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TECHNICAL NOTE

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TITLE: FUEL CELL POWER SYSTEMS FOR NAVY APPLICATIONS

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NAVAL CIVIL ENGINEERING LABORATORY
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METRIC CONVERSION FACTORS

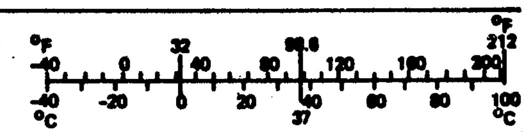
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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A fuel cell power plant can supply both thermal and electrical energy to a site load. The technical and economic attractiveness of using a fuel cell system for a given application depends on many factors such as: satisfying load requirements, reliability, local energy costs, and capital costs. Satisfying site load requirements cost effectively requires a properly sized fuel cell system operating in its optimum mode. A computer program was

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developed to simulate the dynamic input/outputs of the fuel cell system (fuel cell, auxiliary boiler, thermal storage, electrical grid) and evaluate the separate system operational costs. Using the computer simulation in an iterative method, the optimum operational mode and size of the fuel cell and thermal storage can be estimated. A life-cycle-cost analysis for a given application can be performed using current manufacturer hardware costs and energy input/output data generated from the computer simulation.

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A fuel cell power plant can supply both thermal and electrical energy to a site load. The technical and economic attractiveness of using a fuel cell system for a given application depends on many factors such as: satisfying load requirements, reliability, local energy costs, and capital costs. Satisfying site load requirements cost effectively requires a properly sized fuel cell system operating in its optimum mode. A computer program was developed to simulate the dynamic input/outputs of the fuel cell system (fuel cell, auxiliary boiler, thermal storage, electrical grid) and evaluate the separate system operational costs. Using the computer simulation in an iterative method, the optimum operational mode and size of the fuel cell and thermal storage can be estimated. A life-cycle-cost analysis for a given application can be performed using current manufacturer hardware costs and energy input/output data generated from the computer simulation.

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CONTENTS

INTRODUCTION

An analysis of the technical and economic feasibility of using fuel cells for Navy shore activity applications was performed. The primary advantage of fuel cell power plants is their ability to generate electrical energy efficiently (approximately 40%) regardless of their size. This feature, in addition to the inherent operating quietness, allows siting of fuel cell plants next to loads where the fuel cell thermal by-product (domestic hot water) can be utilized. Fuel efficiencies as high as 80% can be realized when operating in the co-generation mode.

This report documents a computer program for simulating the operation of a fuel cell power plant at a Navy site. The computer program was initially developed to simulate a 40-kW phosphoric acid fuel cell operating with or without an electrical grid and auxiliary boiler. The program was later extended to include thermal storage and phosphoric acid fuel cells of any size.

APPROACH

In this investigation of fuel cell power systems, a model was developed to simulate the operation of an existing fuel cell system. The United Technology 40-kW phosphoric acid fuel cell was chosen to model because it is currently the most commercially developed fuel cell power plant system available.

As a first step in the analysis, data were collected for the 40-kW fuel cell. Available data consisted of performance curves and subsystem operational "thermodynamic state points" for the power plant operating at 20- and 40-kW. From these data and the objectives of the investigation, output requirements for the computer simulation were established.

In the development of the computer program, a mathematical model of the fuel cell power plant subsystems was employed. A mathematical model was developed through a thermodynamic analysis of each power plant subsystem, using the thermodynamic state point data collected. Most subsystems could be modeled accurately, but it was found that the data was insufficient for an accurate model of the entire system. Therefore, the mathematical model was modified to include manufacturer performance test curves in lieu of state points. Subsystem models from the thermodynamic analysis, such as the effect of ambient air temperature on the fuel cell performance, were kept for thermal effects not well-represented in performance curves.

A computer flow chart was then prepared, based on the modified mathematical model and computer program input/output requirements. From this flow chart, a computer simulation program was developed for this particular fuel cell operating at a Navy site. After achieving a working computer simulation model for the 40-kW fuel cell, the program was extended to include phosphoric acid fuel cells of any size. This enhanced the computer program capability while requiring relatively minor alterations to the program itself. Because fuel cell electrical efficiencies are consistent over a wide range of sizes, the same performance curves could be used for the extended program. Thermal storage sizing capability was also added.

With the modified program used in an iteration scheme, the optimum operational size of a fuel cell and thermal storage can be determined for a given Navy site application. From current fuel cell capital costs, site-specific energy load and rates, and energy consumption/displacement data generated from the computer simulation, a life cycle cost analysis can be performed for a given application.

DISCUSSION

United Technology 40-kW Fuel Cell Power Plant

The 40-kW fuel cell power plant is an on-site energy system which simultaneously generates AC electrical power and recoverable thermal energy. It uses pipeline gas or peak-shaved gas for fuel (Table 1).

Figure 1 illustrates the 40-kW fuel cell power plant. The plant features include: high efficiency; quiet, nonpolluting, automatic, unattended operation; and instantaneous load response. The power plant consists of the following major subsystems:

1. Fuel processor
2. Power section
3. Thermal management subsystem
4. Power conditioner

Figure 2 is a simplified block diagram of the fuel cell power plant. The fuel processor delivers a hydrogen-rich gas to the anode side of the power section. The power section electrochemically consumes this gas and oxygen, which has been delivered to the cathode side of the power section, to produce direct electric current. This direct current goes to an inverter to produce AC electrical power with characteristics shown in Table 2. The thermal management system controls the power section reaction temperature (approximately 370°F) and supplies thermal energy for fuel preprocessing/processing, high and low grade heat exchangers, and condensate preheating. The high grade heat exchanger is connected in the cooling loop of the power section, and the low grade heat exchanger is connected to the power section cathode exhaust. Both heat exchangers supply domestic hot water between 110 and 180°F.

At the time of this investigation, the most detailed operational data available for the United Technology 40-kW fuel cell system were the "thermodynamic state point" data for the power plant operating at 20 and

40 kW. This operational data were generated by United Technologies and supplied to the NASA-Lewis Research Center under contract. Figure 3 illustrates the operational schematic of the 40-kW fuel cell power plant, and Table 3 is a list of the accompanying thermodynamic state point data for the fuel cell operating at 20- and 40-kW. System performance curves also generated by United Technologies (Figures 4 through 7) exist for system electrical efficiencies, low and high grade heat availability, and power plant percent fuel utilization.

Development Of 40-kW Phosphoric Acid Fuel Cell Computer Model

As a first step in developing this computer model, computer input and output requirements were established. Data inputs that are available or can be approximated for a given site include: daily electrical and thermal load data, ambient air temperature, electrical costs (buying and selling), and auxiliary boiler and fuel cell fuel costs. Using these input data, computer output requirements were determined as follows:

A. Energy Printouts (every 1/2 hour)

1. Fuel cell electrical output
2. Fuel cell thermal output
3. Fuel cell thermal energy dumped
4. Grid output
5. Grid input (from fuel cell)
6. Auxiliary boiler output

B. Total Daily Cost Printouts

1. Fuel cell fuel consumption
2. Electricity purchased
3. Electricity sold
4. Auxiliary boiler fuel consumed

The printout requirements listed are available for four different load following schemes: the fuel cell running at rated output; electrical load following; thermal load following; and the fuel cell at zero output. The computer program simulates fuel cell operation for a maximum of 24 hours per total data set entry.

Development of the computer model to meet these output requirements proceeded with a thermodynamic analysis of the fuel cell power plant subsystems, using the thermodynamic state point data. These data were found insufficient for a complete and accurate mathematical model of the system. Equations derived from manufacturer performance test curves were then combined with specific subsystem thermodynamic models (ambient air temperature effects, thermal management system) to provide a more accurate model of the fuel cell system.*

Four of the performance curves used in the mathematical model of the 40-kW power plant are shown in Figures 4 through 7. Equations generated from these curves represent the fuel cell plant's low- and high-grade thermal and electrical outputs and the ambient air temperature enthalpy effect on the power section cathode exhaust. These equations are all interrelated and are solved in the mathematical model by equating the appropriate equation variables to either the electrical or the thermal load requirement and sequentially (rated output; electrical load following) or simultaneously (thermal load following) solving for the remaining variables. By using the mathematical model and program input/output requirements, a computer flow chart was developed. The flow chart is divided into six major sections as follows:

1. Data input and load following scheme selection

2. Fuel cell power plant running at rated output

3. Plant electrical output set equal to the electrical load requirement

4. The combined thermal output of the fuel cell (low- and high-grade heat) set equal to the total thermal load requirement

5. Fuel cell output set equal to zero

6. Printout of desired energy and operational cost data

The computer program developed from this flow chart reads in one electrical and thermal load data set for every 1/2 hour of simulated operation. Each data set is run through the separate load following schemes and all output requirements are computed before the next data set is read. After computations are completed for the last data set entry, the user may select a variety of printouts pertaining to the program load following schemes, energy input/outputs, and cost analysis. This computer simulation of the United Technologies 40-kW fuel cell power plant is available, but a program listing is not included in this report as it is not the final product of this investigation.

Extended 40-kW Fuel Cell Power Plant Computer Simulation

The extended computer simulation is similar to the 40-kW computer program but also allows the user to select the size fuel cell and thermal storage capacity desired. A simplified operational schematic of the integrated fuel cell, utility grid, thermal storage, and auxiliary heater

*Forty-eight United Technology fuel cell power plants are currently being manufactured and tested in a variety of locations. Verification of manufacturer performance curves will accompany the associated field test data.

system used for this simulation is shown in Figure 8. Figure 9 shows the flow chart of the extended fuel cell computer program with fuel cell and thermal storage size selection capability.

The extended 40-kW fuel cell computer program optimizes the fuel cell and thermal storage size with respect to energy inputs/outputs and operational costs through an interation method. Initial fuel cell size and thermal storage capacity is selected by the user based on electrical and thermal load data and desired operational mode. Table 4 lists all input requirements for the extended computer program. With these inputs, an initial computer simulation is run. From this simulation the user would observe energy input/output data printouts to determine if all energy requirements are satisfied for the size of fuel cell and storage capacity selected. The total system energy operating costs would also be noted for comparison with subsequent simulations having the same load requirement data sets. This method can be repeated until the lowest operating cost is obtained and all energy requirements of a particular application are satisfied.

Appendix A lists the extended computer simulation for the phosphoric acid fuel cell power plant. Operating options and use of this simulation are presented in Table 5.

APPLICATION

Simulation At Naval Air Station (NAS) Sewell's Point

To provide an example for using the extended computer program, a computer simulation was done for NAS Sewell's Point, Va. This example simulated a fuel cell operating with grid and auxiliary boiler with operating options and use outlined in Table 5. Bachelor's Enlisted Quarters (BEQ) (Building U-16) at Sewell's Point was chosen for simulation for its comparable hot water and electrical load profiles. Detailed electrical consumption data for this activity were obtained from Reference 1. Hot water consumption data were generated on a per man basis in accordance with Reference 2. The electrical, fuel, and thermal energy unit cost data for Sewell's Point and the Navy-wide averages obtained from FY82 DEIS II reports (Ref 3 and 4) are listed in Table 6. For this computer simulation example, electrical energy was "sold back" to the grid for $0.01/kW less than its purchase cost. Actual sell back rates vary greatly, depending on utility company policy and local laws governing those rates. Printouts of this simulation are shown in Appendix B.

A 150-kW fuel cell size, between the minimum (115-kW) and maximum (195-kW) electrical load, was selected for the initial simulation. Thermal storage size was initially selected at 10% of the total daily consumption (Ref 2). User inputs for the initial simulation are listed in Appendix B. Tables B-1, B-2, and B-3 list the 24-hour total energy inputs/outputs every 1/2 hour for a grid, auxiliary heater (boiler), thermal storage, and fuel cell operating under three separate load following schemes: rated output (Table B-1); electrical load following (Table B-2); thermal load following (Table B-3). The columns on each page show how all components of the fuel cell energy system react to the electrical and thermal load for the selected load following scheme.

Each table has eight columns defined as follows:

1. TIME - actual time of simulation in increments of 1/2 hour up to 24 hours

2. ELEC - the BEQ electrical load

3. THERM - the BEQ thermal load

4. F/C - the fuel cell electrical output

5. GRID - electrical energy delivered from (+) or to (-) the grid

6. F/C - the fuel cell thermal output

7. BOILER - the auxiliary boiler/heater thermal output

8. STORAGE - the hot water storage thermal output

Note that columns 4 and 5 together equal column 2 (electrical load) and that columns 7 and 8 together equal column 3 (thermal load) for a given simulation time. Column 6, the fuel cell thermal output, contributes to the thermal load and hot water storage, and in some instances must be dumped by means of cooling fans in the fuel cell power unit.

To aid in the interpretation of the fuel cell thermal outputs, the computer program incorporates a separate printout sheet titled "Thermal System Input/Output." Table B-4 lists the thermal system inputs/outputs for a 150-kW fuel cell and 3,000-gallon thermal storage. Each of these pages has six columns defined as follows:

1. TIME - actual time of simulation in increments of 1/2 hour up to 24 hours

2. LOAD - the BEQ thermal load

3. AVAIL - thermal energy available from the fuel cell

4. DUMPED - thermal energy dumped by the fuel cell (cooling fans)

5. OUTPUT - hot water storage contribution to the thermal load

6. LEVEL - actual storage in 1,000 Btu's of hot water storage at a given time.

The change in storage level for any 1/2-hour period (any two adjacent figures in column 6) equals 1/2(column 3 - column 4 - column 5). For example, in Table B-4, from 0 to 30,

$$\Delta 6 = 1/2(358.94 - 0 - 64.34) = 147.30 \text{ Btu}$$

These printouts are used primarily for sizing thermal storage to handle system thermal level fluctuations created by (1) high fuel cell thermal output at low thermal load and (2) low fuel cell thermal output at high thermal load. Optimizing thermal storage size is accomplished by minimizing the auxiliary boiler output and fuel cell thermal dumping and maximizing the thermal storage contribution to the thermal load. For comparison, the thermal storage size was changed to 500 gallons and the simulation was run with identical load data. Table B-5 lists the thermal inputs/outputs for this simulation.

Operational cost printouts for a 150-kW fuel cell operating with grid and auxiliary boiler are shown in Table B-6. Sewell's Point energy unit cost data (Ref 4) were used for these printouts. Similar cost printouts were also generated for a 100-, 150-, and 200-kW fuel cell with 3,000 gallon thermal storage, using both Navy-wide average and Sewell's Point energy unit cost data. A summary of these printouts and an operational cost total for a 150-kW fuel cell with 500-gallon storage are presented in Table 7, which can be used in combination with energy input/output printouts to determine the lowest operating costs for given application requirements and to explain the varied costs.

The following are observations and comments for Table 7.

1. Observation: For the rated and electrical load following schemes, daily operational costs for the 150-kW fuel cell with 3,000-gallon thermal storage are approximately $5/day lower than the 150-kW fuel cell with 500-gallon thermal storage.

Comments: The 500-gallon storage thermal system input/output printouts (Table B-5, column 4) show that a high percentage of the fuel cell thermal energy is dumped and that the storage thermal output (column 5) is considerably lower than the thermal demand (column 2), resulting in higher auxiliary boiler costs. The 3,000-gallon thermal storage (Table B-4, column 4) minimizes the thermal load fluctuations, thereby utilizing the fuel cell thermal energy more efficiently.

2. Observation: Using Sewell's Point energy unit costs, the lowest system operating cost is obtained with fuel cell electrical load following. When Navy-wide energy unit costs are used, the lowest operating cost is obtained by running the fuel cell at rated output.

Comments: Table 6 shows that Navy-wide average purchased electrical unit costs are considerably higher than Sewell's Point electrical unit costs but that Navy-wide natural gas unit costs are lower than at Sewell's Point. Operational costs are lower using Navy-wide energy unit costs since the fuel cell can cost effectively produce excess electrical energy to sell back to the grid. These operational costs will decrease for larger fuel cells until the fuel cell thermal by-product cannot be utilized efficiently because they exceed the thermal load. When using Sewell's Point energy unit costs, it is not cost-effective to produce excess electrical energy; consequently, the electrical load following scheme has lower operating costs.

3. <u>Observation</u>: The fuel cell thermal load following scheme operational costs are higher than the electrical load following costs.

<u>Comments</u>: The thermal load following energy input/output printouts (Table B-3, column 5) show that a considerable amount of electrical energy had to be purchased from the grid. This is due to the low fuel cell electrical output when the fuel cell is following a minimal thermal load. Although each application must be considered separately, this investigation found that thermal load following was not advantageous when extreme fluctuations in the thermal load existed.

4. <u>Observation</u>: Daily cost "savings" (operational cost without fuel cell minus operational cost with fuel cell) using Navy-wide energy unit costs are over $100/day more than when using Sewell's Point energy unit costs.

<u>Comments</u>: This large operational cost savings difference is due directly to the differences in the Navy-wide average and the Sewell's Point energy unit costs. The effects of such cost differences on the economics of a given application are discussed briefly in the following section.

<u>Phosphoric Acid Fuel Cell Economics</u>

A total life-cycle-cost product analysis for a 150-kW fuel cell operating with grid, auxiliary boiler, and 3,000-gallon thermal storage is shown in Table 8. The analysis was done in accordance with Reference 5 using a 25-year projected life, a 9.524 cumulative uniform series discount factor, and Navy-wide levelized fuel prices shown in Table 9. Energy consumption and displacement data used in lines 9 and 11 in Table 8 was taken directly from the 150-kW fuel cell electrical load following computer simulation printouts of Appendix B and extrapolated to represent one year's energy consumption/displacement. Since fuel cells are an emerging technology, projected commercial capital costs were used for this analysis. A unit fuel cell capital cost of $1,500/kW-energy was selected from a range of $400 to $1,600/kW-energy (Ref 6). Applying Navy-wide levelized unit energy costs to the Sewell's Point example, line 12 of Table 8 shows a life-cycle-cost of $10.51/MBtu. When compared to Table 9's purchased electricity levelized price ($10.66/MBtu), this application is seen as marginally cost effective. Using Sewell's Point levelized energy unit costs would make this application not cost effective for the fuel cell unit capital cost selected. However, the majority of fuel cell capital cost projections are lower than used in this example, and more desirable energy unit costs can be obtained by selecting a different Navy site.

SUMMARY

Since phosphoric acid fuel cells produce electricity with high efficiency, have instantaneous load response, are nonpolluting, and can be sited next to loads (quiet operation) for thermal by-product use, the technical feasibility of fuel cells for Navy applications becomes a question of operational reliability and life cycle costs. Although high reliability is a design feature of phosphoric acid fuel cells, actual operating data is needed to verify this reliability. The economics of each fuel cell system (grid, auxiliary heater, thermal storage) application are determined primarily by capital costs, local energy unit costs, and fuel cell system operational mode and handling of electrical and thermal loads. An example was given of a Navy application at NAS Sewell's Point. This example had a marginal economic return due to a high fuel cell unit capital cost of $1,500/kW-energy. Industry's projected lower capital costs could greatly increase the cost-effectiveness and number of potential Navy fuel cell applications.

The computer program developed in this investigation simulates the fuel cell system (grid, auxiliary heater, thermal storage) daily operation and generates energy consumption and displacement data required for an economic analysis. Since a variety of phosphoric acid fuel cell sizes are not currently available, this computer program is best utilized for projecting Navy fuel cell applications and evaluating phosphoric acid fuel cells as they become commercially available. Fuel cell sizing applications using computer methods will increase with fuel cell commercialization. The phosphoric acid fuel cell is currently the most commercially developed but other types of fuel cells (molten carbonate, solid electrolyte) having greater technical and economic potential are emerging. The enclosed computer program (Appendix A) is structured such that it can be modified to simulate the operation of these different fuel cells without excessive alterations to the existing program.

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Table 1. Pipeline and Peak-Shaved Gas Specifications

Component	Specification	Maximum Allowable Volume
	Peak-Shaved Gas	
Natural Gas	Minimum, 45% by Volume Total Gas Mix	
Peak-Shaved Gas Mix	Maximum, 55% by Volume Total Gas Mix	
Liquified Petroleum (L.P.) Gas	Maximum, 36% by Volume, in Total Gas Mix	
Air	Maximum, 23.5% by Volume, in Total Gas Mix	
Propylene	Maximum, 10% by Volume, in L.P. Gas (Equal to 3.6% in Total Gas Mix)	
Total Sulfur	Maximum, 30 ppm_V	
Thiophene Sulfur	Maximum, 10 ppm_V	
Maximum NH_3	Maximum, 1.0 ppm_V	
Chlorine	0.05 ppm_W	
	Pipeline Gas	
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	Maximum, 30 ppm_V	
Thiophane Sulfur	Maximum, 10 ppm_V	
Maximum NH_3	Maximum, 1.0 ppm_V	
Chlorine	0.05 ppm_W	

Table 2. Electrical Characteristics

Characteristic	Description
Output Power Form	4-wire, 3-phase
Frequency	60 Hertz
Frequency Stability	±0.0002%/yr
Voltage	120/208 VAC
Voltage Regulation	±5% with up to 30% load unbalance under steady state conditions
Voltage Recovery	Within 2 cycles
Phase Separation	120 ±5 degrees electrical
Current Limit	Up to 300 amperes RMS for line-to-line short circuits and 450 amperes RMS for line to neutral short circuits
Maximum Duration of Current Limit	5 seconds
Total Harmonic Distortion	$\leq$15%
Electromagnetic Noise	Shall not degrade performance of conventional electrical equipment located farther than 10 feet from the power plant

Table 3. Thermodynamics State Point Data

Station No.	Temperature (°F)	Pressure (psia)	Hydrogen (pph)	Carbon Dioxide (pph)	Carbon Monoxide (pph)	Nitrogen[a] (pph)	Oxygen (pph)	Water (pph)	Methane (pph)	Total (pph)
A. 20-kW AC Net, 70°F Ambient, 500 hr performance										
1	70	14.8							8.0	8.0
2	407	13.1	0.403	2.162	0.032			1.48	8.07	12.1
3	366	13.0	0.403	2.162	0.032			1.48	8.07	12.1
4	474	13.0	0.403	2.162	0.032			1.48	8.07	12.1
5	448	11.7	0.403	2.162	0.032			1.48	8.07	12.1
6	505	15.4	0.403	2.162	0.032			30.75	8.07	41.6
7	656	14.9	3.555	11.128	7.020			19.11	0.80	41.6
8	602	14.9	3.555	11.128	7.020			19.11	0.80	41.6
9	378	14.9	3.555	11.128	7.020			19.11	0.80	41.6
10	363	14.8	3.555	11.128	7.020			19.11	0.80	41.6
11	443	14.8	4.037	21.648	0.325			14.81	0.80	41.6
12	438	14.8	0.403	2.162	0.032			1.48	0.08	4.2
13	362	14.7	3.634	19.486	0.292			13.33	0.72	37.5
14	355	14.7	3.634	19.486	0.292			13.33	0.72	37.5
15	374	14.7	0.715	19.488	0.292			4.43	0.72	25.6
16	677	14.7		21.947		37.679	2.63	12.44		74.7

Continued

Table 3. Continued

Station No.	Temperature (°F)	Pressure (psia)	Hydrogen (pph)	Carbon Dioxide (pph)	Carbon Monoxide (pph)	Nitrogen[a] (pph)	Oxygen (pph)	Water (pph)	Methane (pph)	Total (pph)
17	242	14.7		22.045		203.64	29.48	63.54		318.7
18	111	14.7		22.045		203.64	29.48	15.21		270.4
19	114	14.7		2.629		4,430.0	1,334.82			5,767.4
20	70	14.7		0.121		203.64	61.36			265.1
21	70	14.7		0.022		37.679	11.35			49.1
22	70	14.7		0.004		7.674	2.116			10.0
23	475	14.7		0.018		30.005	9.234			39.1
24	70	14.7		0.098		165.961	50.01			216.1
25	374	14.7		0.098		165.961	26.84	34.97		227.9
26	185	14.7		0.098		165.961	26.84	34.97		227.9
27	111	14.7						48.33		48.33
28	212	14.7						44.20		44.20
29	71	14.2						44.20		44.20
30	203	164.5						44.20		44.20
31	358	164.5						1,800.0		1,800.0
32	366	165.2						1,800.0		1,800.0

Continued

Table 3. Continued

Station No.	Temperature (°F)	Pressure (psia)	Hydrogen (pph)	Carbon Dioxide (pph)	Carbon Monoxide (pph)	Nitrogen[a] (pph)	Oxygen (pph)	Water (pph)	Methane (pph)	Total (pph)
33	366	165.2						1,800.0		1,800.0
34	366	165.0						1,800.0		1,800.0
35	366	164.8						1,800.0		1,800.0
36	366	164.7						1,800.0		1,800.0
37	366	164.5						1,800.0		1,800.0
38	365	164.5						1,755.8		1,755.8
39	362	164.5						1,755.8		1,755.8
B. 40-kW net, 70°F Ambient, 500 hr performance										
1	70	14.8							16.1	16.1
2	443	13.2	0.854	4.546	0.097			3.10	16.24	24.8
3	351	13.1	0.854	4.546	0.097			3.10	16.24	24.8
4	476	13.0	0.854	4.546	0.097			3.10	16.24	24.8
5	467	10.3	0.854	4.546	0.097			3.10	16.24	24.8
6	594	16.5	0.854	4.546	0.097			61.89	16.24	83.6
7	795	15.3	7.086	20.150	15.718			39.07	1.60	83.6
8	746	15.2	7.086	20.150	15.718			39.07	1.60	83.6

Continued

Table 3. Continued

Station No.	Temperature (°F)	Pressure (psia)	Hydrogen (pph)	Carbon Dioxide (pph)	Carbon Monoxide (pph)	Nitrogen[a] (pph)	Oxygen (pph)	Water (pph)	Methane (pph)	Total (pph)
9	483	15.2	7.086	20.150	15.718			39.07	1.60	83.6
10	352	15.0	7.086	20.150	15.718			39.07	1.60	83.6
11	483	15.0	8.150	43.393	0.922			29.56	1.61	83.6
12	481	15.0	0.854	4.546	0.097			3.10	0.17	8.8
13	403	14.7	7.296	38.846	0.826			26.46	1.44	74.9
14	345	14.7	7.296	38.846	0.826			26.46	1.44	74.9
15	372	14.7	1.501	38.845	0.826			9.21	1.44	51.8
16	825	14.7		44.132		74.026	4.18	25.85		148.2
17	301	14.7		44.324		397.395	55.62	113.25		610.6
18	105	14.7		44.324		397.395	55.62	25.07		522.4
19	135	14.7		3.647		6,144.897	1,851.55			8,000.1
20	70	14.7		0.236		397.395	119.74			517.4
21	70	14.7		0.044		74.026	22.31			96.4
22	70	14.7		0.004		7.674	2.116			10.0
23	608	14.7		0.040		66.352	20.194			86.4
24	70	14.7		0.192		323.359	97.43			421.0

Continued

Table 3. Continued

Station No.	Temperature (°F)	Pressure (psia)	Hydrogen (pph)	Carbon Dioxide (pph)	Carbon Monoxide (pph)	Nitrogen[a] (pph)	Oxygen (pph)	Water (pph)	Methane (pph)	Total (pph)
25	372	14.7		0.192		323.359	51.44	69.06		444.1
26	230	14.7		0.192		323.359	51.44	69.06		444.1
27	105	14.7						88.2		88.2
28	212	14.7						88.2		88.2
29	72	13.8						88.2		88.2
30	203	131.9						88.2		88.2
31	338	131.9						1,800.0		1,800.0
32	350	134.3						1,800.0		1,800.0
33	350	134.1						1,800.0		1,800.0
34	349	133.6						1,800.0		1,800.0
35	349	133.1						1,800.0		1,800.0
36	349	132.5						1,800.0		1,800.0
37	348	132.0						1,800.0		1,800.0
38	348	131.9						1,711.8		1,711.8
39	345	131.9						1,711.8		1,711.8

[a]Includes argon in air.

Table 4. User Inputs for Extended 40-kW Computer Program

Input	Units
Fuel cell size	kW
Date/location/total hours of simulation	
Electrical load data	kW
Thermal load data	kBtu/hr
Ambient air temperature	°F
Thermal storage volume	gal
Thermal storage initial temperature	°F
Required hot water temperature	°F
System feed water temperature	°F
Natural gas unit cost	$/MBtu
Thermal energy unit cost	$/MBtu
Purchased electricity unit cost	$/kW
Sell electricity unit cost	$/kW

Table 5. Extended Fuel Cell Computer Simulation Operating Options and Use

Option	Load Following Schemes	Fuel Cell Size Selection	Storage Size Selection	Auxiliary Heater Size
Can Buy and Sell Electricity				
I. Operating With Grid and Auxiliary Heater	(a) Rated output (b) Electrical load following (c) Thermal load following (program determines lowest operating cost)	Vary size to obtain lowest operating cost for the three load-following schemes	Vary size to minimize: (a) Fuel cell thermal energy dumping (b) Auxiliary heater thermal output	(a) With existing heater: do not exceed maximum (b) With new heater: size to maximum heater load
II. Operating With Grid and No Auxiliary Heater	(a) Rated output (b) Electrical load following (if combination of thermal storage and fuel cell output is sufficient (c) Thermal load following	Must have enough output to meet maximum thermal load	Size to handle thermal demand fluctuations	Not applicable
Can Buy Electricity Only				
I. Operating With Grid and Auxiliary Heater	Electrical load following only	Vary size to obtain lowest operating cost for electrical load following	Vary size to minimize: (a) Fuel cell thermal energy dumping (b) Auxiliary heater thermal output	(a) With existing heater: do not exceed maximum (b) With new heater: size to maximum heater load
II. Operating With Grid and No Auxiliary Heater	Electrical load following only	Must have enough output to meet maximum thermal load	Size to handle thermal demand fluctuations	
No Grid Connection				
III. No Grid Connection and Auxiliary Heater Available	Electrical load following only	Fuel cell sized to maximum electrical demand	Sized to minimize fuel cell thermal dumping and auxiliary heater output	Sized to meet thermal demand not handled by fuel cell and thermal storage
IV. Remote Operation	Electrical load following only	Size to maximum electrical or thermal demand (whichever is higher)	Size to handle all thermal demand fluctuations	
V. Dual Use of Fuel Cells (Reliability)	Run one fuel cell at rated power	Subtract thermal and electrical output from load requirement data	Simulate other fuel cells operating with modified load requirement data	

Table 6. Navy-wide and Sewell's Point FY82 Energy Prices

Energy Type	NAS Sewell's Point	Navy-wide Average
Natural Gas	$4.95/MBtu	$4.24/MBtu
Thermal Energy[a]	$7.80/MBtu	$9.33/MBtu
Purchased Electricity	$37.43/MWh	$57.54/MWh

[a]Based on average fuel oil price and 0.75 boiler conversion efficiency.

Table 7. Operational Cost Summary for 24-Hour Simulation of Building U-16 at Sewell's Point

Fuel Cell Output/Size	3,000-Gallon Thermal Storage						500-Gallon Thermal Storage
	Navy-wide Energy Unit Costs ($) for--			Sewell's Point Energy Unit Costs ($) for--			Navy-wide Energy Costs ($) for--
	100 kW	150 kW	200 kW	100 kW	150 kW	200 kW	150 kW
Rated	254.49	218.05	191.37	230.77	231.77	240.90	223.80
Electrical load following	254.49	218.84	216.33	230.77	224.67	224.21	223.93
Thermal load following	275.06	240.29	218.19	238.07	229.83	229.95	240.29
Fuel Cell Output = 0[a]		369.26			265.20		369.26

[a]All electricity is supplied by utility grid, and all thermal energy is supplied by auxiliary heater/boiler.

Table 8. Total Life-Cycle-Cost Analysis

Product: 150-kW Phosphoric Acid Fuel Cell operating with utility grid and auxiliary boiler

Location: Building U-16, NAS Sewell's Point

Item	Cost
1. Acquisition cost of (typical) single application	$225K
2. Present worth, terminal value of single application	$0K
3. Net adjusted capital investment of single application [1 - 2]	$225K
4. Economic life of application	25 years
5. CUS factor for economic life of single application	9.524
6. Capital investment, annualized [3 ÷ 5]	$23.62K/yr
7. Annual non-energy O&M costs	$2K/yr
8. Annual energy use	
a. Energy Type Natural Gas	
(1) Annual energy consumption	11,640 MBtu/yr
(2) Unit cost	$9.07/MBtu
(3) Annual energy cost	$106K/yr
b. Energy Type Fuel Oil	
(1) Annual energy consumption	3,595 MBtu/yr
(2) Unit cost	$13.29/MBtu
(3) Annual energy cost	$47.78K/yr
c. Energy type Electricity	
(1) Annual energy consumption	614 MBtu/yr
(2) Unit cost	$10.66/MBtu
(3) Annual energy cost	$6.54K/yr
d. Total annual cost for energy [8a (2) + 8b (2) + 8c (2)]	$160.32K/yr
9. Total annual recurring costs [(8d) + (7)]	$162.32K/yr
10. Annual energy generated/displaced	17,688 MBtu/yr
11. Life-cycle-costs [(6 + 9)/10]	$10.51/MBtu

Table 9. Levelized Fuel Prices by Fuel Type[a]

[1985-2010 time period]

Fuel Type	Cost ($/MBtu)
Purchased Electricity	10.66[b]
Fuel Oil	13.29
Natural Gas	9.07
Coal	4.17
Propane	29.30
Purchased Steam/Hot Water	24.42

[a]Steps developed by NCEL to project levelized fuel prices in 1982 dollars:

1. 1980 prices are derived from least-squares analysis of historical DEIS and UCAR data (1970 - Second Quarter 1980).
2. 1985 prices are projected from 1980 prices using short-term escalation rates, but ignoring inflation.
3. Prices are levelized over 1985-2010 time period using long-term differential escalation rates.

[b]The $/MBtu number given for electricity includes the power plant conversion efficiency of 11,600 Btu/kWh.

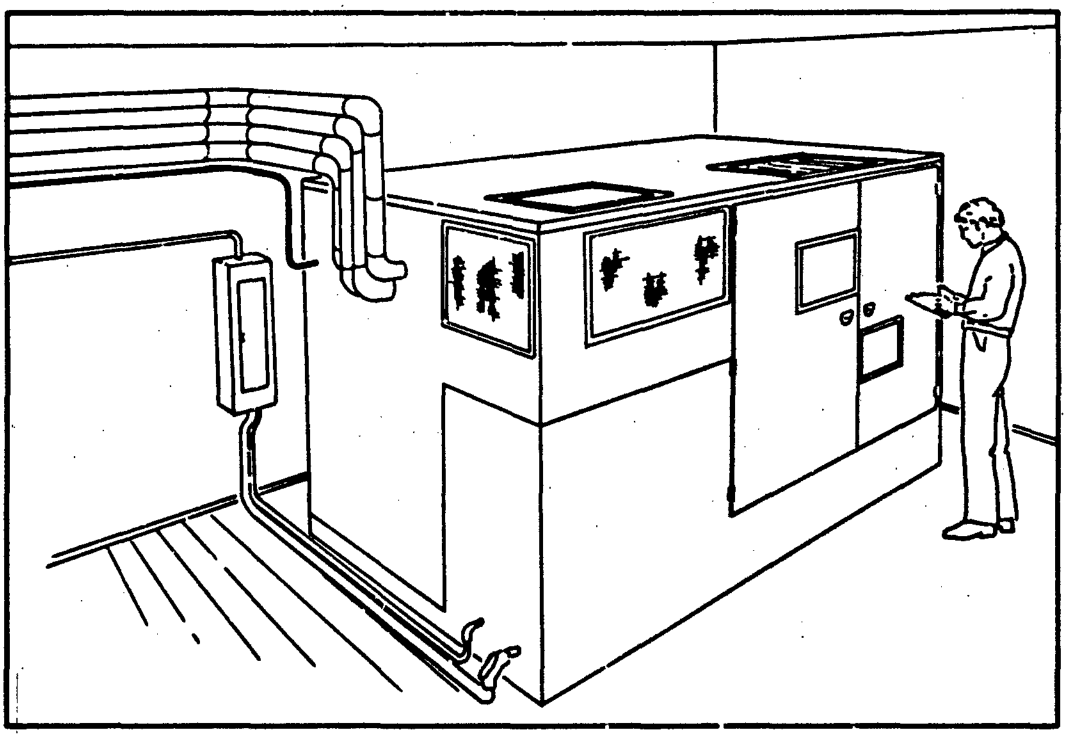

Figure 1a. Outer configuration.

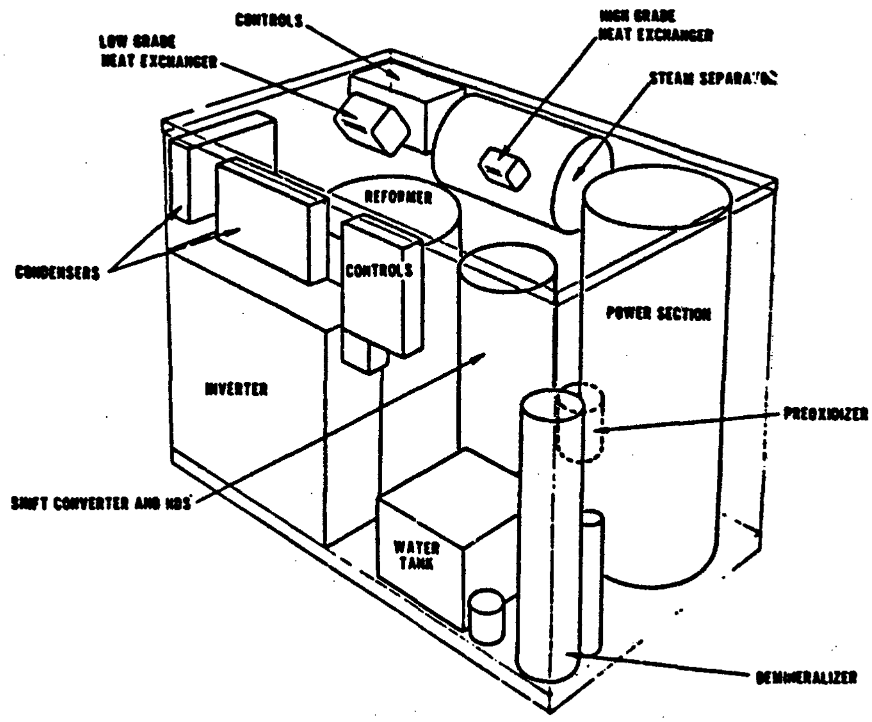

Figure 1b. Major component locations.

Figure 1. 40-kW power plant (from Ref 7).

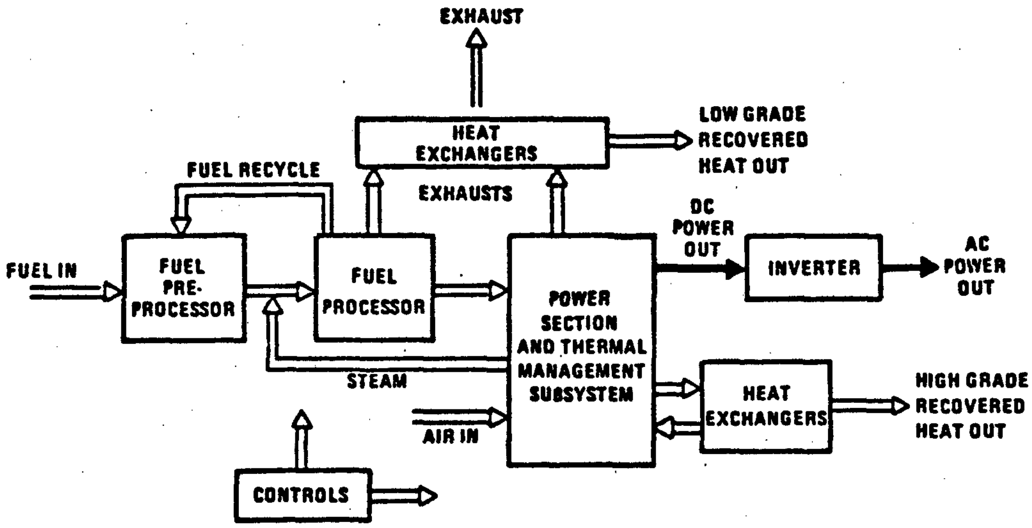

Figure 2. Simplified block diagram (from Ref 7).

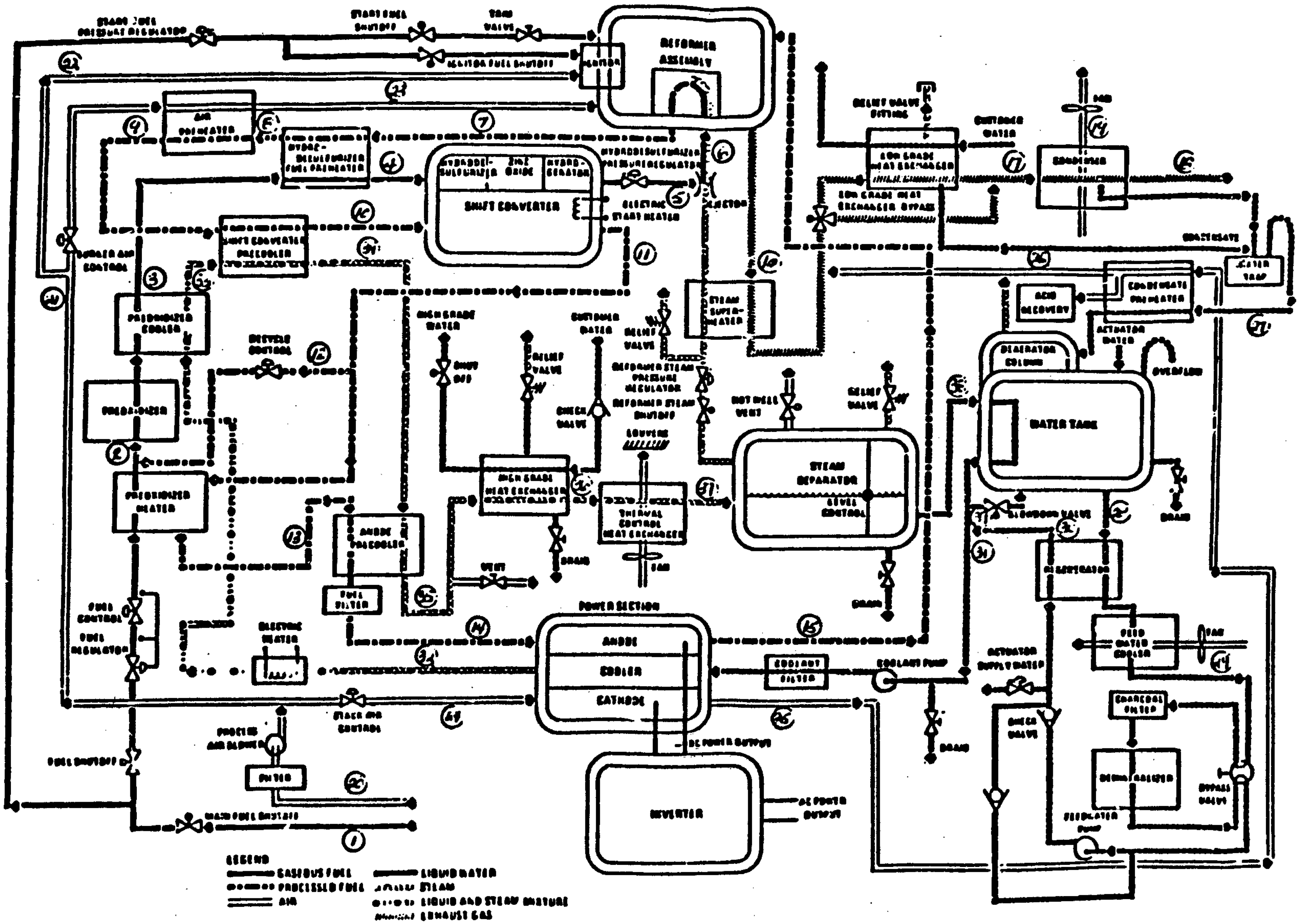

Figure 3. Power plant schematic (from Ref 7).

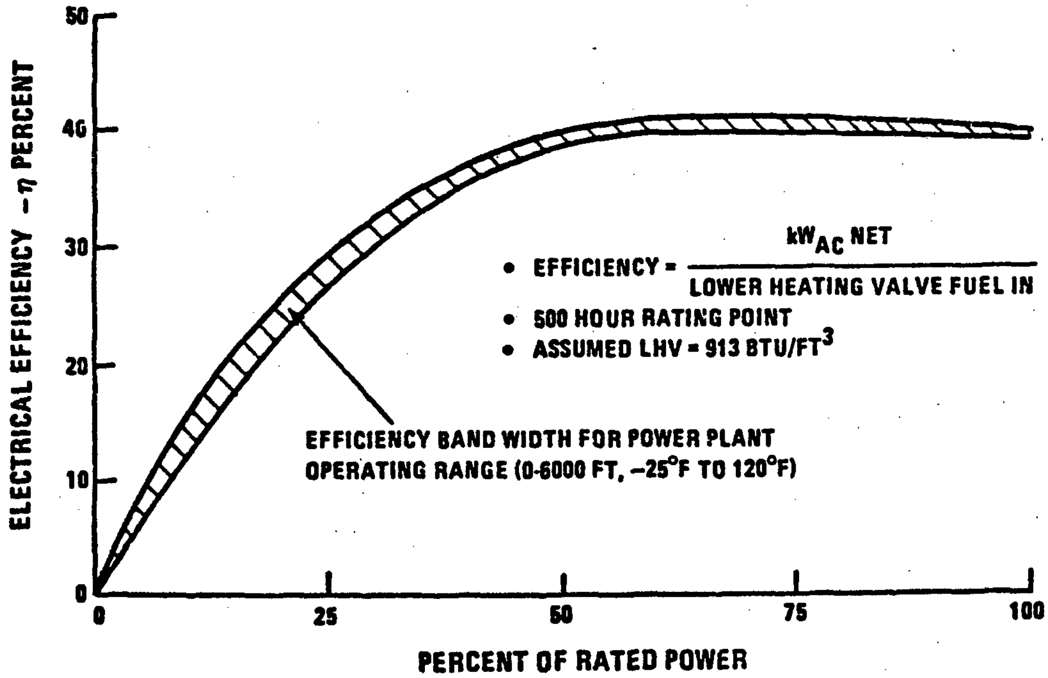

Figure 4. Electrical efficiency bandwith (from Ref 7).

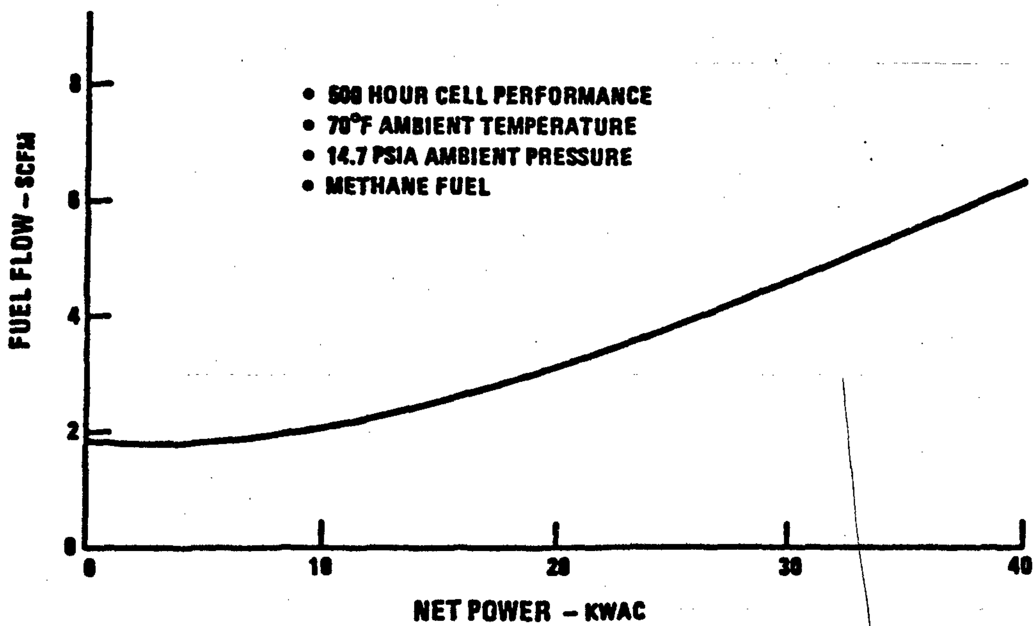

Figure 5. Power plant fuel flow (from Ref 7).

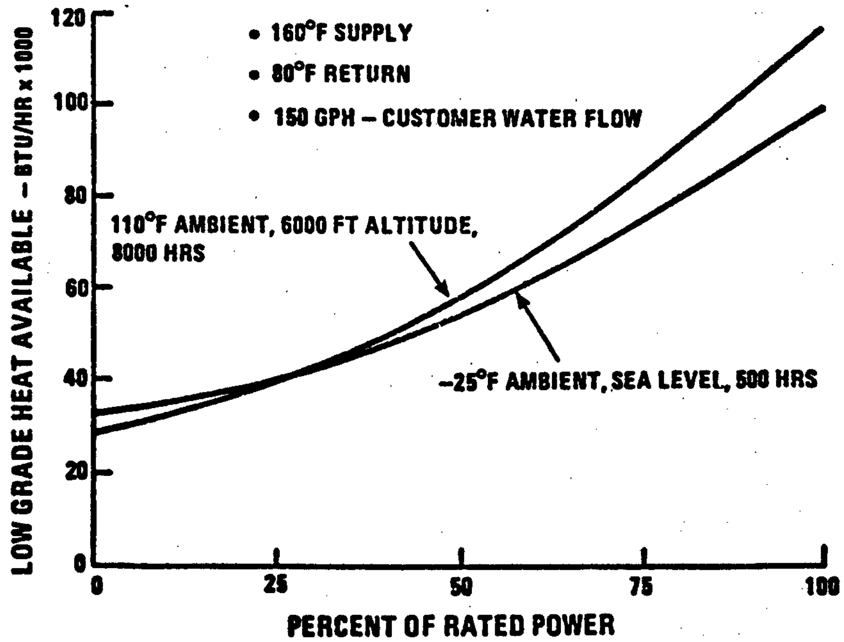

Figure 6. Low grade heat availability (from Ref 7).

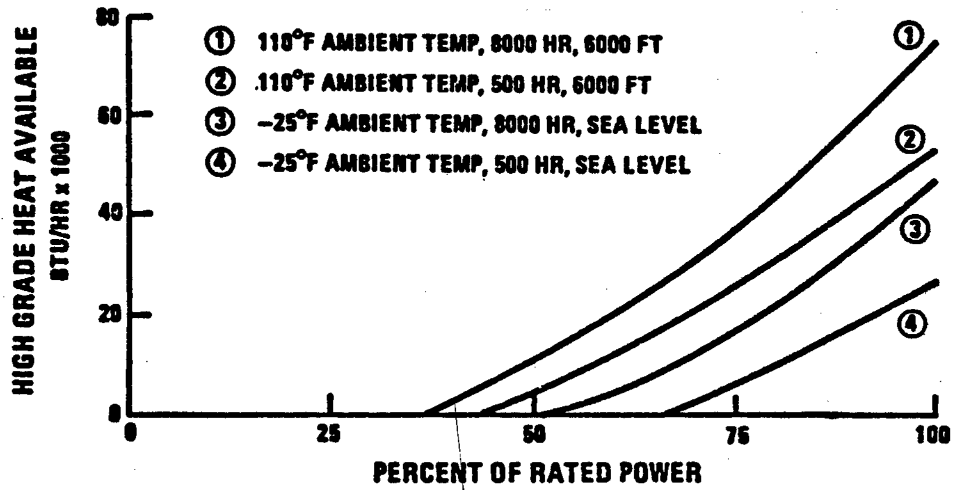

Figure 7. High grade heat availability (from Ref 7).

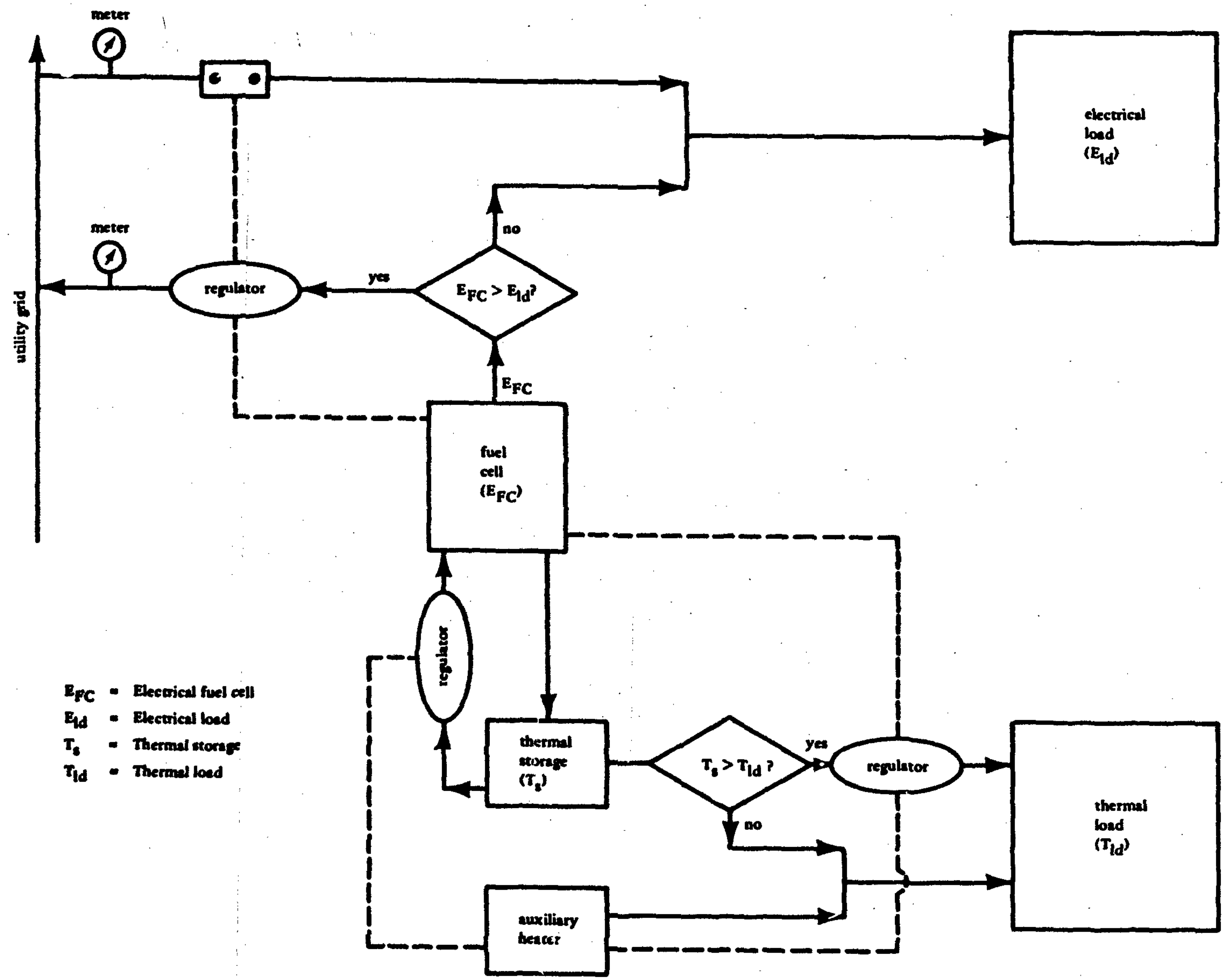

Figure 8. Fuel cell operating with utility grid, thermal storage, and auxiliary heater.

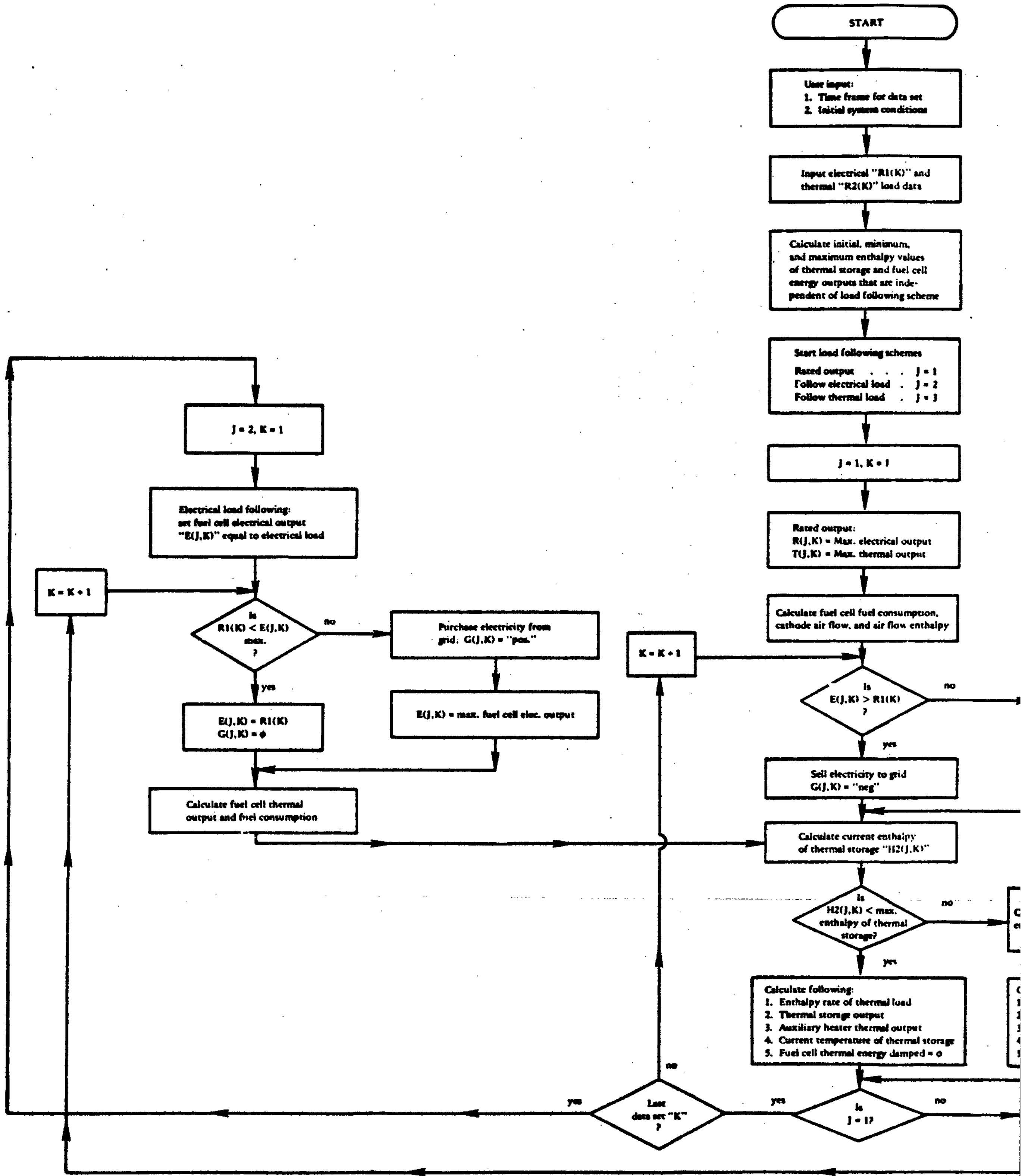

Figure 9. Steps for extended fuel ce

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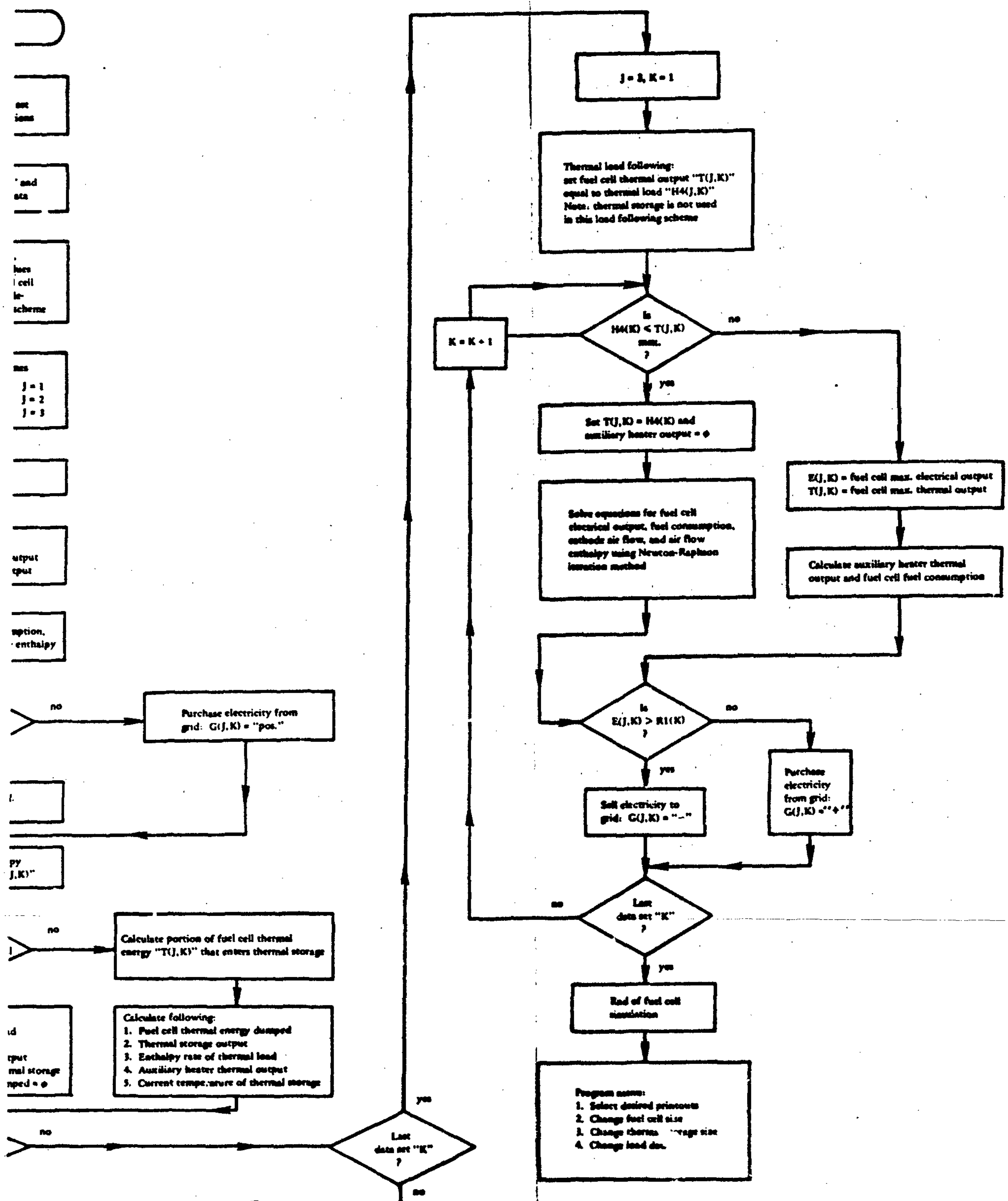

ıded fuel cell computer program.

Appendix A

PROGRAM LISTING FOR EXTENDED 40-kW FUEL CELL COMPUTER SIMULATION

```
LIST
2 GO TO 10
4 GO TO 1950
10 INIT
11 SET KEY
88 PRINT "L**************  FUEL CELL POWER SYSTEM  ****************"
89 D5=0
90 PRINT "JJTHIS PROGRAM EVAULUATES OPTIMUN RUNNING CONDITIONS OF AN"
91 PRINT "ENERGY SYSTEM (FUEL CELL PLANT, AUX BOILER, ELEC GRID)"
92 PRINT "SUPPLYING ELECTRICAL AND THERMAL ENERGY."
100 PRINT "JJJJENTER INITIAL,FINAL TIME FOR ELEC/THERM LOAD REQUIREMENT"
110 PRINT "DATA."
120 PRINT "JEXAMPLE: 600,1700"
130 INPUT T4,T5
140 T6=(T5-T4)/100
150 IF T6<>0 THEN 180
160 T6=25
170 GO TO 210
180 IF T6>0 THEN 200
190 T6=24+T6
200 T6=2*T6+1
210 DIM R1(T6),R2(T6),E(3,T6),F(3,T6),A(3,T6),Q(3,T6),T1(3,T6),T2(2,T6)
220 DIM G(3,T6),D(3,T6),S8(3,T6),B(3,T6),S(3,T6),X1(6),X2(6),X3(6)
230 DIM X4(6),X5(6),X6(6),U3(4),U4(4),U5(4),U6(4),U7(4),U8(4)
240 DIM F9(4),D1(4),D2(4),D3(4),D4(4),D9(4),T(3,T6),X(6),T7(T6)
250 DIM H2(3,T6),H3(3,T6),H4(T6),H5(3,T6),A5(3,T6),X9(6),U9(4),T3(3,T6)
260 DIM L5(4)
270 PRINT "LENTER SIZE OF FUEL CELL TO BE EVALUATED  (UNITS: KW)"
280 INPUT F5
290 IF D5=8 THEN 890
300 PRINT "JJJENTER LOCATION OF FUEL CELL PLANT THEN PRESS RETURN"
310 INPUT A$
320 PRINT "JJJENTER DATE OF LOAD REQUIREMENT DATA"
330 INPUT D$
340 PRINT "JJJENTER AVERAGE AMBIENT TEMPERATURE (DEG-F)"
```

```
350 INPUT T8
360 GO TO 380
370 PRINT "L"
380 PRINT "JJJENTER VOLUME OF THERMAL STORAGE  (UNITS: GALLONS)"
390 INPUT V9
400 IF D5=7 THEN 890
410 PRINT "JJJENTER INITIAL TEMP OF THERMAL STORAGE  (UNITS: DEG F)"
420 INPUT A3
430 T9=T8-70
440 PRINT "LENTER REQUIRED HOT WATER TEMPERATURE     (UNITS: DEG F)"
450 INPUT A2
460 PRINT "JJENTER SYSTEM FEEDWATER TEMPERATURE      (UNITS: DEG F)"
470 INPUT A1
540 GO TO 560
550 T6=T6+1
560 PRINT "LENTER THERMAL LOAD REQUIREMENT DATA  (NOTE:DATA ENTRIES"
570 PRINT "MUST BE FOR EVERY 1/2 HOUR)."
580 PRINT "JJJTIMEKIHOT WATER REQ_I(GALLONS/HR)_"
590 L=T4-70
600 K5=2
610 FOR K=1 TO T6
620 IF K5=2 THEN 660
630 L=L+30
640 K5=2
650 GO TO 700
660 L=L+70
670 K5=1
680 IF K=T6 THEN 720
700 PRINT L;"I";
710 INPUT R2(K)
720 T7(K)=L
730 NEXT K
740 R2(K-1)=R2(K-2)
750 GO TO 780
760 T6=T6-1
```

```
770 GO TO 850
780 PRINT "LENTER ELECTRICAL LOAD REQUIREMENT DATA  (NOTE:DATA ENTRIES"
790 PRINT "MUST BE FOR EVERY 1/2 HOUR)."
800 PRINT "JJJTIMEKIELEC REQ_I  (KW)_"
810 FOR K=1 TO T6
820 IF K=T6 THEN 850
830 PRINT T7(K);"I";
840 INPUT R1(K)
850 NEXT K
860 R1(K-1)=R1(K-2)
870 T6=T6-1
880 PRINT "JJJPROGRAM IN PROGRESS"
890 H9=8.33*V9*(A2-A1)/1000
900 R9=F5/40
910 H1=8.33*V9*(A3-A1)/1000
920 J=1
930 FOR K=1 TO T6+1
940 REM ***************  POWER PLANT @ RATED POWER (J=1)  ************
950 E(J,K)=F5
960 F(J,K)=4.07*R9*EXP(0.0354*E(J,K)/R9)
970 A(J,K)=26.5*F(J,K)
980 Q(J,K)=0.24*A(J,K)*T9/1000
990 T1(J,K)=26.75*R9*EXP(0.029*E(J,K)/R9)
1000 T2(J,K)=0.5398*R9*(E(J,K)/R9-0.5*F5/R9)↑1.493+Q(J,K)
1010 T(J,K)=T1(J,K)+T2(J,K)
1015 C9=T(1,1)
1020 G(J,K)=R1(K)-E(J,K)
1030 REM FOLLOWING DETERMINES THERMAL STORAGE AND AUX HEATER
1040 REM INPUT/OUTPUTS
1050 IF K<>1 THEN 1090
1060 REM H2(J,K) IS A STORAGE TANK LEVEL WITH UNITS (KBTU)
1070 H2(J,K)=1/(1+0.5*R2(K)/V9)*(H1+T(J,K)/2)
1080 GO TO 1100
1090 H2(J,K)=1/(1+0.5*R2(K)/V9)*(H2(J,K-1)+T(J,K)/2)
1100 IF H2(J,K)<=H9 THEN 1200
```

```
1110 REM DETERMINE AMOUNT OF T(J,K) THAT ENTERS STORAGE - T3(J,K)
1120 H2(J,K)=H9
1130 IF K<>1 THEN 1160
1140 T3(J,K)=2*(H2(J,K)*(1+0.5*R2(K)/V9)-H1)
1150 GO TO 1170
1160 T3(J,K)=2*(H2(J,K)*(1+0.5*R2(K)/V9)-H2(J,K-1))
1170 D(J,K)=T(J,K)-T3(J,K)
1180 H3(J,K)=R2(K)*H2(J,K)/V9
1190 GO TO 1220
1200 H3(J,K)=R2(K)*H2(J,K)/V9
1210 D(J,K)=0
1220 H4(K)=8.33*R2(K)*(A2-A1)/1000
1230 H5(J,K)=H4(K)-H3(J,K)
1240 A5(J,K)=H2(J,K)*1000/(8.33*V9)+A1
1260 NEXT K
1270 IF J=2 THEN 1510
1280 REM *******  FUEL CELL PLANT ELECTRIC LOAD FOLLOWING (J=2)  ******
1290 J=2
1300 FOR K=1 TO T6+1
1310 IF R1(K)>F5 THEN 1360
1320 REM OBTAIN ELECTRIC POWER FROM FUEL CELL OUTPUT ONLY
1330 E(J,K)=R1(K)
1340 G(J,K)=0
1350 GO TO 1390
1360 REM OBTAIN ELECTRIC POWER FROM FUEL CELL AND GRID
1370 E(J,K)=F5
1380 G(J,K)=R1(K)-F5
1390 REM DETERMINE FUEL CELL PLANT THERMAL OUTPUT
1400 F(J,K)=4.07*R9*EXP(0.0354*E(J,K)/R9)
1410 A(J,K)=26.5*F(J,K)
1420 Q(J,K)=0.24*A(J,K)*T9/1000
1430 T1(J,K)=26.75*R9*EXP(0.029*E(J,K)/R9)
1440 IF E(J,K)<0.5*F5 THEN 1470
1450 T2(J,K)=0.5398*R9*(E(J,K)/R9-0.5*F5/R9)↑1.493+Q(J,K)
1460 GO TO 1480
```

```
1470 T2(J,K)=0
1480 T(J,K)=T1(J,K)+T2(J,K)
1490 REM DETERMINE THERMAL STORAGE AND AUXILARY HEATER INPUT/OUTPUTS
1500 GO TO 1030
1510 REM ****************  FOLLOW CUSTOMER THERMAL LOAD ***************
1520 J=3
1530 FOR K=1 TO T6
1540 D(J,K)=0
1550 REM C9 IS MAXIMUM THERMAL OUTPUT OF FUEL CELL
1560 IF H4(K)>C9 THEN 1810
1570 T(J,K)=H4(K)
1580 H5(J,K)=0
1590 N=0
1600 REM PROGRAM USES NEWTON-RAPHSON ITERATION METHOD TO SOLVE
1610 REM FOR E(J,K) AT EACH VALUE OF T(J,K).
1620 N=N+1
1630 X(1)=0.5*F5+5
1640 X9(N)=0.5398*R9*(X(N)/R9-0.5*F5/R9)↑1.493
1650 X3(N)=26.75*R9*EXP(0.029*X(N)/R9)+X9(N)
1660 X4(N)=0.026*T9*R9*EXP(0.0354*X(N)/R9)-T(J,K)
1670 REM X1(N)=T1(J,K)+T2(J,K)-T(J,K)=0
1680 X1(N)=X3(N)+X4(N)
1690 X5(N)=0.776*EXP(0.029*X(N)/R9)+0.806*(X(N)/R9-0.5*F5/R9)↑0.493
1700 X6(N)=9.0E-4*T9*EXP(0.0354*X(N)/R9)
1710 REM X2(N)=THE DERIVATIVE OF T1(J,K)+T2(J,K)-T(J,K)=0
1720 X2(N)=X3(N)+X6(N)
1730 X(N+1)=X(N)-X1(N)/X2(N)
1750 IF X(2)<0.5*F5 THEN 1850
1760 IF X(N+1)>X(N)+0.05 THEN 1620
1770 IF X(N+1)<X(N)-0.05 THEN 1620
1790 E(J,K)=X(N+1)
1800 GO TO 1920
1810 E(J,K)=F5
1820 T(J,K)=C9
1830 H5(J,K)=H4(K)-T(J,K)
```

```
1840 GO TO 1920
1850 REM E(J,K) IS LESS THEN HALF FUEL CELL RATED OUTPUT
1860 REM THEREFORE T(J,K)=T1(J,K) AND TERMS T2(J,K) & Q(J,K) DROP OUT
1870 IF T(J,K)>26.85*R9 THEN 1910
1880 T(J,K)=26.85*R9
1890 E(J,K)=0
1900 GO TO 1920
1910 E(J,K)=R9*(LOG(T(J,K))-LOG(R9)-3.29)/0.029
1920 G(J,K)=R1(K)-E(J,K)
1930 F(J,K)=4.07*R9*EXP(0.0354*E(J,K)/R9)
1940 NEXT K
1950 PRINT "L*******************  MENU  ************************"
1960 PRI "JJJLIST FUEL CELL ENERGY SYSTEM INPUT/OUTPUT (SELECT 1,2,OR3)"
1970 PRINT "J1-RATED POWER"
1980 PRINT "J2-ELECTRICAL LOAD FOLLOWING"
1990 PRINT "J3-THERMAL LOAD FOLLOWING"
2000 PRINT "JJ4-ECONOMIC EVALUATION"
2010 PRINT "J5-LIST CURRENT USER INPUTS"
2020 PRINT "J6-ENTER NEW LOAD REQUIREMENT DATA SET"
2030 PRINT "J7-CHANGE VOLUME OF THERMAL STORAGE"
2040 PRINT "J8-CHANGE SIZE OF FUEL CELL"
2050 PRINT "J9-RUN NEW PROGRAM"
2060 PRINT "JJJSELECT NUMBER THEN PRESS RETURN."
2070 INPUT T$
2080 D5=VAL(T$)
2090 IF D5=4 THEN 2620
2100 IF D5=5 THEN 2230
2110 IF D5=6 THEN 550
2120 IF D5=7 THEN 370
2130 IF D5=8 THEN 270
2140 IF D5=9 THEN 2
2150 GOSUB D5 OF 2170,2190,2210
2160 GO TO 2330
2170 F$="RATED POWER"
2180 RETURN
```

```
2190 F$="ELECTRICAL LOAD FOLLOWING"
2200 RETURN
2210 F$="THERMAL LOAD FOLLOWING"
2220 RETURN
2230 PRINT "LFUEL CELL SIZE =              ";F5;" (KW)"
2240 PRINT "JAMBIENT TEMPERATURE =         ";T8;" (DEG F)"
2250 PRINT "JTHERMAL STORAGE VOLUME =      ";V9;" (GALLONS)"
2260 PRINT "JSTORAGE INITIAL TEMP =        ";A3;" (DEG F)"
2270 PRINT "JREQUIRED HOT WATER TEMP =     ";A2;" (DEG F)"
2280 PRINT "JSYSTEM FEEDWATER TEMP =       ";A1;" (DEG F)"
2290 PRINT "JJJJJJJJJJJPRESS RETURN FOR MENU"
2300 INPUT P$
2310 GO TO 1950
2320 F5=120
2330 PRINT "L          ";F5;"KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT"
2340 PRINT "JJDATE:    ";B$
2350 PRINT "LOCATION:  ";A$
2360 PRINT "F/C LOAD:  ";F$
2370 PRINT "AVG TEMP:  ";T9;"  (DEG-F)"
2380 PRINT "J
2390 IMAGE L,9X,10A,10X,10A,12X,14A
2400 IMAGE "TIME",4X,16A,6X,11A,14X,9A
2410 IMA L,8X,"ELEC",4X,"THERM",7X,"F/C",6X,"GRID",7X,"F/C",5X,6A,3X,7A
2420 G$="ENERGY REQ"
2430 H$="ELECTRICAL"
2440 I$="THERMAL OUTFUT"
2450 P$="STORAGE"
2460 J$="(KW)   (KBTU/HR)"
2470 K$="OUTPUT (KW)"
2480 L$="(KBTU/HR)"
2490 M$="BOILER"
2500 N$="LEVEL"
2510 PRINT USING 2390:G$,H$,I$
2520 PRINT USING 2400:J$,K$,L$
2530 PRINT USING 2410:M$,P$
```

```
2540 PRINT " "
2550 IMAGE 4D,6D.2D,6D.2D,8D.2D,6D.2D,8D.2D,6D.2D,6D.2D
2560 IMAGE 4D,6D.2D,6D.2D,8D.2D,6D.2D,8D.2D,6D.2D,6X,"-"
2570 IMAGE "TOTAL",5D.2D,6D.2D,8D.2D,6D.2D,8D.2D,6D.2D,6D.2D
2580 X$="(KBTU)"
2590 IMAGE 6X,"(KW-HR)",2X,9A,7X,"(KW-HR)",18X,9A
2600 REM INITIALIZE TOTAL ENERGY INPUT/OUTPUT VARIABLES
2610 IF D5<>5 THEN 2640
2620 FOR J=1 TO 3
2630 GO TO 2650
2640 J=D5
2650 U1=0
2660 U2=0
2670 U3(J)=0
2680 U4(J)=0
2690 U5(J)=0
2700 U6(J)=0
2710 U7(J)=0
2720 U8(J)=0
2730 U9(J)=0
2740 FOR K=1 TO T6
2750 IF D5=4 THEN 2810
2760 IF D5<>3 THEN 2800
2770 PRINT USING 2560:T7(K),R1(K),H4(K),E(J,K),G(J,K),T(J,K),H5(J,K)
2780 H3(J,K)=0
2790 GO TO 2810
2800 PRI USI 2550:T7(K),R1(K),H4(K),E(J,K),G(J,K),T(J,K),H5(J,K),H3(J,K)
2810 U1=U1+R1(K)/2
2820 U2=U2+H4(K)/2
2830 U3(J)=U3(J)+E(J,K)/2
2840 IF G(J,K)<0 THEN 2870
2850 U4(J)=U4(J)+G(J,K)/2
2860 GO TO 2880
2870 U5(J)=U5(J)-G(J,K)/2
2880 U6(J)=U6(J)+T(J,K)/2
```

```
2890 U7(J)=U7(J)+H5(J,K)/2
2900 U8(J)=U8(J)+D(J,K)/2
2910 IF J=3 THEN 2930
2920 U9(J)=U9(J)+H3(J,K)/2
2930 NEXT K
2940 IF D5=4 THEN 3080
2950 PRINT "J";T6/2;"-HR"
2960 PRINT USING 2570:U1,U2,U3(J),U4(J)-U5(J),U6(J),U7(J),U9(J)
2970 PRINT USING 2590:X$,X$
2980 PRINT "JJJJJJJJJJJJJJJJJJJJJJJJJJJ"
2990 PRINT USING 3040:U4(J)
3000 PRINT USING 3050:U5(J)
3010 PRINT "JJJTHERMAL ENERGY"
3020 PRINT USING 3060:U8(J)
3030 IMAGE "FINAL =",11X,3D.2D," (KBTU)"
3040 IMAGE P,"ENERGY PURCHASED",/,"FROM GRID =",7X,4D.2D," (KW-HR)"
3050 IMAGE L,"ENERGY SOLD",/,"TO GRID =",8X,4D.2D," (KW-HR)"
3060 IMAGE "DUMPED =",8X,4D.2D," (KBTU)"
3070 IMAGE 2L,"TOTAL FUEL USED =",1X,3D.2D," (#'S METHANE)"
3080 F9(J)=F(J,1)/2
3090 FOR K=2 TO T6
3100 F9(J)=F9(J)+F(J,K)/2
3110 NEXT K
3120 IF D5<>4 THEN 3150
3130 NEXT J
3140 GO TO 3580
3150 PRINT USING 3070:F9(J)
3160 PRINT "JJJJJPRESS RETURN FOR MENU."
3170 INPUT P$
3180 IF D5=3 THEN 1950
3190 PRINT "LWOULD YOU LIKE PRINT OUT OF THERMAL STORAGE SIZING"
3200 PRINT "ROUTINE    (Y OR N?)"
3210 INPUT P$
3220 IF P$="N" THEN 1950
3230 REM START THERMAL STORAGE SIZING PRINTOUT ROUTINE
```

```
3240 PRINT "L                              THERMAL SYSTEM INPUT/OUTPUT"
3250 PRINT "J                                    ";F$
3260 IMAGE 3L,8X,"THERMAL",5X,"FUEL CELL THERMAL",9X,"THERMAL STORAGE"
3270 IMAGE L,8X,"LOAD",9X,"AVAIL",5X,"DUMPED",8X,"OUTPUT",6X,"LEVEL"
3280 G$="(KBTU/HR)"
3290 H$="(KBTU)"
3300 IMAGE 6X,9A,9X,9A,10X,9A,4X,6A
3310 IMAGE 4D,6D.2D,10D.2D,7D.2D,13D.2D,8D.2D
3320 IMAGE 4D,6X,"-",12X,"-",9X,"-",15X,"-",10D.2D
3330 IMAGE "TOTAL",5D.2D,10D.2D,7D.2D,13D.2D,8D.2D
3340 PRINT USING 3260:
3350 PRINT USING 3270:
3360 PRINT "KTIME"
3370 PRINT USING 3300:G$,G$,G$,H$
3380 PRINT
3390 FOR K=1 TO T6
3400 IF K<>1 THEN 3430
3410 PRINT USING 3310:T7(K),H4(K),T(J,K),D(J,K),H3(J,K),H1
3420 GO TO 3440
3430 PRINT USING 3310:T7(K),H4(K),T(J,K),D(J,K),H3(J,K),H2(J,K-1)
3440 NEXT K
3450 PRINT USING 3320:T7(K),H2(J,K-1)
3460 PRINT "J";T6/2;"-HR"
3470 L5(J)=H2(J,K)-H1
3480 PRINT USING 3330:U2,U6(J),U8(J),U9(J),L5(J)
3490 IMAGE 7X,"(KBTU)",7X,"(KBTU)",4X,"(KBTU)",10X,"(KBTU)",6X,"(KBTU)"
3500 PRINT USING 3490:
3510 IMAGE 57X,"(CHANGE)"
3520 PRINT USING 3510:
3530 PRINT "JJJTHERMAL STORAGE MAX CAP =  ";H9;" (KBTU)"
3540 PRINT "JJFINAL STORAGE TEMP =        ";A1+120*H2(J,K-1)/V9;"(DEG-F)"
3550 PRINT "JJJJJPRESS RETURN FOR MENU"
3560 INPUT P$
3570 GO TO 1950
3580 REM *****************  ECONOMICS  ***************************
```

```
3590 PRINT "LIS ENERGY/FUEL COST INFORMATION ENTERED PREVIOUSLY CORRECT"
3600 PRINT "FOR CURRENT LOAD REQUIREMENT DATA SET?  (Y OR N)?"
3610 INPUT P$
3620 IF P$="Y" THEN 3730
3630 REM METHANE LHV=1031 (BTU/SCF)
3640 PRINT "LENTER DOLLAR VALUES FOR ENERGY/FUEL COSTS IN"
3650 PRINT "FOLLOWING ORDER:"
3660 PRINT ""
3670 PRI "J1). FUEL CELL FUEL ($/MBTU-CH4)I(METHANE LHV=1031 (BTU/SCF))"
3680 PRINT "2). BOILER THERM ENERGY ($/MBTU)"
3690 PRINT "3). ELEC PURCHASED ($/KW-HR)"
3700 PRINT "4). ELEC SOLD ($/KW-HR)"
3710 PRINT "JEXAMPLE: 4.25,8.26,.054,.045"
3720 INPUT F4,B4,G4,G5
3730 REM DETERMINE ENERGY CONSUMPTION COSTS
3740 FOR J=1 TO 3
3750 REM TOTAL COST OF FUEL CELL FUEL "D1(J)" FOR SELECTED TIME PERIOD
3760 D1(J)=F4*F9(J)*0.023
3770 REM TOTAL COST OF BOILER HEAT "D2(J)"
3780 D2(J)=B4*U7(J)*1.0E-3
3790 REM TOTAL COST OF ELEC PURCHASED FROM GRID "D3(J)"
3800 D3(J)=G4*U4(J)
3810 D4(J)=G5*U5(J)
3820 REM TOTAL COST "D9(J) OF SPECIFIC LOAD FOLLOWING SCHEME "J"
3830 D9(J)=D1(J)+D2(J)+D3(J)-D4(J)
3840 NEXT J
3850 REM FUEL CELL OUTPUT = 0
3860 D1(4)=0
3870 D2(4)=B4*U2*1.0E-3
3880 D3(4)=G4*U1
3890 D4(4)=0
3900 D9(4)=D2(4)+D3(4)
3910 IMAGE 2L,"FUEL CELL",16X,"ELEC",8X,"ELEC"
3920 V$="BOILER"
3930 W$="TOTAL COST"
```

```
3940 IMAGE"OUTPUT      ",3X,"F/C",8X,"PURCHASED",3X,"SOLD",8X,6A,6X,10A
3950 IMAGE 14X,"($)",9X,"($)",9X,"($)",9X"($)",11X,"($)"
3960 IMAGE L,"RATED",10D.2D,9D.2D,9D.2D,9D.2D,11D.2D
3970 IMAGE L,"ELEC LOAD",6D.2D,9D.2D,9D.2D,9D.2D,11D.2D
3980 IMAGE L,"THERM LOAD",5D.2D,9D.2D,9D.2D,9D.2D,11D.2D
3990 IMAGE L,"F/C=0",10D.2D,9D.2D,9D.2D,9D.2D,11D.2D
4000 PRINT "LDATE:        ";B$
4010 PRINT "TIME:         ";T4;"-";T5
4020 PRINT "LOCATION:     ";A$
4030 PRINT "AUG TEMP:     ";T8;"  (DEG-F)"
4040 PRINT "JJ        ";F5;"KW FUEL CELL SYSTEM ENERGY CONSUMPTION COSTS"
4050 PRINT USING 3910:
4060 PRINT USING 3940:V$,W$
4070 PRINT USING 3950:
4080 PRINT USING 3960:D1(1),D3(1),D4(1),D2(1),D9(1)
4090 PRINT USING 3970:D1(2),D3(2),D4(2),D2(2),D9(2)
4100 PRINT USING 3980:D1(3),D3(3),D4(3),D2(3),D9(3)
4110 PRINT USING 3990:D1(4),D3(4),D4(4),D2(4),D9(4)
4120 PRINT "JJJJPRESS RETURN FOR MENU."
4130 INPUT P$
4140 GO TO 1950
```

Appendix B

PROGRAM PRINTOUTS OF EXTENDED 40-kW FUEL CELL COMPUTER SIMULATION

The following are the conditions for the computer printouts Tables B-1 through B-4.

```
FUEL CELL SIZE =              150 (KW)
AMBIENT TEMPERATURE =         65 (DEG F)
THERMAL STORAGE VOLUME =      3000 (GALLONS)
STORAGE INITIAL TEMP =        80 (DEG F)
REQUIRED HOT WATER TEMP =     130 (DEG F)
SYSTEM FEEDWATER TEMP =       55 (DEG F)
```

Tables B-5 through B-8.

```
PRESS RETURN FOR MENU
```

Table B-1. Printout based on fuel cell load: rated power.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: RATED POWER
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW) ELEC	ENERGY REQ (KBTU/HR) THERM	ELECTRICAL OUTPUT (KW) F/C	ELECTRICAL OUTPUT (KW) GRID	THERMAL OUTPUT (KBTU/HR) F/C	THERMAL OUTPUT (KBTU/HR) BOILER	THERMAL OUTPUT (KBTU/HR) STORAGE
0	125.00	156.19	150.00	-25.00	495.29	86.40	69.79
30	125.00	140.57	150.00	-25.00	495.29	62.12	78.44
100	115.00	124.95	150.00	-35.00	495.29	41.49	83.46
130	115.00	93.71	150.00	-35.00	495.29	20.57	73.15
200	110.00	62.47	150.00	-40.00	495.29	6.39	56.08
230	110.00	62.47	150.00	-40.00	495.29	0.00	62.47
300	120.00	31.24	150.00	-30.00	495.29	0.00	31.24
330	115.00	31.24	150.00	-35.00	495.29	0.00	31.24
400	115.00	93.71	150.00	-35.00	495.29	0.00	93.71
430	138.00	124.95	150.00	-12.00	495.29	0.00	124.95
500	135.00	499.80	150.00	-15.00	495.29	0.53	499.27
530	150.00	937.12	150.00	0.00	495.29	89.16	847.96
600	150.00	1062.08	150.00	0.00	495.29	203.88	858.20
630	160.00	1436.93	150.00	10.00	495.29	460.33	976.59
700	150.00	1749.30	150.00	0.00	495.29	781.10	968.20
730	150.00	1999.20	150.00	0.00	495.29	1105.29	893.91
8-HR TOTAL	1041.50 (KW-HR)	4302.97 (KBTU)	1200.00 (KW-HR)	-158.50 (KW-HR)	3962.30 (KBTU)	1428.63 (KBTU)	2874.33 (KBTU)

Table B-1. Continued.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: RATED POWER
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW) ELEC	ENERGY REQ (KBTU/HR) THERM	ELECTRICAL OUTPUT (KW) F/C	ELECTRICAL OUTPUT (KW) GRID	THERMAL OUTPUT (KBTU/HR) F/C	THERMAL OUTPUT (KBTU/HR) BOILER	THERMAL OUTPUT (KBTU/HR) STORAGE
800	165.00	1874.25	150.00	15.00	495.29	1159.37	714.88
830	160.00	1749.30	150.00	10.00	495.29	1136.79	612.51
900	155.00	1436.93	150.00	5.00	495.29	935.96	500.96
930	160.00	1062.08	150.00	10.00	495.29	664.20	397.88
1000	145.00	749.70	150.00	-5.00	495.29	433.11	316.59
1030	150.00	624.75	150.00	0.00	495.29	327.86	296.89
1100	195.00	624.75	150.00	45.00	495.29	299.52	325.23
1130	180.00	812.17	150.00	30.00	495.29	376.46	435.71
1200	170.00	1062.08	150.00	20.00	495.29	508.74	553.33
1230	150.00	874.65	150.00	0.00	495.29	411.47	463.18
1300	150.00	687.22	150.00	0.00	495.29	302.95	384.28
1330	150.00	624.75	150.00	0.00	495.29	254.56	370.19
1400	150.00	562.27	150.00	0.00	495.29	207.96	354.32
1430	160.00	499.80	150.00	10.00	495.29	163.63	336.17
1500	160.00	468.56	150.00	10.00	495.29	133.39	335.17
1530	150.00	468.56	150.00	0.00	495.29	115.60	352.96
8-HR TOTAL	1275.00 (KW-HR)	7090.91 (KBTU)	1200.00 (KW-HR)	75.00 (KW-HR)	3962.30 (KBTU)	3715.79 (KBTU)	3375.13 (KBTU)

Table B-1. Continued.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: RATED POWER
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW)	(KBTU/HR)	ELECTRICAL OUTPUT (KW)		THERMAL OUTPUT (KBTU/HR)		
	ELEC	THERM	F/C	GRID	F/C	BOILER	STORAGE
1600	185.00	812.17	150.00	35.00	495.29	225.54	586.63
1630	180.00	999.60	150.00	30.00	495.29	325.32	674.28
1700	170.00	1374.45	150.00	20.00	495.29	563.18	811.27
1730	170.00	1749.30	150.00	20.00	495.29	887.71	861.59
1800	160.00	1499.40	150.00	10.00	495.29	830.39	669.01
1830	155.00	1249.50	150.00	5.00	495.29	707.54	541.96
1900	155.00	874.65	150.00	5.00	495.29	473.35	401.30
1930	150.00	749.70	150.00	0.00	495.29	380.51	369.19
2000	150.00	687.22	150.00	0.00	495.29	324.50	362.73
2030	150.00	499.80	150.00	0.00	495.29	208.76	291.04
2100	135.00	312.38	150.00	-15.00	495.29	106.37	206.00
2130	130.00	249.90	150.00	-20.00	495.29	64.44	185.46
2200	130.00	249.90	150.00	-20.00	495.29	45.08	204.82
2230	125.00	218.66	150.00	-25.00	495.29	22.02	196.64
2300	120.00	218.66	150.00	-30.00	495.29	5.56	213.10
2330	118.00	187.43	150.00	-32.00	495.29	0.00	187.43
8-HR TOTAL	1191.50 (KW-HR)	5966.36 (KBTU)	1200.00 (KW-HR)	-8.50	3962.30	2585.14 (KBTU)	3381.22

Table B-2. Printout based on fuel cell load: electrical load following.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: ELECTRICAL LOAD FOLLOWING
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW)	(KBTU/HR)	ELECTRICAL OUTPUT (KW)		THERMAL OUTPUT (KBTU/HR)		
	ELEC	THERM	F/C	GRID	F/C	BOILER	STORAGE
0	125.00	156.19	125.00	0.00	358.94	91.85	64.34
30	125.00	140.57	125.00	0.00	358.94	71.78	68.78
100	115.00	124.95	115.00	0.00	312.03	55.71	69.24
130	115.00	93.71	115.00	0.00	312.03	35.44	58.27
200	110.00	62.47	110.00	0.00	290.31	19.51	42.97
230	110.00	62.47	110.00	0.00	290.31	15.45	47.02
300	120.00	31.24	120.00	0.00	334.92	5.15	26.09
330	115.00	31.24	115.00	0.00	312.03	2.79	28.45
400	115.00	93.71	115.00	0.00	312.03	2.84	90.88
430	138.00	124.95	138.00	0.00	426.51	0.00	124.95
500	135.00	499.80	135.00	0.00	410.27	10.53	489.27
530	150.00	937.12	150.00	0.00	495.29	104.17	832.96
600	150.60	1062.08	150.00	0.00	495.29	217.13	844.95
630	160.00	1436.93	150.06	10.00	495.29	473.29	963.63
700	150.00	1749.30	150.00	0.00	495.29	791.86	957.44
730	150.00	1999.20	150.00	0.00	495.29	1113.30	885.90
8-HR TOTAL	1041.50 (KW-HR)	4302.97 (KBTU)	1036.50 (KW-HR)	5.00	3097.38	1505.40 (KBTU)	2797.57

Table B-2. Continued.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: ELECTRICAL LOAD FOLLOWING
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW)	ENERGY REQ (KBTU/HR)	ELECTRICAL OUTPUT (KW)		THERMAL OUTPUT (KBTU/HR)		
	ELEC	THERM	F/C	GRID	F/C	BOILER	STORAGE
800	165.00	1874.25	150.00	15.00	495.29	1159.37	714.88
830	160.00	1749.30	150.00	10.00	495.29	1136.79	612.51
900	155.00	1436.93	150.00	5.00	495.29	935.96	500.96
930	160.00	1062.08	150.00	10.00	495.29	664.20	397.88
1000	145.00	749.70	145.00	0.00	465.89	438.01	311.69
1030	150.00	624.75	150.00	0.00	495.29	331.36	293.39
1100	195.00	624.75	150.00	45.00	495.29	302.52	322.23
1130	180.00	812.17	150.00	30.00	495.29	379.67	432.51
1200	170.00	1062.08	150.00	20.00	495.29	512.01	550.07
1230	150.00	874.65	150.00	0.00	495.29	413.65	461.00
1300	150.00	687.22	150.00	0.00	495.29	304.40	382.83
1330	150.00	624.75	150.00	0.00	495.29	255.69	369.06
1400	150.00	562.27	150.00	0.00	495.29	208.84	353.44
1430	160.00	499.80	150.00	10.00	495.29	164.33	335.47
1500	160.00	468.56	150.00	10.00	495.29	133.97	334.59
1530	150.00	468.56	150.00	0.00	495.29	116.11	352.45
8-HR TOTAL	1275.00 (KW-HR)	7090.91 (KBTU)	1197.50 (KW-HR)	77.50 (KW-HR)	3947.60 (KBTU)	3728.43 (KBTU)	3362.48 (KBTU)

Table B-2. Continued.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: ELECTRICAL LOAD FOLLOWING
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW)	ENERGY REQ (KBTU/HR)	ELECTRICAL OUTPUT (KW)		THERMAL OUTPUT (KBTU/HR)		
	ELEC	THERM	F/C	GRID	F/C	BOILER	STORAGE
1600	185.00	812.17	150.00	35.00	495.29	225.54	586.63
1630	180.00	999.60	150.00	30.00	495.29	325.32	674.28
1700	170.00	1374.45	150.00	20.00	495.29	563.18	811.27
1730	170.00	1749.30	150.00	20.00	495.29	887.71	861.59
1800	160.00	1499.40	150.00	10.00	495.29	830.39	669.01
1830	155.00	1249.50	150.00	5.00	495.29	707.54	541.96
1900	155.00	874.65	150.00	5.00	495.29	473.35	401.30
1930	150.00	749.70	150.00	0.00	495.29	380.51	369.19
2000	150.00	687.22	150.00	0.00	495.29	324.50	362.73
2030	150.00	499.80	150.00	0.00	495.29	208.76	291.04
2100	135.00	312.38	135.00	0.00	410.27	112.91	199.46
2130	130.00	249.90	130.00	0.00	384.06	76.30	173.60
2200	130.00	249.90	130.00	0.00	384.06	63.14	186.76
2230	125.00	218.66	125.00	0.00	358.94	44.47	174.19
2300	120.00	218.66	120.00	0.00	334.92	35.61	183.05
2330	118.00	187.43	118.00	0.00	325.63	22.49	164.93
8-HR TOTAL	1191.50 (KW-HR)	5966.36 (KBTU)	1129.00	62.50 (KW-HR)	3575.38	2640.87 (KBTU)	3325.49

Table B-3. Printout based on fuel cell load: thermal load following.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: THERMAL LOAD FOLLOWING
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW)	ENERGY REQ (KBTU/HR)	ELECTRICAL OUTPUT (KW)		THERMAL OUTPUT (KBTU/HR)		
	ELEC	THERM	F/C	GRID	F/C	BOILER	STORAGE
0	125.00	156.19	56.81	68.19	156.19	0.00	-
30	125.00	140.57	43.18	81.82	140.57	0.00	-
100	115.00	124.95	27.95	87.05	124.95	0.00	-
130	115.00	93.71	0.00	115.00	100.69	0.00	-
200	110.00	62.47	0.00	110.00	100.69	0.00	-
230	110.00	62.47	0.00	110.00	100.69	0.00	-
300	120.00	31.24	0.00	120.00	100.69	0.00	-
330	115.00	31.24	0.00	115.00	100.69	0.00	-
400	115.00	93.71	0.00	115.00	100.69	0.00	-
430	138.00	124.95	27.95	110.05	124.95	0.00	-
500	135.00	499.80	150.00	-15.00	495.29	4.51	-
530	150.00	937.12	150.00	0.00	495.29	441.84	-
600	150.00	1062.08	150.00	0.00	495.29	566.79	-
630	160.00	1436.93	150.00	10.00	495.29	941.64	-
700	150.00	1749.30	150.00	0.00	495.29	1254.01	-
730	150.00	1999.20	150.00	0.00	495.29	1503.91	-
8-HR TOTAL	1041.50 (KW-HR)	4302.97 (KBTU)	527.95 (KW-HR)	513.55	2061.25	2356.35 (KBTU)	0.00

Table B-3. Continued.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: THERMAL LOAD FOLLOWING
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW)	ENERGY REQ (KBTU/HR)	ELECTRICAL OUTPUT (KW)		THERMAL OUTPUT (KBTU/HR)		
	ELEC	THERM	F/C	GRID	F/C	BOILER	STORAGE
800	165.00	1874.25	150.00	15.00	495.29	1378.96	-
830	160.00	1749.30	150.00	10.00	495.29	1254.01	-
900	155.00	1436.93	150.00	5.00	495.29	941.64	-
930	160.00	1062.08	150.00	10.00	495.29	566.79	-
1000	145.00	749.70	150.00	-5.00	495.29	254.41	-
1030	150.00	624.75	150.00	0.00	495.29	129.46	-
1100	195.00	624.75	150.00	45.00	495.29	129.46	-
1130	180.00	812.17	150.00	30.00	495.29	316.89	-
1200	170.00	1062.08	150.00	20.00	495.29	566.79	-
1230	150.00	874.65	150.00	0.00	495.29	379.36	-
1300	150.00	687.22	150.00	0.00	495.29	191.94	-
1330	150.00	624.75	150.00	0.00	495.29	129.46	-
1400	150.00	562.27	150.00	0.00	495.29	66.99	-
1430	160.00	499.80	150.00	10.00	495.29	4.51	-
1500	160.00	468.56	145.46	14.54	468.56	0.00	-
1530	150.00	468.56	145.46	4.54	468.56	0.00	-
8-HR TOTAL	1275.00 (KW-HR)	7090.91 (KBTU)	1195.46 (KW-HR)	79.54	3935.57	3155.34 (KBTU)	0.00

Table B-3. Continued.

150KW FUEL CELL ENERGY SYSTEM INPUT/OUTPUT

DATE: 27MAR80
LOCATION: SEWELL'S POINT NAS
F/C LOAD: THERMAL LOAD FOLLOWING
AVG TEMP: 65 (DEG-F)

TIME	ENERGY REQ (KW)	ENERGY REQ (KBTU/HR)	ELECTRICAL OUTPUT (KW)		THERMAL OUTPUT (KBTU/HR)		
	ELEC	THERM	F/C	GRID	F/C	BOILER	STORAGE
1600	185.00	812.17	150.00	35.00	495.29	316.89	-
1630	180.00	999.60	150.00	30.00	495.29	504.31	-
1700	170.00	1374.45	150.00	20.00	495.29	879.16	-
1730	170.00	1749.30	150.00	20.00	495.29	1254.01	-
1800	160.00	1499.40	150.00	10.00	495.29	1004.11	-
1830	155.00	1249.50	150.00	5.00	495.29	754.21	-
1900	155.00	874.65	150.00	5.00	495.29	379.36	-
1930	150.00	749.70	150.00	0.00	495.29	254.41	-
2000	150.00	687.22	150.00	0.00	495.29	191.94	-
2030	150.00	499.80	150.00	0.00	495.29	4.51	-
2100	135.00	312.38	115.08	19.92	312.38	0.00	-
2130	130.00	249.90	99.84	30.16	249.90	0.00	-
2200	130.00	249.90	99.84	30.16	249.90	0.00	-
2230	125.00	218.66	90.81	34.19	218.66	0.00	-
2300	120.00	218.66	90.81	29.19	218.66	0.00	-
2330	118.00	187.43	79.63	38.37	187.43	0.00	-
8-HR TOTAL	1191.50 (KW-HR)	5966.36 (KBTU)	1038.00	153.50 (KW-HR)	3194.90	2771.46 (KBTU)	0.00

Table B-4. [illegible]intout for Navy-wide 3,000-gallon thermal storage.

THERMAL SYSTEM INPUT/OUTPUT

ELECTRICAL LOAD FOLLOWING

TIME	THERMAL LOAD (KBTU/HR)	FUEL CELL THERMAL AVAIL (KBTU/HR)	FUEL CELL THERMAL DUMPED (KBTU/HR)	THERMAL STORAGE OUTPUT (KBTU/HR)	THERMAL STORAGE LEVEL (KBTU)
0	156.19	358.94	0.00	64.34	624.75
30	140.57	358.94	0.00	68.78	772.05
100	124.95	312.03	0.00	69.24	917.13
130	93.71	312.03	0.00	58.27	1038.53
200	62.47	290.31	0.00	42.97	1165.41
230	62.47	290.31	0.00	47.02	1289.08
300	31.24	334.92	0.00	26.09	1410.72
330	31.24	312.03	0.00	28.45	1565.14
400	93.71	312.03	0.00	90.88	1706.93
430	124.95	426.51	188.08	124.95	1817.51
500	499.80	410.27	0.00	489.27	1874.25
530	937.12	495.29	0.00	832.96	1834.75
600	1062.08	495.29	0.00	844.95	1665.92
630	1436.93	495.29	0.00	963.63	1491.09
700	1749.30	495.29	0.00	957.44	1256.91
730	1999.20	495.29	0.00	885.90	1025.83
800	-	-	-	-	830.53
8-HR TOTAL	4302.97 (KBTU)	3097.38 (KBTU)	94.04 (KBTU)	2797.57 (KBTU)	78.41 (KBTU) (CHANGE)

Table B-4. Continued.

THERMAL SYSTEM INPUT/OUTPUT

ELECTRICAL LOAD FOLLOWING

TIME	THERMAL LOAD (KBTU/HR)	FUEL CELL THERMAL AVAIL (KBTU/HR)	FUEL CELL THERMAL DUMPED (KBTU/HR)	THERMAL STORAGE OUTPUT (KBTU/HR)	THERMAL STORAGE LEVEL (KBTU)
800	1874.25	495.29	0.00	714.88	824.67
830	1749.30	495.29	0.00	612.51	714.88
900	1436.93	495.29	0.00	500.96	656.26
930	1062.08	495.29	0.00	397.88	653.43
1000	749.70	465.89	0.00	311.69	702.13
1030	624.75	495.29	0.00	293.39	779.23
1100	624.75	495.29	0.00	322.23	880.18
1130	812.17	495.29	0.00	432.51	966.70
1200	1062.08	495.29	0.00	550.07	998.09
1230	874.65	495.29	0.00	461.00	970.71
1300	687.22	495.29	0.00	382.83	987.85
1330	624.75	495.29	0.00	369.66	1044.08
1400	562.27	495.29	0.00	353.44	1107.19
1430	499.80	495.29	0.00	335.47	1178.12
1500	468.56	495.29	0.00	334.59	1258.02
1530	468.56	495.29	0.00	352.45	1338.37
1600	-	-	-	-	1409.79
8-HR TOTAL	7090.91 (KBTU)	3947.60 (KBTU)	0.00 (KBTU)	3362.48 (KBTU)	648.61 (KBTU) (CHANGE)

Table B-4. Continued.

THERMAL SYSTEM INPUT/OUTPUT

ELECTRICAL LOAD FOLLOWING

TIME	THERMAL LOAD (KBTU/HR)	FUEL CELL THERMAL AVAIL (KBTU/HR)	FUEL CELL THERMAL DUMPED (KBTU/HR)	THERMAL STORAGE OUTPUT (KBTU/HR)	THERMAL STORAGE LEVEL (KBTU)
1600	812.17	495.29	0.00	586.63	1399.44
1630	999.60	495.29	0.00	674.28	1353.77
1700	1374.45	495.29	0.00	811.27	1264.27
1730	1749.30	495.29	0.00	861.59	1106.28
1800	1499.40	495.29	0.00	669.01	923.13
1830	1249.50	495.29	0.00	541.96	836.27
1900	874.65	495.29	0.00	401.30	812.93
1930	749.70	495.29	0.00	369.19	859.93
2000	687.22	495.29	0.00	362.73	922.98
2030	499.80	495.29	0.00	291.04	989.26
2100	312.38	410.27	0.00	199.46	1091.38
2130	249.90	384.06	0.00	173.60	1196.78
2200	249.90	384.06	0.00	186.76	1302.01
2230	218.66	358.94	0.00	174.19	1400.67
2300	218.66	334.92	0.00	183.05	1493.04
2330	187.43	325.63	0.00	164.93	1568.98
2400	-	-	-	-	1649.33
8-HR TOTAL	5966.36 (KBTU)	3575.38 (KBTU)	0.00 (KBTU)	3325.49 (KBTU)	326.41 (KBTU) (CHANGE)

Table B-5. Printout for Navy-wide 500-gallon thermal storage.

THERMAL SYSTEM INPUT/OUTPUT

ELECTRICAL LOAD FOLLOWING

TIME	THERMAL LOAD (KBTU/HR)	FUEL CELL THERMAL AVAIL (KBTU/HR)	FUEL CELL THERMAL DUMPED (KBTU/HR)	THERMAL STORAGE OUTPUT (KBTU/HR)	THERMAL STORAGE LEVEL (KBTU)
0	156.19	358.94	0.00	113.44	104.13
30	140.57	358.94	47.38	140.57	226.00
100	124.95	312.03	187.08	124.95	312.38
130	93.71	312.03	218.32	93.71	312.38
200	62.47	290.31	227.83	62.47	312.38
230	62.47	290.31	227.83	62.47	312.38
300	31.24	334.92	303.69	31.24	312.38
330	31.24	312.03	280.80	31.24	312.38
400	93.71	312.03	218.32	93.71	312.38
430	124.95	426.51	301.56	124.95	312.38
500	499.80	410.27	0.00	460.01	312.38
530	537.12	495.29	0.00	642.18	287.51
600	1062.08	495.29	0.00	581.40	214.06
630	1436.93	495.29	0.00	583.57	171.00
700	1749.30	495.29	0.00	551.90	126.86
730	1999.20	495.29	0.00	527.54	98.55
800	-	-	-	-	82.43
8-HR TOTAL	4302.97 (KBTU)	3097.38 (KBTU)	1006.40 (KBTU)	2112.68 (KDTU)	-25.54 (KDTU) (CHANGE)

Table B-5. Continued.

THERMAL SYSTEM INPUT/OUTPUT

ELECTRICAL LOAD FOLLOWING

TIME	THERMAL LOAD (KBTU/HR)	FUEL CELL THERMAL AVAIL (KBTU/HR)	FUEL CELL THERMAL DUMPED (KBTU/HR)	THERMAL STORAGE OUTPUT (KBTU/HR)	THERMAL STORAGE LEVEL (KBTU)
800	1874.25	495.29	0.00	577.63	137.45
830	1749.30	495.29	0.00	506.02	96.27
900	1436.93	495.29	0.00	471.36	90.50
930	1062.08	495.29	0.00	440.88	102.47
1000	749.70	465.89	0.00	395.58	129.67
1030	624.75	495.29	0.00	412.47	164.83
1100	624.75	495.29	0.00	453.88	206.23
1130	812.17	495.29	0.00	536.49	226.94
1200	1062.08	495.29	0.00	571.68	206.34
1230	874.65	495.29	0.00	485.08	168.14
1300	687.22	495.29	0.00	440.93	173.24
1330	624.75	495.29	0.00	448.07	200.42
1400	562.27	495.29	0.00	446.85	224.03
1430	499.80	495.29	0.00	440.80	248.25
1500	468.56	495.29	0.00	448.41	275.50
1530	468.56	495.29	0.00	468.50	298.94
1600	-	-	-	-	312.33
8-HR TOTAL	7090.91 (KBTU)	3947.60 (KBTU)	0.00 (KBTU)	3772.71 (KBTU)	174.93 (KBTU) (CHANGE)

Table B-5. Continued.

THERMAL SYSTEM INPUT/OUTPUT

ELECTRICAL LOAD FOLLOWING

TIME	THERMAL LOAD (KBTU/HR)	FUEL CELL THERMAL AVAIL (KBTU/HR)	FUEL CELL THERMAL DUMPED (KBTU/HR)	THERMAL STORAGE OUTPUT (KBTU/HR)	THERMAL STORAGE LEVEL (KBTU)
1600	812.17	495.29	0.00	543.61	233.24
1630	999.60	495.29	0.00	562.12	209.08
1700	1374.45	495.29	0.00	582.05	175.66
1730	1749.30	495.29	0.00	559.89	132.28
1800	1499.40	495.29	0.00	490.76	99.98
1830	1249.50	495.29	0.00	466.52	102.24
1900	874.65	495.29	0.00	424.98	116.63
1930	749.70	495.29	0.00	435.74	151.78
2000	687.22	495.29	0.00	449.64	181.56
2030	499.80	495.29	0.00	401.80	204.38
2100	312.38	410.27	0.00	304.17	251.12
2130	249.90	384.06	117.76	249.90	304.17
2200	249.90	384.06	134.16	249.90	312.38
2230	218.66	358.94	140.28	218.66	312.38
2300	218.66	334.92	116.26	218.66	312.38
2330	187.43	325.63	138.21	187.43	312.38
2400	-	-	-	-	312.38
8-HR TOTAL	5966.36 (KBTU)	3575.38 (KBTU)	323.33 (KBTU)	3172.91 (KBTU)	79.13 (KBTU) (CHANGE)

Table B-6. Energy consumption costs first eight hours.

DATE: 27MAR80
TIME: 0-800
LOCATION: SEWELL'S POINT NAS
AVG TEMP: 65 (DEG-F)

150KW FUEL CELL SYSTEM ENERGY CONSUMPTION COSTS

FUEL CELL OUTPUT	F/C ($)	ELEC PURCHASED ($)	ELEC SOLD ($)	BOILER ($)	TOTAL COST ($)
RATED	57.28	0.19	4.41	11.14	64.19
ELEC LOAD	47.76	0.19	0.00	11.74	59.68
THERM LOAD	31.75	19.28	0.28	18.38	69.20
F/C=0	0.00	38.54	0.00	33.56	72.10

PRESS RETURN FOR MENU.

Table B-7. Energy consumption costs second eight hours.

DATE: 27MAR80
TIME: 800-1600
LOCATION: SEWELL'S POINT NAS
AVG TEMP: 65 (DEG-F)

150KW FUEL CELL SYSTEM ENERGY CONSUMPTION COSTS

FUEL CELL OUTPUT	F/C ($)	ELEC PURCHASED ($)	ELEC SOLD ($)	BOILER ($)	TOTAL COST ($)
RATED	57.28	2.87	0.07	28.98	89.06
ELEC LOAD	57.12	2.87	0.00	29.08	89.07
THERM LOAD	56.98	3.04	0.07	24.61	84.56
F/C=0	0.00	47.18	0.00	55.31	102.48

PRESS RETURN FOR MENU.

Table B-8. Energy consumption costs third eight hours.

DATE: 27MAR80
TIME: 1600-2400
LOCATION: SEWELL'S POINT NAS
AVG TEMP: 65 (DEG-F)

150KW FUEL CELL SYSTEM ENERGY CONSUMPTION COSTS

FUEL CELL OUTPUT	F/C ($)	ELEC PURCHASED ($)	ELEC SOLD ($)	BOILER ($)	TOTAL COST ($)
RATED	57.28	2.31	1.92	20.16	77.84
ELEC LOAD	53.01	2.31	0.00	20.60	75.92
THERM LOAD	48.77	5.68	0.00	21.62	76.07
F/C=0	0.00	44.09	0.00	46.54	90.62

PRESS RETURN FOR MENU.

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