field Test Application Analysis project will aid Air Force Engineering and Services personnel identify candidate sites for demonstrating kilowatt-sized fuel cell energy systems. The initial phase of this project is the program plan described in

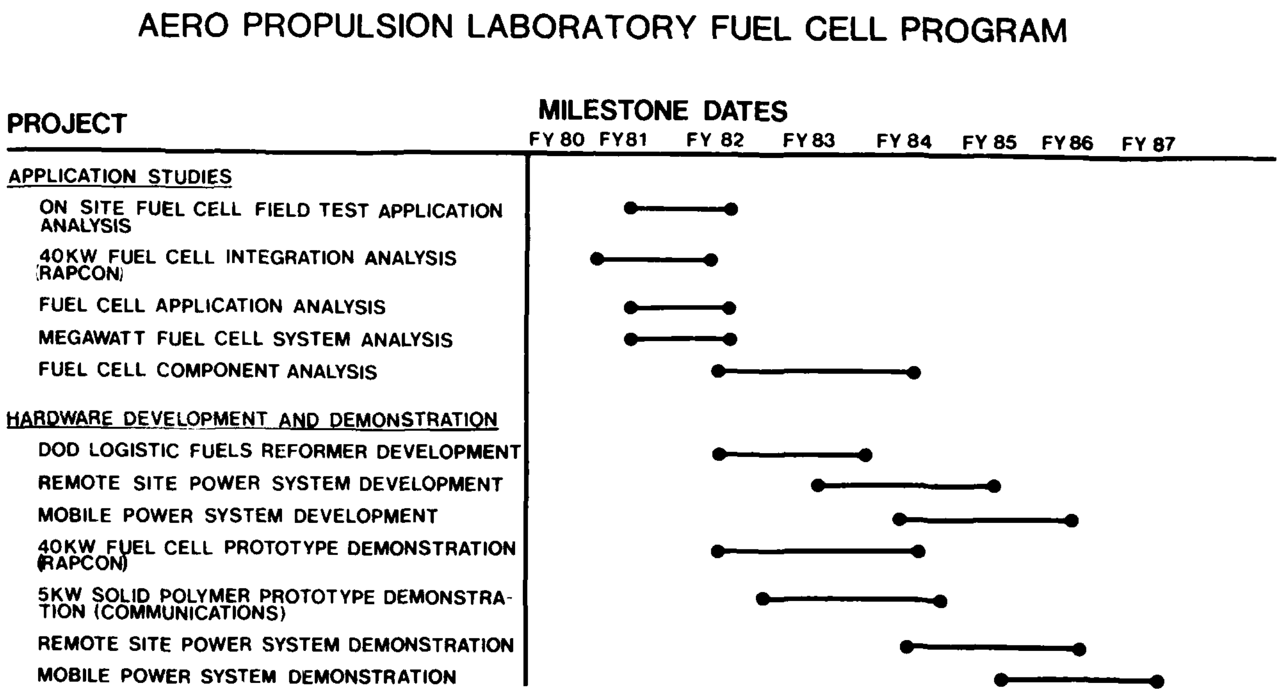

Figure 19. The Aero Propulsion Laboratory Fuel Cell Energy System Program Plan. (13)

Section V of this report. Studies are being completed to integrate the prototype 40 kw UTC Fuel Cell System into a Radar Approach Control Facility (RAPCON) at McClellan AFB, California. Also, the APL has under contract a one-year Fuel Cell Applications Analysis Study. The objective of this study is to quantify the numerous technical and non-technical parameters which define the operational characteristics of practical fuel cell energy systems. Additionally, these parameters are to be matched against specific U.S. Air Force system requirements and applications. Preliminary conceptual designs and technical risk assessments will be prepared; prototype systems development will be initated on those very technically sound or high potential systems. A subsequent two year contract is planned that will detail specific subcomponent problems and recommend solutions. These application studies are intended to compliment and build upon the present projects initiated by the National Fuel Cell Coordinating Group.

The U.S. Air Force plans to test subcomponents specifically tailored to the needs of the military. Projects include analyzing and bench testing specific DOD logistic fuels and identifying reformer problems and recommend solutions. Both remote site and tactical mobile power systems will be specially fabricated and field tested to determine their reliability in theater of operations applications. Emphasis in this program is placed on complementing and extending the work of the Department of Energy. Military-unique applications, utilizing the technology as developed by DOE, is the major thrust of the APL program plan.

The U.S. Army is also interested in the development of silent, lightweight, electric energy plants. Currently, the Army is developing 1.5, 3.0, and 5.0 kw fuel cell systems that will utilize methanol as a fuel stock.

These phosphoric acid fuel cell energy systems are intended to develop into a family of small power supply units. The Army is also investigating the use of solid polymer electrolyte fuel cell energy systems for low power (120w and 30w) continuous long duration applications (12). The U.S. Army has committed a large investment to the exploratory and advanced development of these lightweight and low power systems.

THE NATIONAL ON-SITE/INTEGRATED ENERGY SYSTEM FUEL CELL OPERATIONAL FEASIBILITY PROGRAM

The objective of the On-Site/Integrated Energy System Fuel Cell Operational Feasibility Program is to establish national acceptance of and commitment to fuel cell energy systems as a new business option with high fuel conservation and environmental value. This acceptance by the utilities, manufacturers, and sponsoring agencies means this program must provide the information that will permit the participants to answer the key question--will they commit to a commercial service including a market test? For the gas industry members this means a commitment to place orders for fuel cell energy systems for market testing; for the manufacturer this means an offer to sell the power plants (which may include a commitment to invest in a facility and the acceptance of front end operating losses). To accomplish this objective, the following program plan has been defined:

- A field test program to verify the operational feasibility of the on-site fuel cell power plant in a variety of attractive early entry markets, and

- Business studies by the potential user utilities to examine and define proposed business scenarios for the commercial fuel cell service to be offered and to assess their meaning to each utility.

To achieve these two general program elements, the following goals must be met:

- Establish operational feasibility and measure reliability of the power plants as a key element of on-site energy systems,
- Verify the fuel conservation and environmental characteristics of on-site fuel cell energy systems,
- Evaluate institutional, regulatory (PUC involvement), code and legal issues under various simulated ownership arrangements,
- Verify the practicality of different on-site fuel cell energy system configurations in a variety of applications and conditions,
- Verify system economic performance including capital cost, installation costs, and operating and maintenance costs,
- Inform the public of the concept in order to prepare for broader acceptance by society, and
- As a result of in-service operation identify power plant improvements requiring design iteration.

Program Scope

The Fuel Cell Operation Feasibility Program consists of a field test program in conjection with business studies by the participating utilities to establish the attractiveness and practicality of entering into commercial fuel cell energy service.

At the beginning of the field test program the participating utilities will select condidate sites for fuel cell installations and instrument these sites to provide thermal and electrical use information. This information will be utilized in evaluating the candidate sites and making final site recommendations.

The fuel cell power plants will be installed by the gas utilities in a range of attractive early entry applications and geographical areas to acquire data covering representative variations in electrical and thermal load use patterns, energy system configurations, climate, competitive service economics, business factors, and institutional, legal, and regulatory matters. The installations will include a variety of multi-unit residential, commercial and light industrial applications. When implemented, it is expected that his program will place systems in about 30 states and will measure the impact of fuel conservation and environmental quality, provide a broad encounter with institutional, franchise, and legal problems, allow widespread public information and customer attitude sensing, and provide fuel cell power plant and system technical data necessary to measure power plant operational suitability.

A business assessment will be conducted by each participating utility in parallel with the field test program. This effort will define the market and business format to be offered to utility customers at the completion of the Operational Feasibility Program and it will determine the overall attractiveness of the business venture. This business analysis and assessment, together with the field test results, will provide the basis for each utility company and their participating customers to reach a position concerning participation in the subsequent market test. The major number of fuel cells involved in this field test program will be manufactured by UTC; however, a significant number of Westinghouse/Energy Research Corporation and Engelhard on-site power plants will also be field tested as they become available.

Field Testing Activities

Field testing will be limited by total program funding and the power plant installation and testing commitments of the participating utility companies and their respective customers. Variations in electrical and thermal loads and system configurations, and wide exposure to policy makers, market decision makers, regulatory jurisdictions and gas utility company practices will be considered. The following criteria will be used as the basis for allocation of power plants:

- All market segments should be tested. The market segments include residential (multi-family), commercial and light industrial applications,
- Various building types in each market segment should be tested to cover the range of electrical and thermal loads, installation requirements, and the influence of policy makers and decision makers,
- Tests should be conducted in markets providing a large fuel conservation impact. The following market segments should be included for consideration in the power plant allocation:

  -Multi-family residential buildings
  -Office buildings and banks
  -Hospitals
  -Nursing homes
  -Laundries
  -Schools
  -Hotels and motels
  -Restaurants
  -Stores
  -Light industries
  -Group of single family homes

THE ON-SITE UTC FUEL CELL POWER PLANT

A limited number of fuel cell energy systems have been assembled and tested in the laboratory and in actual field applications. Current emphasis by the fuel cell manufacturers is on developing more efficient phosphoric acid cell stack assembly techniques and higher energy efficiency. Preprototype system development is progressing; systems should reach the initial phases of commercialization by 1985. Currently, UTC has developed a comprehensive on-site fuel cell energy system specification. This specification has been abstracted to provide the reader an order-of-magnitude feel for the pertinent system performance characteristics. Other manufacturer's specifications may differ. The UTC unit is illustrated in Figure 20. It is a compact and self contained power plant which weighs 7000 pounds and measures 9 feet long, 5 feet wide and 6 feet, 6 inches tall (Figure 21). The power plant is composed of the following major subsystems:

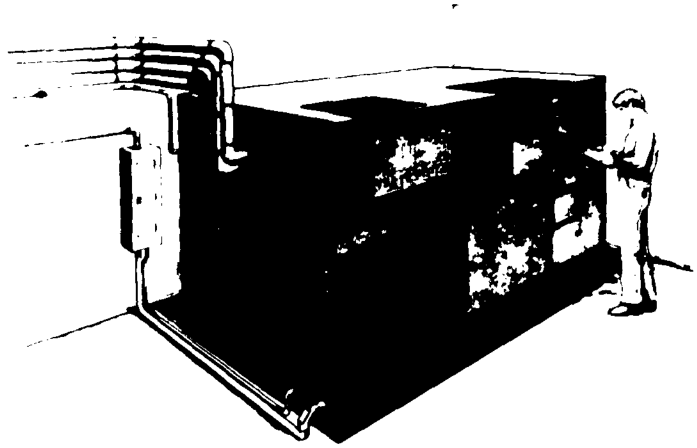

Figure 20. The UTC 40 kw Fuel Cell Power Plant. (16)

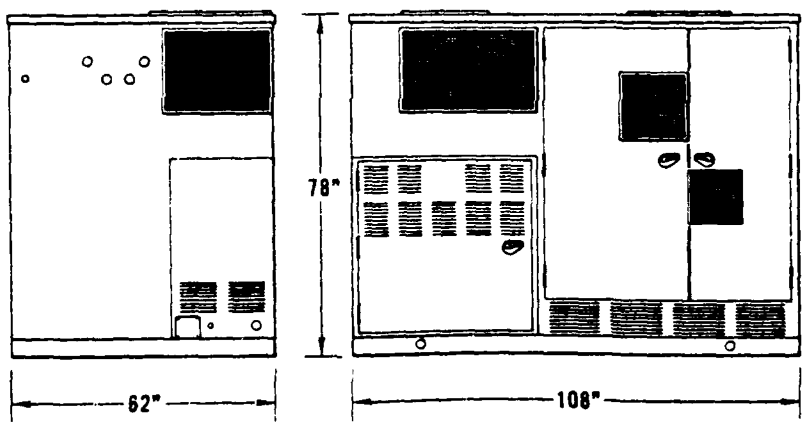

Figure 21. Exterior Dimensions of the UTC 40 kw Fuel Cell Power Plant. (16)

- Fuel processor (including preprocessor),
- Power section,
- Thermal management subsystem (including heat recovery), and
- Power conditioner

A simplified block diagram of the power plant is shown in Figure 22. The location of major components within the power plant is illustrated in Figure 23.

Electrical Description

The power plant electrical system block diagram is at Figure 24. The power section supplies dc voltage to the inverter. The inverter is a three-phase solid-state switch which inverts the dc voltage and regulates the ac voltage at a nominal level of 120/208 volts ac. Single phase, 120 volt ac is provided through use of a neutral forming autotransformer. A portion of this power is supplied to the power plant controller making the power plant electrically self-sufficient. This inverter provides an uninterruptible power source to maintain operation of critical power plant components during fault clearing periods of up to 5 seconds. The inverter also provides various ac voltages and a power section output dc current signal for use by the controller.

The power plant system includes a programmed microcomputer which provides the control intelligence for the three basic power plant operating modes: start, run and shut down. This controller also acts as the master synchronizer for grid-connected operation.

A master control unit (not included within the power plant envelope) is used to parallel power plants in multi-unit installations. The master control

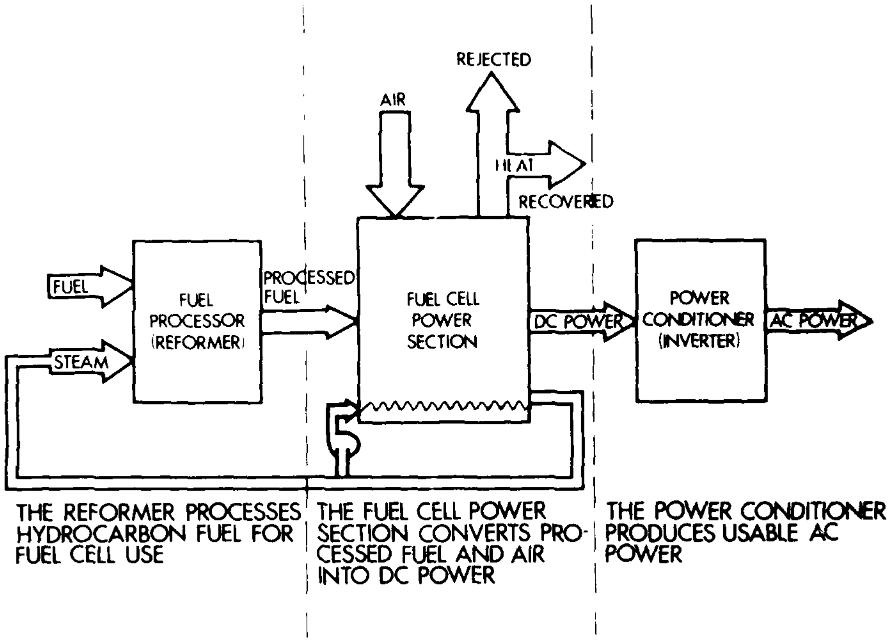

Figure 22. Block Diagram of The UTC 40 kw Fuel Cell Power Plant. (16)

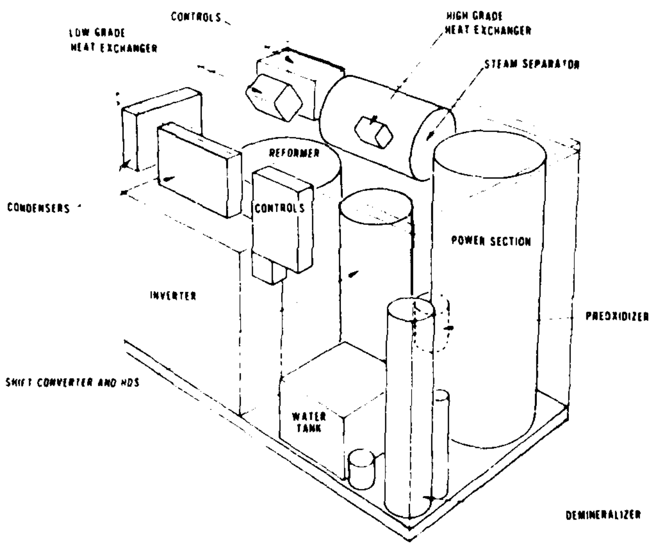

Figure 23. Component Layout of a Fuel Cell Power Plant. (16)

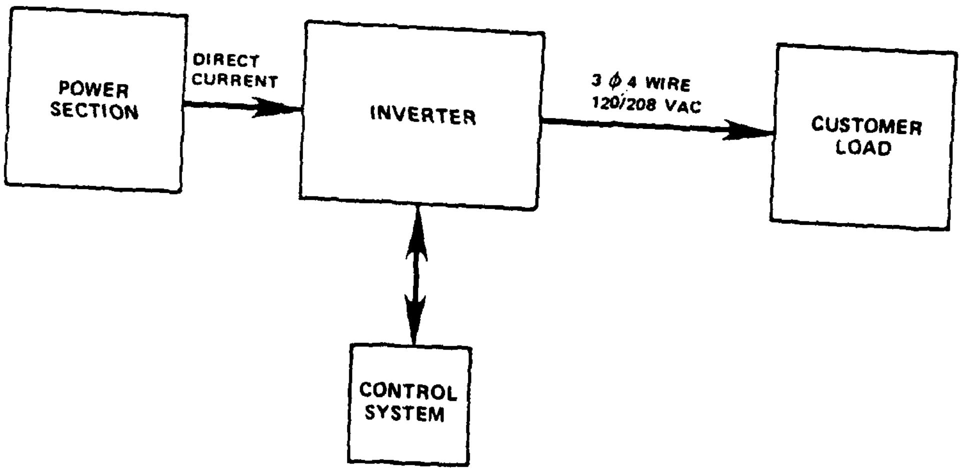

Figure 24. Block Diagram For The Fuel Cell Electrical System. (16)

unit provides for equal load sharing among power plants. The system can be manufactured so that it can operate in a grid connected mode, or in a stand alone mode of operation.

Heat Recovery System

A schematic of the heat recovery system is shown in Figure 25, high grade heat is provided by directing the power section coolant to the high grade heat exchanger where water from an external customer loop may be heated to a maximum temperature of 275^{o}F. Low grade heat is provided by passing the power section and fuel processing exhausts through a low grade heat exchanger where heat is transferred to a customer water loop. Under maximum heat recovery conditions a total fuel utilization of approximately 80 percent is attainable. If either high or low grade heat is not required by the customer, air-cooled heat exchangers will automatically provide sufficient cooling for power plant operation. The system heat exchanger performance relationships are shown in Figure 26.

Operation

Startup is semi-automatic with a service-person present and requires approximately 4 hours from 70^{o}F ambient conditions. Approximately 4 1/2 hours are required from the minimum startup temperature of 33^{o}F.

Operation is fully automatic and is load following. Transient response is witnin two cycles from zero to rated power output.

Shutdown is either manually initiated, or automatically initiated, based on monitoring or critical power plant parameters.

Parallel Operation

The power plant installation may include up to six units with the present master control unit design. Shut down of any one power plant in a multiple installation will not interfere with the operation of other parallel units.

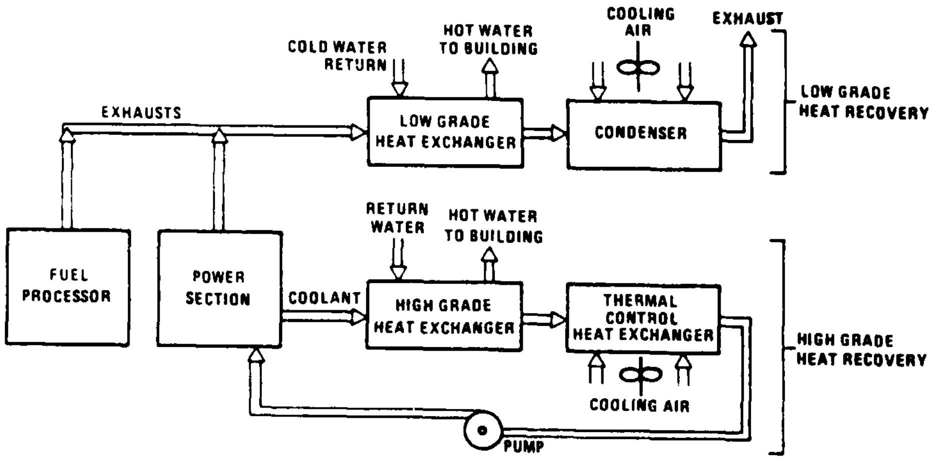

Figure 25. Heat Recovery System Schematic for the UTC 40 kw Fuel Cell Power Plant. (16)

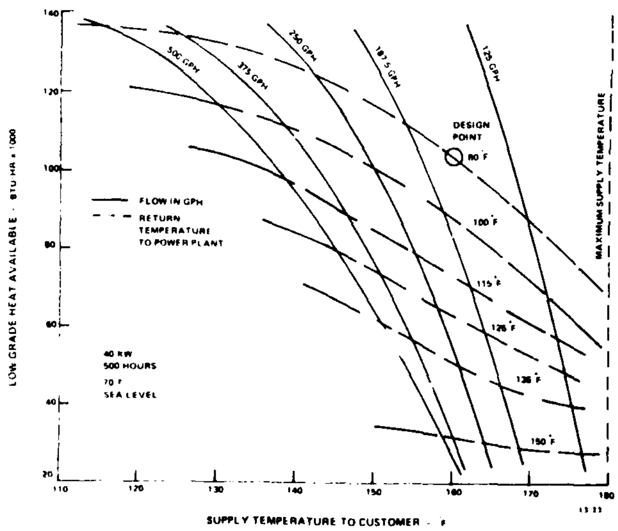

Figure 26. Heat Recovery System Potential Versus Supply Temperature. (16)
Note: Only low grade heat exchanger performance data is available at this time.

Environmental Conditions

The power plant will provide rated power and 5 seconds of overload or current limit operation within an ambient temperature range of -25°F to 110°F. In ambients up to 120°F, the power plant will continue to supply rated power but will have limitations in overload and current limit capacity. The power plant is provided with an all weather cabinet. It has been designed to withstand the environmental conditions specified in Table 8. If shut down occurs at or below an ambient temperature of 33°F, service procedures are required to prevent the water in the power plant from freezing. The power plant is capable of operating at altitudes up to 6000 feet with some limitation of transient overload capability.

Fuel Requirements

Power plant fuel is either pipeline or peak shaved gas. The allowable range of fuel supply pressure is 4 to 14 inches of water. Specifications for these fuels, as coordinated with the gas industry, are presented in Tables 9 and 10. These specifications encompass virtually all normal gas compositions anticipated for pipeline and peak shaved gas.

Design Safety

The power plant is designed so that no single component failure will result in a hazard to personnel or major equipment. The codes and standards presented in Table 11 have been selected as applicable and their spirit and intent included in the power plant design criteria. A program has been initiated which will lead to certification of future commercial power plants by a nationally recognized laboratory.

TABLE 8

40 KW ON-SITE POWER PLANT

ENVIRONMENTAL

Ambient Temperature Range, (^{o}F)	-25 to +120
Maximum Side Wall Wind Velosity, (mph)	80
Snow or Ice Roof Load, (Lb/Ft^2)	40
Rain/Wind Quantity, (inch/hr/35 mph)	1
Solar Radiation, ($\frac{BTU}{Ft^2\text{-}Hr}$)	300
Exhaust Emissions	
• NOX (lbs/MBTU input)	0.02
• SO_2 (lbs/MBTU input)	0.00003
• Particulates	0.000003
• Smoke	none

TABLE 9

PIPELINE GAS SPECIFICATION

COMPONENT	MAXIMUM ALLOWABLE. Vol%
Methane	100.0
Ethane	10.0
Propane	5.0
Butanes	1.25
Pentanes, Hexanes C_6+	0.5
CO_2	3.0
O_2	2.5
N_2 (Continuous)	15.0
Total Sulfur	30 PPM_V
Thiophane Sulfur	10 PPM_V
NH_3	1 PPM_V
Chlorine	0.05 PPM_W

TABLE 10

PEAK SHAVED GAS SPECIFICATION

COMPONENT	SPECIFICATION
Natural Gas	Min. 45% by Volume Total Gas Mix
Peak Shave Gas Mix	Max. 55% by Volume Total Gas Mix
Liquified Petroleum (L.P.) Gas	Max. 36% by Volume, in Total Gas Mix
Air	Max. 23.5% by Volume, in Total Gas Mix
Propylene	Max. 10% by Volume, in L.P. Gas (Equal to 3.6% in Total Gas Mix)
Max. Total Sulfur	30 PPM_V
Max. Thiophane Sulfur	10 PPM_V
Max. NH_3	1.0 PPM_V
Chlorine	0.05 PPM_W

TABLE 11

CODES AND STANDARDS FOR POWER PLANT DESIGN CRITERIA

- National Electrical Code
- ASME Boiler and Pressure Vessel Code
- ANSI 331 Code for Pressure Piping
- JL 795 Commercial-Industrial Gas Heating Equipment
- ANSI Z 21.17 - 1974 (AGA) Domestic Gas Conversion Burners

The power plant controller includes automatic sensing for equipment protection and automatic shut down in the event of critical out-of-limits component operation. Table 12 presents the parameters monitored.

Dependability

The design life goal of the mature, commercial power plant with periodic overhaul and maintenance is twenty years with an operational goal of no more than one unscheduled shut down per year. However, it is anticipated that the field test power plants will be operated for 8000 hours each and these early power plants may experience unscheduled shut downs in excess of above goal. Minor maintenance (e.g. demineralizer bed change) is intended to be accomplished at 2000 hour intervals. An annual shut down is required for more comprehensive maintenance procedures. A goal of 8 hours has been established for the annual maintenance. Sufficient space is incorporated in the design to assure efficient and safe maintenance, adjustment and repair.

Electrical Interfaces

Electrical interfaces between the power plant and the site consist of output power and control wiring; and power from the electrical bus for startup and grounding connections. In addition, a separate dc power supply unit is required for power plant startup.

Fluid Interfaces

There are two types of site fluid interface requirements. The first type is the environmental interface such as air intakes or exhausts. The second interface is required where a fluid such as water or fuel is moved between the site and the power plant.

Water Recovery Interfaces

Water to satisfy the fuel processing steam requirements is provided by condensing the power section and reformer exhausts. The power plant provides

TABLE 12

AUTOMATIC POWER PLANT SHUT DOWN PARAMETERS

- High TMS Temperature (Steam Separator)
- High Reformer Temperature
- Low Reformer Temperature
- Cabinet Overtemperature (Multiple)
- Preoxidizer Overtemperature
- Loss of Reformer Burner Air
- Invertor Failure Conditions
- Loss of Coolant Flow
- Power Section Ground Fault

sufficient water recovery to permit operation under normal load requirements and ambient conditions and thus requires no external water supply. Excess water produced will be discharged to a drain.

SUMMARY

This section has identified the long-term technological and commercialization efforts underway by DOE and the private sector. The government has spent over $150 million in the last four years for the development and commercialization of fuel cell systems. Ongoing research and development efforts by government and industry should allow for the commercial offering of on-site phosphoric acid fuel cell energy systems by 1985 by three competing manufacturers.

One major joint program underway by government and industry is the On-Site/Integrated Energy System Operational Feasibility Program. The major objective of this program is to demonstrate, in attractive early-entry market areas, on-site fuel cell energy systems.

The purpose of the next section is to highlight the economic advantages and potential energy savings anticipated with fuel cell energy systems.

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SECTION IV

FUEL CELL ECONOMICS

INTRODUCTION

An on-site fuel cell power plant, combined with cogeneration features a very efficient energy conversion process. The application of these systems results in an economic payback when compared to conventional building energy-consuming systems. Numerous government-sponsored fuel cell economic studies have been completed and demonstrate the usefulness of this technology (1,2,3,4,5). These studies indicate that on-site fuel cell cogeneration systems, given a full scale commercial development scenario, could payback in less than 5 years (6).

This section reports the details of a recently published fuel cell energy system economic analysis. Further, this section analyzes the economic consequences of a significant U.S. Air Force investment in fuel cell energy systems. This section concludes that a major investment in fuel cell energy systems could payback on military installations in less than 2 years.

FUEL CELL ECONOMICS - CASE STUDIES*

Fuel cells have been shown to be economically competitive in certain market areas. For example, the United Technologies Corporation (UTC), under contract to the Department of Energy (DOE), has completed a comprehensive on-site fuel cell study for commercial and multifamily facilities (1). In order to evaluate the market potential of on-site fuel cells, UTC developed a detailed computer model of five specific building types and examined the energy and economic tradeoffs between alternative on-site fuel cell

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*This material has been abstracted from References 1 and 2.

systems and conventional energy conservation technologies. These studies were in turn used to analyze the national fuel cell market potential. The computer simulations utilized consisted of a hour-by-hour analysis of thermal and electric energy use patterns in five different buildings in three geographic locations. The building types were representations of pre-1975 construction. Both conventional energy conservation strategies and advanced fuel cell systems were evaluated. Analysis of these data show that the integrated fuel cell-heat pump system combined with a moderate energy storage (water storage) capability is a superior system when compared to a conventional gas-fired system. Specifically, the major findings of the study were:

- The fuel cell on-site energy system saved gross energy resources in all building types studied. Savings ranged from 50 to 10 percent,
- On a national aggregate basis, the resource requirements for present commercial buildings could be reduced by 30 percent with the fuel cell system,
- In buildings where thermal energy use was high relative to electric use, the fuel cell on-site energy system provided both the thermal and electric energy requirements for less resources than were required to supply the thermal requirements alone, and
- Resource conservation, and to a greater degree life cycle costs, were greatly influenced by the building's thermal-to-electric load ratio.

The UTC Case Study

The resource energy consumption and life cycle cost for each of the individual buildings in three locations are summarized in Figures 27 through 31. For these comparisons, the fuel cell system costs were analyzed for both utility ownership and customer ownership. In the cases studied, utility

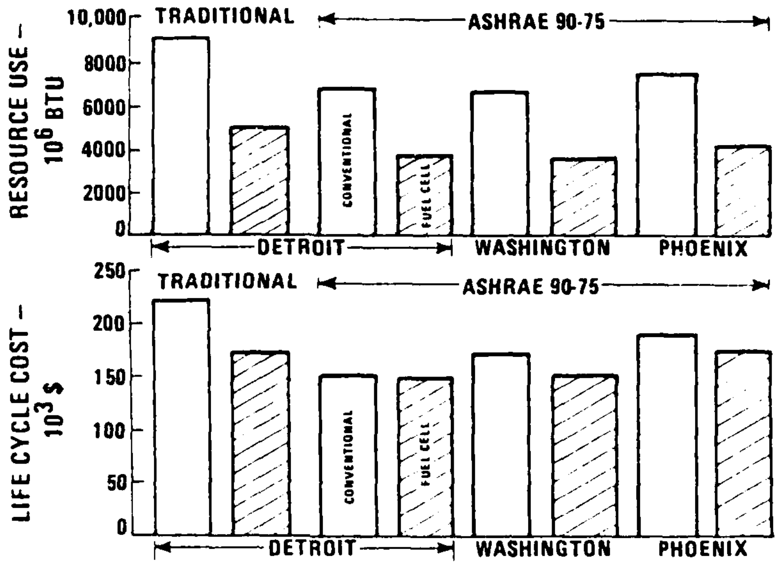

Figure 27. Fuel Cell Resource and Economic Comparisons--Nursing Homes. (1)

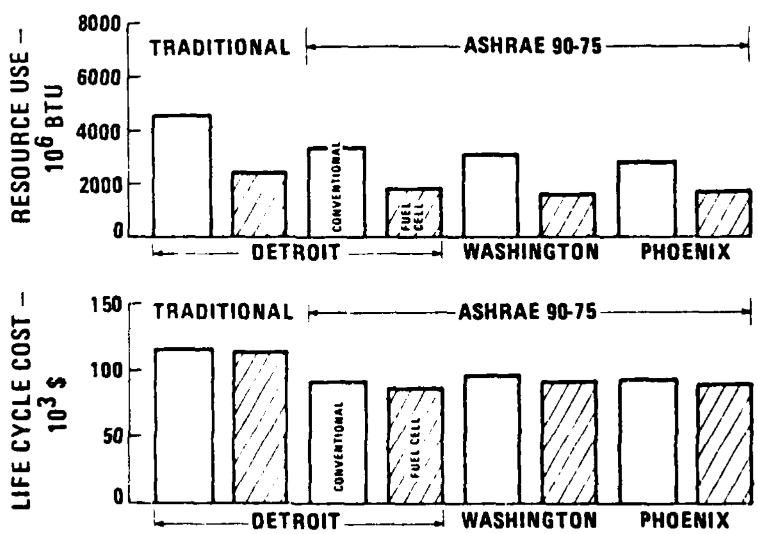

Figure 28. Fuel Cell Resource and Economic Comparisons--Apartment Buildings. (1)

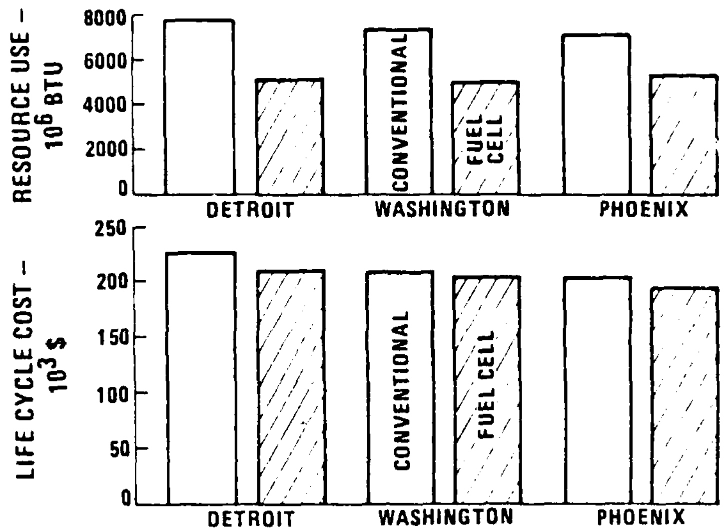

Figure 29. Fuel Cell Resource and Economic Comparisons-- Restaurants. (1)

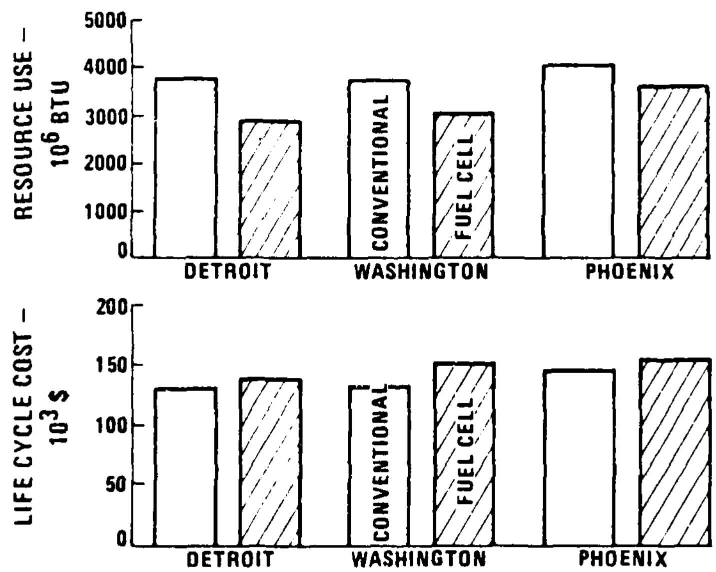

Figure 30. Fuel Cell Resource and Economic Comparisons--Office Buildings. (1)

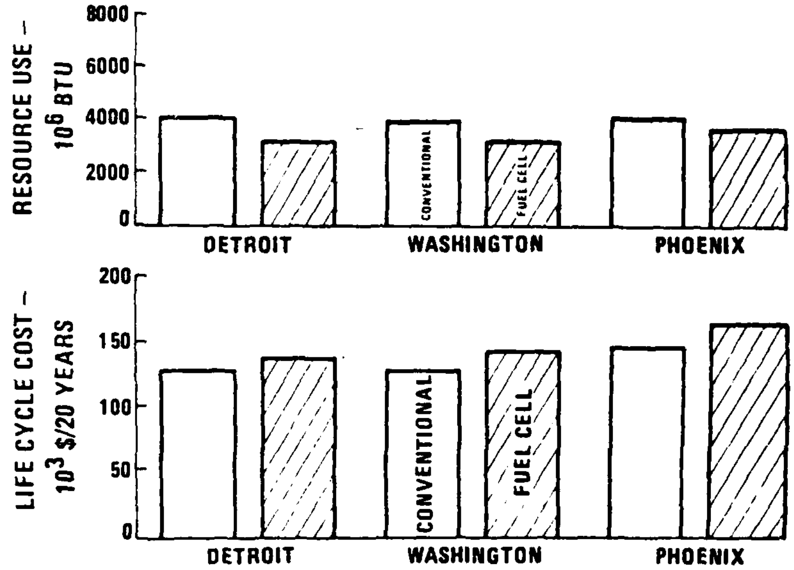

Figure 31. Fuel Cell Resource and Economic Comparisons--Retail Stores. (1)

ownership was found to be slightly more economically favorable.* For the case in which the fuel cell was sold like an appliance to a customer, the building owner installed first cost was fixed at $625/kw. Whereas, with gas utility ownership, it was assumed that the utilities would purchase fuel cells and related equipment directly from the manufacturer, thereby saving distribution and set up charges. For this case, the power plant installed costs were assumed to be $435/kw. This economic model was used to study fuel cell energy systems in nursing homes, apartment buildings, offices, restaurants, and retail stores.

In the nursing home application, the on-site fuel cell system demonstrated a 44 to 47 percent resource savings and a 9 to 16 percent life cycle cost savings over the conventional option (Figure 27). For the nursing home in Detroit, the effect of upgrading construction practice to the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) 90-75 standard resulted in a 25 percent reduction in conventional system resource consumption. The combination of upgraded construction and the use of on-site fuel cells resulted in an overall 60 percent reduction in total resource use.

Similarly, in the apartment building application the on-site fuel cell system demonstrated a 39 to 50 percent resource savings and a 3 to 5 percent life-cycle cost savings over the conventional option (Figure 28). For the apartment in Detroit, the effect of upgrading construction to an ASHRAE 90-75 level resulted in a 27 percent reduction in conventional system resource use.

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*Utility ownership was found to be more cost effective than customer ownership. However, this difference is only seven percent over a 20-year life cycle analysis period and results partly from the economic model utilized in this study. Additionally, no customer credit was given for excess electric energy sold back to the utility during non-peak operation.

The combined effect of upgraded construction and use of on-site fuel cells resulted in an overall 63 percent reduction in total resource use.

Studies conducted with the restaurant (Figure 29), office building (Figure 30), and the retail store (Figure 31) indicated that these were less favorable fuel cell applications. Specifically, the use of an on-site fuel cell power plant with heat recovery and heat pumps in these applications resulted in a net savings in resources; however, the overall life cycle cost benefit was marginal. For example, in the restaurant, resource savings ranged from 27 to 35 percent (Figure 29); however the life cycle cost savings was only 1 percent over the conventional system.

As a group, the office building and retail store were the lowest in terms of building thermal use relative to electrical use. This reduced the opportunity to utilize the byproduct heat produced as a consequence of on-site electric generation. At low levels of thermal use relative to electrical use, there was a lower probability for the coincident need for recovered heat. This would tend to reduce the level of resource and economic benefit of any on-site or cogeneration energy system. In fact, in the store and office cases in Phoenix, the relative thermal use was so low that the fuel cells with thermal storage supplied sufficient recovered heat that the heat pumps were never utilized in the heating mode.

As shown in Figures 30 and 31, the on-site fuel cell system in the office building and retail store demonstrated resource savings. In these cases the savings ranged from 9 to 23 percent. The fuel cell system life-cycle costs for the specific store and office modeled were somewhat higher than the conventional option. This result is dependent upon the specific rates and use patterns defined for these buildings.

In summary, for these 17 building cases the fuel cell-heat pump system always saved resources, in some cases as much as 50 percent savings, when compared with the conventional option. In addition, this system was economically attractive in all but the office building and retail store cases. Subsequent investigations to determine the predominant influences on system economics suggested that it was the extremely low thermal use in these specific model building that penalized the fuel cell system or, for that matter, any on-site cogeneration energy system. These investigations led to correlations of the building results which are discussed next.

Individual Building Study Correlations

As discussed previously, the potential resource benefit of any on-site energy system offering heat recovery is dependent upon the coincident need for the heat produced during electric generation. Buildings with high thermal requirements (space heat, domestic hot water, absorption cooling) relative to electric requirements present more opportunity to utilize heat produced by an electric generating device. Therefore, the annual thermal-to-electric energy consumption of a building is a useful parameter to indicate the potential to use heat recovered from an on-site fuel cell energy system. Specifically, Figure 32 shows the conservation savings of fuel cell-heat pump systems in the 17 model building/climate combinations plotted against building thermal-to-electric ratio. The upper line shows that, based on the 17 buildings studied, the on-site fuel cell system will always save resources (electrical and thermal energy), but that the absolute level of savings is diminished at low thermal-to-electric ratios. The lower line illustrates the savings in on-site fuel consumption (natural gas) achieved with fuel cell systems in the model buildings. For buildings with thermal-to-electric ratios

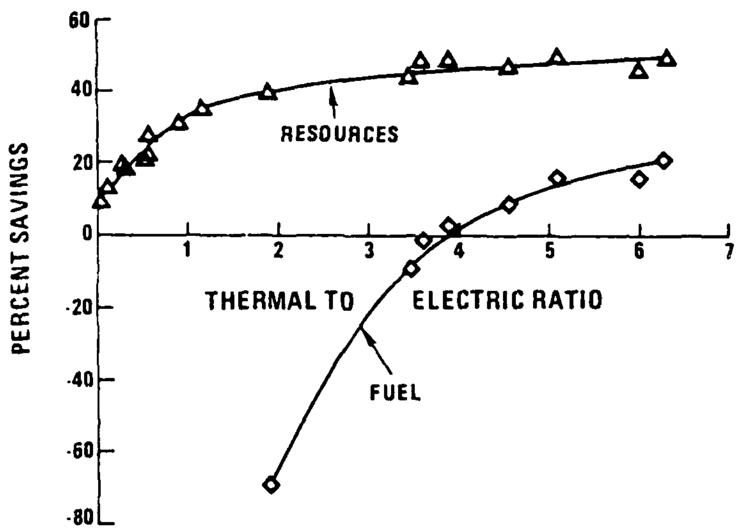

Figure 32. Conservation Potential of Fuel Cell--Heat Pump Systems Versus Building Thermal-to-Electric Ratio. (1) Recoverable resources include generated electricity and thermal energy; whereas fuel input excludes the recoverable heat content available to do work.

greater than four, the fuel cell system required less natural gas to provide the building energy resource (both electric and thermal) requirements than would be required by the conventional system to provide building heating alone. At ratios less than four, a conventional system would be more economical, since at these lower thermal to electric ratios, the thermal energy available from a fuel cell is not required and must be either stored or dumped to the environment.

An economic correlation was also made. Specifically, the ratio of life-cycle cost for the fuel cell-heat pump system to that for the conventional system was correlated against building electrical load factor and thermal-to-electric ratio. The resulting multivariate analysis lead to a family of curves that represent the results from the 17 buildings with a greater than 95 percent confidence. As the curves in Figure 33 show, the economic potential of an on-site fuel cell system is strongly dependent upon both building electrical load factor and the thermal-to-electrical energy ratio. Also plotted in Figure 33 are the load factor and thermal-to-electric ratio values for 27 actual office buildings. These data suggest that with office buildings there will be certain combinations of the electric load and thermal-to-electric ratios for which the on-site fuel cell system could be economically attractive. It is important to note; however, that these studies did not include an analysis of the potential economic savings of electric energy "sell-back" from the fuel cell system into the electric grid. An analysis utilizing the benefits of energy "sell-back" to the electric utility grid could enhance the life-cycle economics reported by UTC. This is particularly true in applications where the excess thermal energy can be utilized for space conditioning or process loads.

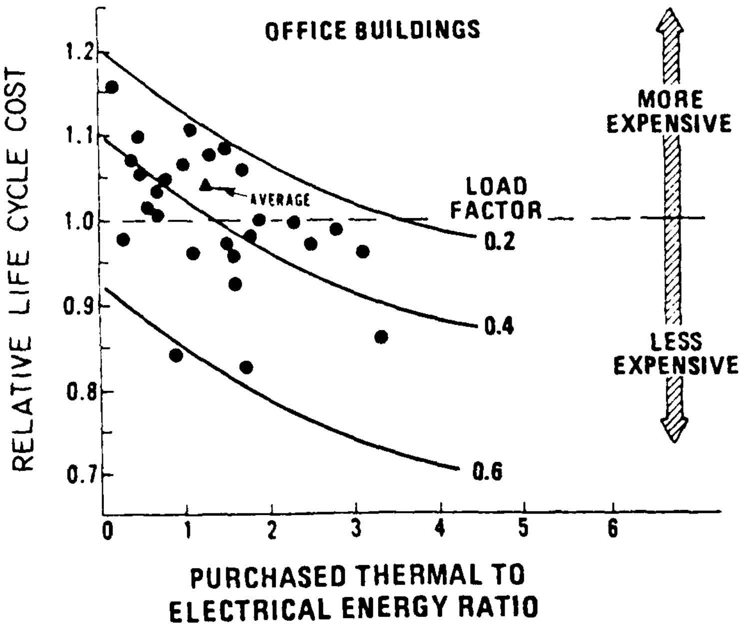

Figure 33. Economic Potential of On-Site Fuel Cell Energy System Versus Thermal and Electric Load Factors.

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The ADL Case Study

Arthur D. Little Inc. (ADL), under contract to NASA, completed a similar on-site fuel cell study for three major industrial facilities (2). The major findings of the ADL study are similar to those findings found by UTC; significant resource savings were realized using fuel cell systems in those industrial facilities with a large coincident thermal-to-electric load. Additionally, fuel cell industrial applications are more economically attractive in the context of utility ownership.

FUEL CELL ECONOMICS-A U.S. Air Force Case Study

The DOD is a major consumer of energy. For example, in FY79, approximately two percent of the nation's total energy usage was consumed by DOD activities (7). The U.S. Air Force utilized over one-half of the DOD total. The U.S. Air Force consumed 36 percent of the DOD total for avaition fuels, 14 percent for facilities, and slightly less than one percent for vehicle operations. Since fuel cell energy systems have been shown to have an economical benefit in certain commercial and industrial applications, then it would be logical to evaluate the potential economic benefit for specific U.S. Air Force applications. Therefore, the emphasis in this section is placed on investigating the cost benefit of fuel cell systems to the U.S. Air Force.

Instead of evaluating the specific cost benefits of particular U.S. Air Force applications, this section evaluates the comprehensive benefits of a large scale application of fuel cell energy systems across the entire U.S. Air Force. Specifically, the following economic analysis is based on these systems meeting the U.S. Air Force long-term facility energy goals.

The U.S. Air Force Long-Term Facility Energy Goals

The U.S. Air Force has established several long-term facility energy goals that can be met by installing fuel cell energy systems (8). First, the U.S. Air Force is committed to reducing, by 35 percent, the average energy consumption per gross square foot of floor area in FY2000 compared to the average energy use per square foot of floor area consumed in FY75. Also, the U.S. Air Force has established a goal to obtain 20 percent of its installation energy from advanced energy technologies, and other renewable sources by FY2000. Additionally, the U.S. Air Force has set a goal to obtain an additional 35 percent of its installation energy from coal, coal gasification, solid waste, refuse derived fuels, and biomass by FY2000. Finally, the U.S. Air Force is committed to achieve a 45 percent reduction in the use of petroleum fuels from FY1975 baseline levels. Fuel cell energy systems could significantly help the U.S. Air Force obtain these long-term goals. Also, these fuel cell cogeneration systems, combined with adequate stockpiles of fuel, could help the U.S. Air Force meet the Defense's needs for national security and on-site energy self-sufficiency.

The U.S. Air Force Fuel Cell Scenario

To determine the cost effectiveness of fuel cell energy systems, it has been assumed that 1000 Mw of these systems could be installed on Air Force bases by FY2000. This represents only 35 percent of the total installed electrical system capacity and this installation would cost approximately $625 million. Assume further that these fuel cell systems are 80 percent efficient and can operate 8000 hours per year. For planning purposes, assume these fuel cells are fueled by a synthetic fuel (e.g. oil shale, biomass, etc.) and the

the Air Force base. Finally, assume that no other energy conservation alternatives are implemented.

Table 13 shows that during the baseline year, over 51.8 percent of the average energy consumption per square foot was in the form of purchased electricity. Likewise, natural gas, petroleum, and coal represented 21, 20, and 7 percent of the total baseline average energy consumption per square foot, respectively. Applying the fuel cell scenario outlined above results in a 45 percent reduction in petroleum and a 58 percent savings in purchased electricity. Additionally, this scenario results in a total of 35 percent of the U.S. Air Force's energy coming from domestic fossil fuel sources (26.8 percent from synethic and 8 percent from coal). The energy conservative fuel cell also reduces the U.S. Air Force's total energy consumption per square foot by 15 percent. Twenty-six percent of the U.S. Air Force's energy would be derived from synthetic fuel--an advanced energy technology.

The total annual energy costs associated with the baseline energy case, in FY2000 dollars, is $2,363 million; whereas, when the fuel cell scenario is studied, this annual energy cost is reduced to $1,785 million. When this potential $578 million annual cost savings is applied to the capital costs of the fuel cell system, the simple payback is calculated to be less than 2 years.

SUMMARY

The economic analysis presented in this section shows that fuel cell energy systems could have an economic benefit for the U.S. Air Force. Specific U.S. Air Force applications have not been evaluated; however, multifamily housing and hospital applications, and other specific applications where a high coincident thermal-to-electric loads exist, have been shown to have an economic benefit.

TABLE 13

COST COMPARISON OF A HYPOTHETICAL U.S. AIR FORCE FUEL CELL SCENARIO

BASELINE YEAR (FY75)	PURCHASED ELECTRICITY	NATURAL GAS AND PROPANE	PETROLEUM	COAL	PURCHASED STEAM AND HTHW	SYNTHETIC FUEL STOCK FOR FUEL CELL	TOTALS
Actual Energy Consumption (Trillion Btu)	110.60	44.55	43.25	14.16	.75	0	213.31
Real Estate Inventory (Million SF)	669.70	669.70	669.70	669.70	669.70	669.70	669.70
FY75 Baseline (MBtu/SF)	.1651	.0664	.0646	.0211	.0011	0	.3185
Fraction of FY75 MBtu/SF total (%)	51.8	20.8	20.3	6.6	.3	0	100
FY75 Energy Costs in FY2000 dollars ($ million)	1,254.2	402.7	622.9	75.14	8.0	0	2,352.94
FUEL CELL SCENARIO (FY2000)							
Projected Energy Consumption (Trillion Btu)	46.40	44.55	23.79	14.16	.75	47.62	177.27
Projected Real Estate Inventory (Million SF)	653.00	653.00	653.00	653.00	653.00	653.00	653.00
Projected Energy Use (MBtu/SF)	.0711	.0682	.0364	.0217	.0011	.0729	.2714
Fraction of FY2000 MBtu/SF total (%)	26	25.2	13.4	8.0	4	26.8	100
FY2000 Energy Costs in FY2000 dollars ($ million)	526.2	402.7	342.5	75.14	8.0	430.48	1,785.02
Savings in MBtu from FY2000 compared to FY75 (%)	58	0	45	0	0	0	15**

* See text for assumptions
** 15% reduction in MBtu/SF

These economic and technical advantages indicate that the fuel cell system should be further evaluated. This evaluation should be a carefully developed field demonstration. The next section outlines how the U.S. Air Force should participate in this Operational Feasibility Program.

REFERENCES:

1. United Technologies Corporation, On-Site Fuel Cell Resource Conservation in Commercial and Multifamily Buildings, FCR-0793, June 28, 1978.

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6. Kirschbaum, H., "Fuel Cell On-Site Integrated Energy System for Multi-Family Application", National Fuel Cell Seminar Abstracts, July 14-16, 1980, pp. 95-99.

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SECTION V

THE U.S. AIR FORCE FIELD TEST DEMONSTRATION PLAN

INTRODUCTION

On-site and utility-based fuel cell energy systems are an energy efficient and a potentially economic energy conversion technology. It has been shown that this technology could replace conventional electromechanical energy conversion devices in certain market areas within twenty years. Specifically, indepth engineering studies have shown that fuel cells are economically competative in those industrial plants, nursing homes, and apartments where a high coincident thermal-to-electric energy load ratio occurs. Since the U.S. Air Force has a significant quantity of industrial, commercial, and institutional facilities that have large coincident thermal-to-electric load ratios, it should investigate first-hand the advantages, and potential limitations of fuel cell energy systems.

This section recommends that the U.S. Air Force become involved in the National On-Site Fuel Cell Operational Feasibility Program and this section provides a framework for initiating this involvement. In order to implement this recommendation, this section identifies the manpower and other resources required to support the program. Additionally, this section provides the Major Commands (MAJCOM's) and Base Civil Engineers (BCE's) the necessary procedures and reports to complete in order to become involved in this program.

OBJECTIVES OF THE U.S. AIR FORCE FIELD TEST DEMONSTRATION PROGRAM

Active participation by the U.S. Air Force in field demonstration and proof-of-concept testing of an on-site fuel cell energy system will provide Air Force managers and their technical staffs the opportunity to evaluate, on a first-hand basis, the operational and reliability characteristics of these unique energy conversion systems. Additionally, the engineers and technicians involved in this program would become thoroughly trained in energy systems data acquisition, fuel cell power systems operation and maintenance, and the economics of on-site fuel cell energy systems. These trained personnel inturn could serve as a core nucleus when follow-on fuel cell energy systems are installed in DOD facilities. Also, based on this first hand experience, the U.S. Air Force, the lead DOD agency involved in fuel cells, would be in a better position to evaluate the regulatory and technical constraints associated with these systems. Finally, active participation in this demonstration program could result in a significant savings in energy at the facilities where fuel cells are installed. Specifically, an agressive U.S. Air Force demonstration program could annually save up to $2880 in electric bills at each field demonstration location*. Of course, petroleum or natural gas currently utilized for space conditioning will also be significantly reduced because of the cogeneration feature of the fuel cell energy system.

The objectives of this U.S. Air Force program must parallel the national program. The major objective of the national program, as described in Section III, is to contribute to the acceptance of this new business obtained by utilities, customers, manufacturers, building owners, and government.

Clearly, the two major objectives of a U.S. Air Force Fuel Cell Operational Feasibility Program are: (1) to provide U.S. Air Force personnel the first-hand opportunity to evaluate the technological reliability,

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*Based on a 240 Mwhr/yr utilization rate with a 3¢/kwhr electric energy credit at 40 percent electrical efficiency.

associated regulatory constraints, and energy savings potential of an on-site fuel cell energy system; and, (2) to allow U.S. Air Force personnel to gain important technological training and experience operating and maintaining the system under typical operational conditions. Table 14 summarizes the advantages for an active U.S. Air Force involvement in the National Fuel Cell Operational Feasibility Program.

THE U.S. AIR FORCE FIELD TEST DEMONSTRATION PROGRAM PLAN

The National Operational Feasibility Program Plan, as outlined in Section III, has two major phases: a field test phase and a business assessment phase. The U.S. Air Force program plan closely parallels this national program plan, however, it is tailored to meet specific U.S. Air Force objectives. One outcome of this program is the initial field testing and demonstration of three fuel cell units on Air Force bases in the continental United States. An additional outcome of this program could be a recommendation to test and evaluate additional fuel cell energy systems.

Additionally, during the markup of the FY81 Military Construction Appropriations Bill, the House of Representatives inserted language on fuel cell energy systems (4). Specifically, the Congress has recommended that a fuel cell energy system be purchased and tested at an Air Force Base. Two additional fuel cell systems are to be purchased and tested by the Aero Propulsion Laboratory. These congressionally directed systems, not to cost over $500,000 each, including the cost of fuel cell energy system, should be installed using the general program guidelines described below.

This program plan recommends that the U.S. Air Force jointly participate in demonstrating the feasibility of on-site fuel cell energy systems with interested local utility companies. The U.S. Air Force will take the lead

TABLE 14

REASONS FOR A U.S. AIR FORCE INVOLVEMENT
IN THE NATIONAL FUEL CELL PROGRAM

Provides technology familiarization

Develops technician training and hands-on experience

Demonstrates unique military related on-site fuel cell applications

Allows for government evaluation of regulatory and technical constraints

Saves facility energy meets DoD established FY 2000 facility energy goals during the field test phase and the participating utility company will be responsible for completing the business assessment phase of the program.

The Field Test Program Plan

This program demonstrates the operational feasibility of on-site fuel cell energy systems at a diverse number of locations. Different market segments will be tested in order to cover the range of typical electrical and thermal load characteristics, installation requirements and influence of policy and decision makers. The U.S. Air Force will be responsible for the initiation of this phase of the program plan. Figure 34 diagrams the milestones to be met during this initial program phase.

The field test program begins with the selection of candidate Air Force bases and an initial determination of local utility interest. The purpose of this step is to determine which utility companies would be interested in joining with the U.S. Air Force in a joint fuel cell system. Table 15 lists the participating utilities that may be interested in a joint venture with the U.S. Air Force. Once this initial installation selection is made, the following steps are to be initiated jointly by the U.S. Air Force and the participating utility company at each installation:

- o Analyze 5-10 candidate buildings for fuel cell energy system compatibility,
- o Select a candidate site for instrumentation,
- o Purchase and install necessary data acquisition equipment,
- o Install and demonstrate the fuel cell energy systems, and
- o Submit the necessary progress reports.

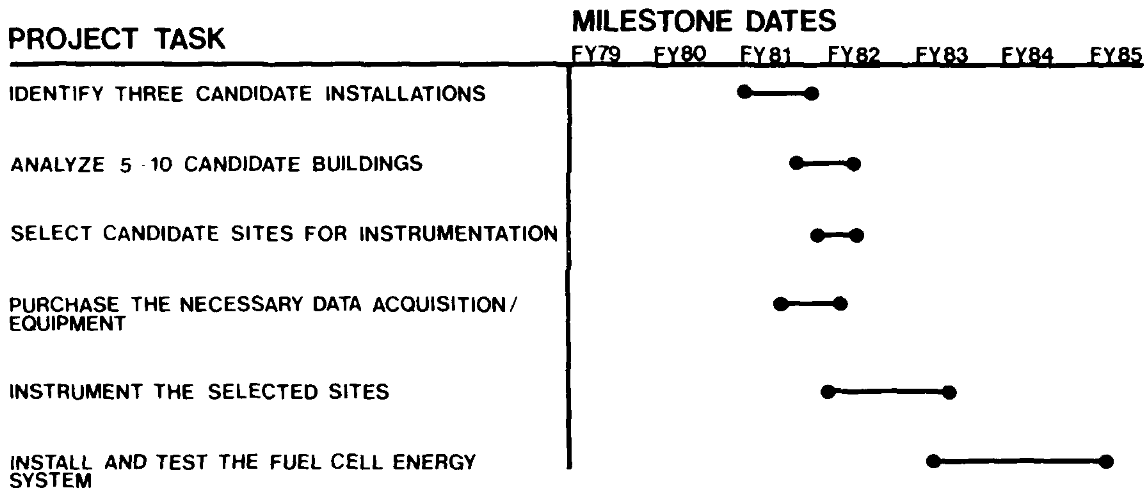

Figure 34. U.S. Air Force Field Test Demonstration Program Plan Milestones.

TABLE 15

PARTICIPATING UTILITY COMPANIES THAT MAY BE INTERESTED IN A JOINT U.S. AIR FORCE/LOCAL UTILITY COMPANY FIELD TEST DEMONSTRATION:

Participating Utility	Air Force Base	Participating Utility	Air Force Base
Southern California Gas Co. P.O. Box 3249 Terminal Annex Los Angeles, CA 90051 (213) 689-2345, x 122276	March Edwards	Michigan Consolidated Gas Company 1 Woodward Avenue Detroit, MI 48226 (313) 965-2430	Selfridge (ANGB)
Georgia Power Company 270 Peachtree Street, 5th Floor Altanta, GA 30302 (404) 522-6060	Robins AFRCE/ER Dobbins (AFR)	Public Service Electric and Gas 80 Park Place Newark, NJ 07101	McGuire
Boston Gas One Beacon Street Boston, MA 02108 (607) 742-8400, x 206	Hanscom Otis	GASCO, Inc. P.O. Box 3379 Honolulu, HI 96842 (808) 548-5361	Hickam
Mountain Fuel Resources, Inc. 180 East 1st South Street Salt Lake City, UT 84139 (801) 534-5463	Hill		
Florida Power Corporation P.O. Box 14042 St. Petersburg, FL 33733 (813) 866-4607	McDill		
Pacific Gas & Electric Co. 245 Market Street San Francisco, CA 94106 (415) 781-4211, x 3151	Mather		
Arizona Public Service Co. P.O. Box 21666 Phoenix, AZ 95036 (602) 271-2457	Williams Luke		
Columbia Gas System Service 1600 Dublin Road Columbus, OH 43215 (614) 486-3681, x 278	Rickenbacker		
Northern Illinois Gas P.O. Box 190 Aurora, IL 60507 (312) 355-8000, x 209	Chanute		

The Air Force Program Manager

This program can only be successful if there is an aggressive program management system is established. It is recommended that central program management be established at the Air Force Engineering and Services Center (AFESC). The AFESC Energy Group has the responsibility for introducing new energy conversion technology into the building inventory. The AFESC program manager should rely on the technical expertise available at the Aero Propulsion Laboratory (APL) when implementating this program.

The AFESC Program Manager is the focal point for the effort and is responsible for establishing program guidance, supporting program expenditures, and reporting program progress to DOD and the Congress. Several immediate taskings are required to be accomplished by AFESC.

First, AFESC must prepare program guidance for HQ USAF/LEE directing the MAJCOM's to select candidate installations. Additionally, AFESC must order the three data acquisition systems necessary to adequately evaluate the candidate sites. Further, AFESC must attend the Fuel Cell User's Group meetings, generally held 4-5 times a year. AFESC must act as the single-point program manager for this effort; all program reports must be submitted through AFESC. Finally, AFESC and HQ/LEEP along with the participating MAJCOM's, must program the real property modifications necessary prior to the installation of fuel cells and the data acquisition system. Table 16 outlines the required manpower and fiscal requirements per site for this field test demonstration program.

TABLE 16

U.S. AIR FORCE FIELD TEST DEMONSTRATION PROGRAM

MANPOWER AND FISCAL REQUIREMENTS

(Per Installation)

	PROGRAM ADMINISTRATION (Man-Yr)	TRAVEL FUNDS ($000)	EQUIPMENT PURCHASE ($000)	SITE PREPARATION ($000)
FY 81	.25	2.0	20.0	
FY 82	.125	2.0		
FY 83	.125	2.0		10.0
FY 84	.25	3.0		
FY 85	.25	3.0		3.3
PROGRAM TOTALS	1.0	12.0	20.0	13.3

Three U.S. Air Force bases are recommended as candidate installations for this joint Air Force/Utility program. Additionally, the congressionally-directed unit should be installed at Nellis AFB, Neveda, as recommended by the McKay Committee(4). These installations have been selected since there already exists an interest in a joint Air Force/Utility Company venture at these locations. Of first priority is Hill AFB, UT. The base has an active and demonstrated interest in conserving resources, the local gas utility company, Mountain Fuel Resources, has expressed an interest in a joint venture testing a grid-isolated system, and finally, numerous buildings on Hill AFB exhibit a high coincident thermal-to-electrical load factor. A second location is Hanscom AFB, MA. Besides the reasons listed, the utility expressing an interest in this location would be interested in demonstrating a "grid connected" fuel cell energy system. This is to be compared to the "grid isolated" system that might be installed at Hill AFB, UT. Tinker AFB, OK is the third location for a candidate fuel cell site. The local utility company which services Tinker AFB is less interested in the program; however, to date no utility company in the South is participating in this National Fuel Cell Operational Feasibility Program. Participation by an Air Force Base/Utility Company from this region would be of benefit to the national program. Alternatively, Public Service Electric and Gas Company has expressed an interest in jointly participating with the U.S. Air Force at McGuire AFB, NJ.

In order to complete this field demonstration phase of the program, a preliminary site selection must be accomplished.

PRELIMINARY SITE SELECTION

Once the site locations have been established and the participating utilities have agreed to the basic concepts of the program plan, the MAJCOM's and ultimately the Base Civil Engineers, must evaluate the economic and energy consequences of an on-site fuel cell system. This section will identify the individual program steps and discuss the necessary program requirements of the U.S. Air Force Fuel Cell Field Test Demonstration Plan. Each of the tasks are itemized below:

Identify Candidate Buildings

The purpose of this task is to initially evaluate enough candidate building types at each of the three installations, so that the best buildings are selected for the follow-on tasks.

Military family housing, administrative complexes, and aircraft support facilities should be surveyed at each location to determine the general energy requirements and applications of a fuel cell energy system for these building types. In order to properly survey these buildings, a standard building information questionaire has been established and is presented in Appendix A. Most of the information required to complete the questionaire in Appendix A is available from the BLAST or TRACE computer simulation input analyses forms, if available for the buildings selected. Using all data available, a ranking of most suitable building types can be made. This ranking will be performed when the completed data survey forms (Appendix A) are submitted through the MAJCOM's to HQ AFESC/DEB, Tyndall AFB.

APL, with the assistance of AFESC, will jointly develop a specialized computer code for simulating the technical and economic consequences of on-site fuel cell energy systems. This computer code can be easily adopted from the existing United Technologies Corporation code or the code available from Union Carbide (1,2). The Base Civil Engineer, and the participating utility company should evaluate 5-10 sites on the installation and complete

Appendix A. The computer-aided rank ordering will be then accomplished and AFESC will recommend to the MAJCOM which sites should be further evaluated. It is envisioned that AFESC will work closely with APL, the MAJCOM, the BCE and the participating utility company in selecting the three candidate sites for instrumentation. APL technical assistance will be made available for this selection process.

The candidate sites may be new or retrofit applications depending on scheduling and goals of the project. A new site would provide close contact with the full range of professions and trades, from architectural to the personnel associated with building use. Additionally, a new facility can be designed to maximize the thermal-to-electric energy ratio, thus optimizing the fuel cell energy system. A major problem for newly constructed sites is the lack of basic load data for the specific installation. Other sites of similar type would have to be evaluated and adapted to fit the new building characteristics. The differences in building construction, heating, and cooling equipment, and process hot water requirements must be carefully considered. Construction schedule dependability may also be a problem for new buildings.

A retrofit building will not provide as many professional and trade contacts as a new building, but will allow the accurate matching of fuel cell equipment to the building load. This can be accomplished through detailed instrumentation of the structure and recording of load patterns.

Areas of prime interest in selecting candidate sites include the building load factor and thermal energy consumption. Also, the coincidence of electrical and thermal loading will be very important for efficient fuel cell operation. When high electrical demand and high thermal demand are coincidental, the fuel cell will be able to supply a larger portion of the building energy requirement.

Instrument Candidate Buildings

The selected buildings will be fully instrumented for one year prior to the actual fuel cell installation. Instrumentation will be standardized across all applications so that a common data management system can evaluate the program results. This same instrumentation package will be used during the fuel cell operational phase. The standardized data acquisition system recommended for this program is the Acurex Autodata Ten/G. This system is fully described in Appendix B.

It is strongly recommended that the data acquisition system (DAS) be purchased in leiu of using an existing Government furnished DAS or Energy Monitoring and Control System (EMCS). The Autodata Ten/G has been especially configured for this program; no special reprogramming will be required in order to monitor the site energy or fuel cell system. Use of an existing EMCS will require extensive software redevelopment and special magnetic tape output formatting. On the other hand, the DAS could be used to support the evaluation of EMCS performance; the unit has been designed and programmed for energy consumption data gathering.

The equipment should be purchased by HQ AFESC/DEB and installed at each site by the HQ AFESC/DEB Energy Analysis Team. The data recording tapes will be replaced periodically by the BCE personnel and dispatched to the demonstration supporting contractor for analysis. The BCE, participating utilities, MAJCOM and HQ AFESC will inturn receive monthly analysis trends for the buildings instrumented.

Fuel Cell Installation

The U.S. Air Force and the participating utility company will jointly install the fuel cell units. The U.S. Air Force will be responsible for completing the site modifications and the participating utility company will be responsible for power plant hook-up and system check out and startup. Once operational, the U.S. Air Force will be responsible for checking the unit daily, submitting monthly data acquisition system recording tapes to the demonstration supporting contractor, and for routine and minor maintenance of the fuel cell energy system. The participating utility will be responsible for repairing major system malfunctions during the one-year test period. The BCE will assist the utility company during these malfunctions. Also, the participating utility will be responsible for developing all market and business assessment studies and reports. Finally, the U.S. Air Force and the utility company will be jointly responsible for conducting public relations tours and visits to the fuel cell system.

Program Reporting Guidelines

The BCE, with the support of the participating utility, will be responsible for submitting to AFESC/DEB all necessary reports. These reports include the Monthly Status Report and Quarterly Cost Report for each of the sites. The outline and format for these reports are shown in Appendix C. It is envisioned that the participating utility would like to review the reports and offer aid in their development.

BUSINESS ASSESSMENT PLAN

The participating utility company will be primarily responsible for completing the Business Assessment Plan. The purpose of this business assessment is to develop and analyze performance data so that the participating utility company will commit to participation in the subsequent market tests and to purchase commercial units. Specifically, this business assessment will:

- o Develop an installation forecast and investigate early entry markets,
- o Analyze potential markets and develop a marketing strategy,
- o Investigate institutional and legal constraints, municipal codes and standards, and labor considerations, and
- o Complete a business venture analysis.

The business venture analysis and the assessment of potential institutional, economic, legal and regulatory inducements and constraints are necessary. The participating utility will develop a business scenario, utilizing a twenty year sales forecast and determine the investment required for this scenario. Specific program assumptions have been standardized and a Business Assessment Guideline has been developed (3).

RECOMMENDATIONS AND CONCLUSIONS

This report recommends that the U.S. Air Force become involved with the National Fuel Cell Operational Feasibility Program. This involvement should lead to the installation of up to three on-site fuel cell energy systems on Air Force Bases. Further, to reduce the risks involved with this program, the U.S. Air Force should participate in a joint venture with the utility companies currently involved in the program. A fourth fuel cell energy system should be purchased and installed at Nellis AFB, Neveda, as directed by the FY 81 Military Construction Appropriations Bill. This fuel cell system would be installed using the general guidelines outlined in the Appendices, except a two-year test and evaluation period will be completed

Upon the successful completion of this program, it is recommended that fuel cell energy systems be retrofitted into cost effective applications; using both on-site (distributed) systems and larger-scale central fuel cell power plant applications.

REFERENCES:

1. 40 Kw Fuel Cell Operational Feasibility Program, Site Selection Guide, Gas Research Institute, December 1979.

2. Pine, G.D., et al, Development of an Energy Consumption and Cost Data Base for Fuel Cell Total Energy Systems and Conventional Building Energy Systems, Oak Ridge National Laboratory, ONRL/CON-38, July 1980.

3. Gas Utility 40 Kw Fuel Cell Operational Feasibility Program, Business Assessement Guidelines, Gas Research Institute, Draft, 1979.

4. Military Construction Appropriation Bill, 1981, 96th Congress, 2nd Session, House of Representatives, June, 1980.

APPENDIX A

PRELIMINARY SITE SELECTION GUIDE

Building Screening Information

INTRODUCTION

The following building screening information will enable the Air Force to evaluate the energy and cost savings of an on-site fuel cell at your installation. Completed forms should be sent to:

On-Site Fuel Cell Program Manager

HQ AFESC/DEB

Tyndall AFB, FL 32403

It is intended that these forms can be copied directly and then completed for each building surveyed. Further, most of the information required is available from TRACE or BLAST computer simulation input analyses reports, if available for the sites selected.

SURVEY INTERVIEW FORM II

BUILDING AND ENERGY SYSTEMS SUPPLEMENTAL QUESTIONNAIRE

INSTALLATION ____________________ YOUR NAME ____________________

DATE ____________________

BUILDING IDENTIFICATION

BUILDING COMMERCIAL NAME ____________________

ADDRESS ____________________

BUILDING USE ____________________

•

INTERVIEWEE ____________________ PHONE __________

BUILDING DESCRIPTION

BUILDING CONSTRUCTION ____________________ APPROX AGE ______

____________________ NUMBER OF FLOORS ______

ACTIVE FLOOR AREA __________ FT^2

INACTIVE FLOOR AREA __________ FT^2 (i.e BASEMENTS STORAGE AREAS PARKING AREAS OR ANY SIGNIFICANT AREAS NOT USED FOR NORMAL BUILDING ACTIVITIES)

TOTAL __________ FT^2

DESCRIPTIVE CHARACTERISTICS (I.E. NUMBER OF ROOMS, OFFICES, BEDS, PATIENTS, OCCUPANCY RATES)

____

SIC CLASSIFICATION: ____________________

TOTAL WEEKLY BUSINESS HOURS __________ TOTAL WEEKLY HOURS BUILDING OCCUPIED __________

ELECTRIC SERVICE MASTER SWITCHED ☐ OR SEQUENCE SWITCHED ☐

SERVICE 1)	_____ VOLTS	_____ PHASE	_____ NUMBER OF WIRES	_____ SERVICE RATING (AMPS)	
SERVICE 2	_____	_____	_____	_____	

LIGHTING FLOURESCENT ____ %

INCANDESCENT ____ % SYSTEM DESCRIPTION ____________________

____

____

BUILDING LOAD MODIFICATIONS

ADDITIONS OR MODIFICATIONS IN THE PAST OR FUTURE 5 YEAR PERIOD PLEASE DESCRIBE.

FLOOR AREA ______________________________

____

ELECTRIC SERVICE ______________________________

____

AIR CONDITIONING ______________________________

____

REFRIGERATION ______________________________

____

CONSERVATION EFFORTS: (I.E. TEMP CONTROL, ECONOMIZERS, INSULATION, LOWER LIGHTING LEVELS, ETC.): ______________________________

____

____

OTOR LOADS (NOT INCLUDING AIR CONDITIONING)*

EQUIPMENT (3 LARGEST)	VOLTAGE	HP

THER MAJOR LOADS (NOT INCLUDING AIR CONDITIONING)

EQUIPMENT	VOLTAGE	AMPERAGE	WATTAGE

RCUIT BREAKER SUMMARY **

MAIN PANEL	SUB PANELS #1	#2	#3	#4	#5	#6
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ ___ AMPS
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ ___ AMPS	___ ___ AMPS	___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ ___ AMPS
___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS
___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS	___ @ ___ AMPS

* FOR ALL MOTORS 3HP AND OVER, LIST RUNNING AND LOCKED MOTOR CURRENTS AND NEMA DESIGN LETTER DESIGNATION.

** IF ADDITIONAL SPACE IS REQUIRED, PLEASE ATTACH EXTRA SHEETS

AIR CONDITIONING (A SIMPLE HVAC SYSTEM SCHEMATIC WOULD BE HELPFUL)

SYSTEM TYPE (CHECK ONE)
- ELECTRIC VAPOR COMPRESSION ☐
- GAS ABSORBTION ☐
- EVAPORATIVE COOLING ☐

SYSTEM CONFIGURATION: (CHECK ONE)
- UNITARY ☐
- REMOTE CHILLER/AIR HANDLER ☐
- SPLIT ☐
- WINDOW ☐
- OTHER ☐ DESCRIBE ______

SYSTEM COMPONENT ______

NO. OF IDENTICAL UNITS ______ MANUFACTURER ______ MODEL NO ______

RATING (BTU/HR, TONS) ______ OR AIR FLOW (CFM) ______

COMPONENT MOTOR DATA *

FUNCTION	NUMBER OF MOTORS	VOLTS	H.P

SYSTEM COMPONENT: ______

NO. OF IDENTICAL UNITS ______ MANUFACTURER ______ MODEL NO ______

RATING (BTU/HR, TONS) ______ OR AIR FLOW (CFM) ______

COMPONENT MOTOR DATA *

FUNCTION	NUMBER OF MOTORS	VOLTS	H.P

SYSTEM COMPONENT ______

NO. OF IDENTICAL UNITS ______ MANUFACTURER ______ MODEL NO. ______

RATING (BTU/HR, TONS) ______ OR AIR FLOW (CFM) ______

COMPONENT MOTOR DATA *

FUNCTION	NUMBER OF MOTORS	VOLTS	H.P

* FOR ALL MOTORS 3HP AND LARGER, LIST RUNNING AND LOCKED MOTOR CURRENTS AND NEMA DESIGN LETTER DESIGNATION

SPACE HEATING

SYSTEM FUEL (i.e. Gas, Oil, Electric) ____________________

SYSTEM TYPE: Forced Air ____

Hydronic ____ Baseboard ____ Fan-Coil ____ Convectors ____

Radiant ____ Walls ____ Floor ____ Ceiling ____

Heat Pump ____

Other ____

CAPACITY (Btu/Hr., KWe) ____________________

DESIGN TEMPERATURES:

Supply & Return Air ________°F ________°F

Supply & Return Water (Hydronic) ________°F ________°F (at Peak Load)

PUMP & FAN MOTORS: *

Use	Motor Capacity (HP)	Voltage	Use Factor (Hr/Day)

DISTRIBUTION SYSTEM COMMON WITH A.C.? YES ☐ NO ☐

DOMESTIC HOT WATER SYSTEM

SYSTEM FUEL ____________________

SYSTEM TYPE: Storage ________ Tank Capacity (gallons) ____

Demand/Instantaneous ________

Circulating Tank ________ Tank Capacity (gallons) ____

HOT & COLD WATER SUPPLY TEMPERATURE: ________°F ________°F

CAPACITY (Btu/Hr., Kw) ____________________

PUMPS:

Functional Use	Motor Capacity (HP) *	Voltage	Use Factor (Hr/Day)

MONTHLY DOMESTIC WATER USE: Yearly Average ________ Peak Month ________

* FOR ALL MOTORS 3HP AND LARGER, LIST RUNNING AND LOCKED MOTOR CURRENTS AND NEMA DESIGN LETTER DESIGNATION

PROCESS HEATING (A simple process flow diagram would be helpful)

SYSTEM FUEL ______________

PROCESS REQUIREMENTS

Use	Heat Load	Input & Output Temperatures		Use Factor (hr/day)
	Btu/hr	°F	°F	
	Btu/hr	°F	°F	
	Btu/hr	°F	°F	

PUMP & FAN MOTORS:*

Use	Motor Capacity (HP)	Voltage	Use Factor

* FOR ALL MOTORS 3HP AND LARGER, LIST RUNNING AND LOCKED MOTOR CURRENTS AND NEMA DESIGN LETTER DESIGNATION.

APPENDIX B

SPECIFICATION FOR DATA AQUISITION SYSTEM

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40KW FUEL CELL OPERATIONAL FEASIBILITY PROGRAM

SITE SELECTION TEST PHASE

SPECIFICATION FOR DATA AQUISITION SYSTEM

These data acquisition system specification defines the functional requirements for instrumentation to procure data on the operations of thermal and electrical systems of a selected building during the Site Evaluation Test Phase. This phase is the first of two test phases in the On-Site Fuel Cell Operational Feasibility Test Program. During this phase existing residential, commercial and industrial buildings will be instrumented to establish thermal and electrical energy systems characteristics in order to determine the building's suitability as a host for a fuel cell power plant installation which would supply both electrical and thermal energy to the building systems.

The data acquisition system for this test phase shall conform to the following requirements:

1.0 Sensors

Sensor characteristics shall be varified by the data logger supplier to provide system compatibility in meeting the recording characteristics contained in the data logger section of this specification. This system supplier shall conform to the minimum requirements in Tale II for required data quantities, their groupings, and their data logger input channel identification.

1.1 Temperature sensing

1.1.1 Resistance temperature detectors (RTD's) shall be state-of-the-art having platinum resistance thermometer elements.

1.1.2 RTD's shall have a nominal resistance of 100 ohms at 32°F and shall operate satisfactorily over a temperature range from minus 50°F to plus 350°F. Temperature range compression may be used to insure accuracy where a small range is needed.

1.1.3. RTD units for all building energy system differential temperature measurements shall be supplied as matched pairs (or appropriate calibration) with a minimum sensing error consistent with system accuracy specified in the data logger section of this specification.

1.1.4 The RTD for outside temperature shall be equipped with radiation shields.

1.1.5 Data logger should be capable of calibration curve fitting.

1.1.6 Temperature devices shall be inserted into the line either direct or in wells. Surface bonding is not acceptable.

1.2 Water flow sensing

1.2.1 Water flow meters of the same type and of appropriate capacities shall be used for the several flow meter installations to measure total accumulated flow.

1.2.2 Flow meter type shall be such as to provide at minimum cost a measuring accuracy consistent with specified system accuracy.

TABLE I INSTRUMENTATION INFORMATION PLAN

	INPUT SOURCE	OUTPUT DATA UNITS	NO. OUTPUT POINTS	TYPE OF OUTPUT	TOTAL MAX. OUTPUT POINTS	RECORD INTERVAL	REMARKS
1.	Building Gas Consumption	Cubic Feet	1	Accumulated	1	Every 1/2 hour	
2.	Thermal Energy Sources, Max. 3	BTU Temp Gallons Water	1 2 1	Accumulated Average Accumulated	3 6 3	Accumulated each scan and record every 1/2 hour	Water flow and temps in and out are used to compute BTU
3.	Peak Electrical Demand	KW	1	Max Peak	1	Record maximum peak every 1/2 hour	Maxuimum peak occurring during all scans. Auto-reset every 1/2 hour
4.	Electrical Energy Consumption	KW	1 1	Average Low	1 1	Record every 1/2 hour	High recorded by input source 3
5.	Selected Electrical Energy Loads	KW	1 1	High Average	3 3	Record every 1/2 hour	Optional (up to 3 channels as needed
6.	Ambient Temp	Fahrenheit	1	Average	1	Record every 1/2 hour	Shielded RTD
7.	Local Fuel Cell Temp if not Ambient	Fahrenheit	1	Average	1	Record every 1/2 hour	Only necessary if fuel cell is not located in ambient temp.
8.	Electical Phase Amps	Amps AC	3 3 3	Low High Average	3 3 3	Accumulate each scan and record every 1/2 hour	Measure amps on each of 3 phases
9.	Electrical Phase Volts	Volts AC	3	Average	3	Accumulate each scan and record every 1/2 hour	Measure volts on each of the 3 phases

TABLE I INSTRUMENTATION INFORMATION PLAN (Cont.)

INPUT SOURCE	OUTPUT DATA UNITS	NO. OUTPUT POINTS	TYPE OF OUTPUT	TOTAL MAX. OUTPUT POINTS	RECORD INTERVAL	REMARKS
10. Unbalance	*Percent unbalance	1	High	1	Record every 1/2 hour	Measure maximum phase unbalance.
11. Net Electrical Power, for Grid Connect Only	KW AC	1	Average	1	Record every 1/2 hour	
12. Fuel Cell Thermal Output for Building Load, High Grade/ Low Grade	BTU Cubic Feet Temp	1 1 2	Accumulated Accumulated Average	2 2 4	Record each point every 1/2 hour	Measuring high grade and low grade outputs as appropriate
13. Fuel Cell Gas Consumption	Cubic Feet	1	Accumulated	1	Record every 1/2 hour	
14. Fuel Cell internal Data (2 Fuel Cells)			Accumulated Average High Low	36	Record every 1/2 hour	Channel specification to be provided by fuel cell manufacturer
15. Site Identification	ID/Date/Time	1		1	Record every 1/2 hour	

TOTAL NUMBER OF OUTPUTS 84

* [(Imax - Iavg)/Iavg] x 100 = Imbalance

TABLE II DATA QUANTITIES AND INPUT CHANNEL IDENTIFICATION

SITE SELECTION PHASE

Input Channel Number	Physical Quantity	Data	Signal**
1	Outside temperature	T_{amb}, °F	--------
2	Fuel cell site temp.	T_{site} °F	--------
	Space water heating		
3	inlet temp.	T_i, °F	--------
4	outlet temp.	T_o, °F	--------
	Domestic water heating		
5	inlet temp.	T_i, °F	--------
6	outlet temp.	T_o, °F	--------
	Process water heating		
7	inlet temp.	T_i, °F	--------
8	outlet temp.	T_o, °F	--------
9	Net electrical power	KW AC	--------
10	*Electrical power	KW AC	--------
11	*Electrical power	KW AC	--------
12	*Electrical power	KW AC	--------
13	Phase current	PhA a AC	--------
14		PhB a AC	--------
15		PhC a AC	--------
16	Phase voltage	PhA v AC	-------
17		PhB v AC	--------
18		PhC v AC	--------
19	Record of peak inter-cycle power	KW AC	--------
20	water flow	V_t, gal	--------
	Domestic water heating		
21	water flow	V_t, gal	--------
	Process water heating		
22	water flow	V_t, gal	--------
23 ***	Building gas consumption	V_t, scf	--------

* Input channels 10, 11 and 12 reserved for selected electrical loads. Channels 9 and 13 through 19 connected to F/C installation interface during F/C field test.

** Supplier will ascertain and state what signal modes are available and supply that which is compatible with the input capabilities of the data logger. All factors relating to electronic signal characteristics should be referenced to the Instrument Society of America Standard #ISA S-50.1, 1975, unless otherwise specified.

*** See Section 1.3

1.3 Natural gas consumption

1.3.1 A gas meter of appropriate capacity shall be used to measure total natural gas consumption for the building and shall be supplied by the participating gas utility.

1.3.2 The gas meter supplied shall be equipped to provide a pulse signal with a maximum pulse rate of 255 pulses per second.

1.4 Net electrical power and energy

1.4.1 A three phase 4 wire watt transducer of appropriate capacity shall be used to measure net electrical power, KW AC.

1.4.2 The transducer shall supply signals compatible with the logger. Response time should be 100 milliseconds or less.

1.4.3 Watt transducer measurement accuracy shall be consistent with specified system accuracy.

1.4.4 A maximum quantity of (3) transducers meeting the requirements of para. 1.4.1, 1.4.2 and 1.4.3 may be required for certain installations to sense the electrical power, KW AC for selected individual electrical loads.

1.4.5 All electrical measuring devices shall have overcurrent capability consistent with electric utility surges.

1.5 <u>Individual phase current</u>

1.5.1 A current transducer shall be used to measure each of the three phase currents and shall have an appropriate capacity of AC amperes.

1.5.2 These transducers shall provide signals compatible with data logger.

1.5.3 These transducers shall have a measurement accuracy consistent with specified system accuracy.

1.5.4 Phase current measurements are to be r.m.s.

1.6 <u>Individual phase voltage</u>

1.6.1 A voltage transducer shall be used to measure each of the three phase voltages within the range of 100 to 130 volts AC.

1.6.2 These transducers shall provide signals compatible with data logger.

1.6.3 Transducers shall have a measurement accuracy consistent with specified system accuracy.

1.6.4 Voltage measurements are to be r.m.s.

2.0 <u>Data logger</u>

The data logger shall conform with the following minimum requirements with consideration for system compatibility with sensors and other system components in order to achieve specified data recording characteristics.

2.1 <u>Input channels</u>

2.1.1 The data logger shall have a minimum input capacity of 23 channels expandable to 55.

2.2 <u>Scanning frequency</u>

2.2.1 Scanning frequency shall be such as to accept signals from all channels in a 5 second interval.

2.3 Data recording and storage

2.3.1 Retained information shall be recorded on a data quality magnetic tape unit in engineering units. One tape shall be capable of unattended recording of a minimum of 15 days of data, based on the 1/2 hour recording interval, for the number of outputs listed in Table I.

2.3.2 Means shall be incorporated to convert sensor signal data to engineering units corrected for instrument calibration. Capability shall be provided to reprogram instrumentation calibrations when required by keyboard entry.

2.3.3 Site identification consisting of test site and test phase shall be recorded on each magnetic tape.

2.3.4 System should guard against writing over recorded data.

2.3.5 Data acquisition and recording process shall have highest priority over all other logger functions.

2.3.6 Some means of error detection shall be provided on the tape.

2.3.7 Internal detected error shall be indicated on the data tape.

2.4 Visual display

2.4.1 A visual display shall be provided with manual control permitting call up and hold on any one input or output channel in engineering units.

2.4.2 Visual display shall not effect scan and recording capability. (See reference 2.3.5).

2.5 Recording frequency

2.5.1 Recording frequency shall be capable of being manually varied by keyboard entry from a minimum of 5 minutes to a maximum of 4 hours.

2.6 Real time record

2.6.1 Provision shall be made for a recorded calendar function

2.6 Real time record

2.6.1 having year/month/day indications and a recorded clock function having hour/minute/second indications. These functions shall be independent of the data logger power supply for a period not less than 2 hours.

2.6.2 If the interruption is cleared without assistance the data logger shall automatically commence normal functioning with auto-reset to channel 1. Duration of outage shall be determined from data on the magnetic tape.

2.7 Recorded data accuracy

2.7.1 Corrected data recorded on tape in engineering units and such data visually displayed shall have a total system accuracy of $\pm$ 2.0 per cent of reading.

2.8 Peak kilowatt record

2.8.1 Capability shall be provided in kilowatts to record the peak instantaneous value that has occurred during the 1/2 hour interval.

2.9 RTD power supply

2.9.1 The RTD sensors can be supplied with power from any reliable and stable source.

2.10 Logic protection

2.10.1 The data logger operating system shall be protected against loss during power interruption up to a period not less than 2 hours.

2.11 Sensor leads and EMI isolation

2.11.1 Sensor signals shall be delivered to the data logger by a three wire input (a high and low twisted pair and shielded).

2.11.2 Sensor lead length limitations, if any, shall be defined.

2.11.3 Data logger circuitry shall accept sensor signals as differential inputs.

2.11.4 Data logger shall have a Common Mode Rejection of at least 100Db at DC with one kilo-ohm unbalance.

2.11.5 Data logger shall have the capability of sustaining Common Mode Voltages of at least $\pm$100 volts peak.

2.11.6 Analog to digital converter shall be an integrating type consistent with scan rate and synchronized with the power supply line to time average cut line frequency noise.

2.12 Data acquisition system instructions

2.12.1 A copy of all instruction manuals, application program listing, and matainance manual shall be supplied with each data aquisition system.

2.13 System check out and start up requirements

2.13.1 System check out and start up procedures shall be established and performed on first unit by the supplier and subject to the approval of GRI.

2.13.2 All procedures shall be included in the instruction manual specified in Section 2.12.

2.14 Btu Calculation

2.14.1 Capability shall be provided in conjunction with each thermal energy source to calculate Btu's each scan from the respective water flow, temperature in and temperature out channels.

2.15 Data Logger Power Supply

2.15.1 Data logger shall be capable of operating from 105 VAC $\pm$ 10% 50 HZ, 105 VAC $\pm$ 10% 60 HZ, and 120 VAC $\pm$ 10% 60 HZ power.

2.16 Data Logger Environment

2.16.1 The data logger will be placed in a protected environment and in a typically non-hazardous area.

2.16.2 Maximum operating ambient temperature is 110°F with 90% humidity non condensing.

FUEL CELL OPERATIONAL FEASIBILITY PROGRAM

FUEL CELL FIELD TEST PHASE

SPECIFICATION FOR DATA ACQUISITION SYSTEM

This specification recognizes that as shown in Table I in the Instrumentation Plan, the Fuel Cell Field Test Phase will require acquisition of the same data on building thermal and electrical systems as was required in the Site Evaluation Test Phase. In addition, however, the Field Test requires additional data to define the fuel cell installation electrical and thermal inputs to the building and to define fuel cell internal performance for verification of operational integrity and assist in establishing fuel cell operational reliability. Consistent with the foregoing, the specification for the Site Evaluation Test Phase will form a part of this specification. Additional requirements of the Fuel Cell Field Test Phase appear as additional numbered paragraphs.

Since the data acquisition system will require additional input channels, Table III identifies these but for convenience repeats the channel indentifications listed for the Site Evaluation Test Phase. This table also shows the groupings of required data quantities. The data acquisition system for this test phase shall conform to the following requirements.

A Fuel Cell test may contain either one or two fuel cells.

1.0 Sensors

Sensors shall conform to the following minimum requirements. Other sensor characteristics shall be determined by the data aquisition system supplier to provide system compatibility in meeting the recording characteristics contained in the data logger section of this specification. Table III identifies the required data quantities, their groupings, and their data logger input channel identification.

1.1 Temperature sensing

(Same requirements as Site Evaluation Test Phase Specification).

1.2 Water flow sensing

1.2.1 (Same requirement as Site Evaluation Test Phase Specification.)

1.2.2 (Same requirement as Site Evaluation Test Phase Specification).

1.2.3 Water flow meters for the fuel cell installation of a common type having a 10:1 turndown ratio shall be used with maximum flow capacity equal to 300gph multiplied by the number of fuel cells in the installation.

1.3 Natural gas consumption

(Same requirements as Site Evaluation Test Phase Specification).

1.4 Net electrical power and energy

1.4.1 A three phase 4 wire watt transducer shall be used to measure net electrical power within the range of 0 to 60 KW AC multiplied by the number of fuel cells in the installation.

1.4.2 through 1.4.9 (Same requirements as Site Evaluation).

TABLE III DATA QUANTITIES AND INPUT CHANNEL IDENTIFICATION

FUEL CELL INSTALLATION FIELD TEST PHASE

Input Channel Number	Physical Quantity	Data	Reorder as Table II Signal**
1	Outside temperature	T_{amb}, °F	--------
2	Fuel cell site temp.	T_{site}, °F	--------
	Space water heating		--------
3	inlet temp.	T, °F	--------
4	outlet temp.	T' °F	--------
	Domestic water heating		
5	inlet temp.	T_i, °F	--------
6	outlet temp.	T_o, °F	--------
	Process water heating		
7	inlet temp.	T_i, °F	--------
8	outlet temp.	T_o, °F	--------
9	Net electrical power	KW AC	--------
10	*Electrical power	KW AC	--------
11	*Electrical power	KW AC	--------
12	*Electrical power	KW AC	--------
13	Phase currents	PhA a AC	--------
14		PhB a AC	--------
15		PhC a AC	--------
16	Phase voltage	PhA v AC	--------
17		PhB v AC	--------
18		PhC v AC	--------
19	Record of peak inter-	KW AC	--------
	cycle power		--------
20	water flow	V_t, gal	--------
	Domestic water heating		--------
21	water flow	V, gal	--------
	Process water heating		--------
22	water flow	V_t, Gal	--------
23 ***	Building gas consumption	V_t, scf	--------

* Input channels 11, 12 and 13 reserved for selected electrical loads. Channels 9 and 13 through 19 connected to F/C installation interface during F/C field test.

** Supplier will ascertain and state what signal modes are available and supply that which is compatible with the input capabilities of the data logger. Input channels 31 to 54 are dedicated to signals from the fuel cell(s) which are 0-10V D.C. All factors relating to electronic signal characteristics should be referenced to the Instrument Society of America Standard #1SA S50.1, 1975, unless otherwise specified.

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TABLE III (CONT.) DATA QUANTITIES AND INPUT CHANNEL INDENTIFICATION

FUEL CELL INSTALLATION FIELD TEST PHASE

Input Channel Number	Physical Quantity	Data	Signal**
24 ****	F/C Installation gas consumption	scf	--------
25	High grade HEX inlet temp.	°F	--------
26	outlet temp.	°F	--------
27	Total customer water flow	gal	--------
28	Low grade HEX inlet temp.	°F	--------
29	outlet temp.	°F	--------
30	Total customer water flow	V gal	--------
31 & 43	F/C internal measurements total voltage	V DC	0-10 V.D.C.
32 & 44	total current	A DC	0-10 V.D.C.
33 & 45	Fuel flow feedback	scfh	0-10 V.D.C.
34 & 46	Power section air feedback	scfh	0-10 V.D.C.
35 & 47	Reformer air feedback	scfh	0-10 V.D.C.
36 & 48	Separator temperature	°F	0-10 V.D.C.
37 & 49	Reformer temperature	°F	0-10 V.D.C.
38 & 50	Preoxidizer exit temp.	°F	0-10 V.D.C.
39 & 51	HDS inlet temperature	°F	0-10 V.D.C.
40 & 52	Shift converter temp.	°F	0-10 V.D.C.
41 & 53	Preprocessor exit temp.	°F	0-10 V.D.C.
42 & 54	Half stack delta voltage	V D C + or -	0-10 V.D.C

Channels 31 through 54 apply to a two fuel cell installation.

Channels 31 through 42 apply to a single fuel cell installation.

Channels 24 through 30 represent one sensing of each quantity for the entire fuel cell installation.

** Supplier will ascertain and state what signal modes are available and supply that which is compatible with the input capabilities of the data logger. Input channels 31 to 54 are dedicated to signals from the fuel cell(s) which are 0-10 V.D.C.

**** See Section 1.7.

Test Phase Specification

1.5 Individual phase current

1.5.1 A current transducer shall be used to measure each of the three phase currents within a range of 0 to 200 amps AC multiplied by the number of fuel cells in the installation.

1.5.2 and 1.5.3 (Same requirements as Site Evaluation Test Phase Specification.)

1.6 Individual phase voltage

(Same requirements as Site Evaluation Test Phase specification.)

1.7 Natural gas consumption-fuel cell installation

1.7.1 with a maximum flow of 600 sch multiplied by number of fuel cells in the installation and having a 10.1 turndown ratio. Meter will be supplied by participating utility.

1.7.2 The meter supplied shall be equipped to provide a pulse signal with a maximum pulse rate of 255 pulses per second.

1.7.3 Measurement accuracy shall be consistent with specified system accuracy.

2.0 Data logger

The data logger shall conform with the following minimum requirements with consideration for system compatibility with sensors and other components in order to achieve specified data recording characteristics.

2.1 Input channels

2.1.1 The data logger shall have a minimum input capacity of 64 channels.

Table III.

2.2	Scanning frequency	(Same requirements as Site Selection Specification)
2.3	Data recording and storage	(Same requirements as Site Selection Specification)
2.4	Visual display	(Same requirements as Site Selection Specification)
2.5	Recording frequency	(Same requirements as Site Selection Specification)
2.6	Real time record	(Same requirements as Site Selection Specification)
2.7	Recorded data accuracy	(Same requirements as Site Selection Specification)
2.8	Peak kilowatt record	(Same requirements as Site Selection Specification)
2.9	RTD power supply	(Same requirements as Site Selection Specification)
2.10	Logic protection	(Same requirements as Site Selection Specification)
2.11	Sensor leads and EMI isolation	(Same requirements as Site Selection Specification)
2.12	Data acquisition system instructions	(Same requirements as Site Selection Specification)
2.13	System check out and start up requirements	(Same requirements as Site Selection Specification)
2.14	BTU calculation	(Same requirements as Site Selection Specification)
2.15	Data logger Power Suppply	(Same requirements as Site Selection Specification)
2.16	Data logger Environment	(Same requirements as Site Selection Specification)

2.17 Fuel cell internal measurements

2.17.1 Signals shall be accepted, as indicated in Table III, from data measurements from inside the fuel cells in a number of measurements amounting to 12 multiplied by the number of fuel cells in the installation.

TABLE IV

INPUT OUTPUT CHANNEL DEFINITION - EXAMPLE

PHASE I

Input Channel	Description	Units	OUTPUT TYPES Avg.	Hi	Low	Integral	Signal
1	Outside Temp.	°F	X				100 RTD
2	Fuel Cell Site Temp.	°F	X				"
3	Space Water Heating Inlet	°F	X				"
4	Space Water Heating Outlet	°F	X				"
5	Domestic Water Heating Inlet	°F	X				"
6	Domestic Water Heating Outlet	°F	X				"
7	Process Water Heating Inlet	°F	X				"
8	Process Water Heating Outlet	°F	X				"
9	Electrical Power (Building)	KWAC	X		X		Analog
10	Electrical Power (Selected)	KWAC	X	X			"
11	Electrical Power (Selected)	KWAC	X	X			"
12	Electrical Power (Selected)	KWAC	X	X			"
13	Phase A Current (Building)	AMPS	X	X	X		"
14	Phase B Current (Building)	AMPS	X	X	X		"
15	Phase C Current (Building)	AMPS	X	X	X		"
16	Phase A Voltage	VOLTS	X				"
17	Phase B Voltage	VOLTS	X				"
18	Phase C Voltage	VOLTS	X				"
19	Maximum Power Demand (Peak Picker)	KWAC		X			"
20	Space Water Heating Flow	GAL.				X	0-255 PPS
21	Domestic Water Heating Flow	GAL.				X	"
22	Process Water Heating Flow	GAL.				X	"
23	Building Gas Consumption	CF.				X	"

TABLE V

CALCULATED OUTPUTS

PHASE I

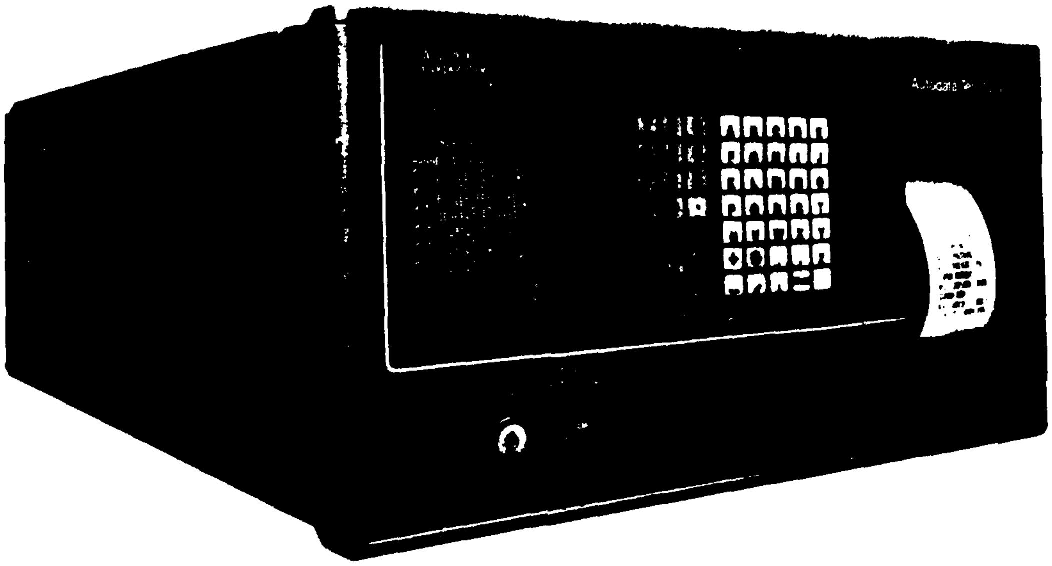
Channels Used in Calculations	Description	Units	OUTPUT TYPES			
			Avg.	Hi	Low	Integral
3, 4, 20	Space Water Heating	BTU				X
5, 6, 21	Domestic Water Heating	BTU				X
7, 8, 22	Process Water Heating	BTU				X
13, 14, 15	*Max. Imbalance of 3 Phases (Building)	%		X		

*Imbalance = [(Imax. - Iavg.)/Iavg.] X 100

ACUREX

Autodata Ten/10

Calculating Datalogger Data Sheet



Multiprocessor Technology and English Communications

Multiprocessor technology is one of the many innovations introduced in the Autodata Ten 10. Using the power of two Intel 8085 microprocessors allows the Autodata Ten 10 to provide data acquisition power and flexibility [illegible] only in expensive [illegible] systems but at a fraction of the [illegible]

It is not necessary for the [illegible] computer language [illegible] efits of this instrument. Program[illegible] done in simple English statements [illegible] uously displayed on the CRT allowing the operator to choose between alternatives.

There are further advantages of English language communication. Storage of user entered English language messages for printout on the on-board printer or output to peripheral devices is also possible. These messages might describe alarm corrective procedures in the event alarming is being done or act as descriptive labels for the points being monitored.

Mathematical Manipulation of Data

[illegible] expressions. [illegible] such as [illegible] and [illegible] func[illegible] Ten 10 the [illegible]

Such [illegible] data logger technology [illegible] alarm logging. It means the Autodata Ten 10 owner now gets real time information which doesn't require deciphering of cryptic printouts or forwarding of data to a computer center for reduction and interpretation.

Data Integrity in Tough Environments

With this instrument Acurex has uncompromisingly continued its historical dedication to analog performance and meeting the challenge of industrial operation. Even at the faster scanner speed rejection of electrical noise is unsurpassed.

Whether your application is for 10 or 1000 channels, the Autodata Ten 10 provides complete data acquisition capabilities. Autodata's careful attention to system performance and system integration prior to shipment allows the user to connect the sensors, select the proper program from the front panel "menu" and begin operation immediately.

The availability of numerous options make Autodata Ten 10 equal to the most demanding monitoring, alarming, and control requirements.

Features

The Autodata Ten 10 datalogger introduces many new and unique concepts to industrial and laboratory data acquisition. They combine to make the Autodata Ten 10 exceptional as a new generation of high performance CALCULATING DATALOGGERS.

STANDARD FEATURES

- **Built-in CRT**
  Display enhances programmability by allowing the operator to select from a "menu" of possible programming steps. Selection of the desired program is achieved by inserting your response into the proper position on the CRT display. This display also allows simultaneous viewing of up to 13 channels of data randomly selected from those channels being scanned.

- **Automatic Calibration**
  Calibration periodically performed automatically by the Ten 10 avoids the necessity for manual recalibration. Self-contained calibration standard is traceable to NBS. This allows the specifying of a guaranteed one year accuracy.

- **Multiple Scans**
  Three totally independent scan intervals can be programmed. These intervals can contain independently assigned contiguous channel groups and varied alarm scanning modes.

- **One Scan Buffer**
  Internal buffer allows system to scan at its maximum speed, storing data for later printout via the on-board printer or output to peripheral devices.

- **Fast Scan Speed**
  A scanning rate of 35 channels per second on standard resolution and 10 channels per second on high resolution with unexcelled noise rejection and accuracy specifications insures data integrity.

- **Improved IDVM**
  Significantly increases system scanning speed and accuracy.

- **Remote Start/Stop**
  Convenient screw terminals on the rear of the Autodata Ten 10 provide convenient connections for initiation of Start, Stop, and Alarm Acknowledge by remote contact closures.

- **Temperature Scaling**
  Types J, K, T, E, R, S, and B thermocouple linearizations, 100 ohm platinum (α = 0.003926), 100 ohm platinum (α = 0.00385) and 10 ohm copper RTD linearizations all included as standard.

- **Measure Resistances**
  5-wire multiplexing allows RTD or other resistance measurements. Constant current and 4-wire measurement eliminates errors of lead length or lead resistance unbalance.

- **Input Flexibility**
  Accepts wide variety of inputs including BCD, pulse rate, contact on-off and resistances as well as thermocouples, ac voltages, dc voltages and dc current. All without external signal conditioning.

- **Linear Scaling**
  Up to 20 linear functions of the form Y = mX + b can be operator entered. These scaling functions are used to scale analog inputs to their appropriate engineering units.

- **Fast Alphanumeric Printer**
  Six lines per second on-board printer is capable of printing the entire 64 character ASCII set.

- **English Labels**
  20-character descriptive label may be used to identify parameter being monitored.

- **Program Start Time**
  Initiates system operation at a pre-programmed time for unattended startup.

- **Program Stop Time**
  Stops system operation at a pre-programmed time of day.

- **Demand Log**
  Single front panel pushbutton initiates printout of a block of operator specified channels.

- **Battery Backup Clock**
  Standard clock maintains correct time even through power outages.

- **Protected Power Supply**
  Insures maximum uninterrupted operation. Protects against operational failure due to line voltage sags as low as 90 volts. Also suppresses line transients and voltage spikes caused by such things as drop out of inductive loads.

- **Watchdog Timer**
  Fail-safe relay closes in the event of microprocessor failure or power loss. Contacts can be wired to an annunciator panel offering annunciation of loss of monitoring system. Screw terminals available on rear of system.

- **Key Lock**
  Prevents unauthorized system shutoff or programming.

- **Mainframe Capacity**
  Up to 120 channels of inputs are available in the mainframe using 2-wire multiplexing (60 channel capacity with 3-wire reed relays).

Optional Features

OPTIONAL FEATURES

- **BCD Output**
  Four full parallel BCD outputs provide capability of driving six digit BCD displays

- **Magnetic Tape Interface**
  Interface to Kennedy 1600 series incremental recorder or Kennedy 9832 buffered continuous recorder provides large volume data storage for future computer processing

- **IEEE 488-1978**
  Capable of performing both talker and listener functions

- **RS-232C Communication**
  Up to two independently controllable output ports for communication with computers, terminals, or other peripheral devices can be accommodated

- **Composite Video**
  Optional 75 ohm connection allows information displayed on the on-board CRT to be simultaneously displayed on an auxiliary monitor up to 100' away

- **Analog Output**
  Monitored channels may be converted to an analog output of 4-20 mA or 0-10V under program control. Suitable for driving chart recorders or analog controllers. Data must be scaled 0-10 000 (MATHPAC™ required)

- **Alarms**
  Up to six alarm setpoints per channel provide flexibility for even tough alarm applications. Alarm messages provide indication of what's wrong, or what to do

- **MATHPAC™**
  MATHPAC™ provides capability to manipulate channel data to provide real-time information on your system. BTU, point difference, etc., are all easily calculated using MATHPAC™. Logic functions provide capability for complex alarm output functions, or initiating outputs at pre-selected points in time. Alarms may be assigned to the calculated results

Algebraic Functions	Initiating Command
Add	+
Subtract	–
Multiply	*
Divide	/
Power (A^B)	A**B
Exp (e^A)	EXP (A)
Square Root	SQRT (A)
Absolute Value	ABS (A)
Natural Log	LN (A)
Log Base 10	LOG (A)
Sin	SIN (A)
Cos	COS (A)
Tan	TAN (A)
Arc Cos	ARC COS (A)
Arc Sin	ARC SIN (A)
Arc Tan	ARC TAN (A)
Time	TIM (A)
Logical Functions	**Initiating Command**
And	∧
Or	+
Not	

- **Averaging**
  Provides averages over time and averages of groups of channels. MIN and MAX functions extract minimum and maximum values of a series of readings or group of channels. (MATHPAC™ required)

- **Contact Outputs**
  Contact outputs provide a means of signaling the process or experiment that some action needs to be taken. Outputs can be initiated by alarm conditions, time, logical condition (i.e., a predetermined series of contacts closed), or calculated value. Contact outputs are interchangeable with analog input cards. One contact output card may be used in the remote scanner. Two may be placed in the mainframe in place of two input cards. There are ten relays on each card. Relays are form C rated at 1A, 26VDC; 0.5A 120VAC, resistive. Open collector outputs are also available rated at 1 amp peak, 70 VDC. Maximum continuous power is 1.8W

- **Analog and Digital Input Versatility**
  Analog inputs and Digital inputs of most common electrical transducers are easily handled by the Autodata Ten/10. See Input Specifications for details

- **High Density Batter Backed CMOS RAM**
  Systems requiring large amounts of memory can make use of high density battery backed RAM memory. This avoids the unnecessary use of additional option slots for more than one RAM memory card

- **Remote Scanner**
  The 1016 Remote Scanner can be used when there are more than six input cards required. Ten channel (3 and 5 wire) and twenty channel (2 wire) cards may be intermixed in the remote scanner. One contact output card may be used in the remote scanner in place of an input card. The remote scanner may be located up to 5,000 feet from the datalogger. Up to ten remote scanners may be used in the system

- **Carrying Case**
  An environmentally rugged fiberglass carrying case is available for the Autodata Ten/10. It provides protection during transit for the datalogger

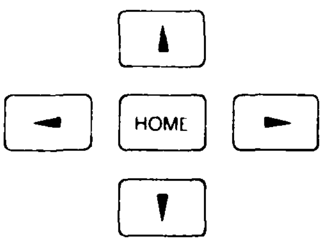
Operation

The Autodata Ten 10 utilizes "menu programming". This is a simplified approach to programming allowing the operator to select from a "menu" of programming alternatives. The menu page is accessible from any point in the datalogger operating sequence by pressing the front panel pushbutton labeled "HOME". This menu page displays page number and a description of the contents of the individual program pages.

```
MN   AUG15 1978 12 07 32 00 00 30
                      SCAN001 999
01 DATA DISPLAY
02 BLOCK DISPLAY
03 DEMAND LOG DISPLAY FORMAT
04 SET TIME SUMMARY TABLES
05 CHANNEL PROGRAMMING
06 SCAN LOG CONTROL
07 LOG FORMAT CONTROL
08 ENGR UNIT CONV VOLTAGE
09 ENGR UNIT CONV TEMPERATURE
10 ENGR UNIT CONV Y MX+B
11 ENGR UNIT CONV Y MX+B
12 ENGR UNIT CONV Y MX+B
13 ENGR UNIT CONV Y MX+B
CONTINUED
```

Program pages may be accessed through either of two methods. Either a series of page forwards until the appropriate page is reached, or the page number may be entered numerically at the MN position of the menu page and the "ENTER" key pressed. The datalogger will respond by immediately accessing the page whose numeric designation was indicated.

Once a programming page has been selected, the operator may choose to enter or alter the program appearing on that page. This is accomplished by moving the flashing cursor to the appropriate position on the page where an entry is to be made. The cursor is moved either up, down, left or right using the cursor control keys (labeled with arrowheads) on the front panel.



When the cursor is in the appropriate position, the alpha or numeric key is depressed to enter the proper character in the position immediately above the flashing cursor. The cursor will then automatically move to the next position where an entry is appropriate. Upon completion of all entries on a single programming line, the "ENTER" key must be depressed. This step enters the program from that particular line into the program memory of the Autodata Ten/10.

Some often used programming pages and their functions will illustrate the programming sequence of the Autodata Ten/10.

Program Page 05

```
    05   OCT15 1978 12 07 52 00 00 45
                          SCAN000-999
    CHANNEL PROGRAMMING
 4  FIRST-LAST CHANNELS  ---/---
 5  SINGLE CHANNEL  ---
 6  E/U CONV --     RESOLUTION(H/L) -
 7  CHNL LABEL ------------
 8  ASN -------------------------
 9  SETPOINTS       H/L MESSAGE
10  1 ----------------------------
11  2 ----------------------------
12  3 ----------------------------
13  4 ----------------------------
14  5 ----------------------------
15  6 ----------------------------
16  DEADBAND -------
```

Program Page 05 is used for channel programming. Channels may be programmed either in blocks of first channel/last channel or as single channels.

E/U conversions are those programs stored in memory which convert the measured signal to engineering units. A two-digit numeric designator is used to indicate these conversions.

Resolution (High Low) selects either 50 000 count resolution or 10 000 count resolution.

Channel labels are alphanumeric entries which can be used to describe the channel being monitored, e.g. OIL TEMP MOTOR #1. These channel labels will appear on the CRT display and are outputted to the printer or other peripheral devices unless they are suppressed (see Page 07).

Up to six set points per individual channel may be programmed if the alarms option has been included. These can be any combination of High or Low set points, and each set point may contain its own 12 character alphanumeric message, e.g., OVERLOAD. An individual deadband (see alarms data sheet) may be entered for each single channel. This deadband would apply to all set points associated with that single channel.

Program Page 06

```
    06   OCT15 1978 12 07 52 00 00 45
                          SCAN000-999
       SCAN LOG CONTROL

            CHANNELS     INTERVAL
    SCN LG FIRST LAST   HR   MN   SC
 7   *   1  000   015   00   15   00
 8
 9

11                      CONTINUOUS
12     START SCAN AT
13     STOP SCAN AT

15     ALARMS
```

Program Page 06

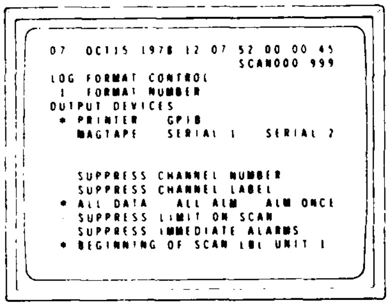
Program Page 06 is utilized to control the scanning and logging sequence. Up to three different groups of channels may be programmed to scan and/or log at different time intervals. Scanning and logging are distinct operations. Scan indicates data that is being sampled; log indicates a printout or output to a peripheral device. For example, channels 000/015 may be scanned every 15 minutes while channels 005/099 are scanned every 35 minutes. In addition to the three interval scanning modes, a single continuous scanning mode is available.

The datalogger may also be programmed to start scanning or stop scanning at a particular time of day.

This page is also used to enable the alarms mode if that option has been incorporated into the datalogger.

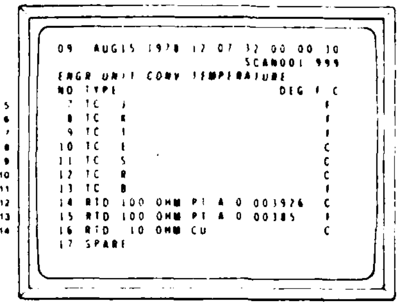
Enabling the programming lines on Page 06 is accomplished by inserting an asterisk into the SCN column(s) desired. When logging is also desired, the log format number is inserted into the LG column. The measurement data will then be output in the manner indicated for that log format on Page 07.

Program Page 07



Program Page 07 is used to define the log format. Up to five different log formats may be defined. A log format is defined by entering its format number (1 5) on the first line of this page. The individual format is then defined by inserting an asterisk into the desired responses under "OUTPUT DEVICES". This allows data to be output to the printer only, printer and GPIB, serial port 1, or other desired combinations of output devices. In the event alarms scanning is being done, the alarms mode is also defined on this page. The log format number defined on this page is then utilized on program Page 06 in the LG column to define the characteristics of the outputs of the scans which have been enabled.

Program Page 09

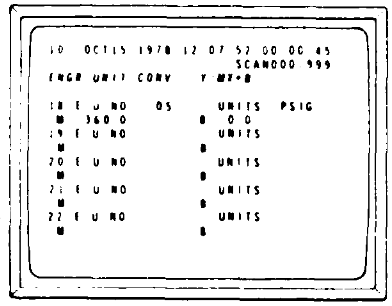


Program Page 09 is used to supply E U conversion numbers (see program Page 05) for temperature conversions of thermocouples or RTD's. Assignment of one of these engineering unit conversion types to a channel will result in applying the linearization sequence appropriate to the input type to the measurement data on that channel. The engineering units associated with these temperature conversions are °C or °F. Changing a measurement from °C to °F *may be done by simply* inserting an F or C (indicating °F or °C) into the extreme right-hand column. This *institutes the proper conversion sequence* to arrive at a reading in the indicated units.

E/U CONVERSIONS/DESCRIPTION

No.	Function
1	SKIP
2	AUTORANGE
3	50 MV RANGE
4	500 MV RANGE
5	5V RANGE
6	10V RANGE
7	T C J
8	T C K
9	T C T
10	T C E
11	T C S
12	T C R
13	T C B
14	RTD α 0.003926
15	RTD α 0.00385
16	RTD 10Ω CU
17	SPARE
18 37	Y MX + B
38	CONT OUT ACK
39	CONT OUT NON ACK
40	CONT IN ALARM ON OPEN
41	CONT IN ALARM ON CLOSE
42	CURRENT 10 50 MA
43	CURRENT 4 20 MA
44	CURRENT 0 1 MA
45	CURRENT 1 5 MA
46	ALGEBRAIC LOGICAL
47	DIGITAL INPUT PULSE
48	DIGITAL INPUT BCD
49	HI VOLTAGE 150V
50	AC VOLTAGE 150 VAC
51	RESISTANCE 500Ω
52	RESISTANCE 5K Ω
53	RESISTANCE 50K Ω

Program Page 10



Program Page 10 is used to define the Y = mx + b functions. The E/U conversion numbers (to be entered on Page 05) are those appearing at the far left side of the screen. Entries on this page would be as follows:

- E/U NO. – defines the range on which measurement data is made. The entry 03 through 16 would normally appear here.
- UNITS – a five-digit alphanumeric label may be entered which will appear following the measurement data. It is normally used to indicate the engineering units to which the mx + b function is converting the measured signal. Such entries as PSI, GPM, etc. would appear here.
- M – this is the slope of the conversion *function. It is normally determined by* the formula

$$M = \frac{Y_1 - Y_2}{X_1 - X_2}$$

where the X values are measurement data and the Y values are the values which will result upon application of the conversion. It in entered in numeric form and must contain a decimal point.

- B – this is the "offset" of the linear conversion. Its value is equal to the value of *Y evaluated at X = 0. It is entered in* numeric characters and must also contain a decimal point.

Other program pages are utilized in the same manner as described above. Moving the cursor to the desired position and making the program entry. A few minutes of practice and the system of "menu programming" in the Autodata Ten/10 will be*come second nature, making this the most* usable datalogger you've ever operated.

Input Specifications

The Autodata 10 input is designed for maximum versatility. The Autodata 10 can handle both AC and DC voltages. DC millivolts, process current (0 1, 4 20, 10 50, 1 5 milliamps), thermocouples, RTD's resistances and an assortment of digital inputs including pulse, BCD and frequency.

AUTOCAL and Auto Zero keep the Autodata 10 accurate. Auto Zero is performed prior to every 10 seconds. This allows the Autodata 10 Integrating Digital Volt Meter (IDVM) to be fast while maintaining excellent zero stability. AUTOCAL provides recalibration to a National Bureau of Standards (NBS) traceable reference every 5 minutes. Add these to Acurex's proven reed multiplexer design and you are assured of accurate data taken today, tomorrow or next year.

Noise rejection is an essential part of any measuring system. Noise is defined as an unwanted signal which may mask the presence of the desired signal if it is not rejected. Acurex's high common-mode rejection has been a standard in our instruments for 15 years. Common-mode rejection of 160 db or 170 db depending on speed selection in the A/D converter virtually eliminates noise.

Typical Measurement Error

Common Mode Voltage	Common Mode Rejection	Noise
120 Volts	160 db	1.2 µV
12 Volts	160 db	12 µV
1 Volt	160 db	01 µV
120 Volts	170 db	4 µV
12 Volts	170 db	04 µV
1 Volt	170 db	003 µV

Input Options

DC Inputs

Four standard DC input ranges are provided:

0 to ± 50 millivolts with 1 µV resolution
0 to ± 500 millivolts with 10 µV resolution
0 to ± 5 volts with .1 millivolt resolution
0 to ± 10 volts with .2 millivolt resolution

All ranges above are with high resolution at 10 channels per second. For higher speed scanning, the resolution above is 5 microvolts, 50 microvolts, .5 millivolts and 1 millivolt. An optional high voltage input card provides a 0 to 150 volt range with 12.5 or 2.5 millivolts resolution.

Current

Process current of 0 to 1 milliamp, 4 to 20 milliamps, 10 to 50 milliamps, and 1 to 5 milliamps is easily handled using either the current input module or by adding 25 ohm shunts to any voltage input card. The E.U. conversions for current convert these inputs directly to 0 to 100% for convenience in scaling into engineering units. Scaling may be accomplished either through the use of the mx + b's or through the use of more complex math pack functions. Process currents may also be converted to analog outputs for control of other functions. Calculations performed on process current inputs may also be output on the analog output board.

Thermocouples

Acurex provides the 7 most common thermocouples as standard in every Autodata 10. Only the isothermal thermocouple input board is required to use the thermocouple capability of the Acurex Autodata 10. Thermocouple types J, K, T, E, R, S and B are included in every Autodata 10. These are selectable on thermocouple-by-thermocouple basis as degrees C or degrees F. Thermocouple accuracy for various types of thermocouples is shown in the table below. Errors include the effect of cold junction as well as all system measurement errors and linearization errors.

Thermocouple Type	Measurement Range (°C)	Inst Temp 20 to 30°C Hi Res °C	Hi Res °F	Lo Res °C	Lo Res °F
J	−200 to −100	0.4	0.7	1.1	1.5
	−100 to 0	0.3	0.5	0.8	1.1
	0 to 400	0.4	0.5	0.8	1.1
	400 to 760	0.3	0.5	0.8	1.1
K	−200 to −100	0.5	0.9	1.3	1.9
	−100 to 0	0.4	0.6	1.0	1.3
	0 to 400	0.3	0.5	0.9	1.2
	400 to 1370	0.4	0.7	1.0	1.2
T	−200 to −100	0.5	0.9	1.3	1.8
	−100 to 0	0.4	0.6	1.0	1.4
	0 to 400	0.3	0.6	0.9	1.2
E	−200 to −100	0.5	0.8	1.1	1.6
	−100 to 0	0.4	0.6	0.9	1.2
	0 to 800	0.3	0.6	0.9	1.3
	800 to 1000	0.6	1.1	1.2	1.7
R	0 to 400	1.2	2.1	2.5	4.5
	400 to 1665	0.7	1.3	1.7	3.1
S	0 to 400	1.1	2.0	2.4	4.3
	400 to 1064	0.8	1.2	1.7	3.1
	1064 to 1665	0.7	1.3	1.6	2.9
B	200 to 600	2.8	5.0	5.7	10.3
	600 to 1100	1.2	2.1	2.5	4.5
	1100 to 1320	0.8	1.2	2.0	3.6

RTD

Five-wire multiplexers for resistance measurements can be made using the five-wire mux card. The five-wire resistance measurement makes possible switching of both the excitation and signal leads individually to each RTD, eliminating any problems with common-mode voltage interaction between the RTD's. A driven current source is used to excite the RTD's, thus problems with settling time are eliminated. Acurex five-wire resistance measurements eliminate errors due to resistance and temperature coefficient of the leads. The switched current source makes possible precise temperature measurements that might otherwise be difficult due to the self-heating of the RTD. The RTD accuracy specifications are shown below

		Inst Temp 20 to 30°C			
RTD	Measurement	Hi Res		Lo Res	
Type	Range	°C	°F	°C	°F
100 Ohm Pt 00385	200 to 100	0.2	0.4	0.9	1.1
	100 to 500	0.3	0.6	1.0	1.3
	500 to 850	0.4	0.7	1.1	1.6
100 Ohm Pt 003926	- 200 to 100	0.2	0.4	0.9	1.1
	100 to 500	0.3	0.6	1.0	1.3
	500 to 850	0.4	0.7	1.1	1.6
10 Ohm Cu	- 200 to 150	1.4	2.5	3.1	5.2

Resistance

The resistance inputs provide true four-wire measurement of resistance. Resistance measurements are from 0 to 500, 0 to 5000 and 0 to 50,000 ohms full scale. Resolution is one part in 50,000 for high resolution and one part in 10,000 for low resolution. Five-wire multiplexing provides switched excitation, signal and guard leads.

AC Inputs

The AC input card consists of a ten-channel card which measures true RMS AC with a 60 cycle or 50 cycle period. A voltage divider, provided per channel, provides capability of intermixing voltage and current measurements on the same card.

Digital Inputs

Digital inputs may be connected to the Autodata 10 in one of three ways... BCD, Pulse and Contact Inputs.

CONTACT INPUTS

The analog inputs may be programmed to look for an open or closed contact and respond to that condition. In this case, contact inputs are intermixed with standard analog channels.

PULSE INPUTS

A special pulse input card provides pulse accumulation, frequency, period, and status for non-contact inputs (i.e. voltages). This card requires one I/O slot for 5-15 channels of input. Versions are available with 5, 10, and 15 channel inputs.

BCD INPUTS

BCD inputs are available in a card that plugs into one of the I/O slots. There are four BCD inputs per card. Each BCD input contains six digits, sign, and decimal point.

Remote Scanner

The Autodata 1016 remote scanner provides a remote housing for up to 100 three-wire channels or 200 two-wire channels. This remote multiplexing in many cases saves money by allowing only one analog cable to be connected between the Autodata 10 mainframe and remote scanner up to 5,000 feet away. A control cable is also required to address the scanner.

Two-Wire Multiplexers

Two-wire multiplexers allow the connection of up to 20 input channels per card to the Autodata 10. Two-wire multiplexers are available for thermocouple volts and volts only. Lower common-mode rejection may be experienced with high source resistance transducers or extremely noisy locations.

Three-wire multiplexers provide the lowest noise connection between the Autodata 10 and external signal source. The high, low and shield are switched together to provide a fully shielded and guarded path between signal source and the datalogger measuring system. Three-wire multiplexers are available with process current inputs, DC inputs, thermocouple inputs and AC inputs.

Five-Wire Multiplexer

Five-wire multiplexers are used when resistance measurement is required. Both excitation and signal leads are switched along with the shield. Voltage inputs may also be brought in on the five-wire multiplexer board by simply not connecting the excitation leads.

Specifications

Specifications Autodata Ten/10

Dimensions: Bench model, 9.2" (23.37 cm) high, 17.75" (45.09 cm) wide, 22.75" (57.79 cm) deep. Rack mount, 8.75" (22.33 cm) high, 19.0" (48.26 cm) wide, 22.75" (57.79 cm) deep.

Weight: Approximately 56 lbs (21.77 kg) dependent on options. Shipping weight adds approximately 20 lbs.

Power Requirements: Operates on field selectable 115/230 VAC, 50 or 60 Hz. Draws less than 80 watts without options.

Power Line Range: 90-126 VAC or 207-253V (230V Tap).

Temperature: Operating 0°C to +50°C. Storage −20°C to +65°C.

Relative Humidity: 0% to +90%, non-condensing.

Option Capacity: Three slots for field-installable options are available in the mainframe.

Clock: Battery backed up to provide uninterrupted time-keeping during power interruption of up to six months.

Clock Output Format: Clock output is in Gregorian month, day, hours, minutes, seconds, i.e., 13:33:25 JUN24, 1983.

CRT Display (Size): 5" (127 mm), measured diagonally.

System Operating Altitude: Up to 10,000 feet minimum.

Printer: Six lines per second, electronic discharge, 21-column line length with complete 64 character ASCII character set printing capability.

Keyboard: Full alphanumeric ASCII keyboard with Cursor control for CRT. Keyboard is sealed for resistance to dust and dirt.

Digital Inputs: BCD and Pulse input options available. BCD is six digits plus sign and decimal point.

Program Memory: All user entered programming variables stored in battery-protected RAM memory. Programs contained in this memory protected for a power outage of up to six months.

Data Buffer: Internal buffer provided for data storage during scanning.

Channel Capacity: 120 channels in mainframe using 2-wire multiplexers (60 channels with 3-wire reed relay multiplexers). Multiplexers can be mixed as desired. Overall system capacity to 1000 points, with optional scanner housings.

Measurement Method: Patented V-F converter, true integrating, utilizing a standard charge dispenser and bipolar counter.

Integration Period: System integrates over one to five line cycles dependent on resolution and scanning speed.

System Scanning Speed: 35 readings per second with standard resolution, 10 readings per second with high resolution. *Auto-range selection may affect scanning speed.*

Automatic Calibration: Totally guarded 10.0000V source periodically used for automatic calibration of IDVM without operator intervention. Calibration source traceable to NBS.

Zero Stability: Fully auto-zeroing; no zero calibration required.

Resolution: Standard or high resolution may be intermixed on a channel-by-channel basis. Range/resolution is indicated in Table E.

Range	Std Res	Hi Res
50 mV	5 μV	1 μV
500 mV	50 μV	10 μV
5V	500 μV	0.1 mV
10V	1 mV	0.2 mV
Auto	—	—

Table E

Thermocouple Conformity: Better than 0.1°C.

Ranges: 0– ± 50 mV, 0– ± 500 mV, 0– ± 5V, 0– ± 10V. Type J, K, T, E, R, S, and B. RTD's 100 ohm Pt and 10 ohm Cu. Resistance 0–500 ohm, 5000 ohm and 50K ohm.

Normal-Mode Rejection: Rejection of normal-mode electrical noise greater than 70 dB at power line frequency (50/60 Hz and harmonics).

Common-Mode Rejection: Rejection of common-mode electrical noise specified with up to 100 ohms source unbalance given in Table A.

Frequency	Hi Res	Low Res
dc	170 dB	160 dB
60 Hz	170 dB	160 dB
0–2 kHz	130 dB	120 dB

Table A

Overall System Accuracy: Table B lists overall system measurement accuracy for voltage measurements. Included in the errors indicated are all system errors occurring between the voltage input termination on the input module and th[illegible] digital readout occurring on the front pa[illegible] is guaranteed performance for [illegible]od of one year without recalibration.

3 Wire Reed Relay Mux		
Input Voltage % of Full Scale	Maximum Error (% of Full Scale)	
	Std Res	Hi Res
0	±0.020	±0.010
33	±0.022	±0.012
67	±0.023	±0.013
100	±0.025	±0.015
120	±0.026	±0.016

* ±2.5 μV

Table B

Warm-up Time: One hour to full accuracy at calibration temperature (25°C).

Temperature Stability: ±0.002% reading, ±0.1 microvolts per °C variation from normal operating range (20–30°C).

Resistance: ±0.005% range ±0.015% rdg ±0.025 ohms (Hi Resolution).

ACUREX Corporation

Autodata Division
485 Clyde Ave., Mt. View, CA 94042
(415) 964-3200 Telex: 34-6391

Acurex Corporation, Europe
Esplanade 6
200 Hamburg 36
West Germany
Phone (4940) 341525
Telex: 84121448

Acurex Far East, Inc.
Kyodo Building, Suite 47
2-2, 4-Chome, Hatchobori
Chuo-ku, Tokyo 104, Japan
Phone: 03-552-2017
Telex: 78128719

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APPENDIX C

PROGRAM REPORTING GUIDELINES FOR PHASE I

INTRODUCTION

To achieve the efficient accomplishment of program goals and schedules, the Fuel Cell Operational Feasibility Program requires close coordination to assure that the efforts of each participating company will be complementary and in accordance with the interests of the Department of Energy. An important consideration in this coordination is the concise, timely, and comprehensive reporting of significant program events, findings, and experiences by the individual utility participants to all participants and sponsors via the Coordinting Contractor. Moreover, the documentation provided in the reports will be available to assist in future efforts related to the current program.

In a diverse, interdisciplinary program involving approximately 25 participants throughout the nation, it is essential that all reports be prepared in accordance with uniform guidelines, and be submitted on schedule. Accordingly, this document establishes and transmitts standard guidelines and outlines for report preparation and submittal to the following by each participant in the Fuel Cell Operational Feasibility Program.

REPORTING INSTRUCTIONS

The reports that have been identified as essential for the efficient achievement of programmatic goals and activities include the following:

I. Monthly Status Reports

Due on the 10th of the month following the month being reported on, starting April 10, 1980.

II. Quarterly Cost Reports

Due on the 20th of the month following the three month period being reported on, starting July 20, 1980.

III. Topical Reports

A. Field Test Activities

1. Preliminary Site Selection

Due 6 weeks prior to delivery of first data logger, approximately July 15, 1980.

2. Final Site Selection

Due 3 months prior to delivery of first power plant.

3. Site Design and Preparation, Power Plant Installation & Checkout

Due 6 weeks after power plant delivery at site.

4. Power Plant Operation, Maintenance, Removal and Site Restoration

   Due 2 months after shipment of power plant back to manufacturer

5. Field Test Data and Evaluation

   Due 3 months after shipment of power plants to manufacturer

B. Business Assessment Activities (Due dates to be determined)

1. Market Survey

2. Institutional, Legal, and Regulatory Considerations

3. Business Service Modes

4. Business Venture Analysis

5. Public Information Activities

Guidelines or outlines for each of the above cited reports are presented in the following sections of this document.

The demonstration coordinating contractor will collate all of the reports for the overall program. These reports will then be distributed to the program participants.

REPORT NAME: Monthly Status Report

PURPOSE: To summarize activities on the program, and identify problems at an early date.

FORMAT:

Project Manager:
Company:

Date:
Reporting Period:

1. Introduction/Summary: (highlights, milestone accomplishments, special problems)

2. Site Selection Activities: (discuss site selection status and progress, summarize information gathered)

3. Field Activities: (describe all field-related activities, site design/preparation work, DAS-related activities, fuel cell operation, etc.)

4. Business Assessment Activities: (in-house marketing activities, economic analyses, code issues, legal, rates, insurance, etc. Cite any results or conclusions).

5. Public Information Activities: (report on:

presentations at meetings of professional societies, local building and trade associations, local conservation and ecology groups, community leaders, and other civic groups, meetings with bankers, insurance companies, investor groups, realtors, housing authorities, and policy makers such as utility commissioners, building union officials, city councilmen, and state legislators, advertising in local building and trade publications, local press news and TV coverage, window and showroom displays, and tours and demonstrations of test sites, articles in trade, financial and professional journals.)

6. Unusual Occurrences: (out-of-limits operation, unscheduled maintenance or shut-downs of DAS or fuel cell systems, legal or regulatory action which stops activity.)

REPORT NAME: Quarterly Cost Report

PURPOSE: To document utility expenditures associated with the program in sufficient detail to allow cost projections for commercial fuel cell service.

FORMAT

Project Manager: Date:
Company: Reporting Period:

I. Summary/Overview: (major cost items/activities, actual vs estimated level of effort, unanticipated costs or problems)

II. Detailed Cost Breakdown for Reporting Period: (salaries, advertising and promotion, overhead, sales and administration, equipment, material, shipping and warehousing, installation, operataing and maintenance, travel, subcontractors)

III. Cumulative Costs Breakdown: (detailed breakdown of total project costs to date using categories in II above, breakdown of costs into recurring and "first-of-a-kind" costs)

IV. Comparative Analysis of Actual vs Estimated Costs: (differences between actual vs estimated costs by dollar amount and percentage, explanation of differences, projection of future costs)

V. Suggestions for Cost Cutting Measures: (improvements in equipment design or procedures, use of employees vs subcontractors, avoidance of labor problems or other constraints)

REPORT NAME: Preliminary Site Selection Report

PURPOSE: To document each utility's reasons for selecting sites to be instrumented, such that USAF/DOE may approve the selections in terms of the overall program.

FORMAT

Project Manager: Date:

Company:

I. Introduction and Summary

II. Identification of 30-60 Candidate Buildings

   A. Early entry market segments

      1. Energy consumption characteristics

      2. Growth potential

      3. Classification by SIC Codes (or other classification process)

   B. Candidate Buildings (30-60 sites)

      1. Grouping by SIC codes

      2. Estimates of energy requirements

      3. Site locations and access

      4. Regulatory environment

5. Space available for visitors and power plant

III. Sites Selected for Instrumentation (3-10)

A. General Building Description (e.g., school, 100,000 sq. ft., single story, etc.)

B. Individual building electrical and thermal energy consumption and load factors

C. Coincidence of electrical and thermal loading (for grid-isolated applications)

D. Power plant configurations to be considered at each site

Verification of coverage of market segments

1. Early entry market segments included

2. Site characteristics vs market segment characteristics

E. Site owner attitudes to concept and field test

F. Matchup of building loading to fuel cell characteristics

G. Installation requirements

1. Instrumentation package

2. Physical compatibility of fuel cell and site

H. Regulatory environment

I. Aesthetics

1. Characteristics of neighborhood

2. 8 x 10 glossy photographs of each site

3. Visitor facilities and access

IV Suggestions for improving site selection procedure

Appendix: Completed Survey Interview Forms for the 30 to 60 Candidate Sites

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