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# WESTINGHOUSE PHASE I FINAL REPORT

## Volume XII —FUEL CELLS

by

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16. Abstract

A parametric assessment of four fuel cell power systems -- based on phosphoric acid, potassium hydroxide, molten carbonate, and stabilized zirconia -- has shown that the most important parameters from electricity-cost reduction and/or efficiency improvement standpoints are fuel cell useful life and power density, use of a waste-heat recovery system, and fuel type. Typical capital costs, overall energy efficiencies (based on the heating value of the coal used to produce the power plant fuel), and electricity costs are: phosphoric acid $350-450/kWe, 24-29%, and 11.7 to 13.9 mills/MJ (42 to 50 mills/kWh); alkaline $450-700/kWe, 26-31%, and 12.8 to 16.9 mills/MJ (46 to 61 mills/kWh); molten carbonate $480-650/kWe, 32-46%, and 10.6 to 19.4 mills/MJ (38 to 70 mills/kWh); stabilized zirconia $420-950/kWe, 26-53%, and 9.7 to 16.9 mills/MJ (35 to 61 mills/kWh). Three types of fuel cell power plants -- solid electrolyte with steam bottoming, molten carbonate with steam bottoming, and solid electrolyte with an integrated coal gasifier -- are recommended for further study.

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# SUMMARY

Four fuel cell power systems, differentiated by electrolyte type, have been investigated from cost and efficiency standpoints. For the phosphoric acid system, operating at 190°C, a power plant efficiency, an overall energy efficiency (based on the limiting value of the coal employed in the production of the power plant fuel), a capital cost and a cost of electricity were calculated for each of sixteen points in the parametric assessment. Similar calculations were performed for aqueous alkaline fuel cell power plants at 343°K [70°C (158°F)] (16 points), molten carbonate plants at 923°K [650°C (1202°F)] (17 points), and stabilized zirconia plants at 1273°K [1000°C (1832°F)] (20 points).

In parametric assessments, the following parameters were varied: useful life and rating of the fuel cell subsystem, fuel cell power density and electrolyte thickness, fuel and oxidant types, performance degradation over the useful life of the fuel cell subsystem, anode and cathode catalyst loadings in the acid and alkaline systems, and temperature of operation and use of waste-heat recovery systems in the molten carbonate and stabilized zirconia power systems. Four of these -- fuel cell useful life and power density, use of a waste-heat recovery system, and fuel type -- proved to be of particular importance in efficiency improvement and/or electricity-cost reduction.

Typical capital costs, overall energy efficiencies, and electricity costs of fuel cell power plants were found to be as follows:

- . Phosphoric acid $350-450/kWe, 24-29%, and 11.7 to 13.9 mills/ MJ (42 to 50 mills/kWh)

- Alkaline $450-700/kWe, 26-31%, and 12.8 to 16.9 mills/MJ (46 to 61 mills/kWh)

- Molten carbonate $480-650/kWe, 32-46%, and 10.6 to 19.4 mills/ MJ (38 to 70 mills/kWh)

- Stabilized zirconia $420-950/kWe, 26-53%, and 9.7 to 16.9 mills/ MJ (35 to 61 mills/kWh).

Projections as to the lowest possible cost of electricity (in mills/kWh) for the acid, alkaline, carbonate, and zirconia systems are mid to high 30's, low 40's, low 30's, and high 20's, respectively.

Three types of fuel cell power plants are recommended for further study in the conceptual design (Task II) and implementation assessment (Task III) phases of the Energy Conversion Alternatives Study. These are: (1) solid-electrolyte plant with steam bottoming; (ii) molten carbonate plant with steam bottoming; and (iii) solid electrolyte plant with an integrated coal-gasification reactor for waste-heat recovery (the Westinghouse Fuel Cell Power System).

# 13. FUEL CELLS

## 13.1 State of the Art

Fuel cell power-generation systems may be grouped in four distinct classes differentiated by electrolyte type. These are:

- Aqueous acid, which encompasses systems based on phosphoric and sulfuric acids, and the solid polymer electrolyte

- Aqueous alkali, based on potassium hydroxide and buffered carbonate-bicarbonate solutions

- Molten salt, specifically molten carbonates

- High-temperature solid electrolyte, specifically stabilized zirconia.

NASA has specified that the minimum power plant rating to be considered in this study should be 25 MWe. No fuel cell power system of even two orders of magnitude lower in rating has been constructed or operated, so there is no utility experience to guide this investigation. All that is available is the self-serving advocacy of their own systems by the corporations engaged in fuel cell research. While there are, of necessity, some constraints on the published estimates of system efficiencies, there appears to be no such restraint shown in the projections of the expected cost and performance of the fuel cell subsystems.

A fuel cell power plant will consist, in general, of fuel-processing and power-conditioning equipment in addition to the fuel cell subsystem. Most of the effort of this study was directed toward the fuel cell component because of the greater degree of uncertainty with respect to its cost and performance. Further, as no fuel cell power plant concept has been conclusively demonstrated as optimal from the standpoints

of technical feasibility or economic desirability, four base cases are considered, rather than the minimum of two mandated by the contract work statement, with one base case selected from each of the four electrolyte-type categories described above.

The scientific literature pertaining to fuel cells was reviewed in order to facilitate this selection procedure and, particularly, to assist in establishing a meaningful framework of parametric values. Within each of the four general areas the fuel cell power systems were considered from the standpoint of their suitability for use in central-station power generation. Among the more important considerations were the voltage efficiency, demonstrated cell and battery useful lifetimes, life-limiting processes, quantities of noble-metal catalysts required, problems posed by the use of coal-derived fuels, and the state of the art with respect to the engineering of the overall power systems. The results of the literature survey in each area are outlined in the following subsections.

### 13.1.1 Aqueous Acid Fuel Cells

Systems based on three distinct electrolyte types have been considered in this area:

- Phosphoric acid fuel cells, which operate in the temperature range 423 to 463°K (302 to 374°F)

- Solid polymer electrolyte fuel cells, operating at 348 or 423°K (167 or 302°F), depending on whether air or oxygen is employed as the oxidant

- Sulfuric acid fuel cells which operate at approximately 333°K (140°F).

The Power Systems Division of United Technologies Corporation (formerly Pratt and Whitney Aircraft Division of United Aircraft) is the undisputed leader in acid fuel cell systems. It has field-tested complete power systems of up to 40 kW capacity and is currently building 26 MW systems (FCG-1) for a number of utilities. The preferred system

employs immobilized phosphoric acid electrolyte at temperatures between 423 and 463°K (302 and 374°F). The higher temperatures in this range are desirable mainly because of air electrode (cathode) activity, but they also serve to accelerate life-limiting processes such as platinum electrocatalyst recrystallization and degeneration of the phosphoric acid matrix. One problem with this system is typical of all acid systems—fuel electrode deterioration due to carbon monoxide blockage of active sites on the anode electrocatalyst, thus denying them to the electrochemically more active hydrogen. This problem is a good deal less severe here than in other acid systems because the fuel electrode functions adequately, provided the carbon monoxide concentration in the fuel gas is maintained at 0.5% or below.

In a recent ERDA-directed assessment study of devices for the generation of electricity from stored hydrogen, conducted at Argonne National Laboratory (ANL), an efficiency of 38% (based on the higher heating value of the fuel gas) was quoted by United Technologies personnel for a fuel consisting of a typical reformer effluent gas, shifted (and perhaps methanated) to meet the carbon monoxide concentration specifications quoted above (Reference 13.1). The selling price (FOB factory) of the fuel cell power system, including the inverter, was given as $225/kW of installed capacity. If an allowance for the inverter system of $40/kW (Reference 13.2) is subtracted from this total, the final cell subsystem cost is $185/kW. The targeted (but as yet unachieved) useful life of the power system is 144 Ms (40,000 hr) of operation with a 5% loss in efficiency in that period.

Over the past 630 Ms (20 yr), the General Electric Company has developed a fuel cell based on an electrolyte consisting of a porous film of a fluorocarbon with chemically-bound sulfonic acid groups (Reference 13.3). The solid polymer electrolyte (SPE), developed and marketed by DuPont under the tradename NAFION, is reportedly extremely stable in the fuel cell environment. With near ambient-pressure air as oxidant, the optimum temperature of operation is approximately 348°K (167°F). Because the air (and fuel) streams must be presaturated to

ensure membrane stability, higher temperatures cause excessive dilution of the oxygen in the air stream by water vapor. When oxygen is employed, operational temperatures up to 423°K (302°F) are possible.

State-of-the-art performances are 180 mW/cm$^2$ (167 W/ft$^2$) of active area at 0.66 V per cell (44% HHV) with air at 348°K (167°F) and 470 mW/cm$^2$ (437 W/ft$^2$) at 0.75 V per cell (51% HHV) with oxygen at 423°K (302°F) (Reference 13.4). This work has also shown that at 348°K (167°F), with a fuel gas containing 0.3% carbon monoxide, the current noble metal catalyst will not tolerate this carbon monoxide level without a prohibitive performance loss, even at noble metal loadings in the anode of approximately 4 mg/cm$^2$ (5.69 x 10$^{-5}$ lb/in$^2$) (Reference 13.4). This phenomenon, discussed above, is obviously an even severer limitation on this power system. The state-of-the-art fuel cell manufacturing cost (not selling price) is estimated to be approximately $400/kW for the system operating on hydrogen and air. Of this total, approximately $260/kW is attributable to the noble-metal loadings and approximately $120/kW to the membrane. The economic viability of this system is seen, therefore, to depend on significant breakthroughs in the areas of noble-metal loading reductions and membrane substitution or cost reduction, as well as the development of methods for the lowering of the carbon monoxide content substantially below concentrations of 0.3%. A carbon monoxide concentration of 10 ppm is considered to be tolerable (Reference 13.3).

Sulfuric acid-based systems, in which the anode electrocatalyst is tungsten carbide, do not suffer from the carbon monoxide poisoning problem described above for the phosphoric acid and SPE systems (Reference 13.5). As is usual in sulfuric acid systems which operate typically at approximately 333°K (140°F), however, the major problem is the low activity of the cathode even when it is operated on oxygen. A further problem arising with long-time operation is the need to reject the water formed in the cathode reaction.

The phosphoric acid-based system was chosen as the best representative of the acid systems because it is the fuel cell which best

addresses the problems of tolerance towards carbon monoxide and minimization of noble-metal loadings while maintaining high levels of anodic and cathodic activities. The confidence of the electrical utilities, as displayed by their support of the United Technologies fuel cell program, tends to support this judgement.

### 13.1.2 Alkaline Fuel Cells

The systems considered in this electrolyte-type group are those based on 30 wt % aqueous potassium hydroxide solutions at approximately 343°K (158°F), 75 wt % aqueous potassium hydroxide solutions at approximately 473°K (392°F), and saturated carbonate-bicarbonate aqueous solutions at temperatures of approximately 333°K (140°F). Although alkaline hydrogen-oxygen ($H_2$-$O_2$) fuel cells have been investigated by many companies, principally Union Carbide, Shell (U.K.), Allis Chalmers, United Technologies, Exxon, Alsthom (France), Varta (G.F.R.), and Siemens (G.F.R.), only a small fraction of the overall effort has been devoted to the use of carbonaceous fuel gases. This neglect is principally due to problems associated with carbonation of the electrolyte by carbon dioxide in air or the fuel gas, or from the oxidation of carbon monoxide from the dissolution of the carbon dioxide formed in the alkaline electrolyte.

Various techniques (References 13.6) have been employed to overcome this problem in bench-scale systems. The electrolyte is circulated in the Allis-Chalmers methanol-oxygen system and is regenerated externally. The Shell (U.K.) methanol-air system employs a silver-palladium tube to separate the hydrogen from the gas mixture after external reformation, so that carbon-containing gases do not have access to the electrolyte. A similar scheme has been employed by United Technologies to provide hydrogen, formed by steam reformation of carbonaceous fuels, to the fuel electrodes of Bacon cells. This technique is impractical from technical and economic considerations in fuel cell power plants of the type considered in this study.

Commercial acid gas-scrubbing systems—for example, Lurgi Rectisol and Benfield—are available, which will permit reduction of the

carbon dioxide content of feed streams to less than 10 ppm. There is, however, a serious question as to whether this level is sufficiently low to prevent electrolyte carbonation and, worse still, solid potassium carbonate formation in the pores of the gas diffusion electrodes, thereby leading to relatively rapid performance degradation. The problem of electrolyte carbonation may be dealt with by electrolyte circulation, followed ultimately by replacement with fresh caustic solution, or by cyclic decarbonation of the electrolyte in an external electrolytic cell, as proposed for the Exxon-Alsthom methanol-air fuel cell power system (Reference 13.7).

Scrubbing carbon dioxide from the air feed to the alkaline fuel cells may also be accomplished by the Lurgi and Benfield processes. This would probably be as expensive as the fuel gas scrubbing described above, despite the much lower carbon dioxide content of air, as the capital costs of the processes are a strong function of the total number of moles of throughput gas. Another approach involves simple caustic scrubbing of the incoming air. This could cost as little as $5/kW (Reference 13.8). Rather than dispose of the approximately one ton of potassium carbonate formed each day in a 25 MW fuel cell power plant, it is probably more desirable to regenerate the caustic by the Exxon-Alsthom technique alluded to above.

Despite the problems associated with scrubbing carbon dioxide from the fuel gas and air feeds, alkaline fuel cell subsystems are very attractive for large-scale power generation from the standpoints of cost and useful life. For example, long-lived air cathodes in alkaline solution operate with significantly better polarization characteristics than they do in acidic solutions. This is all the more remarkable since these cathodes do not require noble metals. Silver may be employed as the perhydroxide ion elimination catalyst with a concomitant substantial lowering of catalyst cost. A further advantage of alkaline fuel cell power systems is that nickel at approximately $4.41/kg ($2/lb) is stable in the cell environment. In contrast, acid systems are restricted to

graphite and other carbon products because of the prohibitive expense of tantalum at $117/kg ($53/lb) and niobium at $33/kg ($15/lb).

Estimated overall system efficiencies for alkaline fuel cell power systems, using carbonaceous gas as a fuel, are similar to those quoted for acid systems, about 35 to 40%. The efficiency advantage of the alkaline fuel cell, resulting from lower cathodic polarization, is almost totally negated by the efficiency penalty associated with elimination of carbon dioxide from the air and fuel gas streams (Reference 13.9).

An alkaline fuel cell, operating in 30 wt % potassium hydroxide solution at approximately 343°K (158°F) has been selected to represent this class of fuel cells in the rest of this study. It is preferred over the Bacon fuel cell, which operates typically in 75 wt % potassium hydroxide solutions at temperatures in excess of 473°K (392°F), because of the well-known severe corrosion problems of this latter system. In contrast, the Exxon-Alsthom carbonate-bicarbonate fuel cell is disqualified from further consideration because of problems relating to low cathodic activity due mainly to excessive concentration polarization (Reference 13.8).

### 13.1.3 Molten Carbonate Fuel Cells

No large molten carbonate fuel cell batteries have been produced. Systems studies have been made for 15 to 22 kW units by Texas Instruments (Reference 13.10) and IGT (References 13.11 and 13.12); and United Technologies has a development program on which few details have been published (References 13.13 and 13.22). Broers (References 13.14 and 13.15) did much of the earlier research on the devices upon which current technology is based but did little work on multiple-cell devices.

Texas Instruments designed a 1 kW test unit which was delivered to the U. S. Army Mobility Equipment R&D Center at Fort Belvoir, Virginia. IGT has operated fuel cell batteries in excess of 2 kW, but the results of their recent work are not published. These units use a separate reformer to supply a suitable mixture of hydrogen and carbon monoxide to the cells.

An economic assessment of molten carbonate fuel cells for large-scale power production with propane feed to an integrated reformer-molten carbonate fuel cell system was published by Hart and Womack (Reference 13.16) in 1967. The calculations they presented were based in part on the unpublished work at the Central Electricity Generating Board Research Laboratories and Marchwood Engineering Laboratories. They used a fuel cell model representing their projection of the best fuel cell performance to be expected in the near future plus an estimation of the cost of individual parts of the model cell. The fuel cell operating at maximum power was assumed to use its waste heat to generate steam. This steam supplied a steam turbine generator for additional power generation. For this system a plant efficiency of 46.5% was calculated based on propane feed as the fuel and assuming that a propane reformer was integrated with the fuel cell system. They concluded that initial capital costs for the system would be at least 25% higher than for a coal-fired steam turbine generator system of similar life. Since the fuel cell life was expected to be short [optimistically 157.7 Ms (5 yr) compared to perhaps 315.4 to 630.7 Ms (10 to 20 yr) for a gas turbine and 630.7 to 946.1 Ms (20 to 30 yr) for a steam turbine], they concluded that such a fuel cell plant was not economically attractive. The economics of a fuel cell for domestic power are different, and von Fredersdorff (IGT) published an analysis of the molten carbonate fuel cell for this use in 1963 (Reference 13.17), concluding that the system could be economical if the fuel cell investment cost was no more than $300 over a 315.4 Ms (10 yr) operation.

All costs—fuel costs in particular—are much higher now than they were at the time of the earlier studies. The molten carbonate fuel cell power capability has been improved significantly; and there are stricter regulations on emissions from power plants, substantially increasing capital cost and reducing efficiency.

The practical efficiencies which may be attained for large fuel cell batteries of this type, based on small battery performance, are still

in dispute, but 45% efficiency based on the higher heating value (HHV) of natural gas is probably feasible (Reference 13.18).

The cells with highest performance reported recently use a paste electrolyte of alkali aluminates suggested by Broers (Reference 13.15), a nickel anode and lithiated nickel oxide cathode. The cells give useful power densities at 923°K (1202°F) of up to about 161 mW/cm$^2$ (150 W/ft$^2$) using air as oxidant, depending on the fuel gas. Oxygen allows greater power densities. Cell temperatures of 873 to 1023°K (1112 to 1382°F) have been used, and corrosion problem increases at the higher temperatures.

In large systems it is anticipated that increased efficiency can be attained by recovering waste heat and using it to generate steam for use in a steam turbine or as process steam, as suggested by Hart and Womack (Reference 13.16). The highest efficiency plants would be large ones to minimize the turbogenerator plant costs.

If methanated (high-Btu) gas or methanol is used as a fuel, a reforming step is necessary. A higher efficiency is attainable if this can be accomplished on the fuel cell electrodes or nearby surfaces within the cell, since the reforming process absorbs heat which would be supplied in situ by the heat produced at the electrodes of the molten carbonate cell. Although a commercial reformer operates at a higher temperature than does the molten carbonate cell, the large electrode area within the cell and the probable slower throughput per unit area makes internal reforming a reasonable possibility. Experiments on internal reforming or reforming on a catalyst at the same temperature as the fuel cell have been successful (References 13.19 and 13.20), but the feasibility of internal reforming at high power densities in multicell systems is still to be demonstrated. The fuel cell plant would have a clean exhaust, since most of the sulfur is removed from the fuel gases initially, and oxides of nitrogen are not formed in significant quantities at these low temperatures. Unused fuel gases can be burned with excess oxygen in the cathode exit gas stream.

In addition to the fuel cell plant cost analysis reported by Hart and Womack for large-scale power production by a molten carbonate system, Bockris and Srinivasan (Reference 13.21) present a list, from different sources, of recent (1969) and future fuel cell costs. A projected cost for the molten carbonate cell system attributed to Broers is $600/kW for large-scale production using natural gas and a reformer. More recently, United Technologies reports (References 13.13 and 13.22) an estimate of ~ $225/kW capital cost (EPRI RP114 Program) for the molten carbonate system with a lower heating value (LHV) efficiency of 47%. They also report multicell life tests, in conjunction with the Electric Power Research Institute, of 36 Ms (10,000 hr) between overhaul, are good performance stability during subscale tests, some of which lasted more than 18 Ms (5000 hr).

Broers and IGT have also reported up to 36 Ms (10,000 hr) fuel cell life, but there is no consensus on the eventual maximum which may be possible.

Variations of the Broers type of molten carbonate fuel cell have been suggested, such as the use of a liquid lead electrode catalyst for oxidation of solid forms of carbon or coal (Reference 13.23), but none has received an extended study effort or been developed as yet.

In summary, on the basis of available information, the eventual useful fuel cell life, cost, type of reforming necessary, and efficiency are still very questionable.

13.1.4  Stabilized Zirconia Fuel Cells

High-temperature solid electrolyte fuel cells have many advantages over other types of fuel cell. As Markin describes (Reference 13.24), these are:

- There are no liquids involved, so problems associated with pore flooding and maintenance of a stable three-phase interface are totally avoided

- The electrolyte composition is invariant and does not
  depend on the composition of the fuel and oxidant
  streams

- Activation polarization losses are negligible.

Further, a power system, based on the use of stabilized zirconia at
operating temperatures of approximately 1273°K (1832°F), has a unique ad-
vantage when coal is employed as a fuel in that the waste heat, generated
because of the thermodynamic and electrochemical inefficiencies of the
fuel cells, may be used directly in the gasification of coal, thus pro-
viding fuel gas for the fuel cells. This thermal coupling leads to high
overall efficiencies for the power system, and practical efficiencies of
greater than 60% are considered possible (Reference 13.25). This effi-
ciency is all the more remarkable because this type of power system em-
ploys coal, rather than natural gas, methanol, or naphtha, as a fuel.

The disadvantages of this fuel cell are related to:

- The relatively high electrolyte resistivity

- The need for an effective, low-cost method of inter-
  connection of cells to form a battery

- Problems involving battery component interactions and
  adequate sealing techniques.

Many companies and other research organizations [e.g., Westinghouse,
General Electric, C. G. E. (France), Brown Boveri (G. F. R.), Battelle
(Geneva, Switzerland), and AERE (Harwell, England)] have explored possi-
ble solutions to these problems in their efforts at component development
and device fabrication. The largest device demonstrated to date was
based on a bell and spigot geometry. It was constructed and operated by
the Westinghouse Electric Corporation and delivered 100 W of electrical
power (References 13.25 and 13.26).

The Westinghouse thin-film concept (Reference 13.27) provides
an economical and effective method for the series-connection of individ-
ual cells in a solid-electrolyte battery. The largest of these devices

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demonstrated to date delivered 8 W and lived for approximately 360 ks
(100 hr)—the first 108 ks (30 hr) saw a 5% voltage degradation at a given
current output (Reference 13.28). The life-limiting problem lay in the
interconnection-electrolyte junction where inadequate sealing led to fuel
gas leakage, resulting in air electrode reduction and, ultimately, per-
formance degradation. This design has been selected for this study.

## 13.2 Description of Parametric Points

To facilitate a comprehensive comparison of the four fuel cell
power-generation systems, the parameter values listed in Table 13.1 below
were fixed for the base cases of all systems.

Table 13.1 - Base Case Values Common to All Systems

| Parameter | Value |
|---|---|
| Size of Power Plant | 25 MW dc |
| Type of Fuel | High-Btu gas |
| Type of Oxidizer | Air |
| Fuel Cell Useful Life | 10,000 hr (5% efficiency degradation) |

The smallest system to be to be considered in this study, 25 MW,
was chosen for the base cases, as no economies of scale are expected for
the fuel cell subsystem. Further, no fuel cell power system of even
two orders of magnitude lower in rating has been constructed or operated,
so that even in this small a power plant the system problems can only
be addressed in the most general fashion, as will be evident from the
schematics provided in the following subsections.

A 25 MW fuel cell power plant is too small to justify the
expense of a dedicated coal gasification reactor. Thus, it will be fueled
with hydrogen, high-Btu gas, or methanol, all of which may be derived from

coal. Because of the flexibility afforded by the existing extensive network of natural gas lines, high-Btu gas was selected as the fuel for the base cases.

A value for the useful lives of all of the fuel cell subsystems was arbitrarily fixed for the base cases at 36 Ms (10,000 hr) at a constant power output, with a 5% degradation in terminal voltage. The degradation specification is important in the determination of the power conditioning costs. The useful life value specified is considered a reasonable estimate of the state of the art for molten carbonate fuel cells, an overestimate by a factor of approximately one hundred for the solid electrolyte fuel cell, and an underestimate by a factor of approximately two for aqueous acid and alkaline fuel cells, as described in the previous section.

In general, the parametric assessment involved the variation of one parameter, with the others retaining the value used in the base case. In certain cases, however, a change in one parameter caused the variation of other parametric values. The change from air to oxygen as the oxidant, for example, was thought to cause an increase in the current density in the acid, alkaline, and molten carbonate fuel cells; and an increase in the cell voltage in the solid electrolyte fuel cells.

Point 1 of the parametric point list for each fuel cell type is the base case. The abbreviations AC, AL, MC, and SE were chosen for the acid, alkaline, molten carbonate, and solid electrolyte fuel cell power systems, respectively. Thus, AC1 represents the base case in the phosphoric acid system. The first eight parametric value changes common to all four systems are shown in Table 13.2. Points 2 through 4 explored the economics of scale realized by increasing the power plant rating. Because of their modular nature, no economy of scale was assumed for the fuel cell subsystems. Any economic benefits realized, therefore, come from the other subsystems. The effect of the replacement of air with oxygen from a dedicated oxygen plant was tested for all systems in Point 5. Three more parametric points per system (6 to 8)

Table 13.2 - Parametric Changes Common to all Four Systems

| Point No. | Parameter | Value | Base Case |
|-----------|-----------|-------|-----------|
| 2 | Size of power plant | 100 MW | 25 MW |
| 3 | Size of power plant | 250 MW | 25 MW |
| 4 | Size of power plant | 900 MW | 25 MW |
|  | Fuel type | Medium-Btu gas | High-Btu gas |
| 5 | Oxidant type | Oxygen | Air |
| 6 | Fuel cell useful life | 30,000 hr (5% Voltage degradation) | 10,000 hr |
| 7 | Fuel cell useful life | 50,000 hr (5%) | 10,000 hr |
| 8 | Fuel cell useful life | 100,000 hr (5%) | 10,000 hr |
| 9 | Fuel cell useful life | 100,000 hr (15%) | 10,000 hr |

were expended to investigate the impact of fuel cell subsystem useful life on the electricity costs. The effect of a terminal voltage decrease of 15% (at constant power output) after 360 Ms (100,000 hr) of plant operation was explored in Point 9.

A cross-comparison of the efficiencies and electricity costs is possible for all systems in Points 4 through 9, and for the acid, alkaline, and molten carbonate systems in Points 2 and 3. The solid electrolyte power system is not available for comparison purposes in Points 2 and 3 because medium-Btu gas was employed as a fuel instead of the high-Btu gas used in the other three systems. Further details of Points 2 through 8, and a description of the parametric points specific to each system, are provided in the following subsections.

### 13.2.1  Phosphoric Acid Fuel Cell Power System

As indicated in the previous subsection, the base case in this power system, AC1, involves a fuel cell subsystem that has a 25 MW dc rating, a useful life of 36 Ms (10,000 hr) of operation, and a 5%

voltage degradation at constant power output. The fuel is a high-Btu gas; air is the oxidant. In the fuel cell subsystem, the fuel cell is considered to have a bipolar design similar to that described by Baker et al. (Reference 13.29). The anode and cathode, each fabricated from carbon as described by Kordesch and Scarr (Reference 13.30), are catalyzed by a platinum addition to each electrode of 1 mg/cm$^2$ (0.002 lb/ ft$^2$). The addition of other electrocatalysts for the reduction of performance sensitivity to carbon monoxide in the fuel stream (Reference 13.31) are considered desirable but were not included in the economic analysis. The electrolyte is 85 wt % aqueous phosphoric acid immobilized in a zirconium pyrophosphate matrix with an effective resistivity of 2 Ω-cm. The electrolyte thickness is 0.5 mm (0.020 in). The fuel cell sub- system operates at 463°K (375°F). Based on a conservative estimate of anticipated advances in the state of the art, beyond that reported by Schiller and Meyer (Reference 13.32) in 1971, values of 0.7 V and 200 mA/cm$^2$ (186 A/ft$^2$) were selected for the cell voltage and current density, respectively.

A schematic of the complete power system is shown in Figure 13.1. High-Btu gas from a 0.689 MPa (100 psi) abs line is assumed to be available, and is fed after preheating to a steam-methane reformer operating at a pressure of 0.689MPa (100 psi) abs and a temperature of 1144°K (1600°F). The reformer effluent, consisting mainly of carbon monoxide, hydrogen, carbon dioxide and steam, is cooled and fed to a shift converter operating at 0.483 MPa (70 psi) abs and 700°K (800°F). The shift converter is operated at as low a temperature as possible in order to minimize the carbon monoxide concentration in the exit gas. The hydrogen-rich fuel gas is further cooled to approximately 422°K (375°F) and is fed to the ten fuel cell modules. Air is supplied to the modules by means of blowers, as shown in Figure 13.1.

Steam, required for the steam reformation of methane (the principal constituent of high-Btu gas) is raised in the cooling of the fuel gas between the reformer and the shift converter, in the shift converter, and between the shift converter and fuel cell subsystem. The water required for the steam generators is reclaimed from the fuel-gas

Fig. 13.1 —Schematic of a phosphoric acid fuel cell power system which employs high-Btu gas as fuel
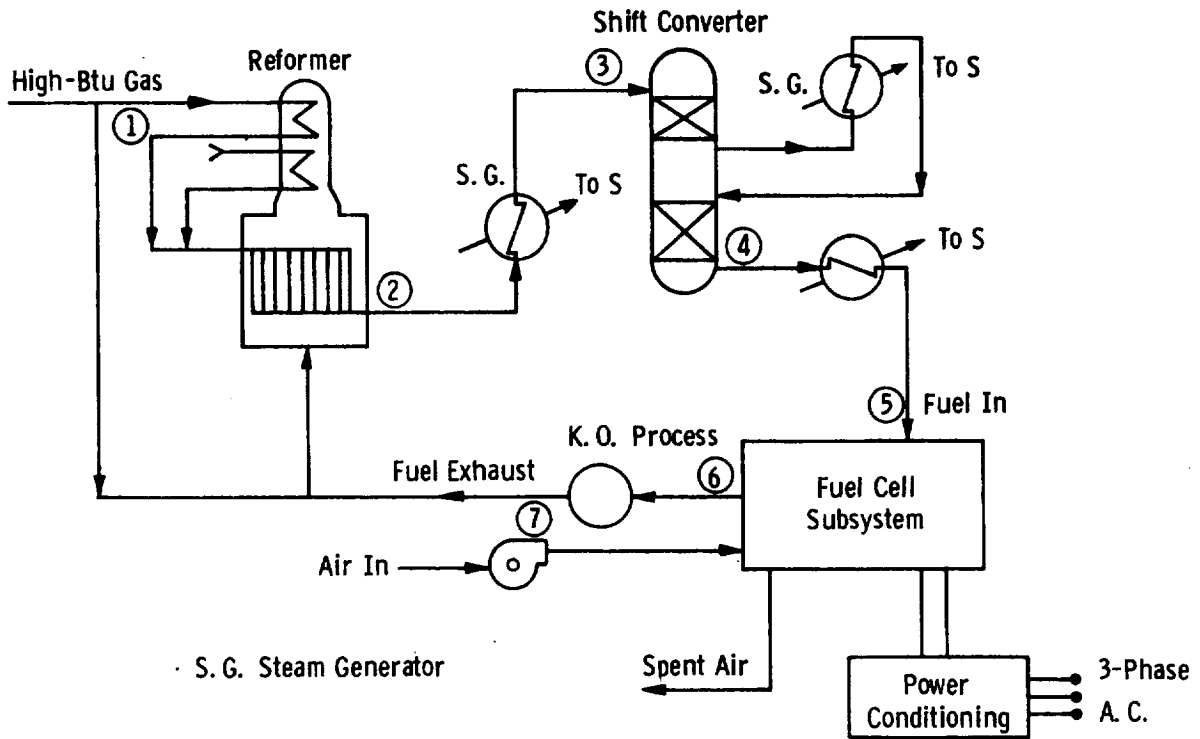
| Point No | Temperature, °F | Pressure, psia | Point No | Temperature, °F | Pressure, psia |
|----------|-----------------|----------------|----------|-----------------|----------------|
| 1 | 60 | 100 | 5 | 300 | 25 |
| 2 | 1600 | 85 | 6 | 375 | 20 |
| 3 | 800 | 70 | 7 | 120 | 18 |
| 4 | 800 | 40 | | | |

exhaust by the knock-out process shown in Figure 13.1. The water-vapor depleted exhaust gases, containing approximately 10% of the hydrogen fed to the fuel cell modules, and the unused carbon monoxide, is mixed with a portion of the incoming high-Btu gas, and the mixture is burned to supply the heat required to cover the endothermic processes in the reformer. Further details of the fuel processing subsystem are provided in Appendix A 13.1.

The fuel cell subsystem, rated at 25 MW dc, consists of ten 2.5 MW modules. Each module is wired into a dedicated power conditioning unit consisting of a force-commutated dc to ac inverter, a transformer, and filters. A more detailed description of the power conditioning subsystem is provided in Appendix A 13.2.

As indicated in the previous subsection, the changes from the base case, characterized by Points 2 through 9 and shown in Table 13.2, are common to all systems. AC2 and AC3 differ from AC1 only in that the fuel cell subsystems are rated at 100 MW and 250 MW dc, respectively. In AC4, the fuel cell subsystem is rated at 900 MW dc. The fuel used in the 900 MW plant is medium-Btu gas, instead of the high-Btu gas employed in AC1, AC2, and AC3. Thus, the steam-methane reformer, shown in Figure 13.1, is unnecessary in this power plant.

AC5 involves the use of oxygen as the fuel cell oxidant instead of air. Because of the reduction of concentration polarization at the fuel cell cathode, the apparent current density was considered to have doubled, i.e., from 200 mA/cm$^2$ (186 A/ft$^2$) to 400 mA/cm$^2$ (372 A/ft$^2$), despite the concomitant increase in the fuel electrode polarization and the cell ohmic polarization losses.

In parametric points AC6, AC7, and AC8, the fuel cell sub-system useful life in a 25 MW dc plant is increased to 108 Ms (30,000 hr), 180 Ms (50,000 hr), and 360 Ms (100,000 hr), respectively. In all three points, as in the base case, AC1, a 5% efficiency or voltage degradation, by comparison with the initial performance, is assumed at the end of useful life. Thus, the initial cell voltage, 0.7 V, will have fallen to 0.665 V at end of life. In AC9, a voltage degradation of 15% (0.105 V) is assumed at the end of a 360 Ms (100,000 hr) useful life.

The changes from the base case, represented in Points AC10 through AC16, are specific to the phosphoric acid fuel cell power system. These are shown in Table 13.3.

Table 13.3 - Parametric Points - Acid Fuel Cell

| Point No. | Parameter | Value/Type | Base Case Value |
|-----------|-----------|------------|-----------------|
| 10 | Current density | 300 mA/cm$^2$ | 200 mA/cm$^2$ |
| 11 | Current density | 400 mA/cm$^2$ | 200 mA/cm$^2$ |
| 12 | Catalyst loading | 0.3 mg Pt/cm$^2$ | 1 mg Pt/cm$^2$ |
| 13 | Catalyst loading | 0.1 mg Pt/cm$^2$ | 1 mg Pt/cm$^2$ |
| 14 | Type of fuel | Methanol | High-Btu gas |
| 15 | Electrolyte thickness | 0.25 mm | 0.5 mm |
| 16 | Oxidant type | Oxygen | Air |
| | Size of power plant | 250 MW | 25 MW |

AC10 and 11 were included to explore the effect of fuel cell subsystems cost reductions, resulting from increases in the apparent current density of the base case, 200 mA/cm$^2$ (186 A/ft$^2$), to 300 mA/cm$^2$ (279 A/ft$^2$) and 400 mA/cm$^2$ (372 A/ft$^2$). Similarly, AC12 and 13 represent advances in the state of the art which result in the lowering of platinum loadings in both cathode and anode from 1 mg/cm$^2$ (0.002 lb/ft$^2$) in the base case to 0.3 mg/cm$^2$ (6 x 10$^{-4}$ lb/ft$^2$) and 0.1 mg/cm$^2$ (2 x 10$^{-4}$ lb/ft$^2$) respectively.

High-Btu gas is replaced by methanol as the fuel in AC14. This will involve storage of methanol in tanks at the power plant. The electrolyte thickness of 0.5 mm (0.020 in) in the base case is reduced to 0.25 mm (0.010 in) in AC15. Because of the resultant reduction in ohmic losses in the electrolyte, the cell voltage at 200 mA/cm$^2$ (180 A/ft$^2$) is considered to have increased from 0.70 V to 0.71 V.

The effects of replacement of air by oxygen in a 250 MW dc power plant are explored in AC16. Once again, as in AC5, the assumed apparent current density of the cell was doubled to 400 mA/cm$^2$ (372 A/ft$^2$). This point was included to demonstrate, by comparison with AC5, the effect of scale in lowering the oxygen cost.

### 13.2.2 Alkaline Fuel Cell Power System

A schematic of the alkaline fuel cell power system base case, AL1, is shown in Figure 13.2. The temperatures and pressures at various system locations are also presented in this figure. For the purposes of this study, it has been assumed that the alkaline power system is similar to its acid counterpart, described in the previous subsection, but with the following differences:

● Carbon dioxide scrubbers - To prevent carbonation of the electrolytes the Lurgi Rectisol process is employed to scrub both the air and the fuel gas inlet streams, as shown in Figure 13.2. Further details of this process, which employs refrigerated methanol to scrub acid gases, are found in Appendix A 13.1.

● Fuel cell subsystem - A bipolar configuration, identical with that described for the acid system, is assumed also for the alkaline fuel cell battery. However, the apparent current density in the base case for this system, 100 mA/cm$^2$ (93 A/ft$^2$), is only half that in the acid fuel cell. The cell voltage, 0.8 V, is higher because of the generally lower cathodic polarizations in the alkaline fuel cell. These values represent a conservative estimate of advances in the state of the art since 1969 (Reference 13.33) for this fuel cell. The anode and cathode are catalyzed with 1 mg of platinum/cm$^2$ (0.002 lb/ft$^2$) and 5 mg of silver/cm$^2$ (0.1 lb/ft$^2$), respectively. The electrolyte thickness is 0.5 mm (0.020 in) with an assumed effective resistivity of 2 $\Omega$-cm (5 ohm-in). The fuel cell operates at a temperature of 343°K (158°F), not only for the base case but also for all parametric points described below.

Fig. 13. 2—Schematic of an alkaline fuel cell power system which employs high-Btu gas as fuel
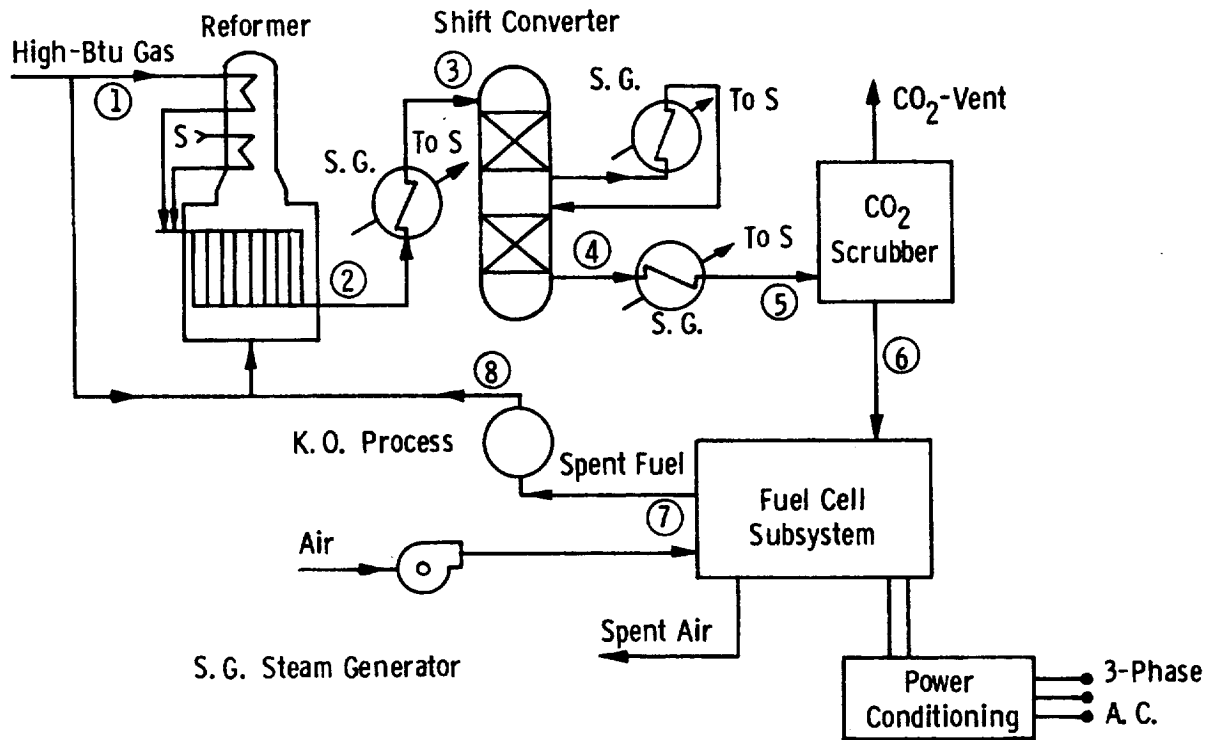
| Point No | Temperature, °F | Pressure, psia | Point No | Temperature, °F | Pressure, psia |
|----------|-----------------|----------------|----------|-----------------|----------------|
| 1 | 60 | 100 | 5 | 400 | 25 |
| 2 | 1600 | 85 | 6 | 100 | 25 |
| 3 | 800 | 70 | 7 | 160 | 20 |
| 4 | 800 | 40 | 8 | 100 | 18 |

Points AL2 through AL9 involve the same changes in parameter values as those for AC1 through AC9 discussed in the previous subsection. Once again, replacement of air as oxidant by oxygen from a dedicated oxygen plant (AL5) is considered to result in a doubling of the base case apparent current density, i.e., from 100 mA/cm$^2$ (93 A/ft$^2$) to 200 mA/cm$^2$ (186 A/ft$^2$).

The changes from the base case, represented by parametric points AL10 through AL16, are specific to the alkaline fuel cell system, and are shown in Table 13.4 below.

Table 13.4  -  Parametric Points - Alkaline Fuel Cell

| Point No. | Parameter | Value/Type | Base Case Value |
|-----------|-----------|------------|-----------------|
| AL10 | Current density | 175 mA/cm$^2$ | 100 mA/cm$^2$ |
| AL11 | Current density | 250 mA/cm$^2$ | 100 mA/cm$^2$ |
| AL12 | Anode catalyst loading | 0.1 mg Pt/cm$^2$ | 1 mg/cm$^2$ |
| AL13 | Anode catalyst loading | 0.01 mg Pt/cm$^2$ | 1 mg/cm$^2$ |
| AL14 | Anode and cathode materials | Raney Nickel | Pt/C |
| AL15 | Cathode catalyst loading | 1 mg Ag/cm$^2$ | 5 mg/cm$^2$ |
| AL16 | Electrolyte thickness | 0.25 mm (0.010 in) | 0.5 mm (0.020 in) |

The effects of increases in the fuel cell apparent current density from 100 mA/cm$^2$ (93 A/ft$^2$) to 175 mA/cm$^2$ (163 A/ft$^2$), brought about by improvements in the state of the art, are tested in parametric points AL10 and AL11, respectively. Points AL12 and AL13 explore the effects of reductions of platinum loadings in the anode from 1 mg/cm$^2$ (2.10$^{-3}$ lb/ft$^2$). Replacement of the carbon gas-diffusion electrodes by Raney nickel electrodes is examined in parametric Point AL14. Point AL15

Fig. 13.3—Schematic of molten carbonate fuel cell power systems (MC 1-3, 6-14 and 16)

| Point No. | Temperature, °F | Pressure, psia | Point No. | Temperature, °F | Pressure, psia |
|-----------|-----------------|----------------|-----------|-----------------|----------------|
| 1 | ambient | 100 | 7 | 752 | 15 |
| 2 | ambient | 35 | 8 | 752 | 15 |
| 3 | 752 | 30 | 9 | 752 | 30 |
| 4 | 752 | 30 | 10 | 752 | 30 |
| 5 | 302 | 15 | 11 | 752 | 30 |
| 6 | 1202 | 25 | | | |

tests the effect of the reduction of the silver loading in the cathode from 5 mg/cm$^2$ (0.01 lb/ft$^2$) to 1 mg/cm$^2$ (0.002 lb/ft$^2$).  In Point AL16, the electrolyte thickness, or electrode separation, is 0.025 cm (0.01 in), i.e., half of that in the base case.  This results in a cell voltage increase of 5 mV, so that the cell voltage at 100 mA/cm$^2$ (93 A/ft$^2$) is 0.805 V in AL16.

### 13.2.3  Molten Carbonate Fuel Cells

The effect of ten plant and operating variables on the cost of electricity was investigated.  These are the effect of power plant size, fuel cell life, cell output degradation, current density at fuel cell electrodes, electrolyte thickness, temperature of the fuel cell, replacement of air by oxygen, oxygen plant size, fuel type, and recovery of waste heat from the fuel cell by a steam turbine generator system.

MC1, the reference or base case, has a 25 MW dc rating with a filter press design similar to that described by IGT (Reference 13.22), with a porous nickel anode and lithiated nickel oxide cathode.  The electrolyte is the Broers type (Reference 13.15), consisting of a semisolid paste of alkali aluminate powder and molten alkali carbonates with the ternary eutectic composition ($Li_2CO_3$-43.5 mole %, $Na_2CO_3$-31.5 mole %, $K_2CO_3$-25.0 mole %, m.p. 670°K (747°F)).  Electrolyte resistance (Reference 13.23) is assumed to be 1.5 times that of the free electrolyte of the same thickness.  This value would actually vary with the paste structure and chemical composition.  High-Btu gas is used as fuel, and it is assumed that it can be reformed on internal cell surfaces.  A schematic of the plant configuration for MC1 is shown in Figure 13.3.  It consists of a split series of fuel cell modules consisting of ten separate banks, each with its own dc-to-ac inverter, transformer, and filters.  It operates at 923°K (1202°F), as do all other plants except MC12 and MC13, which operate at 973 and 1023°K (1292 and 1382°F), respectively.

Fuel and oxidant streams enter the fuel cell at (3) and (4), (Figure 13.3) and react electrochemically at the anode and cathode, respectively, at the fuel cell temperature of 923°K (1202°F).  After

| Point No. | Temperature, °F | Pressure, psia | Point No. | Temperature, °F | Pressure, psia |
|-----------|-----------------|----------------|-----------|-----------------|----------------|
| 1 | ambient | 100 | 7 | 752 | 15 |
| 2 | ambient | 35 | 8 | 752 | 15 |
| 3 | 752 | 30 | 9 | 752 | 30 |
| 4 | 752 | 30 | 10 | 752 | 30 |
| 5 | 302 | 15 | 11 | 752 | 30 |
| 6 | 1202 | 25 | | | |

Fig. 13.4—Schematic of a molten carbonate fuel cell power plant with heat recovery by a steam turbine generator (MC 4)

leaving the fuel cell, part of the anode (fuel) gas stream is added to the cathode gas stream at (6) to replace carbon dioxide lost in the cathode electrochemical reactions. The two gas streams, thus modified, enter a . heat recovery steam generator and exit at a temperature between 673 and 823°K (752 and 1022°F), depending on the recycle flow rate necessary to minimize concentration polarization at the fuel cell electrodes and to remove excess heat from the fuel cell.

Part of the cathode gas stream is then diverted at (9) through a counterflow heat exchanger, leaving as stack exhaust at (5) at 423°K (302°F), and in the process preheating incoming air and desulfurized fuel from ambient temperature to 573 to 723°K. The exhaust gas stream contains carbon dioxide, water vapor, nitrogen, a small amount of oxygen, but no combustible gases.

Preheated air and desulfurized fuel, entering at (2) and (1) are then combined with the cathode and anode gas streams at (11) and (10) and enter the fuel cell again at (4) and (3). This completes the cycle.

The steam produced can be sold as process steam, used to operate a steam turbine to produce more electricity as in MC4, or operate a turbine drive for an oxygen plant as in Points MC5 and MC17.

MC1, MC2, and MC3 differ only in plant size, being 25 MW dc, 100 MW dc, and 250 MW dc, respectively.

MC4 differs in size (900 MW dc) and also in utilizing a steam turbine generator to produce additional electricity from waste heat, as shown in Figure 13.4. The plant configuration differs from MC1 not only in size but also in allowing space for the steam turbine generator system with its ac transformer.

MC5 is similar to MC1 except for inclusion of an oxygen plant capable of supplying about 3.461 to 3.623 kg/s (330 to 345 tons/day) of oxygen to be used in place of air. The schematic is shown in Figure 13.5.

MC6, 7, and 8 differ from MC1 only in fuel cell lifetimes of 108, 180, and 360 Ms (30,000, 50,000, and 100,000 hr), respectively; and

Fig. 13.5—Schematic of a molten carbonate fuel cell system using oxygen (MC 5 and 17)

| Point No. | Temperature, °F | Pressure, psia | Point No. | Temperature, °F | Pressure, psia |
|-----------|-----------------|----------------|-----------|-----------------|----------------|
| 1 | ambient | 100 | 7 | 752 | 15 |
| 2 | ambient | 35 | 8 | 752 | 15 |
| 3 | 752 | 30 | 9 | 752 | 30 |
| 4 | 752 | 30 | 10 | 752 | 30 |
| 5 | 302 | 15 | 11 | 752 | 30 |
| 6 | 1202 | 25 | | | |

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MC9 is similar to MC8 except for the assumption of 15 rather than 5% voltage degradation.

MC10 and 11 assume a current density of 150 and 250 $mA/cm^2$ (139 $A/ft^2$ and 232 $A/ft^2$) as compared to 200 $mA/cm^2$ (186 $A/ft^2$) for MC1.

MC12 and 13 assume an operating temperature of 973 and 1023°K (1292 and 1382°F), respectively, as compared to 923°K (1202°F) for MC1. Electrolyte resistance (Reference 13.23) is a little lower at the higher temperatures, but corrosion is worse.

MC14 uses medium-Btu gas as fuel rather than the high-Btu gas used by MC1.

MC15 uses methanol as fuel, which requires a storage tank as shown in Figure 13.6. Otherwise, it is similar to MC1.

MC16 differs from MC1 in using an electrolyte thickness of 0.5 mm (0.020 in) rather than 1 mm (0.040 in) used for MC1.

MC17 is similar to MC3 (250 MW dc) but uses oxygen rather than air as oxidant. This is included as a comparison to MC5 (25 MW dc) to show the effect of the lower oxygen cost with larger plant size.

### 13.2.4  Solid Electrolyte Fuel Cell Power System

A schematic of the power plant corresponding to the base case, SE1, is shown in Figure 13.7. The basic plant layout is relatively simple in that it consists of the fuel cell generator, the power conditioning subsystem, recuperative heat exchangers (to allow the fuel cell exit gases to heat up the incoming fuel and air streams), and an air blower. The temperatures and pressures at various locations in the power system are also tabulated in Figure 13.7.

All parametric points, including SE1, employ the Westinghouse thin-film solid-electrolyte fuel cell battery in the fuel cell subsystem. This device, built on porous tubes of stabilized zirconia, is described in greater detail in Reference 13.25. The electrolyte film of yttria-stabilized zirconia ($ZrO_2$-10% $Y_2O_3$) is gas-impervious and 40 $\mu$m (1.6 mils)

Fig. 13. 6—Schematic of a molten carbonate fuel cell system using methanol as fuel (MC 15)
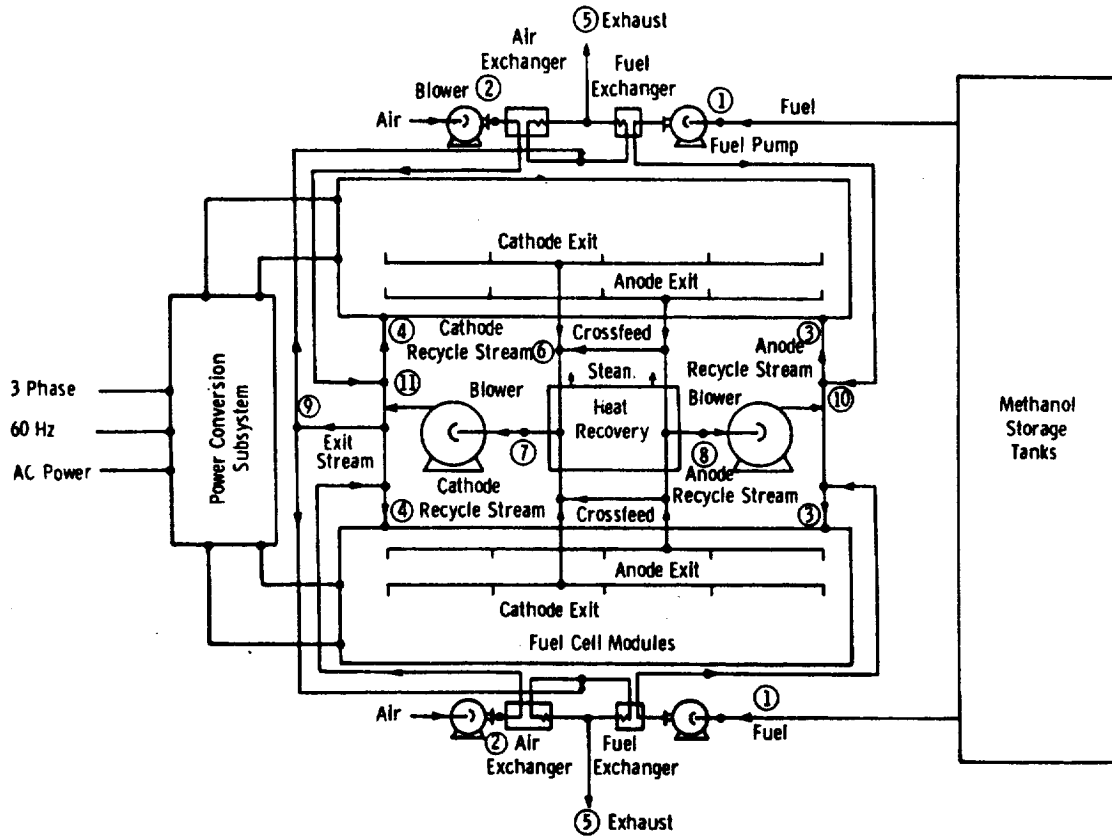
| Point No. | Temperature, °F | Pressure, psia | Point No. | Temperature, °F | Pressure, psia |
|-----------|-----------------|----------------|-----------|-----------------|----------------|
| 1 | ambient | 15 | 7 | 752 | 15 |
| 2 | ambient | 35 | 8 | 752 | 15 |
| 3 | 752 | 30 | 9 | 752 | 30 |
| 4 | 752 | 30 | 10 | 752 | 30 |
| 5 | 302 | 15 | 11 | 752 | 30 |
| 6 | 1202 | 25 | | | |

13-28
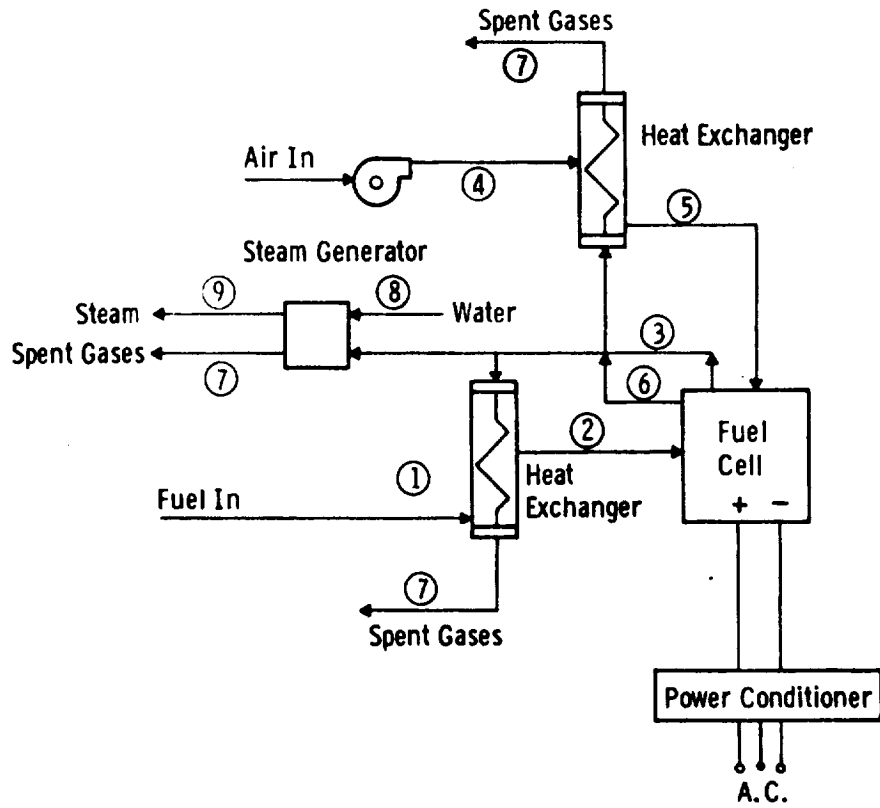
| Point No. | Temperature (°F) | Pressure (psia) | Point No. | Temperature (°F) | Pressure (psia) |
|-----------|------------------|-----------------|-----------|------------------|-----------------|
| 1 | 80 | 60 | 6 | 1300 | 30 |
| 2 | 1100 | 45 | 7 | 200 | 15 |
| 3 | 1300 | 30 | 8 | 70 | 650 |
| 4 | 80 | 60 | 9 | 1000 | 600 |
| 5 | 1100 | 45 | | | |

Fig. 13. 7—Schematic of a solid-electrolyte fuel cell power plant employing high-or medium - Btu gas as a fuel. (SE 1-3, SE 6-17, SE 20)
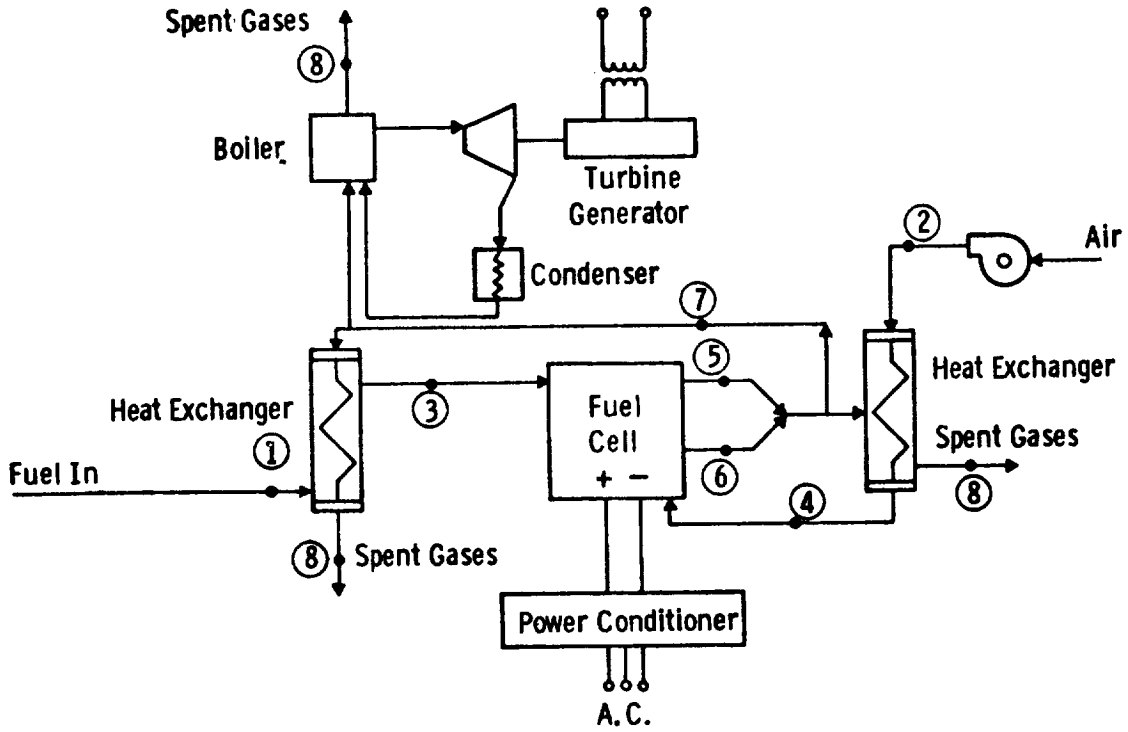
| Point No. | Temperature (°F) | Pressure (psia) | Point No. | Temperature (°F) | Pressure (psia) |
|-----------|------------------|-----------------|-----------|------------------|-----------------|
| 1 | 80 | 60 | 5 | 1300 | 30 |
| 2 | 80 | 60 | 6 | 1300 | 30 |
| 3 | 1100 | 45 | 7 | 1300 | 30 |
| 4 | 1100 | 45 | 8 | 200 | 15 |

Fig. 13. 8—Schematic of a solid-electrolyte fuel cell power plant which employs a steam bottoming plant for waste heat recovery. (SE4)

in thickness. The air electrode is a porous layer of tin oxide-doped indium sesquioxide activated with praesodynium cobaltite. A porous layer of a nickel-stabilized zirconia cermet serves as the fuel electrode. The interconnection layer, which serves to series-connect adjacent cells, consists of a gas-impervious layer of chromium sesquioxide, 20 μm (0.8 mils) in thickness. The device is assumed to operate at 1273°K (1832°F) and with high-Btu gas as fuel. The current density in the electrolyte region of the unit cell is taken as 400 mA/cm$^2$ (372 A/ft$^2$).

Parametric Points SE2, SE3, and SE4, explore the economies of scale achievable in power plants. The fuel cell subsystems are rated at 100 MW dc, 250 MW dc and 900 MW dc, respectively. These three power plants are fueled with medium-Btu gas, as are all plants, except in the base case (high-Btu) and in parametric Point SE19, in which low-Btu gas from an integrated gasifier system is employed. A steam bottoming plant, is included in the 900 MW power plant, SE4, similar to that described for MC4 in the previous subsection. With medium-Btu gas, the average cell voltage at 400 mA/cm$^2$ (372 A/ft$^2$) is 0.66 V, corresponding to a voltage efficiency of 80%. The plant layout corresponding to SE4 is shown schematically in Figure 13.8.

Point SE5 explores the effect of the replacement of air as the oxidant by oxygen from a dedicated oxygen plant (see Figure 13.9). The average cell voltage increases to 0.76 V, as most of the concentration polarization in the fuel cell battery is associated with the cathode. Points SE6 through SE8 explore the effects of increases in the useful life of the fuel cell batteries. The effect of increased power conditioning costs associated with an increase in the permissible voltage degradation and described in the previous subsections is investigated in Point SE9.

The changes represented by Points SE10 through SE20 are specific to the solid electrolyte power system and are presented in Table 13.5.

Fig. 13. 9—Schematic of a solid-electrolyte fuel cell power plant employing oxygen as an oxidant. (SE5)
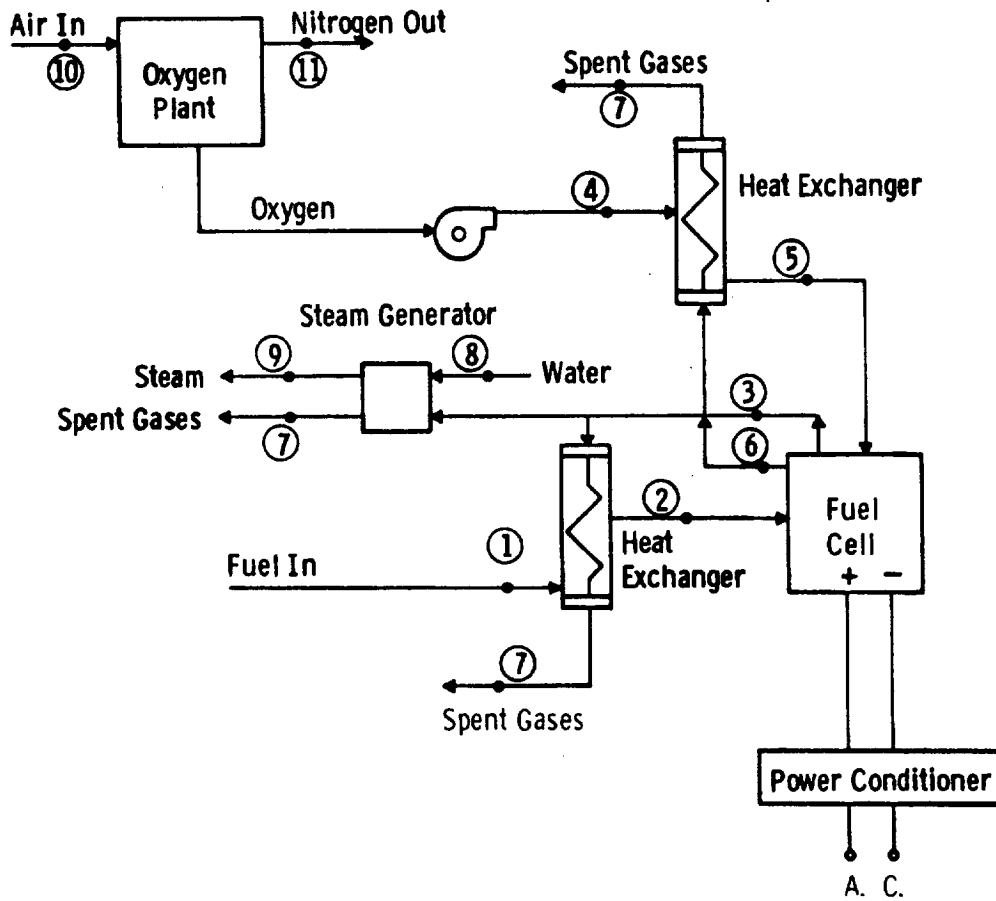
| Point No. | Temperature (°F) | Pressure (psia) | Point No. | Temperature (°F) | Pressure (psia) |
|-----------|------------------|-----------------|-----------|------------------|-----------------|
| 1 | 80 | 60 | 7 | 200 | 15 |
| 2 | 1100 | 45 | 8 | 70 | 650 |
| 3 | 1300 | 30 | 9 | 1000 | 600 |
| 4 | 80 | 60 | 10 | 70 | 15 |
| 5 | 1100 | 45 | 11 | 70 | 15 |
| 6 | 1300 | 30 | | | |

Table 13.5 - Parametric Points - Solid-Electrolyte Fuel Cell

| Point No. | Parameter | Value/Type |
|---|---|---|
| 10 | Current density | 600 mA/cm$^2$ (557 A/ft$^2$) |
| 11 | Current density | 800 mA/cm$^2$ (743 A/ft$^2$) |
| 12 | Electrolyte thickness | 20 μm (0.8 mils) |
| 13 | Interconnection material | Mn-doped CoCr$_2$O$_4$ |
| 14 | Electrolyte material | Calcia-stabilized zirconia |
| 15 | Air electrode material | Sb-doped SnO$_2$ |
| 16 | Temperature | 1173°K (1652°F) |
| 17 | Temperature | 1373°K (2012°F) |
| 18 | Type of fuel | Coal |
| | Current density | 800 mA/cm$^2$ (743 A/ft$^2$) |
| | Power plant size | 250 MW dc |
| | Electrolyte thickness | 20 μm (0.8 mils) |
| 19 | Type of fuel | Low-Btu gas |
| | Power plant size | 900 MW dc |
| 20 | Current density | 800 mA/cm$^2$ (743 A/ft$^2$) |
| | Electrolyte thickness | 20 μm (0.8 mils) |
| | Type of fuel | High-Btu gas |

Points SE10 and SE11 investigate the effect of battery operation at higher power densities. At current densities of 600 and 800 mA/cm$^2$ (557 and 743 A/ft$^2$), the cell voltages were 0.59 and 0.51 V, respectively, because of increased ohmic and concentration polarization losses. A reduction of electrolyte thickness in SE12 from 40 to 20 μm (1.6 to 0.8 mils) leads to a cell voltage increase from 0.66 to 0.67 V. The effect of the replacements of chromium sesquioxide by manganese-doped cobalt chromite, and of tin-doped indium oxide by antimony-doped tin oxide, are explored in SE12 and SE14. Substitution of yttria-stabilized

13-33
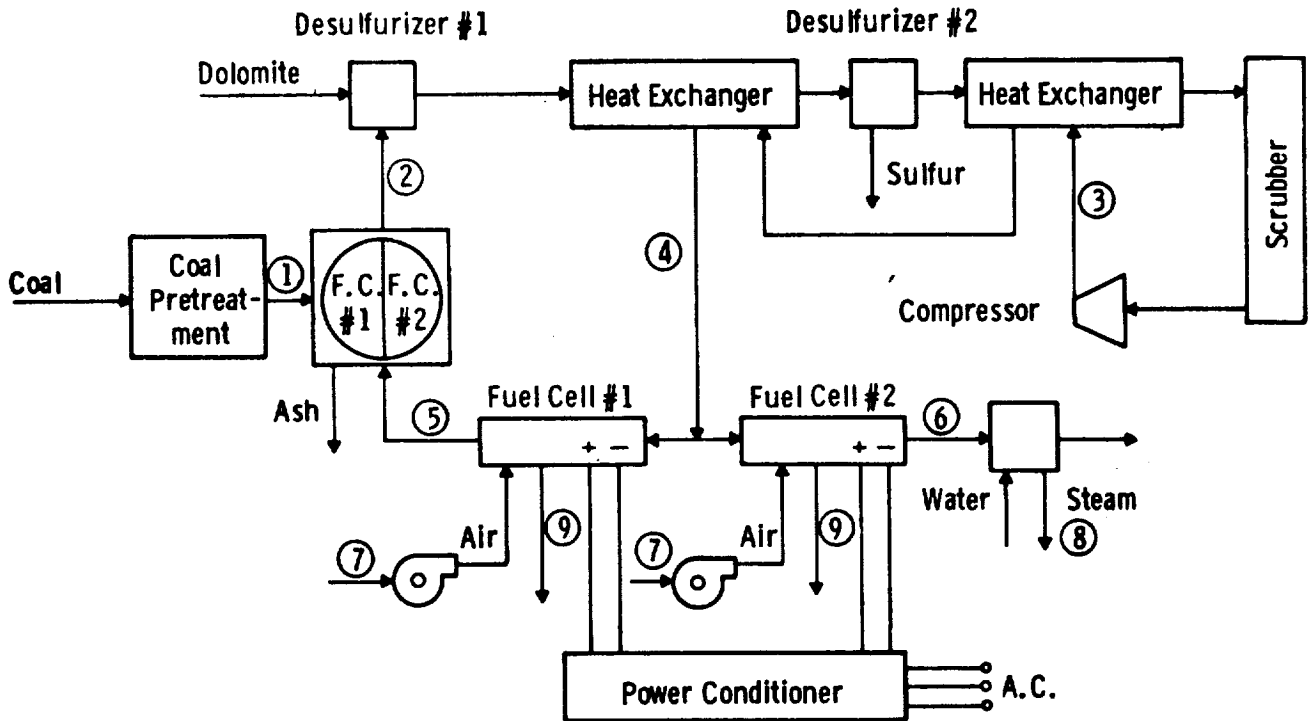
| Point No. | Temperature (°F) | Pressure (psia) | Point No. | Temperature (°F) | Pressure (psia) |
|---|---|---|---|---|---|
| 1 | 70 | — | 6 | 1870 | 23.5 |
| 2 | 1750 | 19 | 7 | 70 | 15 |
| 3 | 200 | 35 | 8 | 1000 | 600 |
| 4 | 1550 | 35 | 9 | 200 | 17 |
| 5 | 1650 | 35 | | | |

Fig. 13. 10—Schematic of the Westinghouse fuel cell power system involving thermal coupling of the fuel cell subsystem and the coal gasifier (SE 18)

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zirconia by calcia-stabilized zirconia in SE13 leads to a reduction of the cell voltage from 0.66 to 0.64 V because of the higher resistivity of the better electrolyte. If the fuel cell subsystem operates at 1173°K (1652°F), resistive losses in the electrolyte and interconnection regions lead to a reduction in cell voltage from 0.66 to 0.55 V. Conversely, an increase in the temperature of operation to 1373°K (2012°F), as in SE17, results in an increase in cell voltage to 0.77 V.

The Westinghouse-OCR fuel cell power generation system is represented by Point SE18. In a 250 MW dc plant, shown schematically in Figure 13.10, a coal gasification reactor and the fuel cell subsystem are thermally coupled. The heat released because of thermodynamic and electrochemical inefficiencies in the fuel cell batteries is employed to gasify coal. The fuel gas thus generated is then fed to the fuel electrodes of the fuel cell subsystem. All the oxygen reaching the gasifier as carbon dioxide and water vapor enters through the fuel cell electrolyte. An electrolyte thickness of 20 μm (0.8 mils), an electrolyte current density of 800 mA/cm$^2$ (743 A/ft$^2$), and an average cell voltage of 0.68 V are assumed. Point SE19 explores the advantages and disadvantages of coupling a 900 MW dc fuel cell subsystem with a low-Btu coal gasifier, as shown schematically in Figure 13.11. Because of the nitrogen diluent in the fuel gas, the fuel electrode concentration polarization is relatively higher. Consequently, the cell voltage is lowered to 0.56 V. Point SE20 investigates the effect of a higher current density, 800 mA/cm$^2$ (743 A/ft$^2$), and a reduced electrolyte thickness, 20 μm (0.8 mils). Even with high-Btu gas as fuel, the average cell voltage is 0.69 V compared with 0.84 V in the base case.

## 13.3 Approach to Efficiency Calculations

Efficiency calculations without the detailed mass and energy balances provided by a comprehensive conceptual design study are, of necessity, approximate. Thus, for Task I, these calculations have been performed with a number of assumptions, some with less justification than
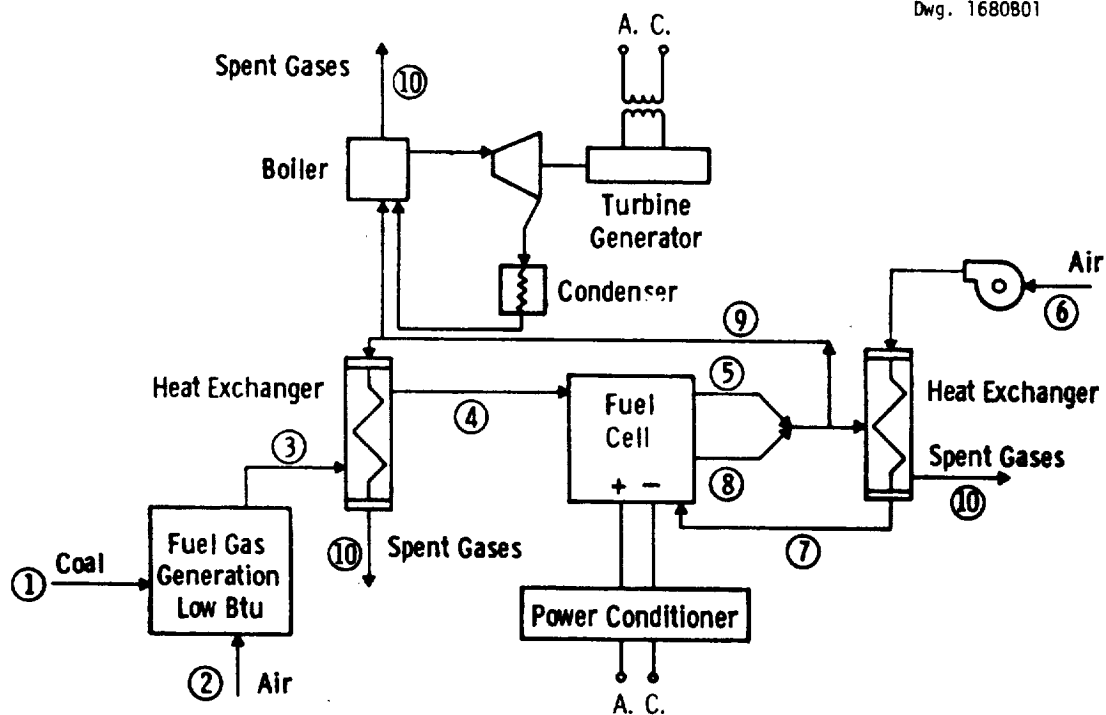
| Point No. | Temperature (°F) | Pressure (psia) | Point No. | Temperature (°F) | Pressure (psia) |
|---|---|---|---|---|---|
| 1 | 70 | – | 6 | 70 | 15 |
| 2 | 70 | 75 | 7 | 1100 | 60 |
| 3 | 100 | 60 | 8 | 1300 | 30 |
| 4 | 1100 | 45 | 9 | 1300 | 45 |
| 5 | 1300 | 30 | 10 | 250 | 15 |

Fig. 13. 11—Schematic of a solid-electrolyte fuel cell power system employing low - Btu gas as a fuel. A steam bottoming plant is employed for waste heat recovery. (SE19)

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desirable. These assumptions, presumably, will undergo further exploration and clarification as part of Task II.

The approaches for the aqueous acid and alkaline power systems were similar; those for the high-temperature systems were specific to the system. Where possible, the approach was consistent, e.g., in the efficiency assumptions for the power conditioning and fuel processing subsystem.

### 13.3.1 Phosphoric Acid Fuel Cell Power System

The power plant efficiency is defined as the quotient of the power output at grid voltages and the higher heating value (HHV) of the fuel (e.g., high-Btu gas etc.) fed to the power system. Similarly, the overall energy efficiency is the quotient of the power output and the HHV of the coal required to produce the fuel.

High-Btu gas, medium-Btu gas and methanol were fuels employed in the acid fuel cell power plants. These are discussed in the first subsection. In the subsequent subsection, the electrical losses associated with the various parasitic plant subsystems are detailed. The methods of calculating the power plant and overall energy efficiencies are discussed in the final subsection.

#### 13.3.1.1 Quantities of Fuel Required

All parametric points involve the use of high-Btu gas, with the exceptions of AC4 (medium-Btu gas) and AC14 (methanol). High-Btu gas must be reformed with steam to accomplish the following reaction:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
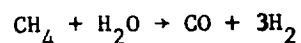
This reaction is endothermic, having an enthalpy of 226 kJ/g-mole (97,380 Btu/lb-mole) at 1144°K (1600°F). The exit stream from the reformer cannot be fed directly to the fuel cell subsystem because the fuel electrode may be deactivated by the presence of carbon monoxide, as discussed in Section 13.1. Consequently, it is passed through a shift

converter in which the mildly exothermic reaction

$$CO + H_2O \rightarrow CO_2 + H_2$$
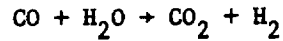
is caused to occur at approximately 700°K (800°F). The carbon dioxide/carbon monoxide ratio in the shift converter exit stream is considered to be approximately 50 to 1. The fuel processing subsystem is discussed further in Appendix A 13.1.

The molar compositions of the high-Btu gas fed to the reformer (Reference 13.34) and to the fuel cell subsystem (after reformation and shift conversion) are given in Table 13.6.

Table 13.6  -  Fuel Gas Molar Compositions

| Component | Initial Composition | After Shift Conversion |
|-----------|---------------------|------------------------|
| $H_2$ | 2.49 | 377.55 |
| $CH_4$ | 94.23 | - |
| $CO_2$ | 0.39 | 92.84 |
| $CO$ | 0.08 | 1.86 |
| $N_2$ | 2.81 | 2.81 |
| S | - | - |
| HHV | 959.2 Btu/scf | - |
| LHV | 864 Btu/scf | - |
| Molecular Weight | 16.15 | - |

Thus, 1 std $m^3$ of high-Btu gas yields 3.776 std $m^3$ of hydrogen. Hydrogen comprises 79.5% of the exit stream from the shift converter, and the concentration of carbon monoxide is 0.39%.

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The hydrogen requirements of the fuel cell subsystems are a function of the dc ratings of the subsystems, the average cell voltage, and the hydrogen utilizations. The four ratings are 25 MW dc (all parametric points with the exception of AC2, AC3, AC4, and AC16), 100 MW dc (AC2), 250 MW dc (AC3 and AC16), and 900 MW dc (AC4). To deliver one kilowatt dc from a fuel cell operating at a terminal voltage of 0.7 V requires a cell current of 1429 A. Thus, 1429/96,489 equivalents or 14.9 mg/s (3.29 x $10^{-5}$ lb/s) of hydrogen are required if the utilization of hydrogen in the fuel gas is 100%. Published data (Reference 13.35) for phosphoric acid fuel cells, however, indicated that hydrogen utilization of 75% represented the state of the art in 1966-67. For simplicity, this treatment assumes a hydrogen utilization of 90% based on the assumptions of a better shift-conversion capability so that the minimum hydrogen-carbon monoxide ratio constraint (i.e., at near-exhaust compositions) can be met at this utilization, and an advance in fuel electrodes technology leading to more porous, thinner electrodes with lower concentration polarizations. Thus, the actual hydrogen requirement is 59.60 g/kWh (0.1314 lb/kWh), corresponding to a high-Btu gas requirement of 51.64 std $cm^3$/kJ (6.56 scf/kWh).

As shown in Figure 13.1, the high-Btu gas stream, fed to the steam-methane reformer, is split in two parts. One part is converted to hydrogen, as described above, while the other is mixed with air and used to provide the heat required for the endothermic reformation process. It can be shown that, under ideal conditions, the minimum volume of the high-Btu gas necessary for firing comprises 22% of the total feedstock. Practical systems in 1963 (Reference 13.36) used 41% of the feedstock in this manner. In this study, a value of 30% has been assumed on the basis of

- Firing the hydrogen not utilized in the fuel cell subsystem to provide some of the reformer heat requirement

- Advances in reformer technology.

Thus, high-Btu gas is fed to the fuel processing subsystem at the rate of 73.49 std $cm^3$/kJ (9.34 scf/kWh) of dc output from the fuel cell subsystem.

The medium-Btu gas, used as a feedstock in the 900 MW dc power plant, does not require reformation, but it must be shift-converted to yield a fuel gas suitable for use in the fuel cell subsystem. The compositions before (Reference 13.37) and after shift conversion are shown in Table 13.7.

Table 13.7 - Medium-Btu Fuel Gas Molar Compositions

| Component | Initial Composition | After Shift Conversion |
|---|---|---|
| $H_2$ | 0.3276 | 0.8618 |
| $CO_2$ | 0.0573 | 0.5915 |
| CO | 0.5460 | 0.0118 |
| $N_2$ | 0.0043 | 0.0043 |
| $H_2O$ | 0.0647 | -- |
| HHV | 281.5 Btu/scf | -- |
| LHV | 265.0 Btu/scf | -- |
| Molecular Weight | 19.76 | -- |

Because of the higher concentration of carbon monoxide in the exit stream of the shift converter, a hydrogen utilization of 80% has been assumed in this case. Thus, the overall medium-Btu gas requirement is 253.6 std $cm^3$/kJ (32.24 scf/kWh) of dc output from the fuel cell subsystem.

The methanol required in parametric point AC14 may be shown to be 0.1183 g/kJ [426 g/kWh (0.939 lb/kWh)] with the assumptions employed in the above discussion of high-Btu gas reformation and shift conversion.

### 13.3.1.2  AC Power Outputs

An efficiency of 95.5% was assumed for the force-commutated inverter power-conditioning subsystem of all 25 MW dc power systems. The rationale for the selection of this type of power-conditioning equipment is outlined in Appendix A 13.2.  In addition, in the acid power system a  further 2% of the ac output of the power-conditioning equipment was allocated for air blowers and sundry control systems.  Thus, the net ac power output from the acid power system, with a dc rating of 25 MW, is (25 MW)(0.955)(0.98), or 23.4 MWe.

In the cases of the 100 MW (AC2), 250 MW (AC3 and AC16), and 900 MW dc (AC4) power plants, a line-commutated inverter was employed in the power-conditioning subsystem (see Appendix A 13.2).  An efficiency of 95% was assumed.  Double transformation was considered necessary  in the 100 MW and 250 MW dc systems, since the contract statement of work specified that all power plants of greater than 50 MWe  should deliver ac power to the grid at 500 kV.  It was assumed that the added transformer would operate at an efficiency of 99.5%.  The 900 MW dc system was considered not to need this double transformation.  As in the case of the 25 MW system, 2% of the ac output was assigned to the air blowers, etc. Thus, the net ac outputs were 92.6 MWe, 231.5 MWe and 838 MWe, respectively.

When a dedicated oxygen plant is employed, as in parametric points AC5 (25 MW dc) and AC16 (250 MW dc), the ac output to the grid must be reduced further.  The power required for oxygen plant operation may be calculated from information given in Appendix A 13.3.  The power plant in AC5 requires approximately 3.15 kg/s (300 tons/d) of oxygen.  The energy required is 0.0975 kJ/Mg (318.4 kWh/ton) or 95.52 MWh corresponding to a power usage of 3.98 MW.  With a 4% allowance for oxygen vented to the atmosphere, the power required is 4.14 MW.  The net ac power output of a 25 W dc power plant employing oxygen as the oxidant (AC5) is 19.3 MW. Similarly, the net ac power output from the power plant of parametric point AC16 is 190.3 MW.

### 13.3.1.3  Calculation of Efficiencies

The heat rates of the power plants may be calculated as follows:

$$\text{Heat Rate} = \frac{(\text{Fuel Rate})(\text{HHV of Fuel})}{(\text{Net ac power output})/(\text{Nominal dc rating})}$$

where the required fuel rate and the fuel HHV are given in units of scf/kWh and Btu/scf, or lb/kWh and Btu/lb, respectively. For example, for AC1:

$$\text{Heat Rate} = \frac{(9.34 \text{ scf/kWh})(959.2 \text{ Btu/scf})}{(23.4 \text{ MW})/(25 \text{ MW})} = 9570 \text{ Btu/kWh}$$

### 13.3.2  Alkaline Fuel Cell Power System

The approach to the calculation of heat rates in the alkaline power system is very similar to that employed for the acid system. The higher cell voltages in alkaline cells (0.8 V vs 0.7 V for acid fuel cells) result in a lower hydrogen requirement, 0.0145 g/kJ [52.2 g/kWh (0.1151 lb/kWh)], and a lower rate at which fuel is fed to the power system. The assumptions of the efficiencies of the power-conditioning subsystems are identical to those given in the previous section and in Appendix A 13.2.

The Lurgi Rectisol process for the removal of carbon dioxide from both fuel and air streams before they are fed to the fuel cell subsystems has been arbitrarily assumed to consume an additional 6% of the ac power output from the power-conditioning subsystem when high-Btu is used as feedstock. When added to the 2% consumed by the air blowers and control systems, the inefficiencies amount to 8% of the total ac output. In parametric point AL4, the use of the medium-Btu feedstock results in a doubling of the carbon dioxide partial pressure in the shift converter exit stream. The inefficiencies are now assumed to total 10% of the ac output of the power-conditioning subsystem.

The oxygen requirements in the power plants corresponding to parametric point AL5, in which oxygen from a dedicated oxygen plant is employed as the fuel cell oxidant, are lower than in the similar acid plant (AC5) because of the higher cell voltages. The power requirement is 3.6 MW, calculable from the value given for AC5 by multiplication by the reciprocal of the ratio of the cell voltages, 0.875.

Thus, all the heat rates for the parametric points of the alkaline fuel cell power system are calculable from the corresponding values of the acid system. For example, in the base case, AL1,

$$\text{Heat Rate} = \frac{(9570 \text{ Btu/kWh})(0.7 \text{ V}/0.8 \text{ V})}{(92\%/98\%)}$$

$$= 8920 \text{ Btu/kWh}$$

### 13.3.3 Molten Carbonate

The plant efficiency is calculated on the basis of the higher heating value of the fuel and of steady-state operation at the voltages and current densities described in Section 13.2.3.

All cells produce an excess of heat during operation at rated power over that necessary to heat the fuel and oxidant streams to the fuel cell temperature. This excess heat is partially converted to steam but does not contribute to the power plant efficiency for MC1-3, and 6-16. For MC4, this excess heat is used to operate a steam turbine generator to produce additional ac electricity and thereby increase the overall plant electrical efficiency. MC5 and 17 also use the excess heat, but to operate a steam turbine drive for the compressor in the oxygen plant. The steam turbine drive was assumed to convert the available energy to shaft work with an efficiency of 40%. The efficiency of plants using pure oxygen was not reduced by 2% since the electrical output is not derated to provide power for the electrical motor drive compressor that is commonly used for an oxygen plant. The nominal dc output of the fuel cell is further derated by the dc-to-ac power conversion subsystem as described in Appendix A 13.2. It is assumed that 90% of the fuel is

consumed by the fuel cell. The remaining 10% is burned in the exit gases by excess oxygen from the cathode exit gas and appears as waste heat.

It is further assumed that various electrical auxiliaries (such as recirculating fans) consume electrical energy equivalent to 3% of the HHV of the fuel. This may be high.

For simplicity, reformed high-Btu gas or methanol are assumed to have only carbon monoxide and hydrogen as fuel species after reforming. Some $CH_4$ and other fuel species, however, will, in practice, be present.

Equation 13.1 is used to calculate all molten carbonate fuel cell efficiencies except for MC4.

$$\text{Efficiency} = \frac{0.9\ [(\Sigma N)(n)(F)(\epsilon)]\ PCE - 0.03\ HHV}{HHV} = \frac{(A)(PCE) - B}{HHV} \quad (13.1)$$

where   0.9 is the fraction of the fuel utilized by the fuel cell,

$\Sigma N$ is the sum mole fraction of carbon monoxide and hydrogen

   present after reforming 1 mole of the original fuel gas,

n is 2 (the number of electrons involved in electrochemical

   oxidation of 1 molecule of carbon monoxide or hydrogen

   with 1/2 molecule oxygen),

PCE is the power-conditioning efficiency (see Appendix A 13.2),

HHV is the higher heating value per mole of original fuel gas,

F is the Faraday 23.062 kcal/eV,

$\epsilon$ is the cell voltage.

For MC4 we utilize the waste heat to increase the plant efficiency. It is assumed that we exchange heat between exhaust gas and incoming fuel and air, with the exhaust leaving the stack at 423°K (302°F); and that other heat loss to the surroundings is 2% of the HHV per mole of fuel gas. It is further assumed that a steam turbine generator with 40% efficiency is used to convert the waste heat to ac electricity. We calculate the overall efficiency of MC4 by Equation 13.2.

Overall Efficiency MC4 =

$$\frac{(A)(PCE)-B+0.4(\Delta H^C_{650°}-A-0.02 \; HHV-[\Delta H_{650}-\Delta H_{25}]_{i.g.} + [\Delta H_{650°}-\Delta H_{150°}]_{e.g.}}{HHV}$$

(13.2)

where   0.4 is the turbine-generator efficiency,

$\Delta H^C_{650°}$ is the heat of combustion of the fuel gases at 650°C,

$[\Delta H_{650°}-\Delta H_{25°}]_{i.g.}$   is the sensible heat difference in the given

°C temperature interval for the input gases to the fuel cell,

$[\Delta H_{650°}-\Delta H_{150}]_{e.g.}$   is the sensible heat difference in the given

°C temperature interval for the exhaust gases from the plant.

Other symbols are as in Equation 13.1.  $\Delta H$ values were taken from the JANAF Thermochemical Tables (Reference 13.38).

### 13.3.4   High-Temperature Solid Electrolyte Fuel Cell

#### 13.3.4.1   Thermodynamic Efficiency

The quotient of average cell voltage and the voltage corresponding to the higher heating value of the fuel is defined as the thermodynamic efficiency $\eta_{th}$.

$$\eta_{th} = \frac{E_{cell}}{E_{HHV}}$$

$E_{cell}$ was calculated in the cases SE2-SE18 on the basis of actual measurements on cells and batteries.

$$E_{cell} = E_0 - E_R - E_P$$

where   $E_0$ is the open-cell voltage, average over the total range of fuel/ combustion product ratios,

$E_R$ is the voltage losses due to ohmic resistance in battery components,

$E_P$ is the polarization loss due to diffusion problems of fuel and combustion products.

The voltage which corresponds to the higher heating value of the fuel, $E_{HHV}$ is calculated from the following relation:

$$E_{HHV} = \frac{HHV}{n.F}$$

where HHV is the higher heating value of fuel in kcal/mole,

n is the number of electrons transferred per mole of fuel gas reacted,

F is the Faraday constant 23.06 kcal/eV.

For SE1 and SE20 an average open-cell voltage was calculated from the free energy change of the oxidation of methane at 1300°K (1880°F). In this instance, a high average open-cell voltage of 1.04 V is achieved. The reason for this is the thermodynamic instability of methane at 1300°K (1880°F). Kinetically, however, it is possible to burn methane electrochemically at this temperature without carbon deposition if, except for the fuel electrode, the cell contains no metal surfaces. An in-situ reformation and oxidation of the methane takes place at the anode. The question, however, remains whether this concept is practical, as experimental data are limited.

### 13.3.4.2 Power Output of the Plant

Since the ac power output is included in the heat rate calculations, we must explain how we derived these figures. The power output of the fuel cell subsystem is reduced by the inefficiencies of the power-conditioning subsystem, as described in Appendix A 13.2. As in the case of molten carbonate fuel cells, it is assumed that an amount of energy equivalent to 3% of the HHV of the fuel is consumed to provide plant auxiliary power. The power output $P_{net}$ was calculated according to the following equation

$$P_{net} = (MW)(PCE) - (0.03) (MW/\eta_{th}) + P_{turb}$$

where   MW is the nominal power output,

PCE is the power conditioning efficiency,

$P_{turb}$ is the ac power output from steam turbine generator

$\eta_{th}$ is the thermodynamic efficiency.

### 13.3.4.3  Heat Rate

Heat rate (HR) calculations for all parametric points except SE18 were performed in the following sequence:

1.  Establish dc power rating in kilowatts
2.  Calculate thermal equivalent from (1) in Btu/hr
3.  Calculate fuel rate from (2) by considering thermodynamic inefficiencies in Btu/hr
4.  Calculate heat rate in Btu/kWh in dividing (3) by the actual ac power output of the power plant.

For example, for a Point SE1

$$HR = \frac{MW}{\eta_{th} P_{net}} = \frac{(25 \times 10^6)(3413)}{(0.76)(22.9 \times 10^6)} = 4900 \text{ Btu/kWh}$$

The heat rate for SE18 was established earlier by Westinghouse under the sponsorship of the Office of Coal Research.  Based on a detailed mass and energy balance for a 100 kW power plant (Reference 13.25) a heat balance of 6370 Btu/kWh was calculated.  This heat rate was used in the present calculations taking no credit for possible improvements as the plant size was increased from 100 kW to 250 MW.

### 13.3.4.4  Power Plant Efficiency

The power plant efficiency, $\eta_{pp}$, is the quotient of the theoretical and calculated heat rates for all parametric points

$$\eta_{pp} = \frac{3413}{HR}$$

In the cases of SE4 and SE19, additional power is produced by utilizing the waste heat of the fuel cell generator.  This, of course, is only

possible in large installations and was not considered for smaller plants. The waste heat was used via a steam turbine generator with an assumed 40% efficiency. This is why the power plant efficiency is higher than the thermodynamic efficiency of the electrochemical generator. This is not a contradiction, because the fuel cell for which the thermodynamic efficiency is calculated delivers only a part of the electrical energy of these plants which could be considered combined-cycle plants. The heat rates of SE4 and SE19 must be viewed this way also.

## 13.4  Capital, Site-Labor, and Operation and Maintenance Costs

This section is devoted mainly to a description of the approaches taken in calculating the capital costs of the fuel cell subsystems. The power-conditioning costs for the power plants corresponding to all 69 parametric points are given in Appendix A 13.2. Similarly, oxygen plant costs for Point 5 in all fuel cell power systems and for AC16 and MC17 are discussed in Appendix A 13.3. The approach to balance of plant costing has already been described in Section 2. The fuel-processing subsystem, required for the low-temperature aqueous acid and alkaline power systems, is costed as described in Appendix A 13.1. This appendix also includes a brief description of costing the air blowers for the low-temperature fuel cell power systems.

It must be emphasized here, as in Subsection 13.3, that without a conceptual design of the fuel cell modules the costing techniques are at best approximate. The assumptions employed as to design and materials of construction are stated, even if extensive justification is not provided. Refinement of these assumptions was anticipated as part of Task II of this study.

The site labor costs for installing the four types of fuel cell module were assumed arbitrarily to be $5/kW for the acid and alkaline systems, $8/kW for the molten carbonate system, and $10/kW for the solid electrolyte system. These relatively low site labor charges reflect the modularity of the assumed fuel cell subsystem, which leads to relatively

straightforward and simple installation procedures at the power plant location. The higher charges for the high-temperature system reflect the slightly more complex procedures of subsystems interconnection, because of increased insulation requirements.

The operation and maintenance (O&M) costs for the fuel cell power plants have, in general, three component charges related to: (a) plant labor; (b) material and component replacement in subsystems other than the fuel cell subsystem, and (c) full replacement of the fuel cell subsystem. These costs are described in greater detail below.

(a) An hourly labor cost is calculable, as described already in Section 2.6.3.4, by the formula:

$$\text{O\&M (labor)} = Z \left( \frac{\text{ac output}}{0.6 + 0.004 \text{ (ac output)}} \right) \left( \frac{\$15,000}{8740 \text{ hr (capacity factor)}} \right)$$

where Z, a factor related to the complexity of O&M procedures, is taken as 1.0 for steam plants. For all plants with a dc rating of 25 MW, it has been assumed that, because of their probable substation locations, remote operation will be possible with control exercised from a central station. Also, because of this probable remote control, the value of Z has been arbitrarily assumed to be 0.2 for these plants. For all power plants of 250 MW or larger, however, a factor of 0.4 has been chosen, reflecting the need for full-time personnel at the plant location. This Z value is substantially less than that for steam plants and may be justified on the basis of the relative cleanliness of the fuels employed in the fuel cell plants, and the ease of maintenance of the power-conditioning subsystem.

(b) To allow for material and component replacement in the fuel-processing and power-conditioning subsystems, and other major components, an O&M charge, amounting to 5% of the total capital and site-costs of the major components (with the exception of the fuel cell sub-system), is allotted for each power plant.

(c) The fuel cell subsystem useful life is only 36 Ms (10,000 hours) (exceptions: Points 6 through 9). This is much less than the 946 Ms (30 yr) life assumed for the other plant components. Accordingly, a special charge, calculated by dividing the replacement cost of the fuel cell subsystem by the product of the ac output and the life, is included in the O&M costs for every parametric point. Because of uncertainties, this calculation omits price escalation, learning, and sinking fund factors.

### 13.4.1 Phosphoric Acid Fuel Cell Power System

A bipolar design has been assumed for the acid fuel cell battery stack. The basic element is a corrugated or embossed graphite plate which serves as the anode current collector of one cell and the cathode current collector of an adjacent cell. The anode and cathode are assumed to be thin carbon electrodes, similar to those described by Kordesch and Scarr (Reference 13.30). These contain active carbon catalyzed by platinum. The electrolyte consists of a matrix-immobilized 85 wt % phosphoric acid. The fuel gas stream flows in the corrugations between the thin carbon anode and the graphite piece. Air flows similarly between the cathode and the corrugated graphite plate.

The cost of the corrugated graphite plate, which may be fabricated by extrusion, is estimated (Reference 13.39) to be approximately $10.76/m$^2$ ($1/ft$^2$). If battery stack end requirements are ignored only one of these plates is required per cell. The active carbon electrodes, without catalyst, are similarly estimated (Reference 13.39) to cost approximately $10.76/m$^2$ ($1/ft$^2$) each. For an inter-electrode separation (i.e., electrolyte thickness) of 0.5 mm (19.7 mils), the quantity of electrolyte required, assuming that it forms 80% by volume of the matrix, is approximately 100 g (0.22 lb). At $0.349/kg ($15.85/100 lb) (Reference 13.40), the electrolyte cost is only $0.377/m$^2$ ($0.035/ft$^2$). The electrolyte matrix component has been assumed to be cost-determining, so that the cost of the immobilized phosphoric acid is taken as $5.38/m$^2$ ($0.50/ft$^2$). Thus, the cost of the bipolar battery stack materials, unassembled and without catalyst, is approximately

$37.67/m^2$ ($3.50/ft^2$). Doubling of this materials cost results in a manufactured cost for the battery stack of $75.35/m^2$ ($7/ft^2$). A further allowance of $5.38/m^2$ ($0.50/ft^2$) for gasketing and insulating the battery stack yields a manufactured cost of $80.73/m^2$ ($7.50/ft^2$) for the fuel cell module. Adding a profit of 20% results in a selling price of $96.88/m^2$ ($9/ft^2$) for a module with uncatalyzed electrodes.

Most parametric points (except for AC12 and AC13) involve platinum loadings in the anode and cathode of 1 $mg/cm^2$ (0.00205 $lb/ft^2$). If chloroplatinic acid ($H_2PtCl_6$) is employed in the catalyst-addition process, the cost of platinum per unit cell area is $117.33/m^2$ ($10.90/ft^2$), for a chloroplatinic acid cost of $5.8675/g of contained platinum ($182.48/oz t platinum)(Reference 13.40). Thus, for most parametric points, the fuel cell module cost is $214.20/m^2$ ($19.90/ft^2$). In Point AC12, where the platinum loadings in the anode and cathode are decreased to 0.3 $mg/cm^2$ (6.144 x $10^{-4}$ $lb/ft^2$), the catalyst cost is reduced to $35.20/m^2$ ($3.27/ft^2$), resulting in a fabricated module cost of $132.07/m^2$ ($12.27/ft^2$). The catalyst and module costs for AC13 [0.1 mg Pt/$cm^2$ (2.05 x $10^{-4}$ $lb/ft^2$)] are calculated in the same manner.

The cost per kW of the fuel cell module is assumed to be inversely proportional to the power density. For AC1, the power density is 140 $mW/cm^2$ (130.1 $W/ft^2$). This corresponds to a cell area requirement of 0.7143 $m^2/kW$ (7.689 $ft^2/kW$), and a module cost of $153/kW, based on the costs given above. This leads to a vendor selling price of $3.8 million for the 25 MW dc fuel cell subsystem. The costs of all fuel cell sub-systems are calculated in the same manner, based on the cell power densities, the dc ratings, and the catalyst loadings.

The replacement cost of the acid fuel cell subsystem is calculated under the following assumptions:

- The cost of recovering the platinum at the end of battery life and reprocessing it into chloroplatinic acid is $1.00/g ($31.10/oz t).

- The rest of the fuel cell module has zero salvage value.

- The installation cost remains at $5/kW.

Thus, the catalyst cost in the replacement modules is only $20/m$^2$ ($1.86/ft$^2$), resulting in a fabricated module cost of $116.88/m$^2$ ($10.86/ ft$^2$). In parametric point AC1, the replacement cost of the 25 MW dc fuel cell subsystem is $2,087,000 plus $125,000 for installation. The corresponding O&M charge is:

$$\frac{\$2,087,000 + \$125,000}{(23,400 \text{ kW})(10,000 \text{ hr})} = 9.45 \text{ mills/kWh}$$

or a charge of $221/operational hour.

### 13.4.2 Alkaline Fuel Cell Power System

A bipolar design, identical to that selected for the acid system, has been assumed also for the alkaline fuel cell modules. Thus, the selling price of $96.88/m$^2$ ($9/ft$^2$) for a module with uncatalyzed electrodes given for the acid fuel cell system is applicable here also. The major differences between the acid and alkaline modules lie in the areas of cathodic catalyst type and power density.

The carbon anode is catalyzed by platinum with a loading of 1 mg/cm$^2$ (0.00205 lb/ft$^2$), and the cathode is catalyzed by silver with a loading of 5 mg/cm$^2$ (0.0103 lb/ft$^2$). Thus, the platinum loading is half of that in the acid system and adds $58.68/m$^2$ ($5.45/ft$^2$) to the uncatalyzed cost quoted above. It is assumed that the cathodes are silver catalyzed with silver nitrate, which costs $0.094/g of contained silver ($2.69/oz av Ag (Reference 13.40)). This adds a further $4.745/m$^2$ ($0.4408/ft$^2$) to the uncatalyzed module cost. The catalyzed cell cost is, therefore, $160.30/m$^2$ ($14.89/ft$^2$).

The power density for most parametric points is 80 MW/cm$^2$ (74.32 W/ft$^2$) leading to a cell area requirement of 1.25 m$^2$/kW (13.46 ft$^2$/kW). The module cost is, therefore, $200/kW, or $5 million for a 25 MW fuel cell subsystem. Subsystem costs for other power

density values are calculated on the basis of the inverse relationship assumed between the cost and the power density. The replacement cost is calculated, as in the acid system, with recovery and reprocessing costs for platinum and silver of $1/g ($31.10/oz t) and $0.03/g ($0.93/oz av), respectively.

### 13.4.3 Molten Carbonate Fuel Cell Power System

This section describes cost estimates for the fuel cell, gas recirculation, and heat recovery systems. Plant costs for siting, construction, and electrical controls are described in Appendix A 13.4. Oxygen plant costs are described in Appendix A 13.3, and power-conditioning costs are given in Appendix A 13.2.

The same cost for materials, fabrication, and assembly per unit area of electrode has been assumed for all molten carbonate fuel cells. Since there have been no cell assemblies of more than a few kilowatts, and constructional details of current test units (Reference 13.22) are not available, only very rough estimates can be made. As a first approach to costing the full cell, we assume a filter press design; estimate a cost based on the somewhat analogous filter press technology; and approximate cell material costs suggested by IGT (Reference 13.11), with 0.715 $m^2$ (7.7 $ft^2$) of electrode area per kilowatt. From Perry's Handbook (Reference 13.41), the lowest cost (1970) of a filter press with filters uninstalled was about $161.50/$m^2$ ($15/$ft^2$) for iron or wood materials. If we update to July 1974 prices by the factor 1.4, subtract a material cost of about $21.50/$m^2$ ($2/$ft^2$) for the wood or iron materials, add a cell material cost suggested by IGT in 1966 (Reference 13.11)($20 to $40/kW escalated to July 1974 prices of about $31 to $62/kW or an average of $46/kW), and add a further 20% for assembly and leakproofing, a cost of ($15 $ft^2$) (7.7 $ft^2$)(1.4) − ($2/$ft^2$) 7.7 $ft^2$ − $15.4 + [31 or 62], i.e., $177 or $208 /kW, may be calculated. If we add 20% to allow for vendor profit, the cost would be $213 to 250/kW, uninstalled.

A second approach to costing the cell is to take the values estimated by Hart and Womack (Reference 13.16). The list price was £ 27.5/kW dc. Adjusting this for an exchange rate of $2.4/£ (in 1966),

for the ratio of power densities assumed in that and the present study of 0.2 to 0.13 (in terms of $kW/ft^2$), a commodity escalation price of $1.58 and a profit factor of 1.2 for fabrication gives $(27.5)(2.4)$ $(0.2/0.13)(1.58)(1.2) = \$192.51/kW$ uninstalled.

For this study we have arbitrarily selected an uninstalled capital cost of $190/kW as being about the lower limit of what we might reasonably expect. An installation cost of $8/kW is assumed.

Without a conceptual design of the fuel cell system, costing of the waste heat recovery system is also arbitrary. Refinement of the estimates on the basis of a detailed design was anticipated as a part of Task II. For example, normal waste heat boilers have a once-through passage of the hot gases, but in the present system we recycle the fuel cell exit gases between the fuel cell and boiler temperatures. Such a system would have to be specifically designed for this application. The installed cost of the heat recovery steam generator is assumed to be $60/kW. Installation cost is estimated as 33% of the total, which is about the same as for the simple steam turbine power plant boiler but much more than the ∿ 5 to 10% for a simple once-through waste heat boiler. The cost of the associated turbine-generator combination in MC4 is taken from a Westinghouse price list (Reference 13.42) adjusted to July 1974 prices.

Heat exchangers are arbitrarily assumed to cost $12.50/kW dc installed. Of this cost about 45% is for the heat exchangers, and 55% involves the installation labor, piping, etc.

Blower costs will depend on the rate of recirculation necessary both to remove heat and to prevent cell concentration polarization. We assume about $1.15/kW plus 10% installation for this item for all plants except MC4; and $2.55 kW for MC4, the 900 MW plant which may require higher temperature blowers.

The sum totals of the blower, heat exchanger, and heat recovery steam generator costs for MC1, the base case, represent only about 3.85% of the total plant capital costs. Substantial errors in

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these estimates, therefore, will not be significant in view of the large uncertainty in estimating the ultimate lifetimes and cost of the fuel cell itself, which represents about 38.5% of the total capital costs.

Capital costs are much greater where an oxygen plant (see Appendix A 13.3) is included, even though the fuel cell is significantly reduced in size due to the higher power output per cell that has been assumed. Due to economics of size the oxygen plant represents about 33% of the total capital cost for MC5, a 25 MW plant, but only 20.5% for MC17, a 250 MW plant. This is more than the corresponding fuel cell capital costs of roughly 15 and 19.6% of the total, respectively. The high capital cost in addition to large power requirement appears to preclude the use of oxygen rather than air in the molten carbonate plants.

### 13.4.4 Solid Electrolyte Fuel Cell Power System

The costing of the fuel cell subsystem is based on a cost analysis for the Westinghouse thin-film battery, discussed in detail in Reference 13.43. For a power output of 0.5 W/cm (1.27 W/in) of a tubular battery having an outside diameter of 1.27 cm (0.5 in), the cost of the battery raw material was $21/kW in mid-1970. The following set of assumptions have been employed in calculating the cost per kilowatt dc output of a fuel cell module in mid-1974:

- Active electrolyte and active interconnection region lengths are equal to each other and to 2 mm (0.079 in).

- Fuel electrode and air electrode gap lengths are equal 0.5 mm (20 mils).

- A fabrication-cost/materials-cost ratio of 7 to 3 is based on Westinghouse manufacturing experience in thick-film device technology, which is comparable to that required for thin-film battery fabrication.

- A factor of 1.34, corresponding to the increase in the Marshall and Stevens index from mid-1970 to mid-1974, is used to estimate the mid-1974 costs of the fabricated batteries.

- An additional $18/kW is allowed for materials and assembly labor necessary to manifold and sheath the fuel cell batteries in the fabrication of the fuel cell module.

- Three percent (3%) of the cost of the fabricated fuel cell module is taken as the cost of insulation (Reference 13.44).

- A profit of 20% is assumed in the estimation of a vendor price.

Thus, for SE2-4, SE6-9, SE13, and SE15, the selling price in $ per kilowatt of a fuel cell module is calculated as follows:

$$P = \left[ (\frac{\$21}{kW}) (\frac{0.5 \ W/cm}{0.4224 \ W/cm}) (\frac{100}{30}) (1.34) + \frac{\$18}{kW} \right] (1.03)(1.2)$$

$$= \$160/kW$$

For all other points the selling price of the fuel cell module were calculated using the above value and an assumed inverse relationship between cost and power density.

No known heat exchanger technology is available for application in high-temperature fuel cells operating up to 1373°K (2012°F). It was assumed, therefore, that heat exchange above 873°K (1112°F) must be accomplished in the fuel cell generator itself. At this temperature, heat shock problems are largely reduced. Based on this assumption, heat exchanger calculations were performed where nearly a 50% reduction of heat exchange surface is achieved and where the maximum metal temperature in the heat exchanger is reduced to 873°K (1112°F). The calculations took into account a 100°K (180°F) mean temperature difference and a base cost of $215/m$^2$ ($20/ft$^2$) of heat exchange surface. The installed cost was assumed to be 230% of this base cost, or $495/m$^2$ ($46/ft$^2$). These costs

were broken down into material and site labor costs, following Guthrie (Reference 13.44), who recommends values of 73% (materials) and 27% (site labor) of the total installed cost.

The cost of the integrated coal gasification reactor in SE18, the Westinghouse Fuel Cell Power System, was estimated on the basis of an economic evaluation of a 200 MW coal-burning fuel cell power plant, performed by IGT in early 1969 (Reference 13.45). The updated installed cost is broken down according to the above Guthrie recommendations for shell-and-tube heat exchangers — 73% for materials and 27% for site labor — because fully 75% of the installed cost of the reactor is attributable to the Incoloy 800 pipe required for encapsulation of the fuel cell modules and for adequate heat exchange between the fuel cell batteries and the coal undergoing gasification. The low-Btu gasifier cost for SE19 was taken from estimates provided in Section 4 of this report.

Estimates of the cost of gas compressors, venturi scrubbers, and waste heat boilers were based on information provided in Reference 13.44. The waste-heat recovery system (i.e., the steam bottoming plant) of SE4 was costed as described in Section 13.4.3.

## 13.5  Results of Parametric Assessment

The power plant efficiency is defined as the quotient of the power output at grid voltages and the higher heating value (HHV) of the fuel fed to the power system. As described in Section 13.3, a heat rate was calculated for the power plant corresponding to each of the 69 points in the parametric assessment. These values were input to a computer program (described in Section 2) in which they were converted to fractional efficiencies, after a minor allowance was made for power plant electrical requirements.

The program was also employed to calculate an overall energy efficiency, defined as the quotient of the power plant ac output and the higher heating value of the coal required in the production of the fuel.

The factors employed to convert the power plant efficiencies to overall energy efficiencies are described in Sections 2.3.1.2, 2.3.1.3, and 2.3.1.6 for high-Btu gas, medium-Btu gas, and methanol, respectively. All of these fuels were considered to have been derived from Illinois No. 6 coal. Point SE18, the Westinghouse Fuel Cell Power System, involves the use of a coal (Illinois No. 6) as fuel so the power plant and overall energy efficiencies for this system are identical. North Dakota Lignite was selected for the low-Btu gasification reactor of SE19 because of its higher gasification efficiency (Section 4).

The cost of electricity (COE) and its three component parts, ascribable to capital, fuel, and O&M charges, were also calculated by means of the computer program from the cost input described in Section 13.4. These costs were based on NASA-mandated values for labor rate, contingency charge, escalation rate, interest during construction, fixed charge rate, fuel cost and capacity factor. The values specified are listed in Table 13.8.

Table 13.8 – Values Selected for Variables in Plant Construction and Operation

| | |
|---|---|
| Labor Rate | $10.60/hr |
| Contingency Charge | 4.5% |
| Escalation Rate | 6.5% |
| Interest during Construction | 10% |
| Fixed Charge Rate | 18% |
| Capacity Factor | 65% |
| Fuel Costs — | |
| High-Btu gas | $2.60/$10^6$ Btu |
| Medium-Btu gas | $2.00/$10^6$ Btu |
| Methanol | $2.70/$10^6$ Btu |
| Coal | $0.85/$10^6$ Btu |

The effect of changes in all of these base case values on the COE were explored for every point in the parametric assessment.

In Sections 13.5.1 through 13.5.4, the efficiency and COE results are shown and discussed for each fuel cell power system. A comprehensive comparison of the four  ypes of fuel cell power systems is given in Section 13.6 in justificatioi, of the conclusions and recommendations of this study.

### 13.5.1 Phosphoric Acid Fuel Cell Power Systems

The power plant and overall energy efficiencies; the capital cost and COE; and the estimated time of construction for each of the plants corresponding to the sixteen parametric points of the acid fuel cell system are shown in Table 13.9. All relevant information pertaining to the operation of each of the fuel cell subsystems in these plants is provided also in this table.

When air is employed as the oxidant, the plant efficiency lies in the range of 35 to 36%, for all points. The overall energy efficiency with high-Btu gas is approximately 24%. For AC4 the overall efficiency is better than 29%, reflecting the use of medium-Btu gas in this power plant. There is no comparable advantage to the use of methanol as a fuel, as shown by the value of 25% for the overall energy efficiency of the power plant corresponding to Point AC14.

Points AC5 and 16, corresponding to 25 MW dc and 250 MW dc power plants which use oxygen instead of air as the oxidant, display power plant and overall energy efficiencies of 30% and 20%, respectively. The efficiency reduction, amounting to a sixth of the total, is attributable to  the power required by the dedicated oxygen plants.

The computer output for Base Case AC1 is shown in Tables A 13.5.1 through A 13.5.3. Listed are all of the cost input, as  well as the capital cost and COE for five levels of labor cost, contingency charge, escalation rate, interest rate during construction, fixed charge rate, fuel cost, and capacity factor. The capital cost and the COE broken

TABLE 13.9 —VALUES OF ALL RELEVANT PARAMETERS FOR THE PARAMETRIC POINTS OF THE AQUEOUS-ACID FUEL CELL POWER SYSTEM

| Parametric Point, AC # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Output, MWe | 23.4 | 92.6 | 231.5 | 838 | 19.3 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 | 23.4 | 190.3 |
| Fuel Cell Rating, MW | 25 | 100 | 250 | 900 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 250 |
| **Fuel** | | | | | | | | | | | | | | | | |
|   High-Btu Gas | X | X | X | | X | X | X | X | X | X | X | X | X | | X | X |
|   Medium-Btu Gas | | | | X | | | | | | | | | | | | |
|   Methanol | | | | | | | | | | | | | | X | | |
| **Oxidant** | | | | | | | | | | | | | | | | |
|   Air | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | |
|   Oxygen | | | | | X | | | | | | | | | | | X |
| Fuel Cell Life, $10^3$ hr | 10 | 10 | 10 | 10 | 10 | 30 | 50 | 100 | 100 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Voltage Degradation, % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 15 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Temperature, °C | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 | 190 |
| **Electrolyte** | | | | | | | | | | | | | | | | |
|   Type: 85 w/o $H_3PO_4$ | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
|   Thickness, cm | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.025 | 0.05 |
| **Anode** | | | | | | | | | | | | | | | | |
|   Type: Pt/C | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
|   Catalyst Loading: mg Pt/cm2 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.3 | 0.1 | 1.0 | 1.0 | 1.0 |
| **Cathode** | | | | | | | | | | | | | | | | |
|   Type: Pt/C | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
|   Catalyst Loading: mg Pt/cm2 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.3 | 0.1 | 1.0 | 1.0 | 1.0 |
| Current Density, mA/cm2 | 200 | 200 | 200 | 200 | 400 | 200 | 200 | 200 | 200 | 300 | 400 | 200 | 200 | 200 | 200 | 400 |
| Average Cell Voltage, Volts | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.71 | 0.7 |
| Thermodynamic Eff, % [1] | | | | | | | | | | | | | | | | |
| Powerplant Eff, % | 35.5 | 35.1 | 35.1 | 34.8 | 29.6 | 35.5 | 35.5 | 35.5 | 35.5 | 35.5 | 35.5 | 35.5 | 35.5 | 35.8 | 36.0 | 29.9 |
| Overall Eff, % | 23.9 | 23.6 | 23.6 | 23.3 | 19.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 24.9 | 24.2 | 20.1 |
| Total Capital Cost × $10^{-6}$, $ | 10.4 | 39.5 | 97.6 | 367 | 16.0 | 10.4 | 10.4 | 10.4 | 10.8 | 8.8 | 7.9 | 8.6 | 8.1 | 10.9 | 10.2 | 117 |
| Capital Costs, $/kWe | 448 | 429 | 424 | 440 | 833 | 448 | 448 | 448 | 463 | 377 | 339 | 371 | 346 | 468 | 440 | 595 |
| **Cost of Elect, Mills/kWh** | | | | | | | | | | | | | | | | |
|   Capital | 14.2 | 13.6 | 13.4 | 13.9 | 26.3 | 14.2 | 14.2 | 14.2 | 14.6 | 11.9 | 10.7 | 11.7 | 10.9 | 14.8 | 13.9 | 18.8 |
|   Fuel [2] | 25.0 | 25.3 | 25.3 | 19.6 | 29.9 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.8 | 24.7 | 29.7 |
|   Oper. & Maint. | 10.9 | 10.9 | 10.8 | 10.5 | 9.9 | 4.6 | 3.3 | 2.3 | 2.4 | 8.0 | 6.5 | 9.9 | 9.6 | 11.0 | 10.8 | 9.2 |
|   Total | 50.1 | 49.7 | 49.5 | 44.0 | 66.2 | 43.8 | 42.5 | 41.5 | 42.1 | 44.9 | 42.2 | 46.6 | 45.5 | 51.5 | 49.4 | 57.7 |
| Est. Time of Construction, yr | 1.5 | 2.0 | 2.5 | 4.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 2.5 |
| Est. Availability Date | 1985 | 1985 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 | 1990 |

Notes:

1 Where Applicable

2 Use Base Delivered Fuel Cost

into its three components — capital, fuel, and O&M — are shown in Table 13.9 for the values of the construction and operation variables of Table 13.8.

The COE for AC1, 13.9 mills/MJ (50.1 mills/kWh) has as its major component the fuel charge, which comprises 50% of the total cost. This is understandable in terms of the low efficiency of this power plant and the costliness of the fuel gas at $2.60/10$^6$ Btu. The importance of the cost of high-Btu gas and its effect on the cost of electricity are shown in Figure 13.12. At $1.50/10$^6$ Btu, the electricity cost is 11.0 mills/MJ (39.5 mills/kWh); and at $4.00/10$^6$ Btu, the cost is 17.7 mills/MJ (63.5 mills/kWh).

A breakdown of the total capitalization required for this plant is provided in Tables A 13.4.1 through A 13.4.3. A graphic display of this breakdown is shown as Figure 13.16 in Section 13.6. The costs of the installed fuel cell, power-conditioning, and fuel-processing subsystems are $169, $62, and $38/kWe of ac output, respectively. The balance of plant cost is $67/kWe, and the indirect costs amount to $112/kWe. The total capitalization is $448/kWe.

In the standard case, defined by the values of Table 13.8, that portion of the COE ascribable to capital is 3.94 mills/MJ (14.2 mills/kWh). Because of the short time (one and a half years) required for plant construction, changes in the escalation rate and the interest rate during construction have very little effect on the cost of electricity. Similarly, because of the modular nature of the fuel cell and power-conditioning subsystems, which minimizes the site labor required, even a doubling of the labor rate results in a relatively small increase (5%) in the electricity cost (Table A 13.4.2). Changes in the fixed charge rate from the base value of 18%, however, have a more pronounced effect — e.g., a lowering of the rate to 10% results in a reduction in the COE of 1.75 mills/MJ (6.30 mills/kWh).

Of the 3.03 mills/MJ (10.9 mills/kWh) O&M charge calculated for the power plant corresponding to Point AC1, only 0.388 mills/MJ
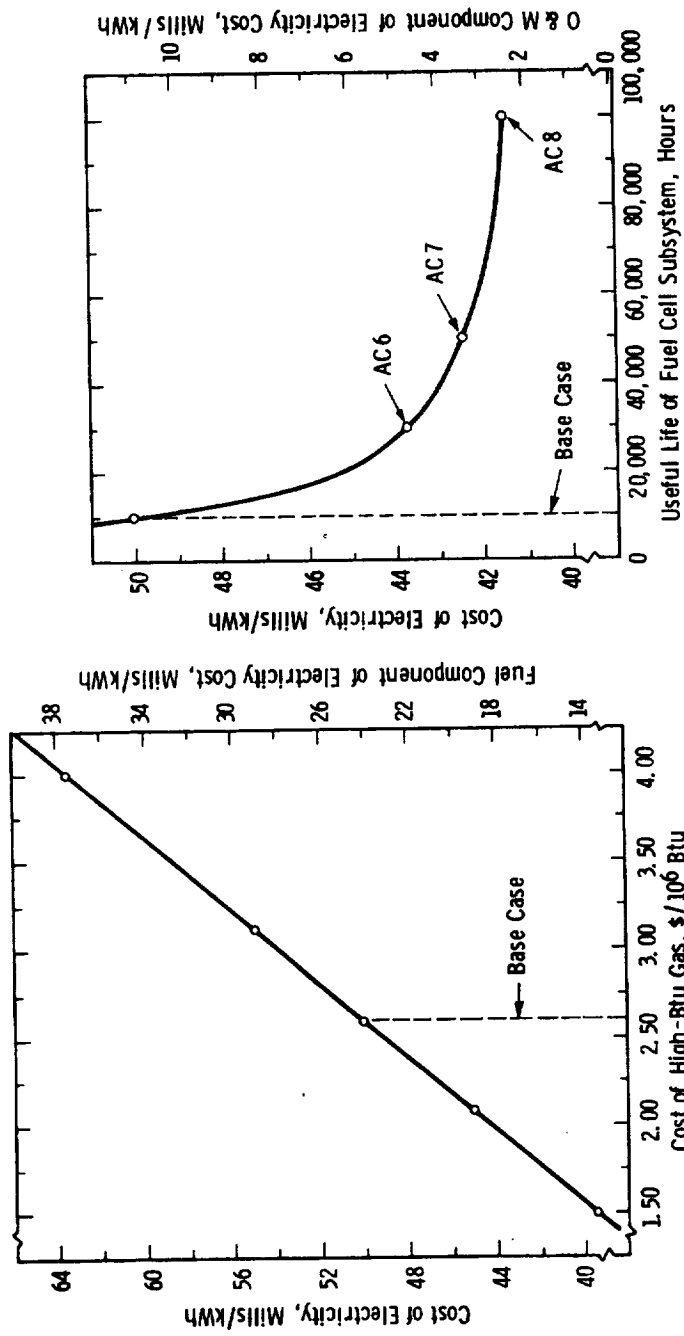
Fig. 13.12— Dependence of the cost of electricity on the fuel cost and the useful life of a 25 MW dc phosphoric acid fuel cell power system

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(1.4 mills/kWh) is attributable to labor and to material and component replacement in all parts of the plant, excluding the fuel cell subsystem. The balance, amounting to 87% of the total, is due to the need for fuel cell replacement after 36 Ms (10,000 hr) of operation. The hyperbolic relationship between the fuel cell useful life and the COE (and its O&M component) is evident from Figure 13.12, which is plotted from data generated for Points AC6, AC7, and AC8, as well as AC1. Lifetimes of 144 Ms (40,000 hr) and 360 Ms (100,000 hr) lead to reductions in the base case COE of 1.97 mills/MJ (7.1 mills/kWh) and 2.36 mills/MJ (8.5 mills/kWh), respectively.

The effect of reducing the platinum loadings in both cell electrodes from 1.0 mg/cm$^2$ (0.002 lb/ft$^2$) in the base case to 0.3 mg/cm$^2$ (6.1 x 10$^{-4}$ lb/ft$^2$) and 0.1 mg/cm$^2$ (2 x 10$^{-4}$ lb/ft$^2$) is explored in Points AC12 and AC13. These results are also included in Table 13.9, and are shown graphically in Figure 13.13. The order of magnitude reduction in electrode platinum loadings caused a reduction of only 1.28 mills/MJ (4.6 mills/kWh) in the cost of electricity. This result is surprising in view of the widely accepted tenet that it is desirable, from an economic standpoint, to avoid platinum as an electrocatalyst. Figure 13.13 indicates that, provided a 0.56 mills/MJ (2 mill/kWh) penalty can be absorbed and an adequate supply of platinum is available, there is little point to efforts to reduce the electrode platinum loadings much below 0.4 mg/cm$^2$ (8.2 x 10$^{-4}$ lb/ft$^2$), corresponding to a platinum usage of approximately 6 g/kW (13.2 lb/MW). This conclusion is supported by Abens, Baker, DiPasquale, and Michalko (Reference 13.29), who stated in a recent paper that "much obfuscation of cell costs has been caused by belaboring the advances made in catalyst cost reductions."

The power density, the product of the electrode current density and the cell voltage, has a marked effect on the COE, as shown by the data for AC10 and AC11 in Table 13.9. These results are also presented in Figure 13.13. A doubling of the base-case power density results in a 2.2 mills/MJ (7.9 mills/kWh) reduction in the COE. This

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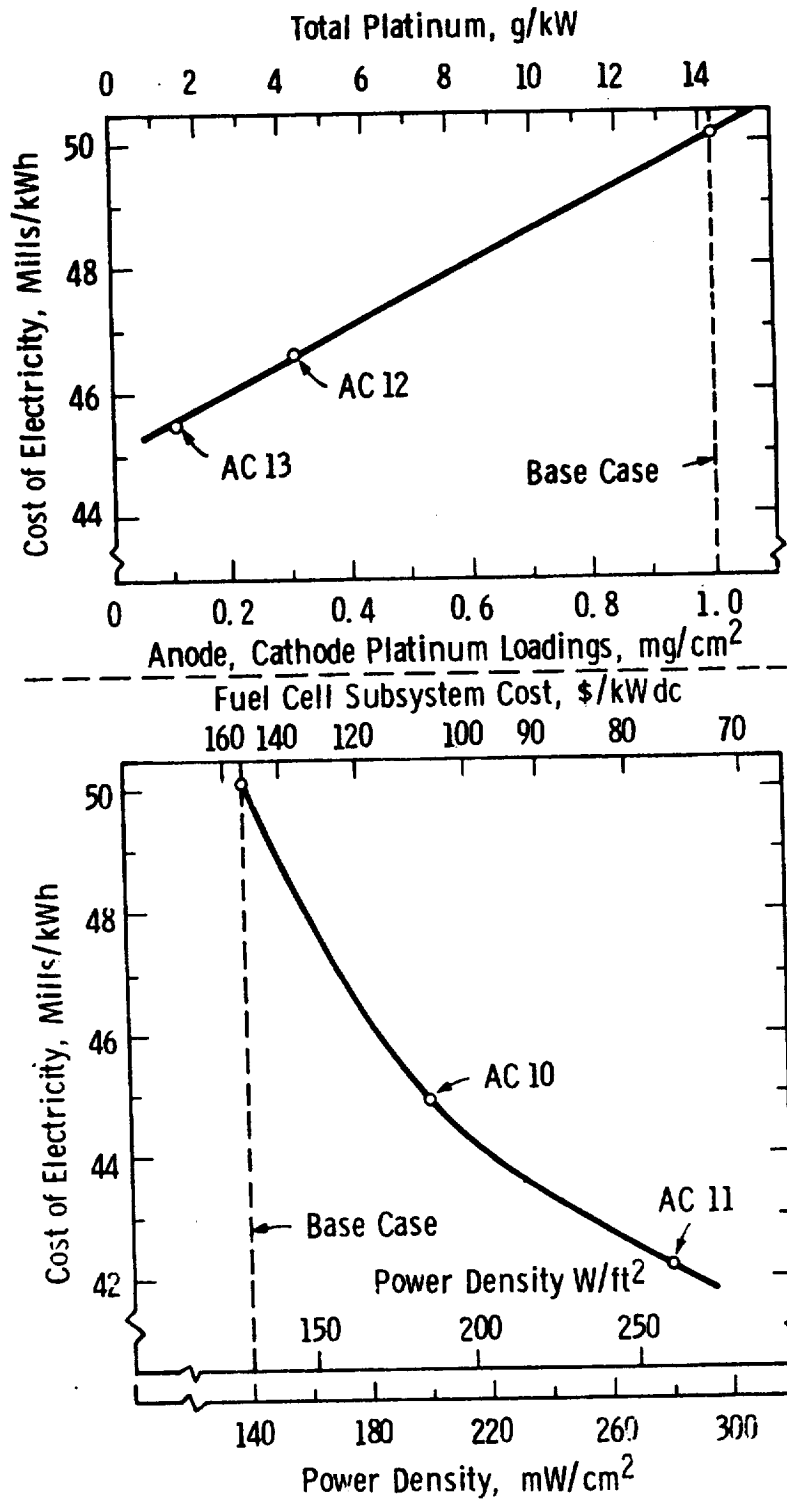
Fig. 13. 13—Dependence of the cost of electricity for phosphoric acid fuel cell power systems on the platinum loadings in the anode and cathode, and on the power density per unit cell area

graph may be used also to compute the effe t of reductions in the selling
price of the fuel cell subsystem because ot the inverse relationship
between the selling price and the power density.

Because of the modular nature of the fuel cell and power-
conditioning subsystems, there is little, if any, economy of scale in
fuel cell power plants.  This is illustrated by the data presented in
Table 13.9 for 100 MW (AC2) and 250 MW dc (AC3) power plants.  Medium-Btu
gas is used in the 900 MW dc power plant (corresponding to Point AC4),
and because of its relatively lower cost (see Table 13.8), the fuel
component of the COE is reduced to 5.44 mills/MJ (19.6 mills/kWh).  In
contrast, substitution of methanol for high-Btu gas, as in Point AC14,
results in an increase in the COE  despite a minimal increase in the power
plant efficiency.  This was caused by the cost of facilities for storing
methanol at the power plant, and by the slightly higher charge for this
fuel (Table 13.8).  The COE is only minimally affected by an electrolyte-
thickness reduction (Point AC15).  An increase in the versatility of the
power-conditioning subsystem to permit handling the lower current or
voltage input  expected as a result of fuel cell performance deterioration
with time (Point AC9)  has only a minor effect on the COE.

Oxygen is substituted for air as the oxidant in the fuel cell
subsystems of the 25 MW and 250 MW dc power plants corresponding to
Points AC5 and AC16, respectively.  A comparison of the  COE for AC1 and
AC5 reveals a 4.5 mill/MJ (16 mill/kWh) penalty for the plant employing
oxygen.  A further comparison of the data for 250 MW dc power plants
(Points AC3 and AC16) indicates that economy of scale in oxygen plants
reduces this differential to 2.3 mills/MJ  8.3 mills/kWh).  These cost
penalties and the efficiency reduction noted above combine to make very
unattractive the replacement of air by oxygen from a dedicated oxygen
plant.

TABLE 13.10—VALUES OF ALL RELEVANT PARAMETERS FOR THE PARAMETRIC POINTS OF THE AQUEOUS-ALKALINE FUEL CELL POWER SYSTEM

| Parametric Point, AL# | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Output, MWe | 22 | 87 | 218 | 770 | 18.8 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 |
| Fuel Cell Rating, MW | 25 | 100 | 250 | 900 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| **Fuel** | | | | | | | | | | | | | | | | |
| High-Btu Gas | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | X |
| Medium-Btu Gas | | | | X | | | | | | | | | | | | |
| **Oxidant** | | | | | | | | | | | | | | | | |
| Air | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | X |
| Oxygen | | | | | X | | | | | | | | | | | |
| Fuel Cell Life, 10³ hr | 10 | 10 | 10 | 10 | 10 | 30 | 50 | 100 | 100 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Voltage Degradation % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 15 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Temperature, °C | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| **Electrolyte** | | | | | | | | | | | | | | | | |
| Type: 30 w/o KOH | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Thickness, cm | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.025 |
| **Anode** | | | | | | | | | | | | | | | | |
| Type: Pt/C | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X |
| Type: Raney Ni | | | | | | | | | | | | | | X | | |
| Catalyst Loading: mg Pt/cm² | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.1 | 0.01 | 0.01 | 1.0 | 1.0 |
| **Cathode** | | | | | | | | | | | | | | | | |
| Type: Ag/C | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X |
| Type: Raney Ni | | | | | | | | | | | | | | X | | |
| Catalyst Loading: mg Ag/cm² | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 1.0 | 5.0 |
| Current Density, mA/cm² | 100 | 100 | 100 | 100 | 200 | 100 | 100 | 100 | 100 | 175 | 250 | 100 | 100 | 100 | 100 | 100 |
| Average Cell Voltage, Volts | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Thermodynamic Eff, % (1) | | | | | | | | | | | | | | | | |
| Powerplant Eff, % | 38.1 | 37.7 | 37.7 | 36.6 | 31.8 | 38.1 | 38.1 | 38.1 | 38.1 | 38.1 | 38.1 | 38.1 | 38.1 | 38.1 | 38.1 | 38.3 |
| Overall Eff, % | 25.6 | 25.4 | 25.4 | 30.7 | 21.4 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.8 |
| Total Capital Cost × 10⁻⁶, $ | 13.6 | 51.9 | 130 | 53.6 | 16.6 | 13.6 | 13.6 | 13.6 | 13.9 | 10.9 | 9.8 | 11.6 | 11.3 | 13.6 | 13.5 | 13.6 |
| Capital Costs, $/kWe | 620 | 599 | 599 | 700 | 890 | 620 | 620 | 620 | 636 | 500 | 448 | 529 | 517 | 620 | 615 | 620 |
| **Cost of Elect, Mills/kWh** | | | | | | | | | | | | | | | | |
| Capital | 19.6 | 18.9 | 18.9 | 22.1 | 28.1 | 19.6 | 19.6 | 19.6 | 20.1 | 15.8 | 14.2 | 16.7 | 16.3 | 19.6 | 19.4 | 19.6 |
| Fuel (2) | 23.3 | 23.6 | 23.6 | 18.7 | 27.9 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.1 |
| Oper. & Maint. | 17.8 | 17.9 | 17.9 | 18.1 | 11.2 | 7.2 | 5.0 | 3.4 | 3.6 | 11.4 | 8.7 | 16.5 | 16.5 | 17.8 | 17.4 | 17.8 |
| Total | 60.8 | 60.4 | 60.4 | 58.9 | 67.2 | 50.1 | 48.0 | 46.4 | 47.0 | 50.6 | 46.2 | 56.5 | 56.1 | 60.8 | 60.1 | 60.6 |
| Est. Time of Construction, yr | 1.5 | 2.0 | 2.5 | 4.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Est. Availability Date | 1985 | 1985 | 1990 | 1990 | 1985 | 1985 | 1985 | 1985 | 1985 | 1985 | 1985 | 1985 | 1985 | 1985 | 1985 | 1985 |

Notes:

(1) Where Applicable

(2) Used Base Delivered Fuel Cost

### 13.5.2 Alkaline Fuel Cell Power System

The results of the parametric assessment for the alkaline fuel cell power system are shown in Table 13.10. In general, the power plant and overall energy efficiencies are higher than those for the acid power system. The margin is not as great as expected with the higher cell voltages — 0.8 V vs 0.7 V — in this system. The lower margin is due to the parasitic losses associated with operation of the Rectisol units for scrubbing the carbon dioxide from the fuel gas and air streams fed to the power system. The capitalization required for alkaline power plants is greater because of the lower power density and, hence, higher costs of the fuel cell subsystem, and because of the costs of the Rectisol units, which are not required in the acid system. Similarly, the O&M charges are higher because of the greater replacement costs of the fuel cell subsystem. The net effect is that the COE for the alkaline fuel cell power systems are approximately 20% higher than those for the phosphoric acid system.

With high-Btu gas as fuel and air as oxidant, the power plant and overall energy efficiencies lie in general at 38% and 25 to 26%, respectively. When medium-Btu gas is employed as the fuel (AL4), the overall energy efficiency increases to 31%, while the power plant efficiency, 37%, is slightly lower. As discussed earlier for the acid system, the substitution of oxygen for air as the oxidant (AL5) results in a substantial lowering of both efficiency values. The power plant and overall energy efficiencies move sharply downward to 32% and 21%, respectively.

A detailed breakdown of all of the direct costs for the base case, AL1, is provided by Tables A 13.4.4 through A 13.4.6. A simplified breakdown is shown later in Figure 13.16 of Section 13.6. It should be noted that the Rectisol unit for air scrubbing is included in the fuel processing cost in this diagram. Table A 13.4.2 shows the effects of variation of the labor rate, contingency charge, escalation rate, fixed charge rate, interest rate during construction, fuel cost, and capacity

factor on the capital costs and COE for the base case power plant. The cost of electricity breakdown for the values of the construction and operation variables listed in Table 13.8 is as follows: 5.44 mills/MJ (19.6 mills/kWh) for capital, 6.48 mills/MJ (23.3 mills/kWh) for fuel, and 4.95 mills/MJ (17.8 mills/kWh) for O&M. The total COE is 16.9 mills/ MJ (60.8 mills/kWh).

As for the acid power system, the high O&M charge is mostly due to the high replacement cost of the fuel cell subsystem. Of the total, 4.4 mills/MJ (16 mills/kWh) is ascribable to the need for total replacement after 36 Ms (10,000 hr) of operation. The data for AL6, AL7, and AL8, shown in Table 13.10, indicate the substantial effect of fuel cell useful life on the COE. Increasing the useful life to 180 Ms (50,000 hr) reduces the COE by 4.0 mills/MJ (14.4 mills/kWh).

An equally profound effect is shown by comparing the data for AL10 and AL11 with those for the base case AL1. A power density increase of 150% results in lowering the COE by 4.05 mills/MJ (14.6 mills/ kWh). A lowering of catalyst loadings, however, as in AC12, AC13, and AC15, leads to less significant reductions of the COE, just as in the case of the acid system.

No economy of scale is observed. The COE for the 100 MW dc (AL2) and 250 MW dc (AL3) power systems differs very little from those for the 25 MW dc base case. The full benefit of the use of the cheaper medium-Btu gas is not realized in the 900 MW dc plant (AL4) because of the additional Rectisol process costs associated with the need to eliminate additional carbon dioxide, which now forms 40% of the shift converter effluent instead of the 20% when high-Btu gas is employed as the fuel.

As for the corresponding case in the acid fuel cell parametric assessment, there is COE penalty associated with the replacement of air by oxygen (AL5) from a dedicated liquid-air distillation plant. The penalty of the alkaline system is less than half that for the acid system, however, because acid gas scrubbing of the oxidant stream is no longer

necessary. The effects of electrolyte-thickness reduction (AL16) and increasing the flexibility of the power conditioning subsystem (AL9) are small.

### 13.5.3 Molten Carbonate Fuel Cell Power System

Table 13.11 is a summary of initial plant and overall efficiencies for the various parametric points. The efficiencies do not represent optimized systems, but allow a comparison of the relative effect of different parameters. The efficiency of the fuel cell for any one fuel is assumed to be the same, with current density being changed by changes in operating variables such as the use of oxygen instead of air or alteration of the electrolyte thickness. Consequently, all systems using high-Btu gas have nearly the same plant and overall efficiencies of 48 to 49% and 32 to 33%, respectively. The small differences are due to different efficiencies of the power-conditioning system for different plant size, as described in Appendix A 13.2.

There will be an efficiency decrease with time from these initial values, depending on the amount of voltage degradation of the cell at constant power.

The fuel type has an important effect on the efficiency. Thus, plant efficiencies of about 36.5% and 45% are obtained for medium-Btu and methanol fuels, respectively, compared to about 49% for high-Btu gas. On the other hand, the overall efficiency of about 30.5% for medium-Btu gas is not much less than the 33 and 31% efficiencies for high-Btu and methanol fuels. This is due to the higher gasification efficiency of the medium-Btu gas.

The use of medium-Btu gas involves much larger heat losses in the cell due to entropy factors in the electrochemical reactions. If we recover this heat and use it to produce additional ac power via a steam turbine generator as in MC4, we increase the power plant efficiency beyond that of the other systems which do not use the waste heat in this way. If we used the analogous combined fuel cell/turbine generator system with high-Btu or methanol fuels we would obtain a plant efficiency of about

TABLE 13.11 —VALUES OF ALL RELEVANT PARAMETERS FOR THE PARAMETRIC POINTS OF THE MOLTEN-CARBONATE FUEL CELL POWER SYSTEM

| Parametric Point, MC# | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Output, MWe | 22.6 | 88.8 | 22.2 | 1190 | 22.5 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.2 | 22.5 | 22.6 | 223.8 |
| Fuel Cell Rating, MWdc | 25 | 100 | 250 | 900 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 250 |
| Fuel | | | | | | | | | | | | | | | | | |
| High-Btu Gas | X | X | X | | X | X | X | X | X | X | X | X | X | X | | | X | X |
| Medium-Btu Gas | | | | X | | | | | | | | | | | X | | |
| Methanol | | | | | | | | | | | | | | | | X | |
| Oxidant | | | | | | | | | | | | | | | | | |
| Air | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | |
| Oxygen | | | | | X | | | | | | | | | | | | X |
| Fuel Cell Life, $10^3$ hr | 10 | 10 | 10 | 10 | 10 | 30 | 50 | 100 | 100 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Voltage Degradation, % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 15 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Temperature, °C | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 700 | 750 | 650 | 650 | 650 | 650 |
| Electrolyte Type | | | | | | | | | | | | | | | | | |
| Paste of Li, Na, K, Carbonates and Alkali Aluminates | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Thickness, cm | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Anode Type | | | | | | | | | | | | | | | | | |
| Ni | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Cathode Type | | | | | | | | | | | | | | | | | |
| Lithiated Ni O | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Current Density, Ma/cm² | 200 | 200 | 200 | 200 | 300 | 200 | 200 | 200 | 200 | 150 | 250 | 201 | 202 | 200 | 200 | 203 | 300 |
| Average Cell Voltage, Volts | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Thermodynamic Eff, % ① | | | | | | | | | | | | | | | | | |
| Powerplant Eff, % | 48.8 | 48.0 | 48.0 | 54.4 | 48.8 | 48.8 | 48.8 | 48.8 | 48.8 | 48.8 | 48.8 | 48.8 | 48.8 | 36.4 | 44.8 | 48.8 | 48.0 |
| Overall Eff, % | 32.9 | 32.3 | 32.3 | 45.7 | 32.9 | 32.9 | 32.9 | 32.9 | 32.9 | 32.9 | 32.9 | 32.9 | 32.9 | 30.6 | 31.2 | 32.9 | 32.3 |
| Total Capital Cost × $10^{-6}$, $ | 11.5 | 45.0 | 114 | 570 | 19.9 | 11.5 | 11.5 | 11.5 | 11.9 | 14.6 | 10.7 | 11.5 | 11.5 | 11.9 | 11.8 | 11.4 | 150 |
| Capital Costs, $/kWe | 514 | 505 | 511 | 482 | 888 | 514 | 514 | 514 | 530 | 653 | 477 | 513 | 511 | 540 | 528 | 510 | 674 |
| Cost of Elect, Mills/kWh | | | | | | | | | | | | | | | | | |
| Capital | 16.3 | 16.0 | 16.2 | 15.2 | 28.1 | 16.3 | 16.3 | 16.3 | 16.7 | 20.7 | 15.1 | 16.2 | 16.2 | 17.1 | 16.7 | 16.1 | 21.3 |
| Fuel ② | 18.2 | 18.5 | 18.5 | 12.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.8 | 20.6 | 18.2 | 18.5 |
| Oper. & Maint. | 23.4 | 23.5 | 23.6 | 16.1 | 20.8 | 8.6 | 5.7 | 3.5 | 3.6 | 30.7 | 19.0 | 23.6 | 23.1 | 23.9 | 23.5 | 23.1 | 18.9 |
| Total | 57.8 | 57.9 | 58.2 | 43.9 | 67.0 | 43.1 | 40.1 | 37.9 | 38.5 | 69.6 | 52.2 | 57.7 | 57.4 | 59.7 | 60.8 | 57.4 | 58.7 |
| Est. Time of Construction, yr | 1.5 | 2.0 | 2.5 | 5.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 2.5 |
| Est. Availability Date | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ | 1990+ |

Notes:

① Where Applicable

② Used Base Delivered Fuel Cost

59% but a lower overall efficiency (40 to 1%) than the 45.5% for MC4 (medium-Btu fuel). This is due to the lower gasification efficiency for the higher-grade fuels.

MC15 uses methanol as fuel. The ~45% power plant efficiency calculated for this system is only 4% less than the value for the corresponding system using high-Btu gas (MC1). Internal reforming of methanol, however, will probably be easier than for high-Btu gas. This might reduce or eliminate efficiency differences between the high-Btu (MC1) and methanol (MC15) systems.

The systems using oxygen, MC5 and MC17, are arbitrarily operated at the same efficiency as MC1 but at higher current densities to reduce fuel cell capital and O&M costs, as explained below. Note that for these systems, power for the air compressor of the oxygen plant is derived from a steam turbine operating with free excess heat from the fuel cell. If an electric drive compressor were used, it would severely reduce the plant efficiency.

In summary, the best overall efficiency of about 45% for the molten carbonate system investigated is attained for a combined system with the fuel cell using medium-Btu fuel and a steam turbine generator to convert excess heat from the fuel cell to electrical energy.

The highest plant efficiencies of about 59% can be obtained for the analogous combined systems using high-Btu or methanol with internal reforming, but their overall efficiencies are only 40 to 41%, due to the inefficiency of the gasification process.

For the fuel cell system only, plant efficiencies of ~49, ~45, and ~36%; and overall efficiencies of ~33, ~31, and ~30.5% are obtained with the high-Btu, methanol and medium-Btu fuels, with little to choose between high-Btu and methanol since internal reforming may be easier with the latter fuel.

The cost input to the computer program and the output data for the power plant corresponding to MC1, the base case, are listed in

Tables A 13.4.7 through A 13.4.9. The cost estimates for COE from the
various unoptimized molten carbonate fuel cell plants selected for analysis
vary from about 10.8 to 19.4 mills/MJ (39 to 70 mills/kWh), as shown in
Table 13.11. If a ten-year fuel cell lifetime with excess heat recovery
were possible, a COE value close to 8.3 mills/MJ (30 mills/kWh) could
perhaps be realized.

Of the parameters investigated, power plant size has only a
small effect of about 0.8% reduction of COE for a factor of ten increase
in plant size, going from MC1 (25 MW) to MC3 (250 MW). If oxygen rather
than air is used as oxidant, however, plant size is important, since the
cost of oxygen varies substantially with the amount of oxygen required.
Thus, MC5, the 25 MW plant, has a COE of about 18.6 mills/MJ (67 mills/
kWh) compared to 16.3 mills/MJ (58.7 mills/kWh) for the corresponding
250 MW plant (MC17) using oxygen. The latter figure, however, is no
improvement over the 25 MW plant using air and assumes the availability
of free waste heat from the fuel cell to operate the turbine-drive
compressor of the oxygen plant.

The effect of fuel type is surprisingly small, with medium-Btu
gas and methanol for the 25 MW plants (MC14 and MC15) having a COE only
about 3 to 5% greater, respectively, than for the corresponding plant
using high-Btu gas (MC1) and no conversion of waste heat.  If the waste
heat from the fuel cell, however, is converted to ac electrical energy
via a steam turbine generator, as in MC4, the COE is better for medium-Btu
than for either high-Btu or methanol fuels,since the overall efficiency is
better and capital and O&M costs are about the same.

If the power density can be increased without decreasing the
efficiency by any means, this has a strong effect on the COE. This is
illustrated by MC10 and 11, in which the power density is reduced by 25%
and increased by 25%, respectively, from that of the Base Case, MC1.
This results in about a 20% increase and about a 9% decrease, respectively,
in the COE.

MC16 shows that the effect of reducing the electrolyte thickness a factor of 2 from an already thin 1 mm (39 mils) is small, only about 0.7% less than the COE for MC1.

MC6, 7, and 8 show that the effect of cell lifetime is the most important factor in reducing the COE. A change from a 36 Ms (10,000 hr) cell lifetime 108, 180, and 360 Ms (30,000, 50,000, and 100,000 hr) gave corresponding reductions of the COE of about 25, 30, and 34%, respectively.

In summary, fuel cell life longer than the presently possible 36 Ms (10,000 hr) production of additional ac energy from excess fuel cell heat, or a substantial increase in power output over that assumed, are the principal factors capable of appreciably reducing the COE below about 16.7 mills/MJ (60 mills/kWh) estimated from available state-of-the-art developments to date for the molten carbonate fuel cell.

Fuel cell size and fuel type (except for combined fuel cell and steam turbine generator systems), electrolyte thickness, and moderate voltage degradation have relatively small effects on the COE.

Oxygen is not competitive with air as the oxidant except possibly in the extreme case of a large (e.g., 250 MW) fuel cell plant, with waste heat being used to run a turbine which operates the air compressor of the oxygen plant.

### 13.5.4 Solid Electrolyte Fuel Cell Power System

The power plant and overall energy efficiencies for all twenty points of the parametric assessment of the solid electrolyte power system are listed in Table 13.12. This table also provides information pertinent to the operation of the fuel cell subsystem in the power plant corresponding to each of the twenty points.

In the Base Case SE1 high-Btu gas is employed as the fuel. Because of the high average cell voltages, predicted on the direct electrochemical oxidation of methane at the fuel electrode, the power plant and overall energy efficiencies are high, lying at 69.7 and 46.9%, respectively. These values are unlikely to be realized in practice

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TABLE 13.12 — VALUES OF ALL RELEVANT PARAMETERS FOR THE PARAMETRIC POINTS OF THE SOLID-ELECTROLYTE FUEL CELL POWER SYSTEM

| Parametric Point, SE # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Output, MWe | 22.9 | 87.6 | 219 | 1164 | 18.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 219 | 1064 | 22.7 |
| Fuel Cell Rating, MW | 25 | 100 | 250 | 900 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 250 | 900 | 25 |
| **Fuel** | | | | | | | | | | | | | | | | | | | | |
|   High-Btu Gas | X | | | | | | | | | | | | | | | | | | | X |
|   Medium-Btu Gas | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
|   Low-Btu Gas | | | | | | | | | | | | | | | | | | | | |
| **Oxidant** | | | | | | | | | | | | | | | | | | | | |
|   Air | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
|   Oxygen | | | | | X | | | | | | | | | | | | | | | |
| Fuel Cell Life, $10^3$ hr | 10 | 10 | 10 | 10 | 10 | 30 | 50 | 100 | 100 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Voltage Degradation, % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 15 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Temperature, °C | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 900 | 1100 | 1000 | 1000 | 1000 |
| **Electrolyte** | | | | | | | | | | | | | | | | | | | | |
|   $(Zr\,O_2)_{1-x}(Ca\,O)_x$ | X | X | X | X | | X | X | X | X | X | X | X | X | | | X | X | | X | |
|   $(Zr\,O_2)_{1-x}(Y_2\,O_3)_x$ | | | | | X | | | | | | | | | X | X | | | X | | X |
| Thickness, cm $10^{-3}$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 2 |
| **Anode** | | | | | | | | | | | | | | | | | | | | |
|   $Ni$–$Zr\,O_2$ – Cermet | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| **Cathode** | | | | | | | | | | | | | | | | | | | | |
|   $In_2\,O_3/Pr\,Co\,O_3$–x | X | X | X | X | X | X | X | X | X | X | X | X | | X | | X | X | X | X | X |
|   $Sn\,O_2/$ Sb-Doped | | | | | | | | | | | | | X | | X | | | | | |
| **Interconnection** | | | | | | | | | | | | | | | | | | | | |
|   $Co\,Cr_2\,O_2$ (Mn-Doped) | | | | | | | | | | | | | X | | | | | | | |
|   $Cr_2\,O_3$ | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X |
| Thickness, cm $10^{-3}$ | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Current Density, mA/cm² | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 600 | 800 | 400 | 400 | 400 | 400 | 400 | 400 | 800 | 400 | 800 |
| Average Cell Voltage, Volts ① | 0.84 | 0.66 | 0.66 | 0.66 | 0.76 | 0.66 | 0.66 | 0.66 | 0.66 | 0.59 | 0.51 | 0.67 | 0.66 | 0.64 | 0.66 | 0.55 | 0.77 | 0.68 | 0.56 | 0.69 |
| Thermodynamic Eff, % | 69.7 | 40.9 | 40.9 | 60.2 | 39.7 | 41.6 | 41.6 | 41.6 | 41.6 | 37.1 | 32.0 | 42.3 | 41.6 | 40.3 | 41.6 | 34.7 | 48.5 | 53.0 | 47.8 | 56.7 |
| Powerplant Eff, % | 46.9 | 34.3 | 34.3 | 50.6 | 33.3 | 35.0 | 35.0 | 35.0 | 35.0 | 31.2 | 26.9 | 35.5 | 35.0 | 33.9 | 35.0 | 29.2 | 40.8 | 53.0 | 47.8 | 38.2 |
| Overall Eff, % | 42.0 | 42.0 | 42.0 | | | | | | | | | | | | | | | | | |
| Total Capital Cost × $10^{-6}$, $ | 9.67 | 42.0 | 106 | 599 | 17.7 | 10.7 | 10.7 | 10.7 | 11.0 | 9.63 | 9.28 | 10.5 | 10.7 | 10.7 | 9.04 | 11.9 | 9.80 | 205 | 893 | 7.67 |
| Capital Costs, $/kWe | 424 | 482 | 488 | 466 | 972 | 481 | 481 | 481 | 496 | 434 | 418 | 474 | 481 | 483 | 407 | 535 | 442 | 948 | 859 | 340 |
| **Cost of Elect, Mills/kWh** | | | | | | | | | | | | | | | | | | | | |
|   Capital | 13.4 | 15.2 | 15.4 | 14.7 | 30.7 | 15.2 | 15.2 | 15.2 | 15.7 | 13.7 | 13.2 | 15.0 | 15.2 | 15.3 | 12.9 | 16.9 | 14.0 | 30.0 | 27.1 | 10.7 |
|   Fuel ② | 12.7 | 16.7 | 16.7 | 11.3 | 17.2 | 16.4 | 16.4 | 16.4 | 16.4 | 18.4 | 21.3 | 16.1 | 16.4 | 16.9 | 16.4 | 19.7 | 14.1 | 5.5 | 6.3 | 15.7 |
|   Oper. & Maint. | 16.0 | 20.8 | 21.1 | 14.2 | 24.2 | 7.9 | 5.3 | 3.4 | 3.5 | 16.2 | 14.5 | 20.2 | 20.6 | 21.1 | 20.6 | 24.3 | 17.9 | 12.2 | 18.4 | 10.9 |
|   Total | 42.1 | 52.7 | 53.2 | 40.2 | 72.2 | 39.5 | 36.9 | 35.0 | 35.6 | 48.3 | 49.0 | 51.3 | 52.2 | 53.3 | 49.9 | 60.9 | 45.9 | 47.7 | 51.9 | 37.3 |
| Est. Time of Construction, yr | 1.5 | 2.0 | 2.5 | 5.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 3.0 | 5.5 | 1.5 |
| Est. Availability Date | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ | 2000+ |

Notes:
① Where Applicable
② Use Base Delivered Fuel Cost

because of the metastability of methane at this temperature, resulting in either reformation on any available metallic surface, including that of the metallic component of the fuel electrode, in the presence of an adequate supply of water vapor, or carbon deposition (Reference 13.46).

For most points in the parametric assessment, medium-Btu gas is the fuel, so that for comparison purposes, Point SE2, corresponding to the 100 MW dc power plant, is much more useful than Point SE1. With medium-Btu gas as fuel, the power plant efficiency lies in the range 40 to 42% (SE2, 3, 5 through 9, 12 through 15), while the overall energy efficiency moves between 33 and 36%. Because of the lowered cell voltages in the fuel cell subsystems, corresponding to Points SE10 and SE11, increases in the power density cause a reduction in the plant and overall efficiencies.

The heat which must be rejected by the fuel cell subsystem results from thermodynamic and electrochemical inefficiencies. This waste heat may be employed in a steam-bottoming plant (SE4) or to supply the heat required by the endothermic processes occurring in a coal gasification reactor, which then meets the fuel requirements of the fuel cell subsystem (SE18 and SE19). The net effect of waste heat recovery is to substantially raise the efficiency of the power system. For Point SE4, the power plant and overall energy efficiencies are 60.2 and 50.6%, respectively. As the fuel in the power plant corresponding to Point SE18, the Westinghouse Fuel Cell Power System, is coal, the power plant and overall energy efficiencies are identical at 53%. Point SE19, which involves the use of a low-Btu gasification reactor, employing coal, air, and steam as input, the power plant efficiency is 47.8% because of the use of a steam-bottoming plant. This is lower than for Point SE18, in which medium-Btu is generated by recycling fuel gas which has been partially oxidized in the fuel cell subsystem. The overall efficiency for Point SE19 is identical with the power plant efficiency because the low-Btu gasifier is considered to be fully integrated with the power system. Thus, coal and air are the inputs.

The computer outputs for Points SE1 and SE2 is shown in Tables
A 13.4.10 through A 13.4.15. The COE and their breakdowns into capital,
fuel, and O&M charges, for the values of plant construction and operation
shown in Table 13.8, are given in Table 13.12.

As discussed above, the results for Point SE2 provides a better
basis for discussion of the parametric assessment of the solid electrolyte
power system  because of the general use  of  medium-Btu gas for most
points, and  also because of the technical uncertainty surrounding the
direct use of high-Btu gas as a fuel.  The COE for the power plant
corresponding to SE2 is 14.6 mills/MJ (52.7 mills/kWh).  The portion
ascribable to capital is 4.23 mills/MJ (15.2 mills/kWh), to fuel 4.64
mills/MJ (16.7 mills/kWh), and to O&M 5.77 mills/MJ (20.8 mills/kWh).  The
O&M charge is high because of the high replacement cost — unlike the
platinum-laden acid fuel cell modules, the solid electrolyte modules
are assumed to have a scrap value of zero.  Of the total charge, 5.35
mills/MJ (19.3 mills/kWh) is ascribable to the need to replace the modules
after 36 Ms (10,000 hr) of useful life.  Points SE6 through 8 explore the
effect of increasing the useful life.  The electricity costs are 11.0
mills/MJ (39.5 mills/kWh) for 108 Ms (30,000 hr) and 9.73 mills/MJ
(35.0 mills/kWh) for 300 Ms (100,000 hr).

Comparison of the COE and efficiency data for SE2, SE10, and
SE11, reveal the effect of  variations in the power density.  An increase
of the active cell power density from 264 to 354 mW/cm$^2$ (245 to 329 W/ft$^2$)
results in a  COE   reduction from 14.6 to 13.4 mills/MJ (53.7 to 48.3
mills/kWh).  A further increase  in the power density to 408 mW/cm$^2$
(379 W/ft$^2$), however, caused a small increase in the COE, as the increase
in the cost component ascribable to fuel (because of the lower cell
voltage and thus plant efficiency) more than outweighs the sum of the
reductions in the costs ascribable to capital and O&M.

The power density changes, also, when the temperature of
operation is changed from 1273°K (1832°F) as in SE2 to 1373°K (2012°F)
and 1173°K (1652°F) in SE17 and SE16, respectively.  The decline in

electrolyte and interconnection resistivities with increasing temperature is assumed to result in a parallel increase in cell voltages. Thus, an increase in the temperature of 100°K (180°F) causes a 20% increase in cell voltage and power plant efficiency resulting in a COE decrease of approximately 1.9 mills/MJ (6.8 mills/kWh). A lowering of the fuel cell temperature by 100°K (180°F) results in COE penalty of 2.27 mills/MJ (8.2 mills/kWh).

Substitution of oxygen for air as the oxidant, as in Point SE5, results in a substantial COE penalty. The penalty is greater here than for Point MC5 because the power required for the oxygen plant is taken from the ac output of the power-conditioning subsystem instead of being generated by a turbine powered by waste heat from the fuel cell subsystem.

Replacement of tin-doped indium oxide by antimony-doped tin oxide, as in SE15, causes a small decrease in the electricity cost. Even smaller decreases are registered by reducing the electrolyte thickness (SE12) and by substituting manganese-doped cobalt chromite for chromium sesquioxide as the interconnection material (SE13). Despite the lower cost of calcia as a stabilizing agent for zirconia (relative to yttria), the use of calcia-stabilized zirconia as an electrolyte (SE14) results in a small electricity cost penalty. This is caused by the higher resistivity of this electrolyte, which, in turn, causes a cell voltage reduction and, consequently, a loss in plant efficiency.

The use of a steam bottoming plant for waste-heat recovery in the power plant corresponding to Point SE4 results in a dramatic reduction in the electricity cost from 14.6 mills/MJ (52.7 mills/kWh) to 11.2 mills/MJ (40.2 mills/MJ). Similarly, a reduction of 1.4 mills/MJ (5 mills/kWh) is observed for the Westinghouse Fuel Cell Power System (SE18). The results for SE19 indicate that partial thermal coupling of the fuel cell subsystem with a low-Btu gasifier offers little advantage from a COE standpoint, despite the use of a steam-bottoming plant for waste heat recovery.

## 13.6 Conclusions and Recommendations

Considerable caution must be exercised when a comparison between fuel cell power systems is attempted on the basis of data provided for individual systems in Subsection 13.5. The calculated power plant efficiencies may be relied upon to within a few percent either way, as they compare favorably with estimates available from other fuel cell work. They are, of course, dependent on the correctness of the assumptions of fuel cell subsystem performance, cited in Subsections 13.2 and 13.3.

As will be evident from the approaches taken in the costing of the fuel cell subsystems in Section 13.4, there is a much greater possibility of error in the estimation of COE. The costing procedures employed represent an unbiased effort to estimate the possible costs of the fuel cell subsystems on the basis of a realization of the performance targets, as discussed in subsection 13.2. Because they are founded on so many arbitrary assumptions, the comparison of the different fuel cell power systems based on the COE derived in this study must be approached with care.

The parametric assessment of the four cell power systems was based on a matrix of 69 points — 16 points each for the phosphoric acid and alkaline systems, 17 for molten carbonate, and 20 for solid electrolyte. The parameters of the power systems, which were varied, are listed in Table 13.13.

### Table 13.13 - Parameters Varied in Fuel Cell Assessment

| | |
|---|---|
| Fuel Cell Useful Life | Fuel Cell Plant Rating |
| Power Density | Electrolyte Thickness |
| Fuel Type | Voltage Degradation |
| Oxidant Type | Waste Heat Recovery System** |
| Catalyst Loading* | Temperature of Operation** |

\* Applicable for acid and alkaline systems.

\*\* Applicable for molten carbonate and solid electrolyte systems.

For each of the 69 points, power plant and overall energy efficiencies, and COE (broken down into capital, fuel, and O&M components) were calculated. Analysis of these results indicated that four of the parameters listed in Table 13.13 were of particular importance in improving efficiency and reducing COE. The four parameters and their areas of impact are shown in Table 13.14.

Table 13.14 - Important Parameters of Fuel Cell Power Systems

| Parameter | Area of Impact |
|-----------|----------------|
| Fuel Cell Useful Life | O&M costs |
| Fuel Cell Power Density | Capital and O&M costs |
| Waste Heat Recovery System | Plant and overall efficiencies |
| Fuel Type | Overall efficiency |

The importance of fuel cell subsystems useful life is seen in Figure 13.14. The decrease in COE with increasing life is most pronounced for the molten carbonate and solid electrolyte systems. The effect is least for the phosphoric acid power system because, at $152/kW dc, the acid fuel cell subsystem not only is the cheapest, but also has a sizeable salvage value due to its platinum content. Although the alkaline system has a similar salvage value, the low power density of the cell results in a higher replacement cost for the final cell subsystem, and, consequently, a greater dependency of the COE on the useful fuel cell life.

Figure 13.15 shows the marked effect of power density, i.e., power output per unit electrode area, on the COE for the acid, alkaline, and molten carbonate systems. Increasing power density at constant efficiency implies advances in the state of the art of cathode and anode fabrication technology. The more conventional technique of power density variation is to increase the current density, accepting a cell voltage reduction and, therefore, an efficiency penalty. This results in an
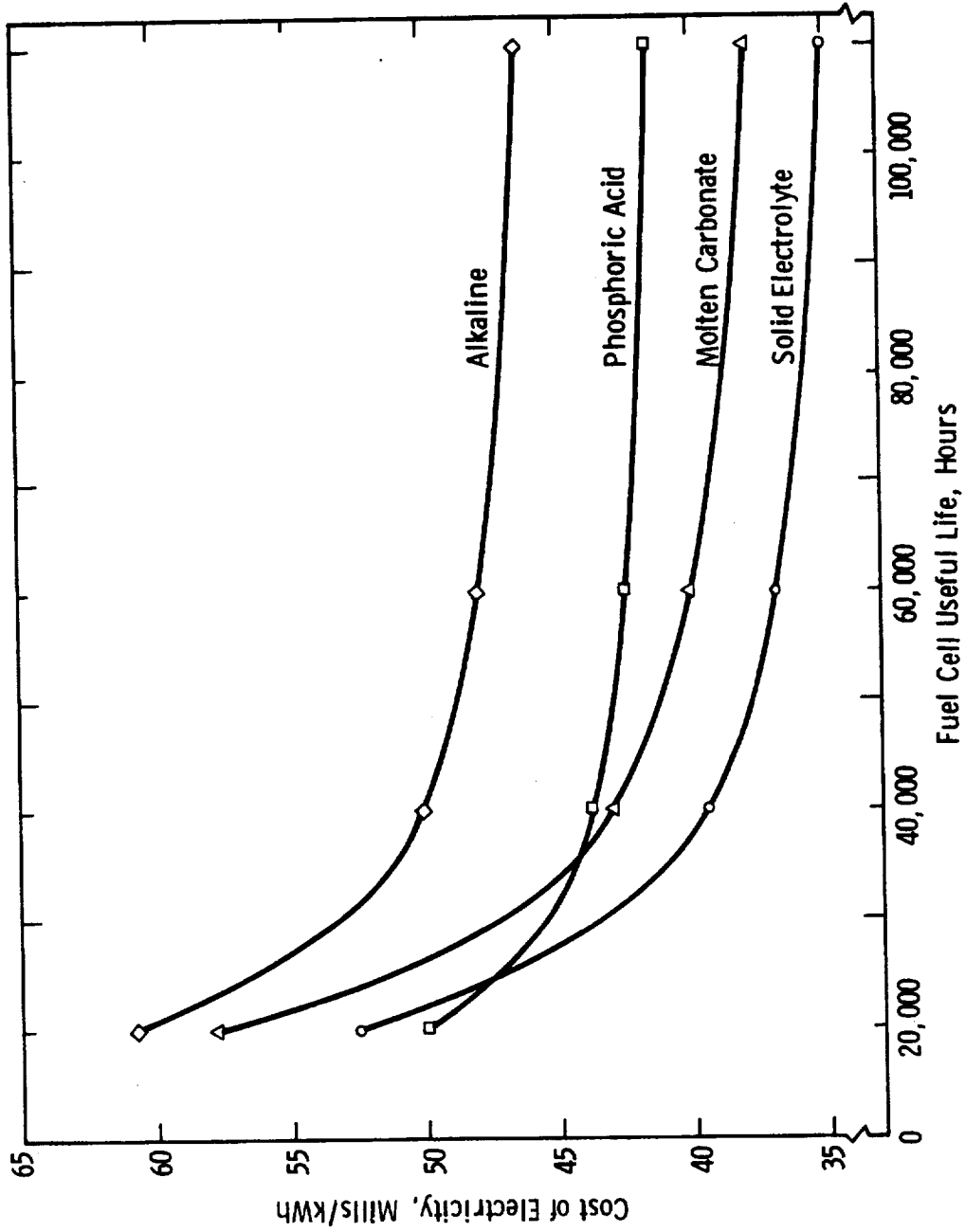
Fig. 13.14 — The effect of the useful life of the fuel cell subsystem on the cost of electricity. The fuel gas for the acid, alkaline and molten carbonate systems is high-Btu gas, while the solid electrolyte system costs were calculated on the basis of the use of medium-Btu gas
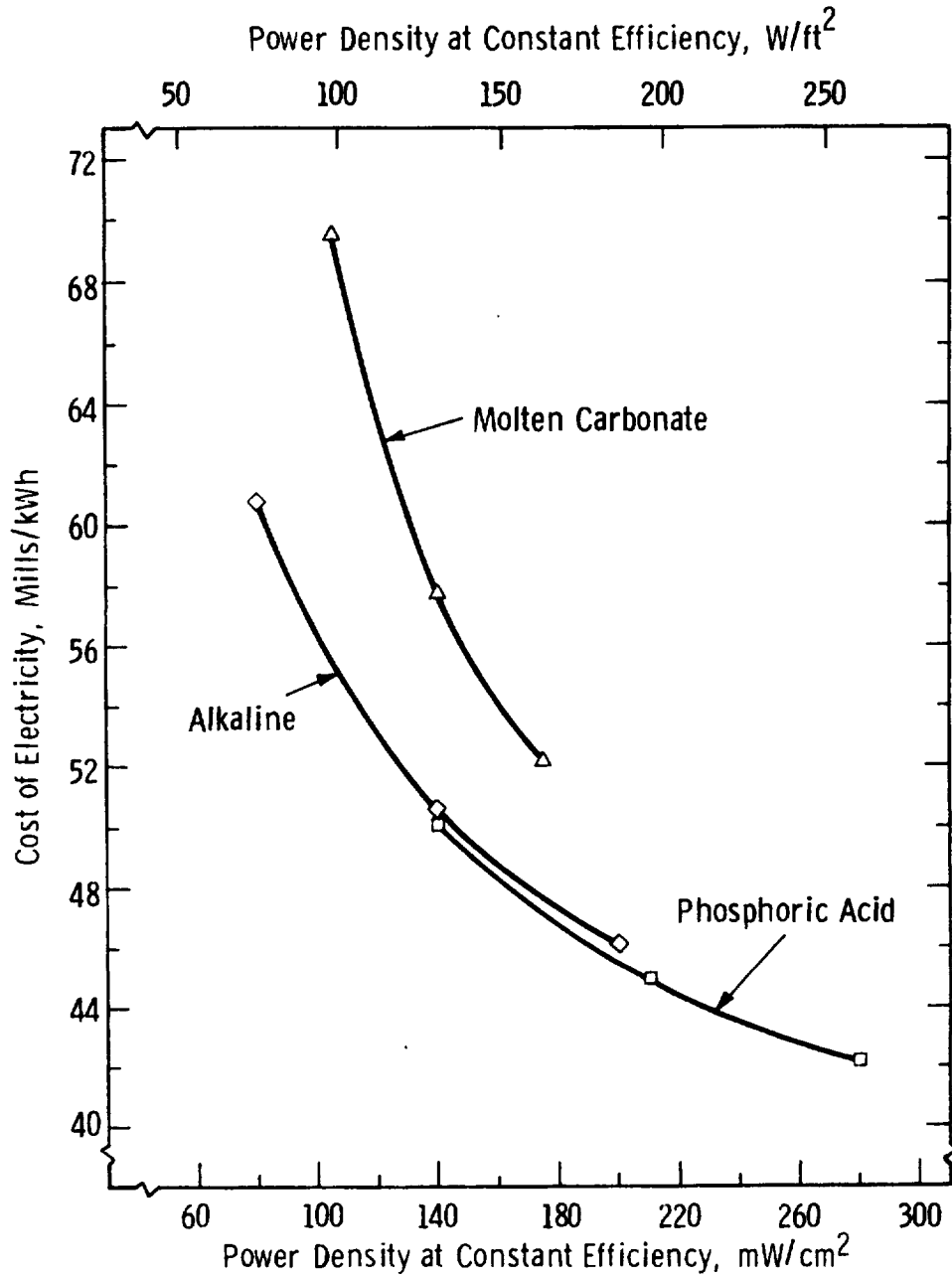
Fig. 13. 15—Dependence of the electricity cost on the power density at constant efficiency for phosphoric acid, alkaline, and molten carbonate fuel cell power systems
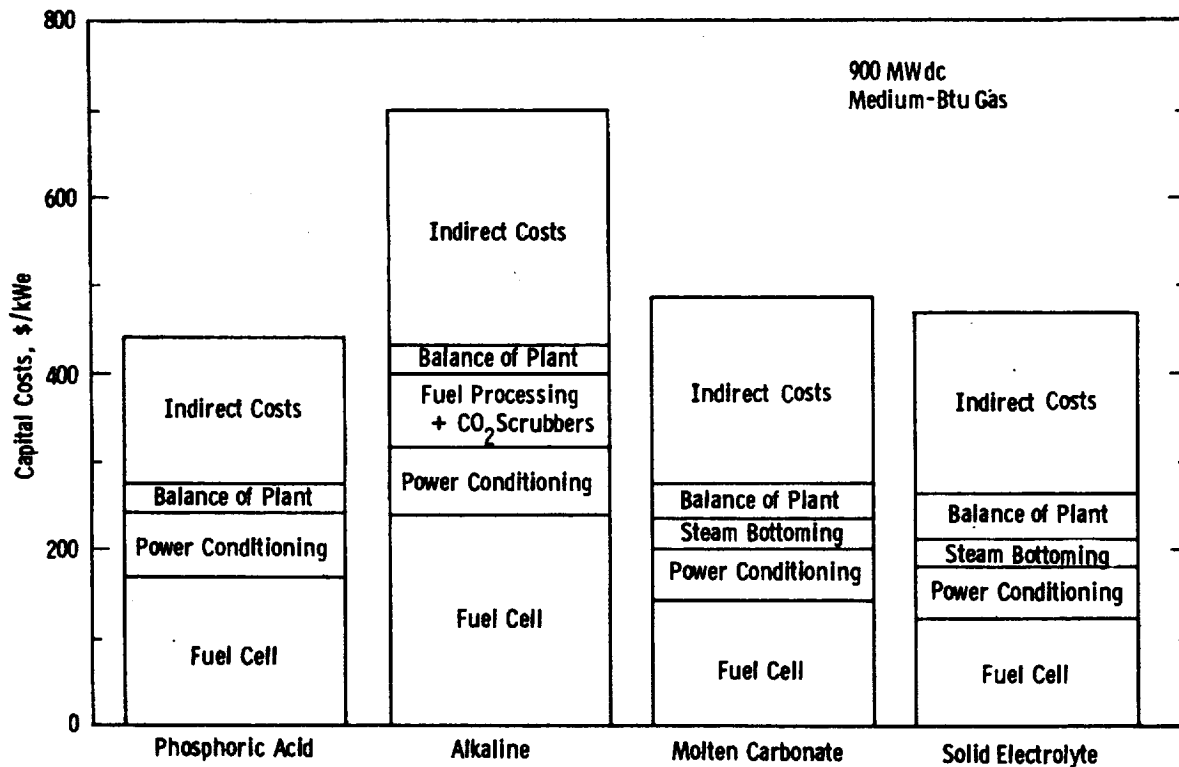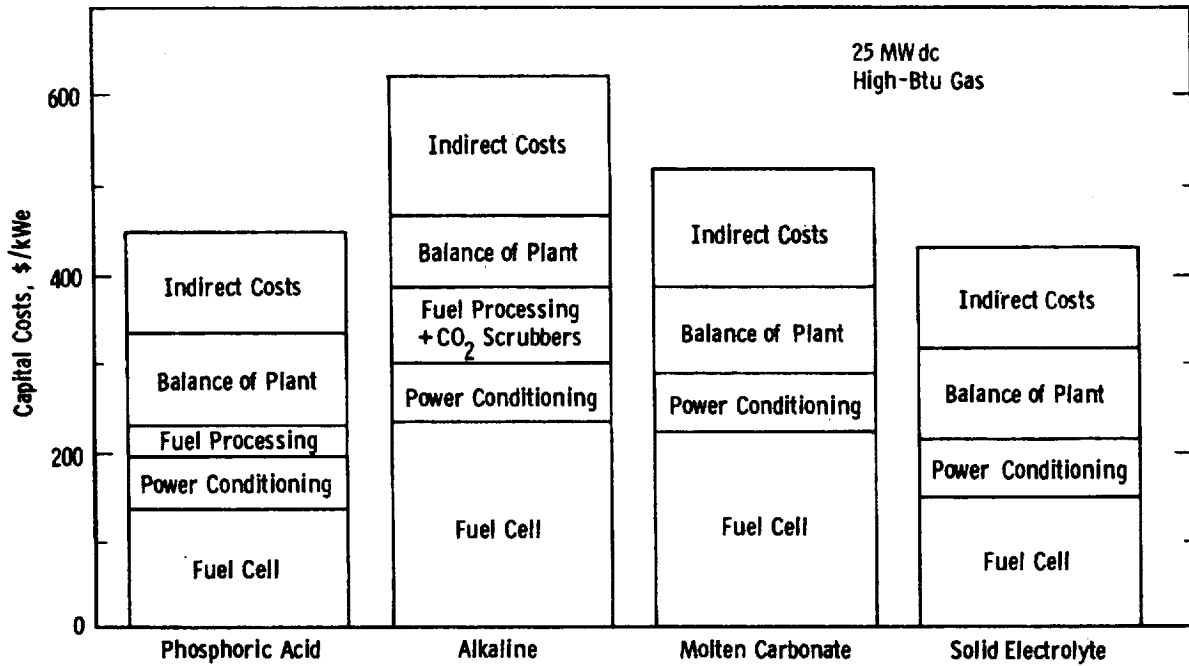
Fig. 13. 16 — Breakdown of capital costs for the base cases (corresponding to parametric points AC1, AL1, MC1, and SE1) and for the 900 MW fuel cell power plants (AC4, AL4, MC4, and SE4)

increased fuel charge which serves to offset the reductions in the capital and O&M components of the COE (as discussed for Points SE10 and SE11 in Section 13.5.4). A further complication of operation at a higher power density was discussed by Kordesch (Reference 13.47) for alkaline fuel cells. The useful life is inversely proportional to the current density, so that operation at a higher power density would result in more frequent replacement of the fuel cell subsystem, and thus, in a higher O&M charge.

The coupling of a steam bottoming plant to the 900 MW solid electrolyte and molten carbonate fuel cell subsystems of the power plants, corresponding to Points SE4 and MC4, raises the ac outputs to 1164 and 1170 MWe, respectively, and the overall energy efficiencies to 50.6 and 45.7%, respectively. Thermal coupling of the fuel cell subsystem with a coal gasifier (another form of waste heat recovery) results in an overall energy efficiency of 53.0%, the highest derived in this study (Point SE18).

Because of the greater efficiency of the production of medium-Btu gas, relative to high-Btu gas, a 25% gain in overall energy efficiency may be registered by the use of this fuel. The lower cost of medium-Btu gas (Table 13.8) results also in a lowering of the fuel component of the COE by greater than 20%, as shown by comparing the data for Points AC1 and AC4.

A comparison of the capital cost breakdowns for all four base cases is provided in Figure 13.16. The balance of plant was calculated by subtracting the sum of the material and site labor costs for the major components — e.g., for the phosphoric acid system, the fuel cell, power-conditioning, and fuel processing subsystems — from the total direct costs of the power plant. The indirect costs, which include the interest during construction, escalation and contingency charges; and the profit and owner costs, were calculated similarly and represent the difference between the total capitalization and total direct costs.

The dominance of the fuel cell subsystem cost, lying in the range of 35 to 42% of the total capitalization, is apparent for every power system. The indirect costs, averaging 25% of the total, are also

Phosphoric Acid



Total: 50. 1 Mills/kWh
Plant Efficiency: 35. 5%
Overall Efficiency: 23. 9%

Alkaline



Total: 60. 8 Mills/kWh
Plant Efficiency: 38. 1%
Overall Efficiency: 25. 6%

Molten Carbonate



Total: 57. 8 Mills/kWh
Plant Efficiency: 48. 8%
Overall Efficiency: 32. 9%

Solid Electrolyte



Total: 42. 1 Mills/kWh
Plant Efficiency: 69. 7%
Overall Efficiency: 46. 9%
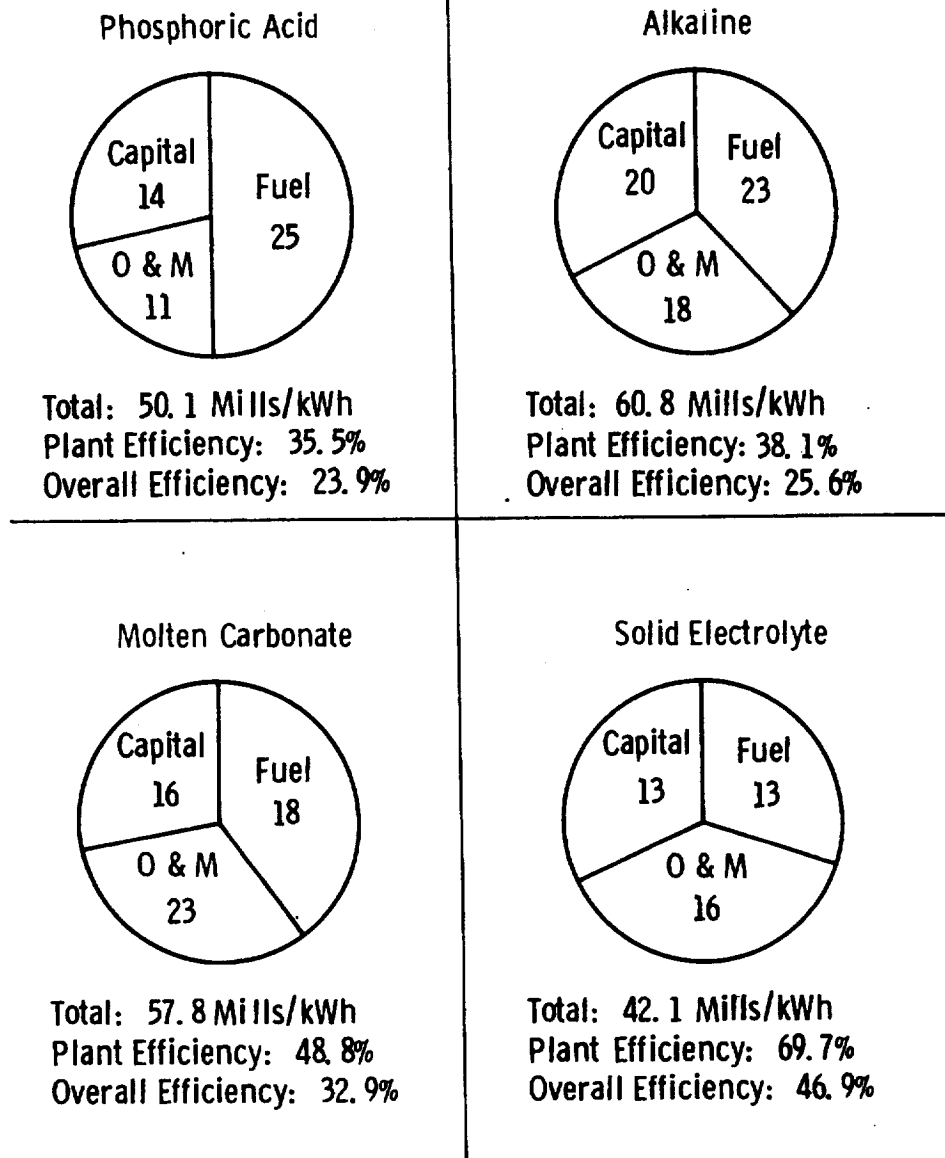
Fig. 13. 17 — Breakdown of electricity costs for the base-case fuel cell power plants (25 MWdc; useful life of 10,000 hours). The fuel gas is high-Btu gas (OTF)

of considerable importance. Although the fuel processing cost for the phosphoric acid system is small, approximately $38/kWe (8.6%), this is not the case for the alkaline system, in which scrubbing of the carbon dioxide from the fuel gas and air before they enter the fuel cell subsystem is necessary. The cost of both scrubbers is included in the total of $87/kWe shown for the alkaline fuel processing. The power-conditioning costs are similar, and lie in the range of $62 to 66/kWe. The differences arise from the assumptions of dissimilar parasitic losses for each system. The balance of plant costs are slightly higher for the two high-temperature power systems because they include charges for recuperative heat exchangers necessary for the heating of the input air and fuel gas streams.

From a total capitalization standpoint, the alkaline power system, at $620/kWe, is the most expensive, due to the low power density assumed for the fuel cell subsystem and the need for carbon dioxide scrubbing. The phosphoric acid and solid electrolyte systems, at $448 and $424/kWe, respectively, require the least investment, and the molten carbonate system requires an intermediate capitalization of $514/kWe. The relative importance of the capitalization, at a fixed charge rate of 18%, is shown in Figure 13.17, which presents a breakdown of the COE for the base cases of all four power systems. The power plant and overall energy efficiencies for each case are also shown. The fuel gas is high-Btu gas costing $2.46/GJ ($2.60/10$^6$ Btu); the useful life of all fuel cell subsystems was assumed to be 36 Ms (10,000 hr). The fuel charges are less for the high-temperature systems because of their greater efficiencies. Their O&M charges are greater, however, because of their higher fuel cell subsystem replacement costs.

A better basis for comparison is afforded by the data for Point 4 of every system. In every case, the 900 MW dc fuel cell subsystem uses medium-Btu gas as a fuel and is assumed to have a useful life of 36 Ms (10,000 hr). In addition, each of the high-temperature systems includes a steam bottoming plant consisting of steam generators,

Phosphoric Acid



Total: 44. 0 Mills/kWh
Plant Efficiency: 34. 8%
Overall Efficiency: 29. 3%

Alkaline



Total: 58. 9 Mills/kWh
Plant Efficiency: 36. 8%
Overall Efficiency: 30. 7%

Molten Carbonate



Total: 43. 9 Mills/kWh
Plant Efficiency: 54. 4%
Overall Efficiency: 45. 7%

Solid Electrolyte



Total: 40. 2 Mills/kWh
Plant Efficiency: 60. 2%
Overall Efficiency: 50. 6%
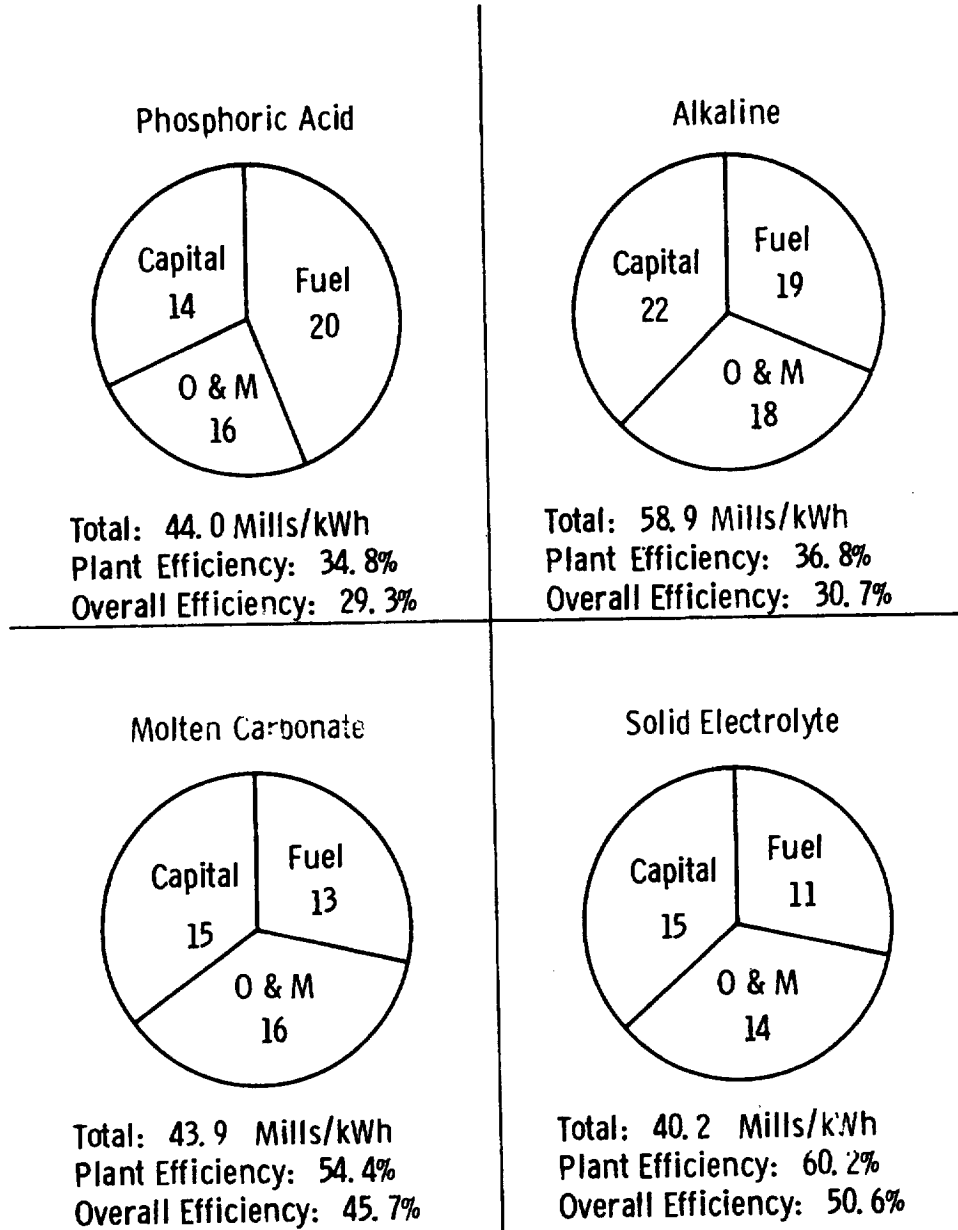
Fig. 13. 18—Breakdown of electricity costs for all 900 MW dc fuel cell power plants. The fuel gas is medium-Btu gas (OTF), and the useful life of all fuel cell subsystems is 10,000 hours

a steam turbine, and a heat rejection facility. This raises the ac output of the molten carbonate and solid electrolyte plants to 1170 and 1164 MW, respectively.

A breakdown of the capital costs for each system is shown in Figure 13.16. The total capitalizations required for the phosphoric acid, molten carbonate, and solid electrolyte systems are seen to be virtually identical, lying in the range of $440 to 480/kWe. These costs would be even closer but for the assumption of a 157.7 Ms (5 yr) construction period for the high-temperature systems, as against a 126.1 Ms (4 yr) period for the acid system. Accordingly, the indirect costs amount to approximately 37.5% of the total for the acid system versus approximately 44% for the high-temperature systems. The alkaline system, with additional problems posed by the use of medium-Btu gas, necessitating the removal of carbon dioxide at twice the rate of that when high-Btu gas is employed as the fuel, is now noncompetitive, lying at $700/kWe. For convenience of presentation, the fuel processing costs for the acid system have been included in the balance of plant costs in Figure 13.16.

The COE breakdowns and both efficiencies for each of the 900 MW dc systems are shown in Figure 13.18. The overall energy efficiencies for the high-temperature systems are, as expected, much higher than for either of the low-temperature systems. The higher fuel cost for the acid system, however, is offset by the lower O&M charge due to the lower fuel cell subsystems replacement cost, so that the total COE is essentially the same for the molten carbonate and acid systems at 12.2 mills/MJ (44 mills/kWh). The COE for the solid electrolyte system is lower still at 11.2 mills/MJ (40.2 mills/kWh). The alkaline system displays a COE of 16.4 mills/MJ (58.9 mills/kWh), which is substantially higher than for any of the other systems.

Projections as to the lowest COE possible for each system may be made on the basis of the data shown in Figure 13.18. These projections are highly tentative and are based on the multitude of assumptions

presented and discussed in Subsections 13.4 and 13.5. If medium-Btu gas, costing $2.46/GJ ($2.60/10$^6$ Btu), is employed as the fuel; air is the oxidant; and the fuel cell subsystem life is at least 144 Ms (40,000 hr); then the COE will be as shown in Table 13.15.

Table 13.15  -  Projections of Possible Efficiencies and Electricity
Costs of Fuel Cell Power Systems

| System Type | Overall Energy Efficiency,% | Possible COE, mills/kWh |
|---|---|---|
| Phosphoric Acid | ~30 | High 30s |
| Alkaline | ~30 | Low 40s |
| Molten Carbonate | ~45 | Low 30s |
| Solid Electrolyte | ~50 | High 20s |

The costs and efficiencies for the high-temperature systems are predicated on the use of a waste-heat recovery system. This probably limits the minimum size of fuel cell subsystem to approximately 200 MW dc in order to allow economical and efficient recovery of the rejected heat.

The selection of fuel cell power systems for inclusion in Task II, Conceptual Design Preparation, and in Task III, Implementation Assessment, of this study, was based on the criterion of an overall energy efficiency significantly in excess of 35%. This eliminates all of the low-temperature fuel cell plants, and most of the high-temperature plants, which do not incorporate a waste-heat recovery system. Because of their high overall efficiencies, a solid electrolyte and molten carbonate power plant, as typified by Points SE4 and MC4, is recommended for the further refinement of efficiency and electricity cost estimates specified for Task II.

The Westinghouse Solid Electrolyte Fuel Cell Power System is recommended also for inclusion in Tasks II and III. Inspection of Figure 13.19, which presents all of the data pertinent to the recommended cases,

reveals why. The overall efficiency has been estimated very conservatively in this study. The estimated value of 53%, lower than previously published values of 60% and 57.5% (Reference 13.25) is, nevertheless, the highest determined in this study. The COE of 13.3 mills/MJ (47.7 mills/kWh) is inflated by the capitalization associated with coal gasification. This estimate of $335/kWe is based on an evaluation performed in late 1968 (Reference 13.45), in which approximately 75% of the installed cost of the special fluidized bed coal gasification reactor was attributable to the cost of Incoloy 800 sheathing, considered necessary for efficient heat transfer from the fuel cell modules. In Task II, alternative materials and methods for efficient and economical thermal coupling of the gasifier and fuel cell subsystem should be explored. The potential for a reduction in the COE, and specifically its capital component, is obvious from Figure 13.19.

**900 MW Solid Electrolyte with Steam Bottoming (SE4) Fuel: Medium-Btu Gas**

Capital 15
Fuel 11
O & M 14

Total: 40.2 Mills/kWh
Plant Efficiency: 60.2%
Overall Efficiency: 50.6%

**900 MW Molten Carbonate with Steam Bottoming (MC4) Fuel: Medium-Btu Gas**

Capital 15
Fuel 13
O & M 16

Total: 43.9% Mills/kWh
Plant Efficiency: 54.4%
Overall Efficiency: 45.7%

**250 MW Solid Electrolyte with Integrated Gasifier (SE18) Fuel: Coal**

Fuel 5
Capital 30
O & M 12

Total: 47.7 Mills/kWh
Plant Efficiency: 53.0%
Overall Efficiency: 53.0%

Capital Costs, $/kWe

Indirect Costs
Balance of Plant
Steam Bottoming
Power Conditioning
Fuel Cell

Indirect Costs
Balance of Plant
Steam Bottoming
Power Conditioning
Fuel Cell

Indirect Costs
Balance of Plant
Coal Processing and Gasification
Power Conditioning
Fuel Cell

Fig. 13.19—Breakdown of electricity and capital costs for the three power plants (corresponding to parametric points SE4, MC4, and SE18) recommended for further investigation in Tasks II and III. Note that the assumed useful life of all fuel cell subsystems is 10,000 hours

## 13.7 References

13.1 J. P. Ackerman, L. E. Link, J. J. Barghusen, "Assessment Study of Devices for the Generation of Electricity for Stored Hydrogen," First Report (Draft Copy), Argonne National Laboratory, Argonne, Illinois 60439; August 1975.

13.2 W. Leuckel, Power Systems Division, United Technologies Corporation; comment in discussion at July 7, 8, 1975 Workshop of Assessment Study for the Generation of Electricity for Stored Hydrogen, Argonne National Laboratory.

13.3 L. J. Nuttall, "Solid Polymer Electrolysis Fuel Cell Status Report," Record of the Tenth Intersociety Energy Conversion Engineering Conference, August 18-22, 1975; pp. 210-7.

13.4 J. W. Harrison in Part II - Appendix of Reference 13.1.

13.5 H. Bohm, K. Maas, "Methanol/Air Acidic Fuel Cell System," 9th Intersociety Energy Conversion Engineering Conference Proceedings, August 26-30, 1974; pp. 836-40.

13.6 J. O'M. Bockris and S. Srinivasan, "Fuel Cells: Their Electrochemistry", McGraw-Hill, New York, 1969; Chapter 10.

13.7 R. Roberts, "Preliminary Draft - Needs and Recommendations for a National Fuel Cell Program," proposed for Division of Conservation, Energy Research and Development Administration, by Mitre Corporation, July 21, 1975; pp. 7-8.

13.8 G. Ciporos, in Part II - Appendix of Reference 13.1.

13.9 A. P. Fickett, Electric Power Research Institute, in Alkaline Fuel Cell Discussions at the EPRI Catalyst Workshop, January 1975.

13.10 J. K. Truitt, "15 kW Hydrocarbon-Air Fuel Cell Electric Power Plant Design," Contract DA-44-009-AMC-1806(T), January 1968.

13.11 L. G. Marianowski, "JP-4 Fueled Molten Carbonate Fuel Cells," Contract DA-44-009-AMC-1456(T), July 1966.

13.12 L. G. Marianowski et al, "JP-4 Fueled Molten Carbonate Fuel Cells," U.S. Army Contract DA-44-009-AMC-1456(T), January 1968.

13.13 "Assessment Study of Devices for the Generation of Electricity from Stored Hydrogen," Part II - Appendix, August 1975, by J. P. Ackerman, J. J. Barghusen, and L. E. Link, Argonne National Laboratory. Contribution from United Technologies entitled "Use of Fuel Cells to Generate Electricity from Hydrogen."

13.14 G. H. J. Broers, "High Temperature Galvanic Fuel Cells," Thesis, University of Amsterdam, 1958.

13.15 G. H. J. Broers and H. J. J. von Ballegoy, Journees Int. Etude Piles Combustibles, Comptes Rendus III, Bruxelles, 77-86 (1969).

13.16 A. B. Hart and G. J. Womack, "Fuel Cells," Chapman and Hall, Ltd., London (1967).

13.17 C. G. von Fredersdorff, "An Outline of the Economics of a Domestic Fuel Cell System," in "Fuel Cells", Vol. 2, J. Young, Editor, Reinhold Publ. Co., New York, 1963.

13.18 EPRI Meeting, High Temperature Fuel Cell Discussion Notes, comments by B. Baker and Houghtby.

13.19 Y. L. Sandler, J. Electrochemical Society, 109, 1115-18, 1962.

13.20 R. W. Hardy, W. E. Chase and J. McCallum in "Hydrocarbon Fuel Cell Technology," B. Baker, Editor, Academic Press, 1965.

13.21 J. O'M. Bockris and S. Srinivasan, "Fuel Cells: Their Electro-chemistry," McGraw Hill Co., 1969, pp. 622-3.

13.22 J. M. King, "Advanced Fuel Cell Technology for Utility Applications," Record of the Tenth Intersociety Energy Engineering Conference, pp. 237-40, Aug. 18-22, 1975.

13.23 M. Anbar, D. F. McMillen, and R. D. Weaver, "Electrochemical Power Generation Using a Liquid Lead Electrode as a Catalyst for the Oxidation of Carbonaceous Fuels," Record of the Tenth Inter-society Energy Engineering Conference, pp. 48-55, Aug. 18-22, 1975.

13.24 T. L. Markin, "Limiting Problems in the Development of a High Temp-
erature Solid Oxide Electrolytic Fuel Cell," Proceedings of the
18th International Symposium on Power Sources, Brighton, England;
September 1972, Paper 3, pp. 31-42.

13.25 Final Report - Project Fuel Cell, Research and Development Report
No. 57, Office of Coal Research, Department of the Interior,
Washington, 1971.

13.26 D. H. Archer, L. Elikan, R. L. Zchradnik, "The Performance of
Solid-Electrolyte Cells in Batteries on $CO-H_2$ Mixtures; A 100-Watt
Solid-Electrolyte Power Supply," in Hydrocarbon Fuel Cell
Technology, Edited by B. S. Baker, Academic Press, New York, 1965;
pp. 51-75.

13.27 E. F. Sverdrup, C. J. Warde, A. D. Glasser, "A Fuel-Cell Power
System for Central-Station Power Generation Using Coal as a Fuel,"
from Electrocatalysis to Fuel Cells, G. Sandstede (Editor),
University of Washington Press, 1972; pp. 255-77.

13.28 C. J. Warde, A. O. Isenberg,   in Part II - Appendix of Reference
13.1

13.29 S. G. Abers, B. S. Baker, R. D. Pasquale, I. Michelko, "Phosphoric
Acid Fuel Cell Stack Development," Record of the Tenth Intersociety
Energy Conversion Engineering Conference, August 18-22, 1975,
pp 218-21.

13.30 K. V. Kordesch, R. F. Scarr, "Thin Carbon Electrodes for Acidic
Fuel Cells," Conference Proceeding, 7th Intersociety Energy
Conversion Engineering Conference, September 25-29, 1972; p. 12-19.

13.31 W. R. Wolfe, Jr., K. B. Keating, V. Mehra,   L. H. Cutler,
"A New Class of Fuel Cell Anode Catalysts," 8th Intersociety
Energy Conversion Engineering Conference Proceedings, August 13-16,
1973; pp. 92-5.

13.32 T. G. Schiller, A. P. Meyer, "1.5-kW Fuel Cell Power Plant,"
Contract DAAK 02-C-0518, U. S. Army Mobility Equipment, Research
and Development Center, Fort Belvoir, Virginia, May 20, 1971.

13.33 Reference 13.2, p. 524.

13.34 "Assumptions, Models and Correlations for Task I", for "Study of Advanced Energy Conversion Techniques for Utility Applications using Coal and Coal-Derived Fuels," compiled by D. T. Beecher, Project Manager, Westinghouse Electric Corporation; January 21, 1975; p. 2-9.

13.35 O. J. Adlhart, A. J. Hartner; "Plastic-Bonded Electrodes," Proceedings of the 21st Power Sources Conference 1967, pp. 4-6.

13.36 G. T. Lee, J. D. Leslie, H. M. Rodikohr, "The Cost of Hydrogen Made from Natural Gas," Hydrocarbon Processing and Petroleum Refiner, 42 (9) 125-8 (1963).

13.37 March Monthly Progress Narative, "Study of Advanced Energy Conversion Techniques for Utility Applications Using Coal and Coal-Derived Fuels," compiled by D. T. Beecher, Project Manager, Westinghouse Electric Corporation, April 14, 1975; p. 42.

13.38 JANAF Thermochemical Tables, 2nd Edition, NSRDS, NBS 37, June 1971.

13.39 K. V. Kordesch, Private Communication, April, 1975.

13.40 Englehard Industries, Murray Hill, N.J.

13.41 R. H. Perry and C. H. Chiltan, "Chemical Engineers Handbook," p. 19-67, McGraw-Hill Book Company, New York, 1973.

13.42 Westinghouse Electric Corporation, Price List No. 1252, p. 19.

13.43 Reference 13.25, pp. 17-36.

13.44 K. M. Guthrie, "Process Plant, Estimating, Evaluation, and Control," Craftsman Book Company of America, 1974.

13.45 "Economic Evaluation of a 200 MW Coal-Burning Fuel-Cell Power Plant," Final report prepared by the Institute of Gas Technology for Westinghouse Electric Corporation, January 1969.

13.46 J. Werssbart, R. Ruka, "A Solid Electrolyte Fuel Cell," J. Electrochem. Soc., 109 (8) 723-6 (1962).

13.47 K. V. Kordesch, "Carbon Electrodes," Conference Proceedings, Fuel Cell Catalysis Workshop, EPRI Special Report, SR-13, August 1975, pp. 101-6.

13.48 "Chemical Engineering," (McGraw-Hill); March 22, 1971, p. 170, and March 17, 1975, p. 120.

13.49 "Engineering Study and Technical Evaluation of the BCR Two-Stage Super-Pressure Gasification Process", R&D Report No. 60, Office of Coal Research, Department of the Interior, Washington, 1971.

13.50 W. P. Hegarty, B. E. Moody, "Evaluating the Bi-Gas SNG Process," Chemical Engineering Progress 69 (3) pp 37-42, March 1973.

13.51 P. Wood, Power Electronics Dept., Westinghouse Research Laboratories, Pittsburgh, Pa., private communication.

13.52 Power Transformer Division, Westinghouse Electric Corporation, Sharon, Pa.

13.53 Switchgear Division, Westinghouse Electric Corporation, Trafford, Pa.

13.54 E. J. Vidt, Chemical Engineering Systems Dept., Westinghouse Research Laboratories, Pittsburgh, Pa., private communication.

13.55 J. F. Strecansky, Air Products and Chemicals, Allentown, Pa., private communication.

Appendix A 13.1

FUEL PROCESSING FOR LOW-TEMPERATURE FUEL CELL POWER PLANTS


The fuels employed in the parametric assessment of the low-temperature fuel cell power systems are medium-Btu gas (AC4 and AL4), methanol (AC14), and high-Btu gas (all other points). In order for these fuels to be usable at the anodes of the acid or alkaline fuel cell modules, they must be converted to a fuel gas consisting principally of hydrogen.

For high-Btu gas, consisting principally of methane, steam reformation coupled with shift conversion is the most economical method of producing this fuel gas. Carbon dioxide removal from the fuel gas stream is necessary in the alkaline case to prevent conversion of the potassium hydroxide electrolyte to potassium carbonate. This step is not required in the acid fuel cell system, as phosphoric acid does not react with carbon dioxide. Auxiliary equipment necessary in both power systems includes steam generators to supply the steam requirements of the reformer. Thus, an acid fuel cell power plant, fueled with high-Btu gas, requires a steam reformer, a shift converter, and a steam generator. In addition to these components, the alkaline fuel cell system must include a carbon dioxide removal subsystem.

When medium-Btu gas, which is principally comprised of carbon monoxide (approximately 55% by volume) and hydrogen (approximately 33% by volume), is the fuel, there is obviously no need for steam reformation. Shift conversion and steam generation, to meet the steam requirements of the shift converter, are still required. As stated in Subsection 13.3, the carbon dioxide content of the medium-Btu gas stream after shift conversion is approximately double that in the shift-converter effluent for high-Btu gas. Thus, for alkaline power plants

13-96

using medium-Btu gas as the fuel  carbon dioxide must be scrubbed at twice the rate necessary in plants operating on high-Btu gas.  Although methanol may be cracked directly to form hydrogen and carbon monoxide (Reference 13.5), this study assumed that methanol, used in the power plant corresponding to Point AC14, is fed to a steam reformer, just as in the case of high-Btu gas.

To deliver one kilowatt of electrical power from a phosphoric acid fuel cell operating at a terminal voltage of 0.7 V, a cell current of 1429 A is required.  Thus, a minimum of 1429/96489 equivalents or 14.9 mg/s (3.28 x $10^{-5}$ lb/s) of hydrogen must be delivered to the anode. The hydrogen requirement for an alkaline fuel cell is lower because of the higher cell voltage  and may be calculated by the use of a multiplier, 0.7 V/0.8 V.

The optimum level of hydrogen utilization  in a  fuel  cell is a complex function of the fuel cell performance  and the relative costs of the fuel cell subsystem, the fuel processing subsystem, and the fuel, as the unused hydrogen may be employed to provide the thermal requirement of the steam reformer, as described below.  The preparation of a detailed conceptual design of the complete power system, coupled with the knowledge of fuel cell performance as a function of hydrogen utilization, would  permit  accurate estimation of this optimum level. For the purposes of this preliminary study, however, utilization rates of 90 and 80% were assumed for feedstocks of high- and  medium-Btu gas, respectively, for the reasons outlined in Subsection 13.3.1. These assumptions lead to the hydrogen requirements for the four ratings of fuel cell subsystems shown in Table A 13.1.1.  The 900 MW power plants operate with medium-Btu gas as fuel; all others employ high-Btu gas as a feedstock.

In the following subsections, the procedures employed in the costing of the reformer, the shift converter, the steam generators and the carbon dioxide removal subsystem, necessary for the production of the required hydrogen, are described.  In addition, a brief description

Feed

S

D

R

SG

to S

BFW

To Shift Converter

D: De-sulfurizer        S: Steam feed to reformer
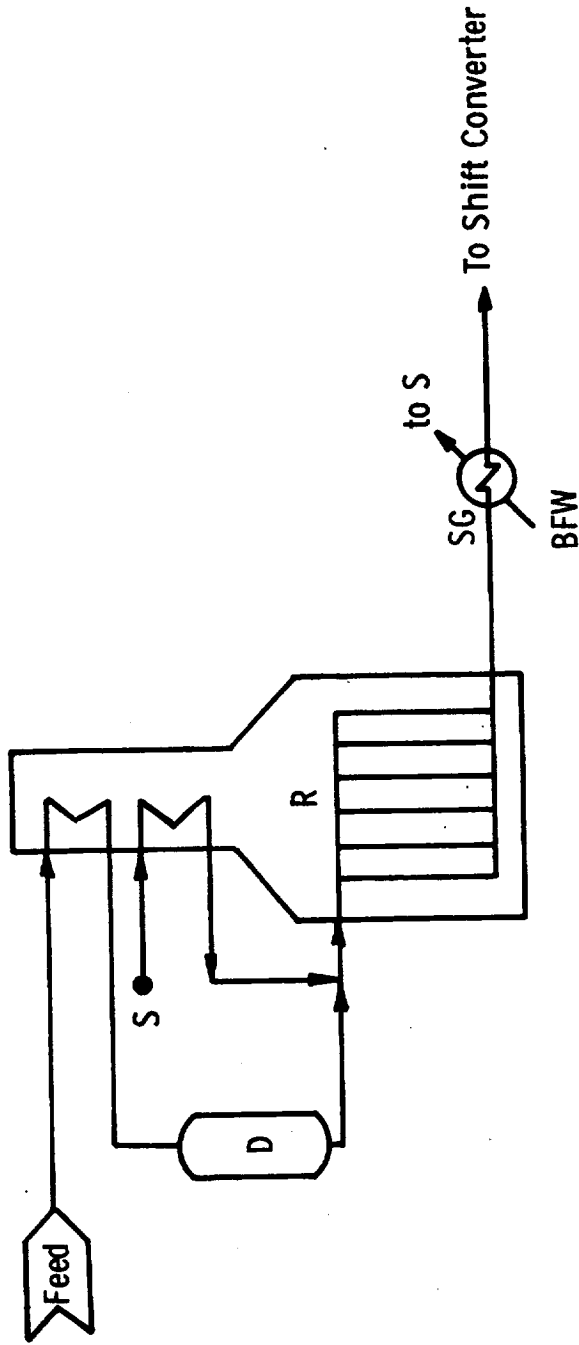
SG: Steam-Generator     BFW: Boiler feed water

R: Gas-Fired Steam Reformer

Fig. A 13.1.1 —Schematic of a steam-methane reformer system

Table A 13.1.1 - Hydrogen Requirements of Low-Temperature
Fuel Cell Power Plants

| Fuel Cell Rating, MW | Hydrogen Requirements, tons/d | |
|---|---|---|
| | Acid | Alkaline |
| 25 | 39.5 | 34.5 |
| 100 | 158 | 138 |
| 250 | 395 | 345 |
| 900 | 1600 | 1400 |

is given of the cost assumptions for the blowers used for the circulation of air through the cathode components of the fuel cell modules.

A 13.1.1  Steam-Methane Reformer

A schematic of a typical steam-reforming unit, is shown in Figure A 13.1.1. The reforming furnace is gas fired, and the convection tube banks are fabricated from carbon steel. The radiant tubes, made from stainless steel, operate at a pressure of 0.689 MPa (100 psi) abs. High-Btu gas is preheated, desulfurized by passage through activated carbon beds, mixed with preheated steam, and fed to the catalyst-filled furnace, which operates at 1033 to 1144°K (1400 to 1600°F). This reaction

$$CH_4 + H_2O \rightarrow CO + 3H_2,$$
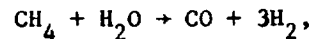
$$\Delta H_{1600°F} = 97,400 \text{ Btu/lb-mole } CH_4$$

is highly endothermic. As one lb-mole of methane produces four moles of hydrogen (after shift conversion) or 42.87 std $m^3$ (1514 scf), the reformer heat duty, Q/P, may be calculated as shown:

Table A 13.1.2 – Heat Duty and High-Btu Gas Requirements and Base Costs (Mid-1974) of Steam-Methane Reformers for Hydrogen Production in Fuel Cell Power Plants

| Hydrogen Production Rate | | Reformer Heat Duty x $10^{-6}$, Btu/hr | High-Btu Gas Usage x $10^{-3}$, scf/hr | Base Cost x $10^{-3}$, $ |
|---|---|---|---|---|
| ton/d | scf/hr x $10^{-3}$ | | | |
| 34.5 | 530 | 34 | 200 | 220 |
| 39.5 | 610 | 39 | 230 | 250 |
| 138 | 2,100 | 140 | 800 | 550 |
| 158 | 2,400 | 160 | 920 | 590 |
| 345 | 5,300 | 340 | 2,000 | 1,100 |
| 395 | 6,100 | 390 | 2,300 | 1,200 |

Table A 13.1.3 – Breakdown of Adjustments to Base Costs (Mid-1974) of Steam-Methane Reformers for Hydrogen Production in Fuel Cell Power Plants

| Base Cost x $10^{-3}$, $ | Adjustment Factors | | | | Purchased Equipment Base Cost x $10^{-3}$, $ |
|---|---|---|---|---|---|
| | Furnace Type | Tube Material | Tube Pressure | Total | |
| 220 | 1.345 | 0.345 | 0.05 | 1.740 | 380 |
| 250 | 1.345 | 0.345 | 0.05 | 1.740 | 440 |
| 550 | 1.342 | 0.341 | 0.05 | 1.733 | 950 |
| 590 | 1.342 | 0.341 | 0.05 | 1.733 | 1,020 |
| 1100 | 1.341 | 0.340 | 0.05 | 1.731 | 1,900 |
| 1200 | 1.341 | 0.340 | 0.05 | 1.731 | 2,100 |

$$Q/P = \frac{97{,}400 \text{ Btu}}{1514 \text{ scf}} = 64.3 \text{ Btu/scf of } H_2 \text{ required.}$$

The reformer heat duty for all six hydrogen production levels is presented in Table A 13.1.2. Shown also are the total quantities of high-Btu gas required, based on arguments presented in Section 13.3.1.

Using these heat-duty values, the base cost of the steam-methane reformer may be calculated. The method of cost estimation for all fuel conditioning costs follows an approach outlined by Guthrie (Reference 13.44) which uses mid-1970 prices. The costs have been factored upward by the ratio of the average Marshall and Stevens indices (Reference 13.48) for the second and third quarters of 1974 and 1970 (1.34). The base costs in mid-1974 terms are shown in the last column of Table A 13.1.2.

These base costs must be adjusted upward by a multiplier which is the sum of factors to allow for furnace type, radiant tube material, and pressure. This yields purchased equipment base costs, which are shown in the last column of Table A 13.1.3.

The total direct cost of the reformer includes the purchased equipment base cost computed earlier, plus the materials and labor required for installation. Following Guthrie (Reference 13.44), installation materials (less concrete) typically average 25.4%. These are summarized in Table A 13.1.4. The total cost shown does not include indirect costs associated with construction overhead, engineering, interest during construction, etc.

A 13.1.2  Shift Converter

After leaving the steam reforming unit, the gases are cooled to between 644 and 700°K (700 and 800°F) and passed over a water-gas shift catalyst to convert the carbon monoxide component to carbon dioxide and hydrogen by the reaction

$$CO + H_2O \rightarrow CO_2 + H_2$$
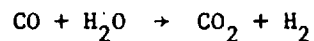
Table A 13.1.4 - Reformer Costs (Mid-1974) for Fuel Cell Power Plants

| System Type | Fuel Cell Rating, MW | Reformer Costs x $10^{-3}$, \$ | | | |
|---|---|---|---|---|---|
| | | Purchased Equipment | Installation Material | Total Material | Site Labor |
| Alkaline | 25 | 380 | 97 | 480 | 110 |
| Acid | 25 | 440 | 110 | 550 | 130 |
| Alkaline | 100 | 950 | 240 | 1,200 | 280 |
| Acid | 100 | 1,020 | 260 | 1,300 | 300 |
| Alkaline | 250 | 1,900 | 480 | 2,400 | 550 |
| Acid | 250 | 2,100 | 530 | 2,600 | 610 |

Table A 13.1.5 - Shift-Converter Volumes, Dimensions, and Base Costs (Mid-1974)

| Hydrogen Required ton/d | Volume, $ft^3$ | | Vessel Dimensions, ft | | Base Costs x $10^{-3}$, \$ |
|---|---|---|---|---|---|
| | Catalyst | Vessel | Length | Diameter | |
| 34.5 | 270 | 540 | 23 | 5.5 | 36 |
| 39.5 | 320 | 640 | 24 | 6 | 45 |
| 138 | 1,100 | 2,200 | 35 | 9 | 77 |
| 158 | 1,250 | 2,500 | 39 | 9 | 81 |
| 345 | 2,700 | 5,400 | 70 | 10 | 140 |
| 395 | 3,200 | 6,400 | 80 | 10 | 180 |
| 1400 | 11,000 | 22,000 | 90 | 18 | 610 |
| 1600 | 13,000 | 26,000 | 100 | 18 | 640 |

A schematic of the shift conversion unit is shown in Figure A 13.1.2.
The shift converter is a pressure vessel loaded with an appropriate
catalyst. In the four smallest sizes a length-to-diameter ratio of
four is assumed. If a space velocity of 0.556 $s^{-1}$ (2,000 $hr^{-1}$) is
assumed, the volume of catalyst required may be calculated. The overall
volume of the vessel is considered to be twice that of the catalyst.

The costing technique again follows that of Guthrie (Reference
13.44), with an escalation factor of 1.34 to convert mid-1970 costs to
those of mid-1974. In the penultimate column of Table A 13.1.6, the base
costs (mid-1974) shown are for a carbon steel vessel operating at 0.345
MPa (50 psi) abs. The costs include shell and two heads, nozzles and
runways, skirt, base ring, and lugs. The shift converter, however,
should operate from 2.76 to 3.45 MPa (400 to 500 psi) abs for compatibility
with the steam-methane reformer. All costs at 0.345 MPa (50 psi) abs
were multiplied by 2.8 to allow for high-pressure design costs. These
costs are shown in the last column of Table A 13.1.7.

Installation costs of vertical pressure vessels are typically
3.05 times the base costs (Reference 13.44). The total material and site
labor costs of the shift converter units for the different ratings of acid
and alkaline fuel-cell power plants are shown in Table A 13.1.5.

A 13.1.3  Steam Generators

An excess of steam, generally three to five times the stoi-
chiometric requirement, is employed in the steam-methane reformer.
Steam is raised in three main locations: 1) between the reformer and
shift converter, in the cooling of the fuel gases from 1144 to 700°K
(1600 to 800°F), as shown in Figure A 13.1.1; 2) by the use of the
heat rejected by the shift converter; and 3) in cooling the hydrogen-
rich fuel gas from 700 to 464°K (800 to 375°F), the temperature of
operation of the acid fuel-cell modules. The steam-generators of 2 and
3 are shown schematically in Figure A 13.1.2.

For the purposes of calculation, it will be assumed that 3
moles of steam are required in the reformer for every 4 moles of hydrogen

Table A 13.1.6 — Shift-Converter Costs (Mid-1974) for Fuel Cell Power Plants

| System Type | Fuel Cell Rating, MW | Shift Converter Costs x $10^{-3}$, $ | | | |
|---|---|---|---|---|---|
| | | Base | Installation Material | Total Material | Site-Labor |
| Alkaline | 25 | 36 | 20 | 56 | 21 |
| Acid | 25 | 45 | 25 | 70 | 26 |
| Alkaline | 100 | 77 | 43 | 120 | 45 |
| Acid | 100 | 81 | 46 | 130 | 47 |
| Alkaline | 250 | 140 | 79 | 220 | 81 |
| Acid | 250 | 180 | 100 | 280 | 100 |
| Alkaline | 900 | 610 | 340 | 950 | 350 |
| Acid | 900 | 640 | 360 | 1,000 | 370 |

Table A 13.1.7 — Steam Requirements and Generator Costs (Mid-1974) for Fuel Cell Power Plants

| Hydrogen Production Rate (ton/d) | (x $10^3$, scf/hr) | Steam Rate x $10^{-3}$, lb/hr | Steam Generator Base Cost x $10^{-3}$, $ |
|---|---|---|---|
| 34.5 | 530 | 19 | 66 |
| 39.5 | 610 | 22 | 77 |
| 138 | 2,100 | 75 | 199 |
| 158 | 2,400 | 85 | 230 |
| 345 | 5,300 | 190 | 350 |
| 395 | 6,100 | 220 | 420 |
| 1400 | 21,000 | 750 | 1,500 |
| 1600 | 24,000 | 850 | 1,600 |
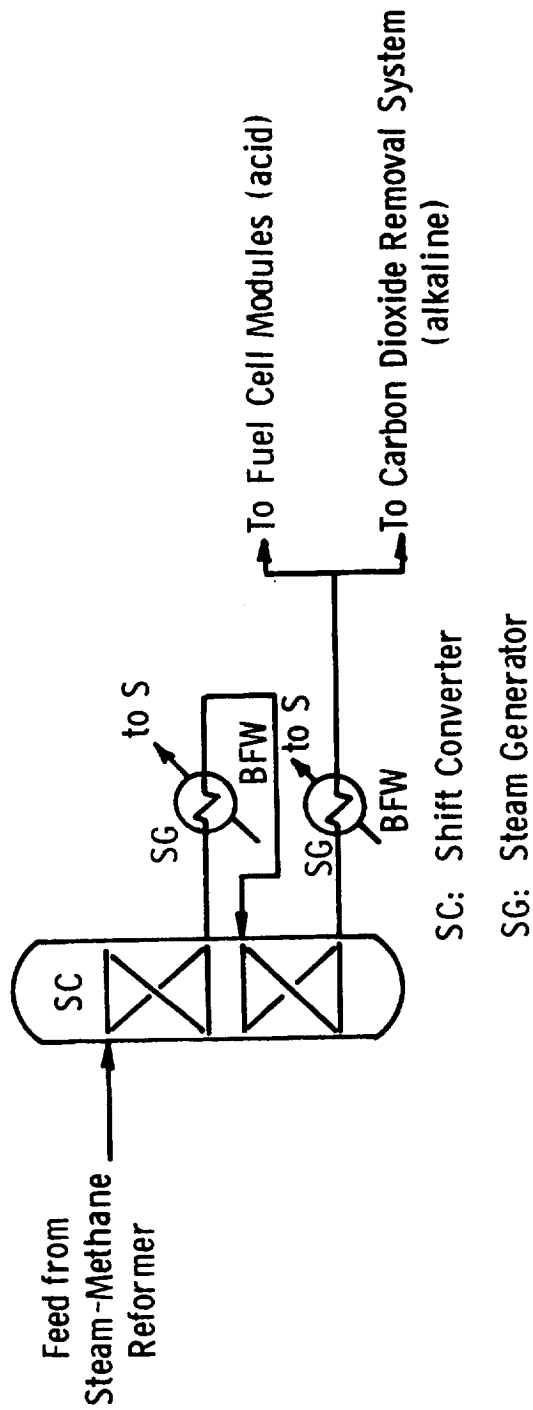
Fig. A 13.1.2 – Schematic of shift conversion unit for fuel-cell power plants

SC: Shift Converter

SG: Steam Generator

Table A 13.1.8 - Steam Generator Costs (Mid-1974) for Fuel Cell Power Plants

| System Type | Fuel Cell Rating, MW | Steam Generator Costs x $10^{-3}$, $ | | | |
|---|---|---|---|---|---|
| | | Base | Installation Material | Total Material | Site-Labor |
| Alkaline | 25 | 66 | 8.4 | 74 | 20 |
| Acid | 25 | 77 | 9.9 | 87 | 24 |
| Alkaline | 100 | 190 | 24 | 210 | 58 |
| Acid | 100 | 230 | 29 | 260 | 70 |
| Alkaline | 250 | 350 | 45 | 400 | 110 |
| Acid | 250 | 420 | 54 | 470 | 130 |
| Alkaline | 900 | 1,500 | 140 | 1,700 | 450 |
| Acid | 900 | 1,600 | 200 | 1,800 | 470 |

Table A 13.1.9 - Estimates of Material and Site Labor Costs for Fuel Gas Scrubbing in an Alkaline Fuel Cell Power Plant

| Fuel Cell Rating, MW | Hydrogen Required, ton/d | Fuel Gas Flow Rate, lb-moles/hr | Material Costs x $10^{-3}$, $ | Site Labor Costs x $10^{-3}$, $ |
|---|---|---|---|---|
| 25 | 34.5 | 1,760 | 420 | 140 |
| 100 | 138 | 7,200 | 1,700 | 560 |
| 250 | 345 | 17,600 | 4,200 | 1,410 |
| 900 | 1400 | 72,000 | 23,000 | 7,700 |

reaching the fuel cell modules. The steam requirements are, therefore, 0.570 kg of steam/std m$^3$ of hydrogen (0.0356 lb of steam/scf of hydrogen). Table A 13.1.7 presents the steam rates and steam generator base costs (mid-1974) as a function of hydrogen production. The costing method again follows that of Guthrie (Reference 13.44). The total material and site labor costs are shown in Table A 13.1.8 for all four ratings of acid and alkaline fuel cell power plants.

A 13.1.4  Carbon Dioxide Removal System

Leaving the shift converter, the fuel gas steam is at a temperature of 700°K (800°F) and a pressure of 0.483 MPa (70 psi) abs. The carbon dioxide-carbon monoxide ratio is approximately 50. The gas composition is ∿ 70% hydrogen, ∿ 10% steam, and the balance carbon oxides and inerts. The steam may be cooled and the steam condensed to yield a gas mixture of 80% H$_2$, 17% carbon oxides, and 3% inerts. This fuel gas may be fed directly to the acid fuel-cell modules.

In the alkaline system, however, carbon dioxide removal must still be accomplished in order to protect the potassium hydroxide electrolyte. The process considered for this application is shown schematically in Figure A 13.1.3. It consists of the Lurgi Rectisol Process, which uses refrigerated methanol. The total capital investment for a Rectisol System capable of stripping carbon dioxide and hydrogen sulfide from 4.16 kg-moles/s (33,000 lb moles/hr) of fuel gas in the Bituminous Coal Research Bi-Gas Process (Reference 13.49) was $23.5 million (mid-1970) (Reference 13.50). When factored upward by 1.34 to convert to mid-1974 costs, the total capital investment required is approximately $0.582 per kg-mole/s ($950 per lb-mole/hr) of fuel gas.

If it is assumed that the direct installed cost of the scrubbing system represents 28.5% of the total capital investment (Reference 13.52) and that the material-to-site labor ratio is equal to three, approximate estimates of the equipment and site labor costs for
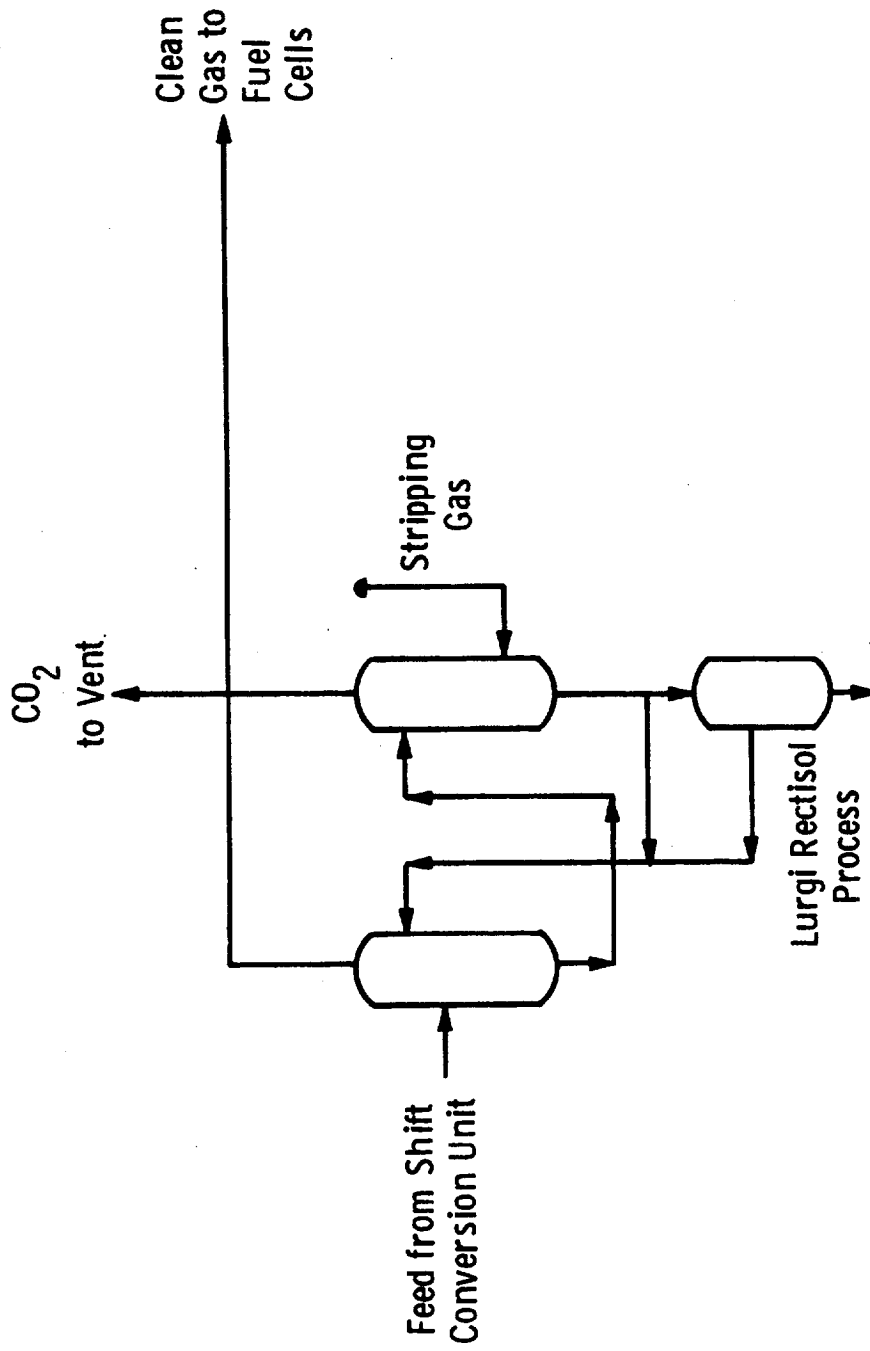
Fig. A 13.1.3—Schematic of carbon dioxide removal system for alkaline fuel-cell power plants

the Rectisol Process may be derived. These are shown for the four ratings of alkaline fuel cell power plants in Table A 13.1.9. A linear relationship is assumed between scrubber cost and volume of gas scrubbed. Because of the additional load on the scrubbing system of the 900 MW plant due to the use of medium-Btu gas as the fuel the costs are multiplied by 1.35.

Two of these scrubbing units are required per power plant, as carbon dioxide must also be removed from air. Although air contains approximately four orders of magnitude less carbon dioxide than does the fuel gas, the costs associated with scrubbing air were assumed to be the same as those given in Table A 13.1.9. In general, the equipment cost was assumed to be a linear function of the quantity of gas passed through the process. For a 50% utilization of oxygen in air, the quantity of throughput air would be approximately a factor of eight greater than that of fuel gas. The advantages associated with the lower concentration of carbon dioxide in air, however, were assumed to approximately negate the eight-to-one flow penalty. The treatment above, though very crude and allowing for no economy of scale, yields reasonable costs for scrubbing equipment to remove carbon dioxide from fuels and air. The value of $22/kW for air scrubbing in this closed-cycle process is acceptable when compared with $5/kW for the much simpler process involving the use of potassium hydroxide on a once-through basis (Reference 13.8).

A 13.1.5 Air Blowers

The costing of air blowers for the fuel cell subsystem was performed following the method of Guthrie (Reference 13.44). The air blower cost, C, in mid-1974 dollars is given by

$$C = \$ \ (9) \ (1.34) \ (\text{Required airflow rate in scfm})^{0.68}$$

With the assumption of 50% utilization of the oxygen in the throughput air, a value of $19,000 is calculated for the air blowers in the 25 MW

phosphoric acid fuel cell power plant. A site labor cost equivalent to 33% of the equipment cost was arbitrarily assumed. The material and site labor costs for all power plants were derived similarly.

Possible errors in these estimates arising from the under-estimation of the pressure drop through the fuel cell modules are likely to have a negligible impact on the total capitalization of the fuel cell power plant. A total material and site labor cost of $25,000 for the 25 MW acid system air blowers is trivial when compared with, for example, a cost of $3.8 million for the fuel cell subsystem.

Appendix A 13.2

POWER-CONDITIONING SUBSYSTEM


Power-conditioning subsystems are necessary in fuel cell power plants for the conversion of the dc output of the fuel cell modules to 60 Hz ac power. NASA has specified that the 25 MW plant* should deliver power at 69 kV to the distribution net, but the output from the other three sizes — 100*, 250*, and 900 MW* — should be at 500 kV. The following is a discussion of inverter subsystems and transformers which are necessary to accomplish the required power conversion, and the resultant implications for the selection of fuel cell module sizes.

In general, there are at least seven power conversion schemes that can be considered for this application. These are: (1) chopper-inverter; (2) inverter; (3) buck-boost inverters; (4) complementary inverters; (5) HF link; (6) hybrid (HF link + simple line-commutated inverter), and (7) force-commutated inverter. In a recent study at Westinghouse Research Laboratories (Reference 13.51), scheme 7 was found to be optimum from an economic and technical standpoint. Force-commutated systems not only operate with lower losses (4-1/2 to 5% versus 5 to 6% for the more conventional line-commutated systems) but also offer considerable operational advantages:

- They will ride through a system fault.

- It is possible to control their behavior with respect to reactive power demand and deliver independently of

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*25, 100, 250 and 900 MW ratings apply to fuel cell subsystems. The overall plant ratings are less,due to inverter subsystem losses and other parasitic losses in the fuel cell power system.
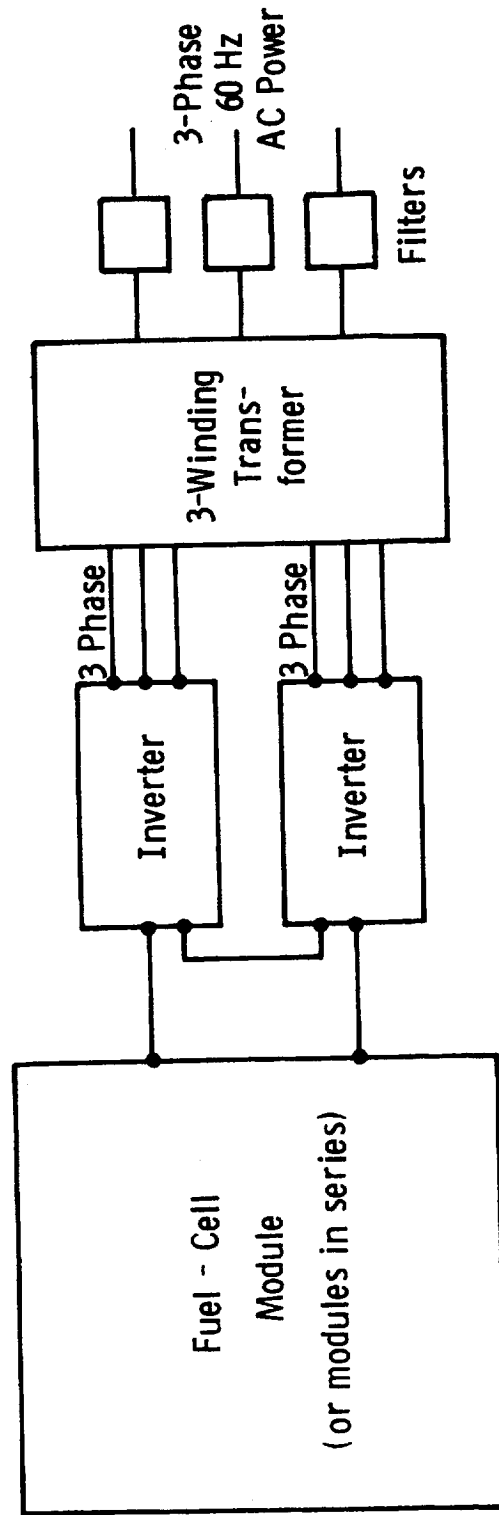
Fig. A 13.2.1 — Block diagram of power conversion equipment required for fuel-cell power plants

real power, thus conferring great stability on the power conversion system.

- They will start and run into a passive load.

Force-commutated inverter systems, however, suffer from a major limitation in that the state of the art indicates an upper limit of approximately 2 kV output voltage. Because of transformer primary-current considerations, this constraint limits use of this type of inverter system to the 25 MW case.

For the larger power plants (100, 250, and 900 MW) a line-commutated inverter system must be used. Systems 1 through 3 are typical line-commutated schemes and represent relatively simple extensions of high voltage dc (HVDC) technology. Of these three, the buck-boost inverter is optimum from a cost standpoint. Further, it is close to being the most efficient and has no operational disadvantages compared to the other line-commutated schemes. Most significantly, power factor improvement is achievable with this scheme. This results in a considerable savings in cost because auxiliary power-factor correction equipment is not needed. Although this inverter system can run, in theory, into a passive load, the stability of this operational mode is questionable in practice unless a synchronous capacitor is used to supply reactive VA. Another disadvantage of line-commutated inverter systems, which applied also to this scheme, is that the dc side must be quickly interrupted after a system fault in order to protect the overall system. From this standpoint, line-commutated schemes compare unfavorably with force-commutated systems, which, as noted above, are able to ride through system faults.

The basic inverter unit, in the force- and line-commutated systems above, is the 3-phase bridge or Graetz connection. This is illustrated in Figure A 13.2.1. It should be noted that the ac outputs of the two inverters are out of phase by $\pi/6$. The transformer required for step-up of the inverters' output to distribution voltages levels should have a twin core structure. For the line-commutated inverter

scheme, wye-delta and delta-delta windings are specified, while in the force-commutated inverter case, one core should involve a wye-open wye winding plus a delta tertiary, and the other a delta-wye winding. These specifications, plus the poor power factor at which the transformers operate, result in transformer costs which are approximately double those of conventional transformers of the same kVA rating (Reference 13.52).

Table A 13.2.1 outlines the relationship between the dc and three-phase ac currents and voltages for the force- and line-commutated systems, where $\alpha$ is the firing angle delay of the line-commutated inverter, and $\phi$ is the phase-shift angle of the force-commutated inverter.

Table A 13.2.1   -   The Relationships Between Electrical Input and Output of Inverter Systems

| System Parameters | Inverter System Type | |
| | Force-Commutated | Line-Commutated |
| --- | --- | --- |
| Voltage | $V_{ac} = \left(\dfrac{\sqrt{6}}{\pi}\right) V_{dc}$ | $V_{ac} = \left(\dfrac{\pi}{3\sqrt{2}}\right) \cos\alpha \; V_{dc}$ |
| Current | $I_{ac} = \left(\dfrac{\pi}{3\sqrt{2}}\right)(\cos\phi)(I_{dc})$ | $I_{ac} = \left(\dfrac{\sqrt{6}}{\pi}\right) I_{dc}$ |
| Power | $\sqrt{3} \; (V_{ac})(I_{ac})(\cos\phi)$ | $\sqrt{3} \; (V_{ac})(I_{ac})(\cos\alpha)$ |

The sizes, weights, and selling prices of inverter systems for the four power plant ratings are shown in Table A 13.2.2. All the data shown are based on the results of a previous study of inverter systems for 25 MW fuel cell power plants. The plan area/MW (Reference 13.51) for the buck-boost systems at the various rating levels were calculated

by multiplication of the plan area requirement at the 25 MW level by the cube root of the ratio of the ratings of the larger system to the 25 MW unit. This factoring upwards ensures adequate clearance at the higher ratings, thus minimizing problems associated with creepage paths. The weights are taken from the above mentioned study (Reference 13.51) The selling price data are derived from estimates of $60/kW and $55/kW for 25 MW line-commutated and force-commutated systems respectively, and from an estimate of $\sim$ $65/kW for the buck-boost system at the 900 MW level. The values for the 100 and 250 MW systems were derived by linear interpolation. The increases in capital costs on going to the larger plant sizes is due to higher costs of filters and the greater need for grading networks for the valves.

Because of the lack of demonstrated reliability of fuel cell modules in extended service, it is not unreasonable to specify for all fuel cell power plants that a fault on the dc side should result in outages of not more than 10% of the rated capacity. Thus, in all cases, ten banks of fuel-cell modules are envisioned, each with its own inverter pair and transformer. In general, only one set of filters and switch-gear will be used on the high sides of the transformers.

In the 25 MW plants, each of the banks of fuel cell module may be run at $\sim$ 2200 A dc (1.15 kV dc). Single transformation from $\sim$ 900 V ac to the required 69 kV ac level is achievable. In the 900 MW plants, ten banks of fuel cell modules are envisioned, each operating at 2900 A dc and $\sim$ 31 kV dc. The $\sim$ 23 kV ac output of the inverter pair permits single transformation to the required level of 500 kV ac.

Single transformation, however, is not possible without a significant inverter cost penalty in the 100 MW plants. Under the 10% outage constraint, each bank would contain 10 MW of fuel cell modules. As the ac output from the inverters must be at least 16 kV to facilitate single transformation to 500 kV ac, the fuel cell dc voltage requirements could be as high as $\sim$ 27 kV, assuming a worst-case inverter power factor of 0.8. This would result in a dc current input to the inverters of

Table A 13.2.2 — Sizes, Weights, and Costs of Inverter Systems for Fuel Cell Power Plants

| Fuel Cell Rating, MW | Inverter Type | Plan Area,* ft$^2$/MW | Weight, lb/MW | Selling Price,** $/MW |
|---|---|---|---|---|
| 25 | Force-commutated | 29 | 7,900 | 55,000 |
| 100 | Buck-boost | 23 | 4,800 | 60,000 |
| 250 | Buck-boost | 32 | 4,800 | 61,000 |
| 900 | Buck-boost | 48 | 4,800 | 65,000 |

* 8 ft total height excluding bushings, for 25 MW; approximately 30 ft for 100, 250, and 900 MW plants because of 500 kV tie.

** Prices include cost of single transformation. If double transformation is required, the costs shown must be increased by $10,000/MW.

Table A 13.2.3 — Vendor, Site Labor, and Total Costs (Mid-1974) of Power Conditioning Subsystems for Fuel Cell Power Plants

| Fuel Cell Rating, MW | Power-Conditioning Costs x 10$^{-3}$, $ | | |
|---|---|---|---|
| | Equipment | Site Labor | Total |
| 25 | 1,380 | 75 | 1,455 |
| 100* | 7,000 | 300 | 7,300 |
| 250* | 17,500 | 750 | 18,250 |
| 900 | 59,000 | 2,700 | 61,700 |

* Costs include additional transformation step at $10,000/MW

∿ 370 A which is too low for the inverters to be economical (Reference 13.51). Rather than pay inverter costs more than twice those for systems operating at ∿ 2200 A dc, it is more reasonable to pay the additional price for double transformation. This is estimated (Reference 13.52) to be ∿ $10,000/MW. An intermediate ac voltage of 34.5 kV will optimize the system with a dc voltage in each 10 MW bank of 4.6 kV (2200 A dc).

Similar considerations apply to the 250 MW plant. The 25 MW banks would supply less than 1 kA dc under the worst-case condition mentioned above. Once again, double transformation is economically more attractive than paying for increased inverter capability. Here, an intermediate ac voltage of 69 kV is envisioned with a dc voltage of ∿ 11.5 kV (2200 A dc) in each 25 MW bank.

For the purposes of this study, an efficiency of 95.5% is assumed for the power-conditioning subsystems of all 25 MW power plants, based on the use of a force-commutated inverter system. Line-commutated inverter systems must be employed in the 100, 250, and 900 MW power plants. Here, an efficiency of 95% is assumed. Double transformation, however, is required in all 100 and 250 MW power plants for the reasons outlined above. The second transformer is assumed to have an efficiency of 99.5%, so the net efficiency of the power-conditioning subsystem of the 100 and 250 MW plants is (95%)(0.995) or 94.5%.

The site labor costs are based on recent experience (mid-1974) of the Westinghouse Electric Corporation with the installation of a VAR generator (a device to inhibit voltage flickering in an arc furnace) in a steel-making facility of Akron Steel (Reference 13.53). The installation of this equipment, which is very similar in character to the power-conditioning subsystems described above, involved a site labor of approximately $3/kW. This value has been employed in this study.

The equipment, site labor, and total costs of the power-conditioning subsystems for the four fuel cell power plant ratings are presented in Table A 13.2.3. The costs for the 100 and 250 MW power plants reflect the cost of double transformation. All these designs and

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costs are based on a maximum input variation of the dc current and voltage
to the power-conditioning subsystem of 5%. Point 9 in all four fuel cell
power systems explores the effect of the variation of the voltage
degradation at constant power for 5 to 15% in 25 MW plants. The power-
conditioning subsystem must, therefore, have the capability of handling
this greater variation of current and voltage characteristic of fuel cell
subsystems. The cost of the power-conditioning equipment may be
assumed to be proportional to the dc current (Reference 13.51). At
constant power the system with 15% voltage degradation would have to
carry 20% more current than the system with a 5% voltage degradation.
The costs of the power-conditioning subsystem for AC9, AL9, MC9, and
SE9 were estimated by adding 20% to the value for the base case.

Appendix A 13.3

OXYGEN PLANTS FOR FUEL CELL POWER SYSTEMS


A fuel cell plant may be integrated with an oxygen plant as well as with a coal gasification plant. If oxygen is supplied to both the coal gasification unit (for production of medium-or high-Btu gas) and to the fuel cell plant, the total oxygen cost will be of similar magnitude to the coal cost.

Oxygen requirements depend on the type and size of the fuel cell and source of the coal, and are roughly 0.8 and 1.4 Mg of oxygen per Mg of coal, respectively, for the gasification and fuel cell plants. Thus, substitution of oxygen for air at the fuel cell cathode would have to give a considerable improvement in the power density at a given efficiency to justify the high oxygen costs involved.

The cost of oxygen from an on-site plant as operated by the utility is a strong function of plant size and the cost of energy for the compressor. Requirement for a 25 MW fuel cell would be about 3.15 kg/s (300 ton/d) of oxygen. The maximum size plant design commercially available is 21 kg/s (∿ 2000 ton/d) of oxygen, so that large fuel cell plants (e.g., 900 MW) would require multiple plants of this size. Only minor cost reductions would be realized for multiple plants on the same site, beyond the single 21 kg/s (2000 ton/d) plant size.

The cost of oxygen produced by different size commercial plants (utility operated) was estimated (Reference 13.54) on the basis of the approximate commercial plant cost and operational data supplied by Air Products Corporation (Reference 13.55). The costs are adjusted to July 1974 dollars. Table A 13.3.1 shows oxygen costs for two plant sizes,

Table A 13.3.1 - Oxygen Production Costs (330 use days per year)

| Size, ton/d | 300 | 2000 |
|---|---|---|
| **A. Motor-Driven Plants** | | |
| Capital charges at 18% | 1,008,000 | 3,412,800 |
| Maintenance at 2% of investment | 112,000 | 379,200 |
| Power at 3.0¢/kWh | 946,600 | 5,132,000 |
| Water at 10¢/1000 gal | 63,100 | 342,100 |
| Labor at $30,000/man year | 180,000 | 240,000 |
| Total | 2,309,700 | 9,506,100 |
| $/ton | 23.33 | 14.41 |
| | | |
| **B. Turbine-Driven Plants** | | |
| Capital charges at 18% | 1,064,200 | 3,603,200 |
| Maintenance at 2% of investment | 118,200 | 400,400 |
| Power at 3.0¢/kWh | 17,900 | 121,200 |
| Water at 10¢/1000 gal | 248,800 | 1,344,400 |
| Labor at $30,000/man year | 180,000 | 240,000 |
| Steam - free | 0 | 0 |
| Total | 1,629,000 | 5,709,200 |
| $/ton | 16.45 | 8.65 |

3.15 and 21 kg/s (300 and 2000 ton/d) and for an electric motor driven compressor or a turbine driven compressor. The calculations assume that the turbine driven compressor is operated on steam generated from the free waste heat from the fuel cell and that the electric motor drive compressor uses electricity from the fuel cell costing 8.3 mills/MJ (30 mills/kWh), which would appear to be about the minimum cost that could be expected from a 315 Ms (10 yr) life optimized fuel cell from the present study. A recirculating water cost of $ 0.026/m$^3$ ($ 0.10/1000 gal) is assumed. Also included are 18% per year capital based charges for depreciation, interest, local taxes, etc., plus 2% per year for maintenance.

We should note that the costs do not include the cost of the steam generating equipment which is used to remove waste heat from the fuel cell for the turbine-drive compressor plants, and that oxygen costs for electric motor-driven compressor plants will vary with the cost of electricity produced by the fuel cell.

Electric-driven compressors are assumed for Point 5 for the 25 MW acid, alkaline, and high-temperature solid electrolyte fuel cells, and the fuel cell electrical output is derated by the energy required. A turbine-driven compressor using steam generated by the waste heat is assumed for the molten carbonate Point 5 (25 MW dc fuel cell) and Point 17 (250 MW dc fuel cell), so the electrical output is not derated for those system points.

Appendix A 13.4

COMPUTER OUTPUT SHEETS

Table A 13.4.1     PHOSPHORIC ACID FUEL CELL SYSTEM     ACCOUNT LISTING
PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **SITE DEVELOPMENT** | | | | | | |
| 1. 1 LAND COST | ACRE | 1.5 | 100000.00 | .00 | 150000.00 | .00 |
| 1. 2 CLEARING LAND | ACRE | 1.5 | 600.00 | .00 | | 299.97 |
| 1. 3 GRADING LAND | ACRE | 1.5 | .00 | 3000.00 | | 4500.00 |
| 1. 4 ACCESS RAILROAD | MILE | .0 | 115000.00 | 110000.00 | | .00 |
| 1. 5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 70000.00 | | .00 |
| 1. 6 SIDING R R TRACK | MILE | .0 | 125000.00 | 80000.00 | | .00 |
| 1. 7 OTHER SITE COSTS | ACRE | .0 | | | 3736.39 | 3736.79 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = 2.063 ACCOUNT TOTAL,$ | | | | | 153736.39 | 8536.76 |
| | | | | | | |
| **EXCAVATION & PILING** | | | | | | |
| 2. 1 COMMON EXCAVATION | YD3 | 9600.0 | .00 | 3.00 | .00 | 28800.00 |
| 2. 2 PILING | FT | .0 | 6.50 | 8.50 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .366 ACCOUNT TOTAL,$ | | | | | .00 | 28800.00 |
| | | | | | | |
| **PLANT ISLAND CONCRETE** | | | | | | |
| 3. 1 PLANT IS. CONCRETE | YD3 | 3200.0 | 70.00 | 80.00 | 224000.00 | 256000.00 |
| 3. 2 SPECIAL STRUCTURES | YD3 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 6.103 ACCOUNT TOTAL,$ | | | | | 224000.00 | 256000.00 |
| | | | | | | |
| **HEAT REJECTION SYSTEM** | | | | | | |
| 4. 1 COOLING TOWERS | EACH | 1.0 | .00 | .00 | .00 | .00 |
| 4. 2 CIRCULATING H2O SYS | EACH | 1.0 | .00 | .00 | .00 | .00 |
| 4. 3 SURFACE CONDENSER | FT2 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| **STRUCTURAL FEATURES** | | | | | | |
| 5. 1 STRL. STRUCTURAL ST. | TON | .0 | 650.00 | 175.00 | .00 | .00 |
| 5. 2 SILOS & BUNKERS | TPH | .0 | 1800.00 | 750.00 | .00 | .00 |
| 5. 3 CHIMNEY | FT | 1.0 | .00 | .00 | .00 | .00 |
| 5. 4 STRUCTURAL FEATURES | EACH | 1.0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| **BUILDINGS** | | | | | | |
| 6. 1 STATION BUILDINGS | FT3 | 5000.0 | 16.00 | 14.00 | 80000.00 | 70000.00 |
| 6. 2 ADMINSTRATION | FT2 | .0 | 16.00 | 16.00 | .00 | .00 |
| 6. 3 WAREHOUSE & SHOP | FT2 | .0 | 12.00 | 8.00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = 1.907 ACCOUNT TOTAL,$ | | | | | 80000.00 | 70000.00 |
| | | | | | | |
| **FUEL HANDLING & STORAGE** | | | | | | |
| 7. 1 COAL HANDLING SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7. 2 DOLOMITE HAND. SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7. 3 FUEL OIL HAND. SYS | GAL | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

Table A 13.4.1   PHOSPHORIC ACID FUEL CELL SYSTEM   ACCOUNT LISTING
Continued                    PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST.$ | INS COST.$ |
|---|---|---|---|---|---|---|
| FUEL PROCESSING | | | | | | |
| 6..1 CCAL GASIFIER | EACH | .0 | .000 | .000 | .00 | .00 |
| 6..2 DESULFURIZER | EACH | .0 | .000 | .000 | .00 | .00 |
| 6..3 VENTURI SCRUBBER | EACH | .0 | .000 | .000 | .00 | .00 |
| 6..4 CCAL PRETREATMENT | EACH | 1.0 | 558000.000 | 114000.000 | 558000.00 | 114000.00 |
| 6..5 REFORMER | EACH | 1.0 | 679000.000 | 25300.000 | 679000.00 | 25300.00 |
| 6..6 SHIFT CONVERTER | EACH | | | | | |
| 6..7 CO2 SCRUBBER | EACH | | | | | |
| 6..8 BLOWER | EACH | 1.0 | 19000.00 | 5000.000 | 13000.00 | 5000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 8 | =10.047 | ACCOUNT TOTAL.$ | | 6449000.00 | 1457000.00 |
| FIRING SYSTEM | | | | | | |
| 9..1 | | | | | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 9 | = .000 | ACCOUNT TOTAL.$ | .00 | .00 | .00 |
| VAPOR GENERATOR (FIRED) | | | | | | |
| 10..1 | | | | | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 10 | = .000 | ACCOUNT TOTAL.$ | .00 | .00 | .00 |
| ENERGY CONVERTER | | | | | | |
| 11..1 FUEL CELL SYSTEM | EACH | 1.0 | 333000.00 | 125000.00 | 333000.00 | 125000.00 |
| 11..2 STM TURBINE GENERATOR | EA | .0 | .00 | .00 | .00 | .00 |
| 11..3 OXYGEN PLANT | EACH | .0 | .25 | | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 11 | =50.287 | ACCOUNT TOTAL.$ | | 3830000.00 | 1250000.00 |
| COUPLING HEAT EXCHANGER | | | | | | |
| 12..1 HEAT REC STEAM GEN | EACH | 1.0 | 96000.00 | 23000.00 | 96000.00 | 23000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 12 | = 2.786 | ACCOUNT TOTAL.$ | | 96000.00 | 23000.00 |
| HEAT RECOVERY HEAT EXCH. | | | | | | |
| 13..1 RECUPERATOR | EACH | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 13 | = .000 | ACCOUNT TOTAL.$ | | | |
| WATER TREATMENT | | | | | | |
| 14..1 DEMINERALIZER | GPM | .0 | 2500.00 | 700.00 | .00 | .00 |
| 14..2 CONDENSATE POLISHING | KWE | .0 | 1.25 | .30 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 14 | = .000 | ACCOUNT TOTAL.$ | | | |
| POWER CONDITIONING | | | | | | |
| 15..1 POWER CONDITIONING EQ | EA | 1.0 | 1380000.00 | 75000.00 | 1380000.00 | 75000.00 |
| 15..2 STD TRANSFORMER | KVA | | | | 1730000.00 | 75000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 15 | =18.500 | ACCOUNT TOTAL.$ | | | |
| AUXILIARY MECH EQUIPMENT | | | | | | |
| 16..1 BOILER FEED PUMP &DR. | KWE | .0 | .55 | .04 | .00 | .00 |
| 16..2 OTHER PUMPS | KWE | .0 | .88 | .12 | .00 | .00 |
| 16..3 MISC SERVICE SYS | KWE | 33855.3 | 1.17 | .73 | 39583.42 | 24700.47 |
| 16..4 AUXILIARY BOILER | PPH | .0 | 4.00 | .30 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | 16 | = .317 | ACCOUNT TOTAL.$ | | 39583.42 | 24700.47 |

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Table A 13.4.1    PHOSPHORIC ACID FUEL CELL SYSTEM    ACCOUNT LISTING
Continued                  PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST.$ | INS COST.$ |
|---|---|---|---|---|---|---|
| PIPE & FITTINGS | | | | | | |
| 17.1 CONVENTIONAL PIPING | TON | 10.0 | 3000.00 | 1800.00 | 30000.00 | 18000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = .610 ACCOUNT TOTAL.$ | | | | | 30000.00 | 18000.00 |
| AUXILIARY ELEC EQUIPMENT | | | | | | |
| 18.1 MISC MOTERS,ETC | KWE | 6767.3 | 1.40 | .17 | 9474.15 | 1150.43 |
| 18.2 SWITCHGEAR & MCC PAN | KWE | 33836.3 | 1.95 | .45 | 65980.70 | 15226.32 |
| 18.3 CONDUIT,CABLES,TRAYS | FT | 100000.0 | 1.32 | 1.36 | 132000.00 | 136000.00 |
| 18.4 ISOLATED PHASE BUS | FT | 0.0 | 510.00 | | | |
| 18.5 LIGHTING & COMMUN | KWE | 33836.3 | .35 | 450.00 | 11842.69 | 14549.59 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 4.911 ACCOUNT TOTAL.$ | | | | | 219297.54 | 166926.34 |
| CONTROL, INSTRUMENTATION | | | | | | |
| 19.1 COMPUTER | EACH | 1.0 | 100000.00 | 3000.00 | 100000.00 | 3000.00 |
| 19.2 OTHER CONTROLS | EACH | 1.0 | 83000.00 | 50000.00 | 83000.00 | 50000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = 3.001 ACCOUNT TOTAL.$ | | | | | 183000.00 | 53000.00 |
| PROCESS WASTE SYSTEMS | | | | | | |
| 20.1 BOTTOM ASH | TPH | 0.0 | .00 | .00 | .00 | .00 |
| 20.2 DRY ASH | TPH | 0.0 | .00 | .00 | .00 | .00 |
| 20.3 WET SLURRY | TPH | | .00 | .00 | | |
| 20.4 ONSITE DISPOSAL | ACRE | 0.0 | 7676.49 | 11070.83 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = .000 ACCOUNT TOTAL.$ | | | | | .00 | .00 |
| STACK GAS CLEANING | | | | | | |
| 21.1 PRECIPITATOR | EACH | 0.0 | .00 | .00 | .00 | .00 |
| 21.2 SCRUBBER | KWE | 0.0 | .00 | .00 | .00 | .00 |
| 21.3 MISC STEEL & DUCTS | | | .00 | | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL.$ | | | | | .00 | .00 |

TOTAL DIRECT COSTS.$                                          6670522.25        994263.16

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Table  PHOSPHORIC ACID FUEL CELL SYSTEM  COST OF ELECTRICITY, MILLS/KW.HR
A 13.4.2  PARAMETRIC POINT NO. 1

ACCOUNT

TOTAL DIRECT COSTS,$
INDIRECT COST,$
PROF & OWNER COSTS,$
CONTINGENCY COST,$
SUB TOTAL,$
ESCALATION COST,$
INTREST DURING CONST,$
TOTAL CAPITALIZATION,$
COST OF ELEC-CAPITAL
COST OF ELEC-FUEL
COST OF ELEC-OP & MAIN
TOTAL COST OF ELEC

Table   PHOSPHORIC ACID FUEL CELL SYSTEM   COST OF ELECTRICITY,MILLS/KW.HR
A 13.4.2 Continued          PARAMETRIC POINT NO. 1

| ACCOUNT | RATE, PERCENT | FIXED CHARGE RATE, PCT | | | | |
|---|---|---|---|---|---|---|
| | | 10.00 | 14.40 | 18.00 | 21.60 | 25.00 |
| TOTAL DIRECT COSTS,$ | | 7864785. | 7864785. | 7864785. | 7864785. | 7864785. |
| INDIRECT COST,$ | 51.0 | 507074. | 507074. | 507074. | 507074. | 507074. |
| PROF & OWNER COSTS,$ | 8.0 | 629183. | 629183. | 629183. | 629183. | 629183. |
| CONTINGENCY COST,$ | 4.5 | 3539915. | 3539915. | 3539915. | 3539915. | 3539915. |
| SUB TOTAL,$ | | 9354958. | 9354958. | 9354958. | 9354958. | 9354958. |
| ESCALATION COST,$ | 6.5 | 534350. | 534350. | 534350. | 534350. | 534350. |
| INTREST DURING CONST,$ | 10.0 | 547132. | 547132. | 547132. | 547132. | 547132. |
| TOTAL CAPITALIZATION,$ | | 10436439. | 10436439. | 10436439. | 10436439. | 10436439. |
| COST OF ELEC-CAPITAL | 25.0 | 7.87220 | 11.33596 | 14.16995 | 17.00395 | 19.68049 |
| COST OF ELEC-FUEL | .0 | 25.01226 | 25.01226 | 25.01226 | 25.01226 | 25.01226 |
| COST OF ELEC-OP & MAIN | .0 | 10.89330 | 10.89330 | 10.89330 | 10.89330 | 10.89330 |
| TOTAL COST OF ELEC | .0 | 43.77775 | 47.24152 | 50.07551 | 52.90950 | 55.58605 |

| ACCOUNT | RATE, PERCENT | FUEL COST, $/10**6 BTU | | | | |
|---|---|---|---|---|---|---|
| | | 1.50 | 2.60 | 4.00 | 2.08 | 3.12 |
| TOTAL DIRECT COSTS,$ | | 7864785. | 7864785. | 7864785. | 7864785. | 7864785. |
| INDIRECT COST,$ | 51.0 | 507074. | 507074. | 507074. | 507074. | 507074. |
| PROF & OWNER COSTS,$ | 8.0 | 629183. | 629183. | 629183. | 629183. | 629183. |
| CONTINGENCY COST,$ | 4.5 | 3539915. | 3539915. | 3539915. | 3539915. | 3539915. |
| SUB TOTAL,$ | | 9354958. | 9354958. | 9354958. | 9354958. | 9354958. |
| ESCALATION COST,$ | 6.5 | 534350. | 534350. | 534350. | 534350. | 534350. |
| INTREST DURING CONST,$ | 10.0 | 547132. | 547132. | 547132. | 547132. | 547132. |
| TOTAL CAPITALIZATION,$ | | 10436439. | 10436439. | 10436439. | 10436439. | 10436439. |
| COST OF ELEC-CAPITAL | 18.0 | 14.16995 | 14.16995 | 14.16995 | 14.16995 | 14.16995 |
| COST OF ELEC-FUEL | .0 | 14.43015 | 25.01226 | 38.48040 | 20.00981 | 30.01471 |
| COST OF ELEC-OP & MAIN | .0 | 10.89330 | 10.89330 | 10.89330 | 10.89330 | 10.89330 |
| TOTAL COST OF ELEC | .0 | 39.49340 | 50.07551 | 63.54365 | 45.07306 | 55.07796 |

| ACCOUNT | RATE, PERCENT | CAPACITY FACTOR, PERCENT | | | | |
|---|---|---|---|---|---|---|
| | | 12.00 | 45.00 | 50.00 | 65.00 | 80.00 |
| TOTAL DIRECT COSTS,$ | | 7864785. | 7864785. | 7864785. | 7864785. | 7864785. |
| INDIRECT COST,$ | 51.0 | 507074. | 507074. | 507074. | 507074. | 507074. |
| PROF & OWNER COSTS,$ | 8.0 | 629183. | 629183. | 629183. | 629183. | 629183. |
| CONTINGENCY COST,$ | 4.5 | 3539915. | 3539915. | 3539915. | 3539915. | 3539915. |
| SUB TOTAL,$ | | 9354958. | 9354958. | 9354958. | 9354958. | 9354958. |
| ESCALATION COST,$ | 6.5 | 534350. | 534350. | 534350. | 534350. | 534350. |
| INTREST DURING CONST,$ | 10.0 | 547132. | 547132. | 547132. | 547132. | 547132. |
| TOTAL CAPITALIZATION,$ | | 10436439. | 10436439. | 10436439. | 10436439. | 10436439. |
| COST OF ELEC-CAPITAL | 18.0 | 76.75392 | 20.46771 | 14.16995 | 18.42094 | 11.51309 |
| COST OF ELEC-FUEL | .0 | 25.01226 | 25.01226 | 25.01226 | 25.01226 | 25.01226 |
| COST OF ELEC-OP & MAIN | .0 | 14.89108 | 11.29559 | 11.16484 | 11.16484 | 10.72358 |
| TOTAL COST OF ELEC | .0 | 116.65726 | 56.77556 | 50.07551 | 54.59804 | 47.24893 |

Table A 13.4.3    PHOSPHORIC ACID FUEL CELL SYSTEM

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT POW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 11 | .00000 | .00000 | 221.00000 | 120000.00000 |
| 18 | .11700 | 100.00000 | | 120000.00000 |
| TOTALS | .11700 | .50251 | 232.55377 | |

PHOSPHORIC ACID FUEL CELL SYSTEM    BASE CASE INPUT    23.2830

| | | | |
|---|---|---|---|
| NOMINAL POWER, MWE | 23.4000 | NET POWER, MWE | 23.4000 |
| NOM HEAT RATE, BTU/KW-HR | 9571.9998 | NET HEAT RATE, BTU/KW-HR | 9620.1001 |
| ST TURB HEAT RATE CHANGE | .0000 | | |

| | | NUMBER OF SHELLS | .0000 |
|---|---|---|---|
| CONDENSER | | TUBE LENGTH, FT | .0000 |
| DESIGN PRESSURE, IN HG A | 2.0000 | TERMINAL TEMP DIFF, F | .0000 |
| NUMBER OF TUBES/SHELL | .0000 | | |
| U, BTU/HR-FT2-F | .0000 | | |
| HEAT REJECTION | | APPROACH, F | .0000 |
| DESIGN TEMP, F | .0000 | OFF DESIGN TEMP, F | .0000 |
| RANGE, F | .0000 | LP TURBINE BLADE LEN, IN | .0000 |
| OFF DESIGN PRES, IN HG A | .0000 | | |

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 23.400 | 2.000 | 8 .000 | 9 .000 | 9572.000 10 1.500 |
| 6 .000 | 7 .000 | 13 .000 | 14 1.000 | 15 .000 |
| 11 .000 | 12 1.500 | 18 3200.000 | 19 5.000 | 20 2.000 .000 |
| 16 .000 | 17 .000 | 23 5000.000 | 24 .000 | 25 .000 .000 |
| 21 .000 | 22 .000 | 28 10.000 | 29 .000 | 30 .200 .000 |
| 26 .000 | 27 .000 | 33 .000 | 34 .000 | 35 .000 1.000 |
| 31 .000 | 32 1.000 | 38 100000.000 | 39 1.000 | 40 1.000 .000 |
| 36 100000.000 | 37 .000 | 43 .000 | 44 3000.000 | 45 83000.000 .000 |
| 41 .000 | 42 5.350 | 48 1.000 | 49 1.000 | 50 1.000 6.000 |
| 46 .000 | 47 .000 | | | |
| 51 .000 | 52 | | | |

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 1 1.000 | | 8 .000 | 9 1.000 | 1.000 |
| 6 .000 | 7 .000 | 13 558000.000 | 14 114000.000 | 15 6790.000 25300.000 |
| 11 .000 | 12 .000 | 18 .000 | 19 19000.000 | 20 600.000 1.000 |
| 16 .000 | 17 .000 | 23 1.000 | 24 383000.000 | 25 125000.000 .000 |
| 21 .000 | 22 .000 | 28 .000 | 29 .250 | 30 1.000 .000 |
| 26 .000 | 27 .000 | 33 .000 | 34 .000 | 35 .000 86000.000 |
| 31 23000.000 | 32 .000 | 38 1380000.000 | 39 75000.000 | 40 .000 .000 |
| 36 .000 | 37 .000 | 43 .000 | 44 .000 | 45 .000 1.000 |
| 41 .000 | 42 .000 | 48 .000 | 49 .000 | 50 .000 .000 |
| 46 .000 | 47 .000 | 53 .000 | 54 .000 | 55 221.000 .000 |
| 51 .200 | 52 | 58 .000 | 59 | 60 120000.000 |

Table A 13.4.4   ALKALINE FUEL CELL SYSTEM   ACCOUNT LISTING
PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| SITE DEVELOPMENT | | | | | | |
| 1. 1 LAND COST | ACRE | 1.5 | 100000.00 | .00 | 150000.00 | .00 |
| 1. 2 CLEARING LAND | ACRE | 1.5 | .00 | 500.00 | | 299.97 |
| 1. 3 GRADING LAND | ACRE | 1.5 | .00 | 300.00 | | 4500.00 |
| 1. 4 ACCESS RAILROAD | MILE | .0 | 115000.00 | 110000.00 | .00 | .00 |
| 1. 5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 70000.00 | .00 | .00 |
| 1. 6 SIDING R R TRACK | MILE | .0 | 125000.00 | 80000.00 | .00 | .00 |
| 1. 7 OTHER SITE COSTS | ACRE | .0 | .00 | .00 | 3736.39 | 3736.39 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = 1.536 ACCOUNT TOTAL,$ | | | | | 153736.39 | 8536.36 |
| | | | | | | |
| EXCAVATION & PILING | | | | | | |
| 2. 1 COMMON EXCAVATION | YD3 | 9600.0 | 3.00 | | 28800.00 | .00 |
| 2. 2 PILING | FT | .0 | 6.50 | 8.50 | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .281 ACCOUNT TOTAL,$ | | | | | 28800.00 | 28800.00 |
| | | | | | | |
| PLANT ISLAND CONCRETE | | | | | | |
| 3. 1 PLANT IS. CONCRETE | YD3 | 3200.0 | 70.00 | 80.00 | 224000.00 | 256000.00 |
| 3. 2 SPECIAL STRUCTURES | YD3 | .0 | .00 | .00 | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 4.691 ACCOUNT TOTAL,$ | | | | | 224000.00 | 256000.00 |
| | | | | | | |
| HEAT REJECTION SYSTEM | | | | | | |
| 4. 1 COOLING TOWERS | EACH | 1.0 | .00 | | | .00 |
| 4. 2 CIRCULATING H2O SYS | EACH | 1.0 | .00 | | | .00 |
| 4. 3 SURFACE CONDENSER | FT2 | .0 | .00 | | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .000 ACCOUNT TOTAL,$ | | | | | | .00 |
| | | | | | | |
| STRUCTURAL FEATURES | | | | | | |
| 5. 1 STAT. STRUCTURAL ST. | TON | .0 | 650.00 | 175.00 | .00 | .00 |
| 5. 2 SILOS & BUNKERS | TPH | .0 | 1800.00 | 750.00 | .00 | .00 |
| 5. 3 CHIMNEY | FT | .0 | .00 | .00 | .00 | .00 |
| 5. 4 STRUCTURAL FEATURES | EACH | 1.0 | 170000.00 | 30000.00 | 170000.00 | 30000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = 1.954 ACCOUNT TOTAL,$ | | | | | 170000.00 | 30000.00 |
| | | | | | | |
| BUILDINGS | | | | | | |
| 6. 1 STATION BUILDINGS | FT3 | 5000.0 | 16.16 | 14.16 | 80000.00 | 70000.00 |
| 6. 2 ADMINSTRATION | FT2 | .0 | 16.00 | .00 | 80000.00 | 70000.00 |
| 6. 3 WAREHOUSE & SHOP | FT2 | .0 | 12.00 | 8.00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = 1.466 ACCOUNT TOTAL,$ | | | | | 80000.00 | 70000.00 |
| | | | | | | |
| FUEL HANDLING & STORAGE | | | | | | |
| 7. 1 COAL HANDLING SYS | TPH | .0 | .00 | | .00 | .00 |
| 7. 2 DOLOMITE HAND. SYS | TPH | .0 | .00 | | .00 | .00 |
| 7. 3 FUEL OIL HAND. SYS | GAL | .0 | .00 | | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

Table A 13.4.4   ALKALINE FUEL CELL SYSTEM           ACCOUNT LISTING
Continued                PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST $ | INS COST $ |
|---|---|---|---|---|---|---|
| FUEL PROCESSING | | | | | | |
| 3.1 COAL GASIFIER | EACH | | .00 | .00 | | .00 |
| 3.2 DESULFURIZER | EACH | | .00 | .00 | | .00 |
| 3.3 VENTURI SCRUBBER | EACH | | .00 | .00 | | .00 |
| 3.4 COAL PRETREATMENT | EACH | 1.0 | 115000.00 | .00 | 115000.00 | .00 |
| 3.5 REFORMER CONVERTER | EACH | 1.0 | 210000.00 | .00 | 210000.00 | .00 |
| 3.6 SHIFT CONVERTER | EACH | 2.0 | 141000.00 | .00 | 282000.00 | .00 |
| 3.7 CO CONVERTER | EACH | | | | | |
| 3.8 BLOWER | EACH | 1.0 | | | 416000.00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT | | | 27.727 | ACCOUNT TOTAL $ | 1355000.00 | |
| FIRING SYSTEM | | | | | | |
| 9.1 | | .0 | .000 | .00 | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 9 = | | | .000 | ACCOUNT TOTAL $ | | .00 |
| VAPOR GENERATOR (FIRED) | | | | | | |
| 10.1 | | .0 | .000 | .00 | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 10 = | | | .000 | ACCOUNT TOTAL $ | | .00 |
| ENERGY CONVERTER | | | | | | |
| 11.1 FUEL CELL SYSTEM | EACH | 1.0 | 125000.00 | .00 | 125000.00 | .00 |
| 11.2 STM TURBINE GENERATOR | EA | | .00 | .00 | | |
| 11.3 OXYGEN PLANT | EACH | 1.0 | | .00 | 125000.00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 11 = | | | .094 | ACCOUNT TOTAL $ | | |
| COUPLING HEAT EXCHANGER | | | | | | |
| 12.1 HEAT REC STEAM GEN | EACH | 1.0 | 74000.00 | .00 | 74000.00 | 20000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 12 = | | | .515 | ACCOUNT TOTAL $ | 74000.00 | 20000.00 |
| HEAT RECOVERY HEAT EXCH. | | | | | | |
| 13.1 RECUPERATOR | EACH | .0 | .000 | .00 | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 13 = | | | .000 | ACCOUNT TOTAL $ | | .00 |
| WATER TREATMENT | | | | | | |
| 14.1 DEMINERALIZER | GPM | .0 | 2500.00 | .00 | | .00 |
| 14.2 CONDENSATE POLISHING | KWE | .0 | 1.05 | .00 | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 14 = | | | .000 | ACCOUNT TOTAL $ | | .00 |
| POWER CONDITIONING | | | | | | |
| 15.1 POWER CONDITIONING EQ | EA | 1.0 | 175000.00 | .00 | 175000.00 | 75000.00 |
| 15.2 STD TRANSFORMER | KVA | | .00 | .00 | 1300000.00 | 75000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 15 = | | | 24.515 | ACCOUNT TOTAL $ | | |
| AUXILIARY MECH EQUIPMENT | | | | | | |
| 16.1 BOILER FEED PUMP & DR | KWE | .0 | .04 | .00 | | .00 |
| 16.2 OTHER PUMPS | KWE | .0 | .12 | .00 | | .00 |
| 16.3 MISC SERVICE SYS | KWE | 31041.7 | .75 | .00 | 37254.79 | 23244.49 |
| 16.4 AUXILIARY BOILER | PPH | .0 | 4.00 | .00 | | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 16 = | | | .531 | ACCOUNT TOTAL $ | 37254.79 | 23244.49 |

| ACCOUNT NO. & NAME, | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **PIPE & FITTINGS** | | | | | | |
| 17. 1 CONVENTIONAL PIPING | TON | 10.0 | 3000.00 | 1300.00 | 30000.00 | 13000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = .469 ACCOUNT TOTAL,$ | | | | | 30000.00 | 18000.00 |
| | | | | | | |
| **AUXILIARY ELEC EQUIPMENT** | | | | | | |
| 18. 1 MISC MOTERS,ETC | | 6368.3 | 1.40 | .17 | 8915.68 | 1082.62 |
| 18. 2 SWITCHGEAR & MCC PAN | KWE | 31841.7 | 1.95 | .45 | 62091.32 | 14328.77 |
| 18. 3 CONDUIT,CABLES,TRAYS | FT | 100000.0 | 1.32 | 1.36 | 132000.00 | 136000.00 |
| 18. 4 ISOLATED PHASE BUS | FT | .0 | 510.00 | 450.00 | .00 | .00 |
| 18. 5 LIGHTING & COMMUN | KWE | 31841.7 | .35 | .43 | 11144.60 | 13691.93 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 3.706 ACCOUNT TOTAL,$ | | | | | 214151.59 | 165103.31 |
| | | | | | | |
| **CONTROL, INSTRUMENTATION** | | | | | | |
| 19. 1 COMPUTER | EACH | 1.0 | 100000.00 | 3000.00 | 100000.00 | 3000.00 |
| 19. 2 OTHER CONTROLS | EACH | 1.0 | 83000.00 | 50000.00 | 83000.00 | 50000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = 2.306 ACCOUNT TOTAL,$ | | | | | 183000.00 | 53000.00 |
| | | | | | | |
| **PROCESS WASTE SYSTEMS** | | | | | | |
| 20. 1 BOTTOM ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 2 DRY ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 3 WET SLURRY | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 4 ONSITE DISPOSAL | ACRE | .0 | 7676.49 | 11070.83 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| **STACK GAS CLEANING** | | | | | | |
| 21. 1 PRECIPITATOR | EACH | .0 | .00 | .00 | .00 | .00 |
| 21. 2 SCRUBBER | KWE | .0 | .00 | .00 | .00 | .00 |
| 21. 3 MISC STEEL & DUCTS | | | .00 | | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

TOTAL DIRECT COSTS,$         8942142.62      12906804.11

Table A 13.4.5   ALKALINE FUEL CELL SYSTEM
PARAMETRIC PCINT NO. 1        COST OF ELECTRICITY, MILLS/KW.HR

ACCOUNT

TOTAL DIRECT COSTS, $
INDIRECT COST, $
PROF & OWNER COST, $
CONTINGENCY COST, $
SUB TOTAL, $
ESCALATION COST, $
INTREST DURING CONST, $
TOTAL CAPITALIZATION, $
COST OF ELEC-CAPITAL
COST OF ELEC-FUEL
COST OF ELEC-OP & MAIN
TOTAL COST OF ELEC

LABOR RATE, $/HR

CONTINGENCY, PERCENT

ESCALATION RATE, PERCENT

INT DURING CONST, PERCENT

Table ALKALINE FUEL CELL SYSTEM
A 13.4.5 Continued

PARAMETRIC POINT NO. 1    COST OF ELECTRICITY, MILLS/KW.HR

**FIXED CHARGE RATE, PCT**

| ACCOUNT | RATE, PERCENT | 10.00 | 14.40 | 18.00 | 21.50 | 25.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 10232827. | 10232827. | 10232827. | 10232827. | 10232827. |
| INDIRECT COST,$ | 51.0 | 658249. | 658249. | 658249. | 658249. | 658249. |
| PROF & OWNER COSTS,$ | 8.0 | 818626. | 818626. | 818626. | 818626. | 818626. |
| CONTINGENCY COST,$ | 4.5 | 460477. | 460477. | 460477. | 460477. | 460477. |
| SUB TOTAL,$ | | 12170179. | 12170179. | 12170179. | 12170179. | 12170179. |
| ESCALATION COST,$ | 6.5 | 695154. | 695154. | 695154. | 695154. | 695154. |
| INTREST DURING CONST,$ | 10.0 | 711782. | 711782. | 711782. | 711782. | 711782. |
| TOTAL CAPITALIZATION,$ | 25.0 | 13577115. | 13577115. | 13577115. | 13577115. | 13577115. |
| COST OF ELEC-CAPITAL | | 10.89292 | 15.68580 | 19.60725 | 23.52870 | 27.23230 |
| COST OF ELEC-FUEL | .0 | 23.31116 | 23.31116 | 23.31116 | 23.31116 | 23.31116 |
| COST OF ELEC-OP & MAIN | .0 | 17.83717 | 17.83717 | 17.83717 | 17.83717 | 17.83717 |
| TOTAL COST OF ELEC | .0 | 52.04124 | 56.83413 | 60.75558 | 64.67703 | 68.38062 |

**FUEL COST, $/10**6 BTU**

| ACCOUNT | RATE, PERCENT | 1.50 | 2.08 | 2.60 | 4.00 | 3.12 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 10232827. | 10232827. | 10232827. | 10232827. | 10232827. |
| INDIRECT COST,$ | 51.0 | 658249. | 658249. | 658249. | 658249. | 658249. |
| PROF & OWNER COSTS,$ | 8.0 | 818626. | 818626. | 818626. | 818626. | 818626. |
| CONTINGENCY COST,$ | 4.5 | 460477. | 460477. | 460477. | 460477. | 460477. |
| SUB TOTAL,$ | | 12170179. | 12170179. | 12170179. | 12170179. | 12170179. |
| ESCALATION COST,$ | 6.5 | 695154. | 695154. | 695154. | 695154. | 695154. |
| INTREST DURING CONST,$ | 10.0 | 711782. | 711782. | 711782. | 711782. | 711782. |
| TOTAL CAPITALIZATION,$ | 18.0 | 13577115. | 13577115. | 13577115. | 13577115. | 13577115. |
| COST OF ELEC-CAPITAL | | 19.60725 | 19.60725 | 19.60725 | 19.60725 | 19.60725 |
| COST OF ELEC-FUEL | .0 | 13.44874 | 18.64892 | 23.31116 | 35.86332 | 27.97339 |
| COST OF ELEC-OP & MAIN | .0 | 17.83717 | 17.83717 | 17.83717 | 17.83717 | 17.83717 |
| TOTAL COST OF ELEC | .0 | 50.89317 | 56.09335 | 60.75558 | 73.30774 | 65.41781 |

**CAPACITY FACTOR, PERCENT**

| ACCOUNT | RATE, PERCENT | 12.00 | 45.00 | 50.00 | 65.00 | 80.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 10232827. | 10232827. | 10232827. | 10232827. | 10232827. |
| INDIRECT COST,$ | 51.0 | 658249. | 658249. | 658249. | 658249. | 658249. |
| PROF & OWNER COSTS,$ | 8.0 | 818626. | 818626. | 818626. | 818626. | 818626. |
| CONTINGENCY COST,$ | 4.5 | 460477. | 460477. | 460477. | 460477. | 460477. |
| SUB TOTAL,$ | | 12170179. | 12170179. | 12170179. | 12170179. | 12170179. |
| ESCALATION COST,$ | 6.5 | 695154. | 695154. | 695154. | 695154. | 695154. |
| INTREST DURING CONST,$ | 10.0 | 711782. | 711782. | 711782. | 711782. | 711782. |
| TOTAL CAPITALIZATION,$ | 18.0 | 13577115. | 13577115. | 13577115. | 13577115. | 13577115. |
| COST OF ELEC-CAPITAL | | 106.20596 | 28.32159 | 25.48943 | 19.60725 | 15.93089 |
| COST OF ELEC-FUEL | .0 | 23.31116 | 23.31116 | 23.31116 | 23.31116 | 23.31116 |
| COST OF ELEC-OP & MAIN | .0 | 23.79024 | 18.43622 | 18.24153 | 17.83717 | 17.58445 |
| TOTAL COST OF ELEC | .0 | 153.30735 | 70.06896 | 67.04212 | 60.75558 | 56.82650 |

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# Table A 13.4.6 ALKALINE FUEL CELL SYSTEM

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT FCW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 11 | .00000 | .00000 | 350.00000 | 168000.00000 |
| 18 | .11000 | 100.00000 | .00000 | 168000.00000 |
| TOTALS | .11000 | .50251 | 360.95094 | |

### ALKALINE FUEL CELL SYSTEM

| | | | |
|---|---|---|---|
| NOMINAL POWER, MWE | 22.0000 | BASE CASE INPUT | 21.8900 |
| NOW HEAT RATE, BTU/KW-HR | 8920.9999 | NET POWER, MWE | 3965.8289 |
| ST TURB HEAT RATE CHANGE | .0000 | NET HEAT RATE, BTU/KW-HR | |
| CONDENSER | | | |
| DESIGN PRESSURE, IN HG A | 2.0000 | NUMBER OF SHELLS | .0000 |
| NUMBER OF TUBES/SHELL | .0000 | TUBE LENGTH, FT | .0000 |
| U, BTU/HR-FT2-F | .0000 | TERMINAL TEMP DIFF, F | .0000 |
| HEAT REJECTION | | | |
| DESIGN TEMP, F | .0000 | APPROACH, F | .0000 |
| RANGE, F | .0000 | OFF DESIGN TEMP, F | .0000 |
| OFF DESIGN PRES. IN HG A | .0000 | LP TURBINE BLADE LEN, IN | .0000 |

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 22.000 | 2.000 | .000 | .000 | 8921.000 |
| 6 | .000 | 7 | 8 | 9 | 10 |
| 11 | .000 | 12 | 1.000 | 14 | 15 |
| 16 | .000 | 17 | 1.500 | 18 | 20 |
| 21 | .000 | 22 | 3200.000 | 5000.000 | 25 |
| 26 | .000 | 27 | 28 | 29 | .200 |
| 31 | 1.000 | 32 | 10.000 | 34 | 1.000 |
| 36 | 100000.000 | 37 | 38 | 39 | 45 |
| 41 | 30000.000 | 42 | 10000.000 | 3000.000 | 83000.000 |
| 46 | .000 | 47 | 1.000 | 1.000 | 1.000 |
| 51 | .000 | 52 | 5.350 | 50 | |

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 1.000 | 2.000 | 2.000 | 1.000 | 1.000 |
| 6 | .000 | 7 | 8 | 9 | 10 |
| 11 | .000 | 12 | 500000.000 | 115000.000 | 56000.000 |
| 16 | 20000.000 | 17 | 141000.000 | 19 | 21000.000 |
| 21 | .000 | 22 | 23 | 24 | 25 |
| 26 | .000 | 27 | 28 | 500000.000 | 125000.000 |
| 31 | .000 | 32 | 33 | 1.000 | 1.000 |
| 36 | 20000.000 | 37 | 1380000.000 | 75000.000 | 74000.000 |
| 41 | .000 | 42 | 43 | 44 | 1.000 |
| 46 | .000 | 47 | 48 | 49 | 50 |
| 51 | .000 | 52 | 53 | 350.000 | 168000.000 |
| 56 | .200 | 57 | 58 | 59 | 60 |

Table A 13.4.7   MOLTEN CARBONATE FUEL CELL SYSTEM   ACCOUNT LISTING
PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| SITE DEVELOPMENT | | | | | | |
| 1. 1 LAND COST | ACRE | 1.5 | 100000.00 | 800.00 | 150000.00 | 299.97 |
| 1. 2 CLEARING LAND | ACRE | 1.5 | .00 | 800.00 | .00 | 4500.00 |
| 1. 3 GRADING LAND | ACRE | 1.5 | .00 | 3000.00 | .00 | .00 |
| 1. 4 ACCESS RAILROAD | MILE | .0 | 115000.00 | 110000.00 | .00 | .00 |
| 1. 5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 70000.00 | .00 | .00 |
| 1. 6 SIDING R R TRACK | MILE | .0 | 125000.00 | 80000.00 | .00 | .00 |
| 1. 7 OTHER SITE COSTS | ACRE | .0 | .00 | .00 | 3736.39 | 3736.39 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = 1.876  ACCOUNT TOTAL,$ | | | | | 153776.39 | 8536.36 |
| | | | | | | |
| EXCAVATION & PILING | | | | | | |
| 2. 1 COMMON EXCAVATION | YD3 | 9600.0 | 6.00 | 3.00 | .00 | 28800.00 |
| 2. 2 PILING | FT | .0 | 6.50 | 8.50 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .333  ACCOUNT TOTAL,$ | | | | | .00 | 28800.00 |
| | | | | | | |
| PLANT ISLAND CONCRETE | | | | | | |
| 3. 1 PLANT IS. CONCRETE | YD3 | 3200.0 | 70.00 | 80.00 | 224000.00 | 256000.00 |
| 3. 2 SPECIAL STRUCTURES | YD3 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 5.549  ACCOUNT TOTAL,$ | | | | | 224000.00 | 256000.00 |
| | | | | | | |
| HEAT REJECTION SYSTEM | | | | | | |
| 4. 1 COOLING TOWERS | EACH | .0 | .00 | .00 | .00 | .00 |
| 4. 2 CIRCULATING H2O SYS | EACH | 1.0 | .00 | .00 | .00 | .00 |
| 4. 3 SURFACE CONDENSER | FT2 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .000  ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| STRUCTURAL FEATURES | | | | | | |
| 5. 1 STAT. STRUCTURAL ST. | TON | .0 | 550.00 | 175.00 | .00 | .00 |
| 5. 2 SILOS & BUNKERS | TPH | .0 | 1800.00 | 750.00 | .00 | .00 |
| 5. 3 CHIMNEY | FT | .0 | .00 | .00 | .00 | .00 |
| 5. 4 STRUCTURAL FEATURES | EACH | 1.0 | 170000.00 | 30000.00 | 170000.00 | 30000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = 2.312  ACCOUNT TOTAL,$ | | | | | 170000.00 | 30000.00 |
| | | | | | | |
| BUILDINGS | | | | | | |
| 6. 1 STATION BUILDINGS | FT3 | 5000.0 | .16 | 14.16 | 30000.00 | 70000.00 |
| 6. 2 ADMINSTRATION | FT2 | .0 | 16.00 | 8.00 | .00 | .00 |
| 6. 3 WAREHOUSE & SHOP | FT2 | .0 | 12.00 | .00 | 30000.00 | 70000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = 1.734  ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| FUEL HANDLING & STORAGE | | | | | | |
| 7. 1 COAL HANDLING SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7. 2 DOLOMITE HAND. SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7. 3 FUEL OIL HAND. SYS | GAL | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = .000  ACCOUNT TOTAL,$ | | | | | .00 | .00 |

Table MOLTEN CARBONATE FUEL CELL SYSTEM          ACCOUNT LISTING
A 13.4.7 Continued       PARAMETRIC POINT NO. 1

| ACCOUNT NC. & NAME. | UNIT | AMOUNT | MAT MAT COST.$ | INS $/UNIT | INS $/UNIT | MAT COST.$ | INS COST.$ |
|---|---|---|---|---|---|---|---|
| **FUEL PROCESSING** | | | | | | | |
| 1 COAL GASIFIER | EACH | .0 | .00 | .00 | .00 | | .00 |
| 2 DESULFURIZER | EACH | .0 | .00 | .00 | .00 | | .00 |
| 3 VENTURI SCRUBBER | EACH | .0 | .00 | .00 | .00 | | .00 |
| 4 COAL PRETREATMENT | EACH | .0 | .00 | .00 | .00 | | .00 |
| 5 REFORMER | EACH | .0 | .00 | .00 | .00 | | .00 |
| 6 SHIFT CONVERTER | EACH | .0 | .00 | .00 | .00 | | .00 |
| 7 CO2 SCRUBBER | EACH | .0 | .00 | .00 | .00 | 3000.00 | 3000.00 |
| 8 BLOWER | EACH | 1.0 | 3000.00 | .00 | 3000.00 | 3000.00 | 3000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 8 = .270 ACCOUNT TOTAL.$ | | | | | | | |
| **FIRING SYSTEM** | | | | | | | |
| 9 1 | | .0 | .000 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 9 = .000 ACCOUNT TOTAL.$ | | | | | | | |
| **VAPOR GENERATOR (FIRED)** | | | | | | | |
| 10 1 | | .0 | .000 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 10 = .000 ACCOUNT TOTAL.$ | | | | | | | |
| **ENERGY CONVERTER** | | | | | | | |
| 11 1 FUEL CELL SYSTEM | EACH | 1.0 | 475000.00 | 200000.00 | 475000.00 | 200000.00 | 200000.00 |
| 11 2 STM TURBINE GENERATOR | EA | .0 | .00 | .00 | .00 | | .00 |
| 11 3 OXYGEN PLANT | EACH | .0 | .00 | .00 | .00 | 200000.00 | 200000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 11 = 57.251 ACCOUNT TOTAL.$ | | | | | | | |
| **COUPLING HEAT EXCHANGER** | | | | | | | |
| 12 1 HEAT REC STEAM GEN | EACH | 1.0 | 102000.00 | 51000.00 | 102000.00 | 51000.00 | 51000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 12 = 1.769 ACCOUNT TOTAL.$ | | | | | | | |
| **HEAT RECOVERY HEAT EXCH.** | | | | | | | |
| 13 1 RECUPERATOR | EACH | 1.0 | 136000.00 | 172000.00 | 136000.00 | 172000.00 | 172000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 13 = 3.607 ACCOUNT TOTAL.$ | | | | | | | |
| **WATER TREATMENT** | | | | | | | |
| 14 1 DEMINERALIZER | GPM | .0 | 3500.00 | .00 | 700.00 | .00 | .00 |
| 14 2 CONDENSATE POLISHING | KWE | .0 | 1.25 | .00 | .30 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 14 = .000 ACCOUNT TOTAL.$ | | | | | | | |
| **POWER CONDITIONING** | | | | | | | |
| 15 1 POWER CONDITIONING EQ | EA | 1.0 | 1780000.00 | 75000.00 | 1780000.00 | 1330000.00 | 75000.00 |
| 15 2 STD TRANSFORMER | KVA | .0 | 15.320 | .00 | | 1330000.00 | 75000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 15 = 15.320 ACCOUNT TOTAL.$ | | | | | | | |
| **AUXILIARY MECH EQUIPMENT** | | | | | | | |
| 16 1 BOILER FEED PUMP &DR. | KWE | .0 | .55 | .04 | | .00 | .00 |
| 16 2 OTHER PUMPS | KWE | .0 | .83 | .12 | | .00 | .00 |
| 16 3 MISC SERVICE SYS | KWE | 22554.0 | 1.17 | .73 | 56088.74 | 56088.74 | 23764.77 |
| 16 4 AUXILIARY BOILER | PPH | .0 | 4.00 | .30 | | .00 | 23764.77 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 16 = .715 ACCOUNT TOTAL.$ | | | | | | | |

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## MOLTEN CARBONATE FUEL CELL SYSTEM   ACCOUNT LISTING
### PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME, | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **PIPE & FITTINGS** | | | | | | |
| 17. 1 CONVENTIONAL PIPING | TON | 10.0 | 3000.00 | 1300.00 | 30000.00 | 18000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = .555 ACCOUNT TOTAL,$ | | | | | 30000.00 | 13000.00 |
| | | | | | | |
| **AUXILIARY ELEC EQUIPMENT** | | | | | | |
| 18. 1 MISC MOTERS,ETC | KWE | 6510.9 | 1.40 | .17 | 9115.25 | 1106.85 |
| 18. 2 SWITCHGEAR & MCC PAN | KWE | 32554.5 | 1.95 | .45 | 63481.23 | 14649.51 |
| 18. 3 CONDUIT,CABLES,TRAYS | FT | 100000.0 | 1.32 | 1.36 | 132000.00 | 136000.00 |
| 18. 4 ISOLATED PHASE BUS | FT | .0 | 510.00 | 450.00 | .00 | .00 |
| 18. 5 LIGHTING & COMMUN | KWE | 32554.5 | .35 | .43 | 11394.07 | 13998.42 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 4.413 ACCOUNT TOTAL,$ | | | | | 215990.54 | 165754.79 |
| | | | | | | |
| **CONTROL, INSTRUMENTATION** | | | | | | |
| 19. 1 COMPUTER | EACH | 1.0 | 100000.00 | 3000.00 | 100000.00 | 3000.00 |
| 19. 2 OTHER CONTROLS | EACH | 1.0 | 83000.00 | 50000.00 | 83000.00 | 50000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = 2.726 ACCOUNT TOTAL,$ | | | | | 183000.00 | 53000.00 |
| | | | | | | |
| **PROCESS WASTE SYSTEMS** | | | | | | |
| 20. 1 BOTTOM ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 2 DRY ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 3 WET SLURRY | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 4 ONSITE DISPOSAL | ACRE | .0 | 7676.49 | 11070.89 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| **STACK GAS CLEANING** | | | | | | |
| 21. 1 PRECIPITATOR | EACH | .0 | .00 | .00 | .00 | .00 |
| 21. 2 SCRUBBER | KWE | .0 | .00 | .00 | .00 | .00 |
| 21. 3 MISC STEEL & DUCTS | | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

TOTAL DIRECT COSTS,$     7491815.56     1158855.91

MOLTEN CARBONATE FUEL CELL SYSTEM    COST OF ELECTRICITY, MILLS/KW.HR
Table A 13.4.8                       PARAMETRIC POINT NO. 1

ACCOUNT

RATE, PERCENT

TOTAL DIRECT COSTS,$
INDIRECT COST,$
PROF & OWNER COSTS,$
CONTINGENCY COST,$
SUB TOTAL,$
ESCALATION COST,$
INTEREST DURING CONST,$
TOTAL CAPITALIZATION,$
COST OF ELEC-CAPITAL
COST OF ELEC-FUEL
COST OF ELEC-OP & MAIN
TOTAL COST OF ELEC

LABOR RATE, $/HR

CONTINGENCY, PERCENT

ESCALATION RATE, PERCENT

INT DURING CONST, PERCENT

MOLTEN CARBONATE FUEL CELL SYSTEM    COST OF ELECTRICITY, MILLS/KW.HR
Table A 13.4.8 Continued    PARAMETRIC POINT NO. 1

**FIXED CHARGE RATE, PCT**

| ACCOUNT | RATE, PERCENT | 10.00 | 14.40 | 18.00 | 21.00 | 25.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 8650671. | 8650671. | 8650671. | 8650671. | 8650671. |
| INDIRECT COST,$ | 51.0 | 591016. | 591016. | 591016. | 591016. | 591016. |
| PROF & OWNER COSTS,$ | 8.0 | 692054. | 692054. | 692054. | 692054. | 692054. |
| CONTINGENCY COST,$ | 4.5 | 389280. | 389280. | 389280. | 389280. | 389280. |
| SUB TOTAL,$ | | 10323022. | 10323022. | 10323022. | 10323022. | 10323022. |
| ESCALATION COST,$ | 6.5 | 589646. | 589646. | 589646. | 589646. | 589646. |
| INTREST DURING CONST,$ | 10.0 | 603750. | 603750. | 603750. | 603750. | 603750. |
| TOTAL CAPITALIZATION,$ | 25.0 | 11516417. | 11516417. | 11516417. | 11516417. | 11516417. |
| COST OF ELEC-CAPITAL | | 9.03430 | 13.00939 | 16.26173 | 19.51408 | 22.58574 |
| COST OF ELEC-FUEL | | 18.16864 | 18.16864 | 18.16864 | 18.16864 | 18.16864 |
| COST OF ELEC-OP & MAIN | | 23.37816 | 23.37816 | 23.37816 | 23.37816 | 23.37816 |
| TOTAL COST OF ELEC | | 50.58109 | 54.55618 | 57.90853 | 61.06088 | 64.13254 |

**FUEL COST, $/10**6 BTU**

| ACCOUNT | RATE, PERCENT | 1.50 | 2.00 | 2.60 | 4.00 | 3.12 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 8650671. | 8650671. | 8650671. | 8650671. | 8650671. |
| INDIRECT COST,$ | 51.0 | 591016. | 591016. | 591016. | 591016. | 591016. |
| PROF & OWNER COSTS,$ | 8.0 | 692054. | 692054. | 692054. | 692054. | 692054. |
| CONTINGENCY COST,$ | 4.5 | 389280. | 389280. | 389280. | 389280. | 389280. |
| SUB TOTAL,$ | | 10323022. | 10323022. | 10323022. | 10323022. | 10323022. |
| ESCALATION COST,$ | 6.5 | 589646. | 589646. | 589646. | 589646. | 589646. |
| INTREST DURING CONST,$ | 10.0 | 603750. | 603750. | 603750. | 603750. | 603750. |
| TOTAL CAPITALIZATION,$ | 18.0 | 11516417. | 11516417. | 11516417. | 11516417. | 11516417. |
| COST OF ELEC-CAPITAL | | 16.26173 | 16.26173 | 16.26173 | 16.26173 | 16.26173 |
| COST OF ELEC-FUEL | | 10.48191 | 14.53491 | 18.16064 | 27.95176 | 21.80237 |
| COST OF ELEC-OP & MAIN | | 23.37816 | 23.37816 | 23.37816 | 23.37816 | 23.37816 |
| TOTAL COST OF ELEC | | 50.12180 | 54.17480 | 57.80853 | 67.59165 | 61.44226 |

**CAPACITY FACTOR, PERCENT**

| ACCOUNT | RATE, PERCENT | 12.00 | 45.00 | 50.00 | 65.00 | 80.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 8650671. | 8650671. | 8650671. | 8650671. | 8650671. |
| INDIRECT COST,$ | 51.0 | 591016. | 591016. | 591016. | 591016. | 591016. |
| PROF & OWNER COSTS,$ | 8.0 | 692054. | 692054. | 692054. | 692054. | 692054. |
| CONTINGENCY COST,$ | 4.5 | 389280. | 389280. | 389280. | 389280. | 389280. |
| SUB TOTAL,$ | | 10323022. | 10323022. | 10323022. | 10323022. | 10323022. |
| ESCALATION COST,$ | 6.5 | 589646. | 589646. | 589646. | 589646. | 589646. |
| INTREST DURING CONST,$ | 10.0 | 603750. | 603750. | 603750. | 603750. | 603750. |
| TOTAL CAPITALIZATION,$ | 18.0 | 11516417. | 11516417. | 11516417. | 11516417. | 11516417. |
| COST OF ELEC-CAPITAL | | 108.08433 | 23.48917 | 21.14025 | 16.26173 | 13.21266 |
| COST OF ELEC-FUEL | | 18.16864 | 18.16364 | 16.16854 | 18.16864 | 18.16864 |
| COST OF ELEC-OP & MAIN | | 26.77361 | 28.71084 | 23.60879 | 23.37816 | 23.23401 |
| TOTAL COST OF ELEC | | 133.02663 | 65.37765 | 62.91768 | 57.80853 | 54.61531 |

Table A 13.4.9

## MOLTEN CARBONATE FUEL CELL SYSTEM

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT POW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 11 | | .00000 | 495.00000 | 98000.00000 |
| 18 | .11250 | 100.00000 | .00000 | 98000.00000 |
| TOTALS | .11250 | .50251 | 506.16736 | |

| | | | BASE CASE INPUT | |
| MOLTEN CARBONATE FUEL CELL SYSTEM | 22.5000 | NET POWER, MWE | | 22.3875 |
| NOMINAL POWER, MWE | 22.5000 | NET HEAT RATE, BTU/KW-HR | | 6987.9395 |
| NOM HEAT RATE, BTU/KW-HR | 6952.9999 | | | |
| ST TURB HEAT RATE CHANGE | .0000 | | | |
| CONDENSER | | | | |
| DESIGN PRESSURE, IN HG A | 2.0000 | NUMBER OF SHELLS | | .0000 |
| NUMBER OF TUBES/SHELL | .0000 | TUBE LENGTH, FT | | .0000 |
| U, BTU/HR-FT2-F | .0000 | TERMINAL TEMP DIFF, F | | .0000 |
| HEAT REJECTION | | | | |
| DESIGN TEMP, F | .0000 | APPROACH, F | | .0000 |
| RANGE, F | .0000 | OFF DESIGN TEMP, F | | .0000 |
| OFF DESIGN PRES, IN HG A | .0000 | LP TURBINE BLADE LEN, IN | | .0000 |

| 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|
| 22.500 | 2 | 22.500 | 7 | .000 | 8 | .000 | 9 | 6953.000 | 10 |
| .000 | 12 | .000 | 17 | 2.000 | 13 | .000 | 14 | .000 | 15 |
| .000 | 16 | 3200.000 | 22 | 1.500 | 18 | 1.000 | 19 | 2.000 | 20 |
| .000 | 21 | 5000.000 | 27 | .000 | 23 | 5.000 | 24 | .000 | 25 |
| .000 | 26 | 10.000 | 32 | .000 | 28 | .000 | 29 | .000 | 30 |
| 1.000 | 31 | .000 | 37 | .000 | 33 | .000 | 34 | .200 | 35 |
| 100000.000 | 36 | 100000.000 | 42 | .000 | 38 | 1.000 | 39 | 1.000 | 40 |
| 30000.000 | 41 | .000 | 47 | 3000.000 | 43 | 8300.000 | 44 | 50000.000 | 45 |
| .000 | 46 | 5.350 | 52 | .000 | 48 | 1.000 | 49 | 6.000 | 50 |
| .000 | 51 | | | | | | | | |

| 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|
| .000 | 7 | .000 | 12 | .000 | 8 | 1.000 | 9 | .000 | 10 |
| .000 | 11 | .000 | 17 | .000 | 13 | .000 | 14 | .000 | 15 |
| .000 | 16 | .000 | 22 | .000 | 18 | .000 | 19 | .000 | 20 |
| .000 | 21 | .000 | 27 | 2900.000 | 23 | 3000.000 | 24 | 1.000 | 25 |
| .000 | 26 | .000 | 32 | 4750000.000 | 28 | 20000.000 | 29 | 102000.000 | 30 |
| 51000.000 | 31 | .000 | 37 | .000 | 33 | 1.000 | 34 | .000 | 35 |
| 1380000.000 | 36 | 1.000 | 42 | 136000.000 | 38 | 176000.000 | 39 | 1.000 | 40 |
| .000 | 41 | .000 | 47 | 75000.000 | 43 | .000 | 44 | .000 | 45 |
| .000 | 46 | .000 | 52 | .000 | 48 | .000 | 49 | .000 | 50 |
| .200 | 51 | | | .000 | 53 | 495.000 | 54 | 98000.000 | 55 |
| | | | | | | | | | 60 |

SOLID ELECTROLYTE FUEL CELL     ACCOUNT LISTING
A 13.4.10
PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| SITE DEVELOPMENT | | | | | | |
| 1.1 LAND COST | ACRE | 1.5 | 100000.00 | .00 | 150000.00 | .00 |
| 1.2 CLEARING LAND | ACRE | 1.5 | .00 | 600.00 | .00 | 299.97 |
| 1.3 GRADING LAND | ACRE | 1.5 | .00 | 3000.00 | .00 | 4500.00 |
| 1.4 ACCESS RAILROAD | MILE | .0 | 115000.00 | 110000.00 | .00 | .00 |
| 1.5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 70000.00 | .00 | .00 |
| 1.6 SIDING R R TRACK | MILE | .0 | 125000.00 | 80000.00 | .00 | .00 |
| 1.7 OTHER SITE COSTS | ACRE | .0 | .00 | .00 | 3736.39 | 3736.39 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = 2.260 ACCOUNT TOTAL,$ | | | | | 153736.39 | 8536.36 |
| | | | | | | |
| EXCAVATION & PILING | | | | | | |
| 2.1 COMMON EXCAVATION | YD3 | 9600.0 | .00 | 3.00 | .00 | 28800.00 |
| 2.2 PILING | FT | .0 | 6.50 | 8.50 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .401 ACCOUNT TOTAL,$ | | | | | .00 | 28800.00 |
| | | | | | | |
| PLANT ISLAND CONCRETE | | | | | | |
| 3.1 PLANT IS. CONCRETE | YD3 | 3200.0 | 70.00 | 80.00 | 224000.00 | 256000.00 |
| 3.2 SPECIAL STRUCTURES | YD3 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 6.685 ACCOUNT TOTAL,$ | | | | | 224000.00 | 256000.00 |
| | | | | | | |
| HEAT REJECTION SYSTEM | | | | | | |
| 4.1 COOLING TOWERS | EACH | .0 | .00 | .00 | .00 | .00 |
| 4.2 CIRCULATING H2O SYS | EACH | 1.0 | .00 | .00 | .00 | .00 |
| 4.3 SURFACE CONDENSER | FT2 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| STRUCTURAL FEATURES | | | | | | |
| 5.1 STAT. STRUCTURAL ST. | TON | .0 | 650.00 | 175.00 | .00 | .00 |
| 5.2 SILOS & BUNKERS | TPH | .0 | 1800.00 | 750.00 | .00 | .00 |
| 5.3 CHIMNEY | FT | .0 | .00 | .00 | .00 | .00 |
| 5.4 STRUCTURAL FEATURES | EACH | 1.0 | 170000.00 | 30000.00 | 170000.00 | 30000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = 2.785 ACCOUNT TOTAL,$ | | | | | 170000.00 | 30000.00 |
| | | | | | | |
| BUILDINGS | | | | | | |
| 6.1 STATION BUILDINGS | FT3 | 5000.0 | 16.00 | 14.00 | 80000.00 | 70000.00 |
| 6.2 ADMINSTRATION | FT2 | .0 | 16.00 | .16 | .00 | .00 |
| 6.3 WAREHOUSE & SHOP | FT2 | .0 | 12.00 | 8.00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = 2.089 ACCOUNT TOTAL,$ | | | | | 80000.00 | 70000.00 |
| | | | | | | |
| FUEL HANDLING & STORAGE | | | | | | |
| 7.1 COAL HANDLING SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7.2 DOLOMITE HAND. SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7.3 FUEL OIL HAND. SYS | GAL | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

Table   SOLID ELECTROLYTE FUEL CELL               ACCOUNT LISTING
A 13.4.10 Continued    PARAMETRIC POINT NO. 1

| ACCOUNT NO. & NAME | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **FUEL PROCESSING** | | | | | | |
| 3. 1 COAL GASIFIER | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 2 DESULFURIZER | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 3 VENTURI SCRUBBER | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 4 COAL PRETREATMENT | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 5 REFORMER | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 6 SHIFT CONVERTER | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 7 CO2 SCRUBBER | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 8 BLOWER | EACH | 1.0 | 67000.00 | 5000.00 | 67000.00 | 5000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 1.530 | | | | ACCOUNT TOTAL,$ | 67000.00 | 5000.00 |
| **FIRING SYSTEM** | | | | | | |
| 9. 1 | | .0 | .00 | .00 | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 9 = .000 | | | | ACCOUNT TOTAL,$ | .00 | .00 |
| **VAPOR GENERATOR (FIRED)** | | | | | | |
| 10. 1 | | .0 | .00 | .00 | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 10 = .000 | | | | ACCOUNT TOTAL,$ | .00 | .00 |
| **ENERGY CONVERTER** | | | | | | |
| 11. 1 FUEL CELL SYSTEM | EACH | 1.0 | 310000.00 | 250000.00 | 310000.00 | 250000.00 |
| 11. 2 STM TURBINE GENERATOR | EA | .0 | .00 | .00 | .00 | .00 |
| 11. 3 OXYGEN PLANT | EACH | | | | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 11 = 46.659 | | | | ACCOUNT TOTAL,$ | 310000.00 | 250000.00 |
| **COUPLING HEAT EXCHANGER** | | | | | | |
| 12. 1 HEAT REC STEAM GEN | EACH | 1.0 | 44000.00 | 18000.00 | 44000.00 | 18000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 12 = .854 | | | | ACCOUNT TOTAL,$ | 44000.00 | 18000.00 |
| **HEAT RECOVERY HEAT EXCH.** | | | | | | |
| 13. 1 RECUPERATOR | EACH | 1.0 | 334000.00 | 110000.00 | 334000.00 | 110000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 13 = 6.184 | | | | ACCOUNT TOTAL,$ | 334000.00 | 110000.00 |
| **WATER TREATMENT** | | | | | | |
| 14. 1 DEMINERALIZER | GPM | .0 | 2500.00 | 700.00 | | |
| 14. 2 CONDENSATE POLISHING | KWE | .0 | 1.25 | .30 | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 14 = .000 | | | | ACCOUNT TOTAL,$ | .00 | .00 |
| **POWER CONDITIONING** | | | | | | |
| 15. 1 POWER CONDITIONING EQ | EA | 1.0 | 1380000.00 | 75000.00 | 1380000.00 | 75000.00 |
| 15. 2 STD TRANSFORMER | KVA | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 15 = 20.265 | | | | ACCOUNT TOTAL,$ | 1380000.00 | 75000.00 |
| **AUXILIARY MECH EQUIPMENT** | | | | | | |
| 16. 1 BOILER FEED PUMP &DR. | KWE | .0 | .55 | .04 | | |
| 16. 2 OTHER PUMPS | KWE | .0 | .89 | .42 | | |
| 16. 3 MISC SERVICE SYS | KWE | 33124.3 | 1.17 | .73 | 32755.49 | 24180.77 |
| 16. 4 AUXILIARY BOILER | PPH | .0 | 4.00 | .80 | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 16 = .877 | | | | ACCOUNT TOTAL,$ | 32755.49 | 24180.77 |

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| ACCOUNT NO. & NAME, | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **PIPE & FITTINGS** | | | | | | |
| 17. 1 CONVENTIONAL PIPING | TON | 10.0 | 3000.00 | 1800.00 | 30000.00 | 18000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = .669 ACCOUNT TOTAL,$ | | | | | 30000.00 | 18000.00 |
| | | | | | | |
| **AUXILIARY ELEC EQUIPMENT** | | | | | | |
| 18. 1 MISC MOTERS,ETC | KWE | 6624.9 | 1.40 | .17 | 9274.82 | 1126.23 |
| 18. 2 SWITCHGEAR & MCC PAN | KWE | 33124.3 | 1.95 | .45 | 64592.48 | 14905.96 |
| 18. 3 CONDUIT,CABLES,TRAYS | FT | 100000.0 | 1.32 | 1.36 | 132000.00 | 136000.00 |
| 18. 4 ISOLATED PHASE BUS | FT | .0 | 510.00 | 450.00 | .00 | .00 |
| 18. 5 LIGHTING & COMMUN | KWE | 33124.3 | .35 | .43 | 11593.52 | 14243.47 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 5.345 ACCOUNT TOTAL,$ | | | | | 217460.81 | 166275.65 |
| | | | | | | |
| **CONTROL, INSTRUMENTATION** | | | | | | |
| 19. 1 COMPUTER | EACH | 1.0 | 100000.00 | 3000.00 | 100000.00 | 3000.00 |
| 19. 2 OTHER CONTROLS | EACH | 1.0 | 83000.00 | 50000.00 | 83000.00 | 50000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = 3.287 ACCOUNT TOTAL,$ | | | | | 183000.00 | 53000.00 |
| | | | | | | |
| **PROCESS WASTE SYSTEMS** | | | | | | |
| 20. 1 BOTTOM ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 2 DRY ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 3 WET SLURRY | TPH | .0 | 7676.49 | 11070.89 | .00 | .00 |
| 20. 4 ONSITE DISPOSAL | ACRE | .0 | | | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| **STACK GAS CLEANING** | | | | | | |
| 21. 1 PRECIPITATOR | EACH | .0 | .00 | .00 | .00 | .00 |
| 21. 2 SCRUBBER | KWE | .0 | .00 | .00 | .00 | .00 |
| 21. 3 MISC STEEL & DUCTS | | | .00 | | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| **TOTAL DIRECT COSTS,$** | | | | | 6021952.62 | 1157792.77 |

SOLID ELECTROLYTE FUEL CELL    COST OF ELECTRICITY, MILLS/KW.HR
PARAMETRIC POINT NO. 1

Table A 13.4.11

## LABOR RATE, $/HR

| ACCOUNT | RATE, PERCENT | 6.00 | 8.50 | 10.60 | 15.00 | 21.50 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 6677307. | 6950371. | 7179745. | 7660339. | 8370306. |
| INDIRECT COST,$ | 0.0 | 334231. | 473494. | 590474. | 835577. | 1197660. |
| PROF & OWNER COSTS,$ | 8.0 | 534185. | 556030. | 574380. | 612827. | 669624. |
| CONTINGENCY COST,$ | 4.5 | 300479. | 312767. | 323089. | 344715. | 376664. |
| SUB TOTAL,$ | | 7846201. | 8292661. | 8667688. | 9453457. | 10614254. |
| ESCALATION COST,$ | 6.5 | 448171. | 473673. | 495094. | 539977. | 606281. |
| INTREST DURING CONST,$ | 10.0 | 458891. | 485002. | 506936. | 552892. | 620782. |
| TOTAL CAPITALIZATION,$ | 18.0 | 8753263. | 9251336. | 9669718. | 10546326. | 11841317. |
| COST OF ELEC-CAPITAL | | 12.14413 | 12.83615 | 13.41560 | 14.63180 | 16.42845 |
| COST OF ELEC-FUEL | 0.0 | 12.72563 | 12.72563 | 12.72563 | 12.72563 | 12.72563 |
| COST OF ELEC-OP & MAIN | 0.0 | 16.00160 | 16.00160 | 16.00160 | 16.00160 | 16.00160 |
| TOTAL COST OF ELEC | | 40.37136 | 41.56238 | 42.14283 | 43.35902 | 45.15567 |

## CONTINGENCY, PERCENT

| ACCOUNT | RATE, PERCENT | 5.00 | 0.00 | 4.50 | 5.00 | 20.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 7179745. | 7179745. | 7179745. | 7179745. | 7179745. |
| INDIRECT COST,$ | 8.0 | 590474. | 590474. | 590474. | 590474. | 590474. |
| PROF & OWNER COSTS,$ | 20.0 | 574380. | 574380. | 574380. | 574380. | 574380. |
| CONTINGENCY COST,$ | | -358987. | 0. | 323089. | 359987. | 1435949. |
| SUB TOTAL,$ | | 7985612. | 8344599. | 8667688. | 8703586. | 9790548. |
| ESCALATION COST,$ | 6.5 | 456134. | 476630. | 495094. | 497144. | 558660. |
| INTREST DURING CONST,$ | 10.0 | 467044. | 488040. | 506936. | 509036. | 572023. |
| TOTAL CAPITALIZATION,$ | 18.0 | 8908790. | 9309278. | 9669718. | 9709766. | 10911231. |
| COST OF ELEC-CAPITAL | | 12.35991 | 12.91654 | 13.41560 | 13.47117 | 15.13806 |
| COST OF ELEC-FUEL | 0.0 | 12.72563 | 12.72563 | 12.72563 | 12.72563 | 12.72563 |
| COST OF ELEC-OP & MAIN | 0.0 | 16.00160 | 16.00160 | 16.00160 | 16.00160 | 16.00160 |
| TOTAL COST OF ELEC | | 41.08713 | 41.64276 | 42.14283 | 42.19839 | 43.86529 |

## ESCALATION RATE, PERCENT

| ACCOUNT | RATE, PERCENT | 5.00 | 6.50 | 8.00 | 10.00 | 12.50 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 7179745. | 7179745. | 7179745. | 7179745. | 7179745. |
| INDIRECT COST,$ | 8.0 | 590474. | 590474. | 590474. | 590474. | 590474. |
| PROF & OWNER COSTS,$ | 4.5 | 574380. | 574380. | 574380. | 574380. | 574380. |
| CONTINGENCY COST,$ | | 323089. | 323089. | 323089. | 323089. | 323089. |
| SUB TOTAL,$ | | 8667688. | 8667688. | 8667688. | 8667688. | 8667688. |
| ESCALATION COST,$ | 12.5 | 380892. | 495094. | 609270. | 751465. | 951654. |
| INTREST DURING CONST,$ | 10.0 | 501561. | 506936. | 512300. | 519434. | 528326. |
| TOTAL CAPITALIZATION,$ | 18.0 | 9550141. | 9669718. | 9789258. | 9948596. | 10147667. |
| COST OF ELEC-CAPITAL | | 13.24971 | 13.41560 | 13.58145 | 13.80250 | 14.07870 |
| COST OF ELEC-FUEL | 0.0 | 12.72563 | 12.72563 | 12.72563 | 12.72563 | 12.72563 |
| COST OF ELEC-OP & MAIN | 0.0 | 16.00160 | 16.00160 | 16.00160 | 16.00160 | 16.00160 |
| TOTAL COST OF ELEC | | 41.97693 | 42.14283 | 42.30868 | 42.52973 | 42.80593 |

## INT DURING CONST, PERCENT

| ACCOUNT | RATE, PERCENT | 6.00 | 8.00 | 10.00 | 12.50 | 15.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 7179745. | 7179745. | 7179745. | 7179745. | 7179745. |
| INDIRECT COST,$ | 8.0 | 590474. | 590474. | 590474. | 590474. | 590474. |
| PROF & OWNER COSTS,$ | 4.5 | 574380. | 574380. | 574380. | 574380. | 574380. |
| CONTINGENCY COST,$ | | 323089. | 323089. | 323089. | 323089. | 323089. |
| SUB TOTAL,$ | | 8667688. | 8667688. | 8667688. | 8667688. | 8667688. |
| ESCALATION COST,$ | 6.5 | 495094. | 495094. | 495094. | 495094. | 495094. |
| INTREST DURING CONST,$ | 15.0 | 305832. | 406652. | 506936. | 631564. | 755818. |
| TOTAL CAPITALIZATION,$ | 18.0 | 9468613. | 9569434. | 9669718. | 9794345. | 9918187. |
| COST OF ELEC-CAPITAL | | 13.13660 | 13.27647 | 13.41560 | 13.58851 | 13.76033 |
| COST OF ELEC-FUEL | 0.0 | 12.72563 | 12.72563 | 12.72563 | 12.72563 | 12.72563 |
| COST OF ELEC-OP & MAIN | 0.0 | 16.00160 | 16.00270 | 16.00160 | 16.00160 | 16.00160 |
| TOTAL COST OF ELEC | | 41.86232 | 42.00270 | 42.14283 | 42.31574 | 42.48755 |

SOLID ELECTROLYTE FUEL CELL  
Table A 13.4.11 Continued  
PARAMETRIC POINT NO. 1  
COST OF ELECTRICITY, MILLS/KW.HR

**FIXED CHARGE RATE, PCT**

| ACCOUNT | RATE, PERCENT | 10.00 | 14.40 | 18.00 | 21.60 | 25.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 7179745 | 7179745 | 7179745 | 7179745 | 7179745 |
| INDIRECT COST,$ | 51.0 | 590474 | 590474 | 590474 | 590474 | 590474 |
| PROF & OWNER COSTS,$ | 8.0 | 574380 | 574380 | 574380 | 574380 | 574380 |
| CONTINGENCY COST,$ | 4.5 | 323089 | 323089 | 323089 | 323089 | 323089 |
| SUB TOTAL,$ | | 8667688 | 8667688 | 8667688 | 8667688 | 8667688 |
| ESCALATION COST,$ | 6.5 | 495094 | 495094 | 495094 | 495094 | 495094 |
| INTREST DURING CONST,$ | 10.0 | 506936 | 506936 | 506936 | 506936 | 506936 |
| TOTAL CAPITALIZATION,$ | 25.0 | 9669718 | 9669718 | 9669718 | 9669718 | 9669718 |
| COST OF ELEC-CAPITAL | | 7.45311 | 10.73248 | 13.41560 | 16.09873 | 18.63278 |
| COST OF ELEC-FUEL | | 12.72563 | 12.72563 | 12.72563 | 12.72563 | 12.72563 |
| COST OF ELEC-OP & MAIN | | 16.00160 | 16.00160 | 16.00160 | 16.00160 | 16.00160 |
| TOTAL COST OF ELEC | | 36.18034 | 39.45971 | 42.14283 | 44.82595 | 47.36001 |

**FUEL COST, $/10\*\*6 BTU**

| ACCOUNT | RATE, PERCENT | 1.50 | 2.60 | 4.00 | 2.08 | 3.12 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 7179745 | 7179745 | 7179745 | 7179745 | 7179745 |
| INDIRECT COST,$ | 51.0 | 590474 | 590474 | 590474 | 590474 | 590474 |
| PROF & OWNER COSTS,$ | 8.0 | 574380 | 574380 | 574380 | 574380 | 574380 |
| CONTINGENCY COST,$ | 4.5 | 323089 | 323089 | 323089 | 323089 | 323089 |
| SUB TOTAL,$ | | 8667688 | 8667688 | 8667688 | 8667688 | 8667688 |
| ESCALATION COST,$ | 6.5 | 495094 | 495094 | 495094 | 495094 | 495094 |
| INTREST DURING CONST,$ | 10.0 | 506936 | 506936 | 506936 | 506936 | 506936 |
| TOTAL CAPITALIZATION,$ | | 9669718 | 9669718 | 9669718 | 9669718 | 9669718 |
| COST OF ELEC-CAPITAL | 18.0 | 13.41560 | 13.41560 | 13.41560 | 13.41560 | 13.41560 |
| COST OF ELEC-FUEL | | 7.34171 | 12.72563 | 19.57789 | 10.18050 | 15.27075 |
| COST OF ELEC-OP & MAIN | | 16.00160 | 16.00160 | 16.00160 | 16.00160 | 16.00160 |
| TOTAL COST OF ELEC | | 36.75891 | 42.14283 | 48.99509 | 39.59771 | 44.68796 |

**CAPACITY FACTOR, PERCENT**

| ACCOUNT | RATE, PERCENT | 45.00 | 50.00 | 65.00 | 80.00 | 95.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | | 7179745 | 7179745 | 7179745 | 7179745 | 7179745 |
| INDIRECT COST,$ | 51.0 | 590474 | 590474 | 590474 | 590474 | 590474 |
| PROF & OWNER COSTS,$ | 8.0 | 574380 | 574380 | 574380 | 574380 | 574380 |
| CONTINGENCY COST,$ | 4.5 | 323089 | 323089 | 323089 | 323089 | 323089 |
| SUB TOTAL,$ | | 8667688 | 8667688 | 8667688 | 8667688 | 8667688 |
| ESCALATION COST,$ | 6.5 | 495094 | 495094 | 495094 | 495094 | 495094 |
| INTREST DURING CONST,$ | 10.0 | 506936 | 506936 | 506936 | 506936 | 506936 |
| TOTAL CAPITALIZATION,$ | | 9669718 | 9669718 | 9669718 | 9669718 | 9669718 |
| COST OF ELEC-CAPITAL | 18.0 | 19.37810 | 17.44029 | 13.41560 | 10.90018 | 9.17907 |
| COST OF ELEC-FUEL | | 12.72563 | 12.72563 | 12.72563 | 12.72563 | 12.72563 |
| COST OF ELEC-OP & MAIN | | 16.35787 | 16.24208 | 16.00160 | 15.85130 | 15.74848 |
| TOTAL COST OF ELEC | | 48.46159 | 46.40799 | 42.14283 | 39.47711 | 37.65318 |

Table A 13.4.12
SOLID ELECTROLYTE FUEL CELL

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT POW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 11 | .00000 | .00000 | 335.00000 | 104000.00000 |
| 18 | .11450 | 100.00000 | .00000 | 104000.00000 |

TOTALS
SOLID ELECTROLYTE FUEL CELL     .11450     .50251     346.33960     104000.00000

| | | BASE CASE INPUT | |
|---|---|---|---|
| NOMINAL POWER, MWE | 22.9000 | NET POWER, MWE | 22.7855 |
| NOW HEAT RATE, BTU/KW-HR | 4869.9999 | NET HEAT RATE, BTU/KW-HR | 4894.4722 |
| ST TURB HEAT RATE CHANGE | .0000 | | |
| CONDENSER | | | |
| DESIGN PRESSURE, IN HG A | 2.0000 | NUMBER OF SHELLS | .0000 |
| NUMBER OF TUBES/SHELL | .0000 | TUBE LENGTH, FT | .0000 |
| U, BTU/HR-FT2-F | .0000 | TERMINAL TEMP DIFF, F | .0000 |
| HEAT REJECTION | | | |
| DESIGN TEMP, F | .0000 | APPROACH, F | .0000 |
| RANGE, F | .0000 | OFF DESIGN TEMP, F | .0000 |
| OFF DESIGN PRES, IN HG A | .0000 | LP TURBINE BLADE LEN, IN | .0000 |

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 22.900 | 2.000 | .000 | .000 | 4870.000 |
| 6 | 7 | 8 | 9 | 10 |
| .000 | .000 | .000 | .000 | .000 |
| 11 | 12 | 13 | 14 | 15 |
| .000 | .000 | 1.000 | 1.000 | 2.000 |
| 16 | 17 | 18 | 19 | 20 |
| .000 | 1.500 | 5.000 | 5.000 | 2.000 |
| 21 | 22 | 23 | 24 | 25 |
| .000 | 3200.000 | .000 | .000 | .000 |
| 26 | 27 | 28 | 29 | 30 |
| .000 | 5000.000 | .000 | .000 | .000 |
| 31 | 32 | 33 | 34 | 35 |
| 1.000 | 10.000 | .000 | .000 | .200 |
| 36 | 37 | 38 | 39 | 40 |
| .000 | .000 | 1.000 | 1.000 | 1.000 |
| 41 | 42 | 43 | 44 | 45 |
| 100000.000 | 100000.000 | 3000.000 | 930.000 | 1.000 |
| 46 | 47 | 48 | 49 | 50 |
| .000 | 30000.000 | 1.000 | 1.000 | 6.000 |
| 51 | 52 | | | |
| .000 | 5.350 | | | |

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| .000 | .000 | .000 | .000 | .000 |
| 6 | 7 | 8 | 9 | 10 |
| .000 | .000 | .000 | 1.000 | 1.000 |
| 11 | 12 | 13 | 14 | 15 |
| .000 | .000 | .000 | .000 | .000 |
| 16 | 17 | 18 | 19 | 20 |
| .000 | .000 | .000 | .000 | 1.000 |
| 21 | 22 | 23 | 24 | 25 |
| .000 | 67000.000 | .000 | 5000.000 | .000 |
| 26 | 27 | 28 | 29 | 30 |
| .000 | 3100000.000 | .000 | 25000.000 | .000 |
| 31 | 32 | 33 | 34 | 35 |
| .000 | 1.000 | .000 | 1.000 | 44000.000 |
| 36 | 37 | 38 | 39 | 40 |
| .000 | 334000.000 | .000 | 110000.000 | .000 |
| 41 | 42 | 43 | 44 | 45 |
| 18000.000 | 75000.000 | .000 | .000 | 1.000 |
| 46 | 47 | 48 | 49 | 50 |
| .000 | .000 | .000 | .000 | .000 |
| 51 | 52 | 53 | 54 | 55 |
| .200 | .000 | .000 | .000 | .000 |
| 56 | 57 | 58 | 59 | 60 |
| 1380000.000 | .000 | .000 | 335.000 | 104000.000 |

Table
A 13.4.13

SOLID ELECTROLYTE FUEL CELL          ACCOUNT LISTING
PARAMETRIC POINT NO.

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| SITE DEVELOPMENT | | | | | | |
| 1.1 LAND COST | ACRE | 2.2 | 10000.00 | .00 | 22500.00 | .00 |
| 1.2 CLEARING LAND | ACRE | .7 | 600.00 | .00 | .00 | 445.95 |
| 1.3 GRADING LAND | ACRE | 2.2 | 3000.00 | .00 | .00 | 6750.00 |
| 1.4 ACCESS RAILROAD | MILE | .0 | 115000.00 | 110000.00 | .00 | .00 |
| 1.5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 70000.00 | .00 | .00 |
| 1.6 SIDING R R TRACK | MILE | .0 | 125000.00 | 80000.00 | .00 | .00 |
| 1.7 OTHER SITE COSTS | ACRE | .0 | .00 | .00 | 5599.76 | 5599.76 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = .134 ACCOUNT TOTAL,$ | | | | | 28099.76 | 12799.72 |
| | | | | | | |
| EXCAVATION & PILING | | | | | | |
| 2.1 COMMON EXCAVATION | YD3 | 12150.0 | .00 | 6.50 | 3.00 | 36450.00 |
| 2.2 PILING | FT | .0 | 6.50 | 8.50 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .119 ACCOUNT TOTAL,$ | | | | | .00 | 36450.00 |
| | | | | | | |
| PLANT ISLAND CONCRETE | | | | | | |
| 3.1 PLANT IS. CONCRETE | YD3 | 4050.0 | 70.00 | 80.00 | 283500.00 | 324000.00 |
| 3.2 SPECIAL STRUCTURES | YD3 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 1.987 ACCOUNT TOTAL,$ | | | | | 283500.00 | 324000.00 |
| | | | | | | |
| HEAT REJECTION SYSTEM | | | | | | |
| 4.1 COOLING TOWERS | EACH | 1.0 | .00 | .00 | .00 | .00 |
| 4.2 CIRCULATING H2O SYS | EACH | 1.0 | .00 | .00 | .00 | .00 |
| 4.3 SURFACE CONDENSER | FT2 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .000 ACCOUNT TOTAL,$ | | | | | | |
| | | | | | | |
| STRUCTURAL FEATURES | | | | | | |
| 5.1 STAT. STRUCTURAL ST. | TON | .0 | 650.00 | 175.00 | .00 | .00 |
| 5.2 SILOS & BUNKERS | TPH | .0 | 1800.00 | 750.00 | .00 | .00 |
| 5.3 CHIMNEY | FT | .0 | .00 | .00 | .00 | .00 |
| 5.4 STRUCTURAL FEATURES | EACH | 1.0 | 280000.00 | 50000.00 | 280000.00 | 50000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = 1.079 ACCOUNT TOTAL,$ | | | | | 280000.00 | 50000.00 |
| | | | | | | |
| BUILDINGS | | | | | | |
| 6.1 STATION BUILDINGS | FT3 | 5000.0 | 16.16 | 14.16 | 80000.00 | 70000.00 |
| 6.2 ADMINSTRATION | FT2 | .0 | 16.00 | .00 | | |
| 6.3 WAREHOUSE & SHOP | FT2 | .0 | 12.00 | 8.00 | 80000.00 | 70000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = .491 ACCOUNT TOTAL,$ | | | | | | |
| | | | | | | |
| FUEL HANDLING & STORAGE | | | | | | |
| 7.1 COAL HANDLING SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7.2 DOLOMITE HAND. SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7.3 FUEL OIL HAND. SYS | GAL | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = .000 ACCOUNT TOTAL,$ | | | | | | |

Table  SOLID ELECTROLYTE FUEL CELL     ACCOUNT LISTING
A 13.4.13 Continued    PARAMETRIC POINT NO. 2

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| FUEL PROCESSING | | | | | | |
| 8.-1 COAL GASIFIER | EACH | .0 | .00 | .00 | .00 | .00 |
| 8.-2 DESULFURIZER | EACH | .0 | .00 | .00 | .00 | .00 |
| 8.-3 VENTURI SCRUBBER | EACH | .0 | .00 | .00 | .00 | .00 |
| 8.-4 COAL PRETREATMENT | EACH | .0 | .00 | .00 | .00 | .00 |
| 8.-5 REFORMER | EACH | .0 | .00 | .00 | .00 | .00 |
| 8.-6 SHIFT CONVERTER | EACH | .0 | .00 | .00 | .00 | .00 |
| 8.-7 CO2 SCRUBBER | EACH | .0 | .00 | .00 | .00 | .00 |
| 8.-8 BLOWER | EACH | 1.0 | 769000.00 | .00 | 253000.00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT  8 = 1.531 ACCOUNT TOTAL,$ | | | | | 260000.00 | .00 |
| FIRING SYSTEM | | | | | | |
| 9.-1 | | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT  9 = .000 ACCOUNT TOTAL,$ | | | | | | |
| VAPOR GENERATOR (FIRED) | | | | | | |
| 10.-1 | | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 10 = .000 ACCOUNT TOTAL,$ | | | | | | |
| ENERGY CONVERTER | | | | | | |
| 11.-1 FUEL CELL SYSTEM | EACH | 1.0 | 15900000.00 | .00 | 158000000.00 | .00 |
| 11.-2 STM TURBINE GENERATOR | EA | .0 | .00 | .00 | .00 | .00 |
| 11.-3 OXYGEN PLANT | EACH | 1.0 | 15800000.00 | .00 | 15800000.00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 11 =54.947 ACCOUNT TOTAL,$ | | | | | | |
| COUPLING HEAT EXCHANGER | | | | | | |
| 12.-1 HEAT REC STEAM GEN | EACH | 1.0 | 618000.00 | 247000.00 | 618000.00 | 247000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 12 = 2.829 ACCOUNT TOTAL,$ | | | | | | |
| HEAT RECOVERY HEAT EXCH. | | | | | | |
| 13.-1 RECUPERATOR | EACH | 1.0 | 1910000.00 | 630000.00 | 1910000.00 | 630000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 13 = 3.308 ACCOUNT TOTAL,$ | | | | | | |
| WATER TREATMENT | | | | | | |
| 14.-1 DEMINERALIZER | GPM | .0 | 2500.00 | 700.00 | | |
| 14.-2 CONDENSATE POLISHING | KWE | .0 | 1.25 | .30 | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 14 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| POWER CONDITIONING | | | | | | |
| 15.-1 POWER CONDITIONING EQ | EA | 1.0 | 700000.00 | 300000.00 | 700000.00 | 300000.00 |
| 15.-2 STD TRANSFORMER | KVA | .0 | .00 | | 700000.00 | 300000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 15 =23.876 ACCOUNT TOTAL,$ | | | | | | |
| AUXILIARY MECH EQUIPMENT | | | | | | |
| 16.-1 BOILER FEED PUMP &DR.KWE | | .0 | .04 | | .00 | .00 |
| 16.-2 OTHER PUMPS | KWE | .0 | .88 | | .00 | .00 |
| 16.-3 MISC SERVICE SYS | KWE | 101402.4 | 1.17 | .73 | 142040.82 | 83623.76 |
| 16.-4 AUXILIARY BOILER | PPH | .0 | 4.00 | .80 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 16 = .754 ACCOUNT TOTAL,$ | | | | | 142040.92 | 83623.76 |

Table
A 13.4.13 Continued

## SOLID ELECTROLYTE FUEL CELL
## PARAMETRIC POINT NO. 2
## ACCOUNT LISTING

| ACCOUNT NO. & NAME | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **PIPE & FITTINGS** | | | | | | |
| 17. 1 CONVENTIONAL PIPING | TON | 30.0 | 3000.00 | 1800.00 | 90000.00 | 54000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = .471 ACCOUNT TOTAL,$ | | | | | 90000.00 | 54000.00 |
| | | | | | | |
| **AUXILIARY ELEC EQUIPMENT** | | | | | | |
| 18. 1 MISC MOTERS,ETC | KWE | 24280.5 | 1.40 | .17 | 33992.67 | 4127.68 |
| 18. 2 SWITCHGEAR & MCC PAN | KWE | 121402.4 | 1.95 | .45 | 236734.69 | 54631.08 |
| 18. 3 CONDUIT,CABLES,TRAYS | FT | 150000.0 | 1.32 | 1.36 | 198000.00 | 204000.00 |
| 18. 4 ISOLATED PHASE BUS | FT | .0 | 510.00 | 450.00 | .00 | .00 |
| 18. 5 LIGHTING & COMMUN | KWE | 121402.4 | .35 | .43 | 42490.84 | 52203.03 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 2.702 ACCOUNT TOTAL,$ | | | | | 511218.20 | 314961.79 |
| | | | | | | |
| **CONTROL, INSTRUMENTATION** | | | | | | |
| 19. 1 COMPUTER | EACH | 1.0 | 100000.00 | 3000.00 | 100000.00 | 3000.00 |
| 19. 2 OTHER CONTROLS | EACH | 1.0 | 83000.00 | 50000.00 | 83000.00 | 50000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = .772 ACCOUNT TOTAL,$ | | | | | 183000.00 | 53000.00 |
| | | | | | | |
| **PROCESS WASTE SYSTEMS** | | | | | | |
| 20. 1 BOTTOM ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 2 DRY ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 3 WET SLURRY | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 4 ONSITE DISPOSAL | ACRE | .0 | 7676.49 | 11070.89 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| | | | | | | |
| **STACK GAS CLEANING** | | | | | | |
| 21. 1 PRECIPITATOR | EACH | .0 | .00 | .00 | .00 | .00 |
| 21. 2 SCRUBBER | KWE | .0 | .00 | .00 | .00 | .00 |
| 21. 3 MISC STEEL & DUCTS | | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

TOTAL DIRECT COSTS,$     27193858.50     3380835.25

Table A 13.4.14
SOLID ELECTROLYTE FUEL CELL
PARAMETRIC POINT NO. 2
COST OF ELECTRICITY,MILLS/KW.HR

**LABOR RATE, $/HR**

| ACCOUNT | RATE, PERCENT | 6.00 | 8.50 | 10.00 | 15.00 | 21.50 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 291C7539. | 2990C4905. | 3C574693. | 3197805C. | 34051212. |
| INDIRECT COST,$ | 8.0 | 2975977. | 13826?4. | 1724226. | ?4369942. | 3497761. |
| PROF & OWNER COSTS,$ | 5.0 | 2535C03. | 2392392. | 2445975. | 2553245. | 2724C27. |
| CONTINGENCY COST,$ | 5.0 | 14553?7. | 14?95245. | 1528735. | 15969903. | 17C2561. |
| SUB TOTAL,$ | | 338C7495. | 35175176. | 362?3629. | 38575148. | 41975120. |
| ESCALATION COST,$ | 16.5 | 26CC6385. | 27C7C022. | 2791557. | 29C6678. | 3230334. |
| INTREST DURING CONST,$ | 10.0 | 27313965. | 28187?56. | 290657BC. | 3091212. | 3363668. |
| TOTAL CAPITALIZATION,$ | 18.0 | 3C187844. | 4C7C09544. | 419719654. | 44635C38. | 48566122. |
| COST OF ELEC-CAPITAL | | 14.21279 | 14.761957 | 15.22254 | 16.18839 | 17.61522 |
| COST OF ELEC-FUEL | | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 |
| COST OF ELEC-OP & MAIN | | 2C.76495 | 2C.76495 | 2C.76495 | 2C.76495 | 2C.76495 |
| TOTAL COST OF ELEC | | 51.68125 | 52.23003 | 52.69101 | 53.65686 | 55.08369 |

**CONTINGENCY, PERCENT**

| ACCOUNT | RATE, PERCENT | -5.00 | 0.00 | 5.00 | 15.00 | 20.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 3C574693. | 3C574693. | 3C574693. | ?C574693. | ?C574693. |
| INDIRECT COST,$ | 8.0 | 1724226. | 1724226. | 1724226. | 1724226. | 1724226. |
| PROF & OWNER COSTS,$ | 20.0 | 2445975. | 2445975. | 2445975. | 2445975. | 2445975. |
| CONTINGENCY COST,$ | | -1528735. | C. | 1528735. | 15287?5. | 6114?39. |
| SUB TOTAL,$ | | 33216160. | 34744894. | 362?3629. | 362?3629. | 4C8598?3. |
| ESCALATION COST,$ | 6.5 | 2555260C. | 267390G8. | 2791557. | 2791557. | 3144509. |
| INTREST DURING CONST,$ | 10.0 | 2661770. | 2784275. | 290678C. | 29C678C. | 3274294. |
| TOTAL CAPITALIZATION,$ | 18.0 | 38434189. | 40203C77. | 419719654. | 419719654. | 47278630. |
| COST OF ELEC-CAPITAL | | 13.93945 | 14.58099 | 15.22254 | 15.22254 | 17.14718 |
| COST OF ELEC-FUEL | | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 |
| COST OF ELEC-OP & MAIN | | 2C.76495 | 2C.76495 | 2C.76495 | 2C.76495 | 2C.76495 |
| TOTAL COST OF ELEC | | 51.40792 | 52.04946 | 52.69101 | 52.69101 | 54.61565 |

**ESCALATION RATE, PERCENT**

| ACCOUNT | RATE, PERCENT | 5.00 | 6.50 | 8.00 | 10.00 | 12.50 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 3C574693. | 3C574693. | 3C574693. | 3C574693. | 3C574693. |
| INDIRECT COST,$ | 3.0 | 1724226. | 1724226. | 1724226. | 1724226. | 1724226. |
| PROF & OWNER COSTS,$ | 5.0 | 2445975. | 2445975. | 2445975. | 2445975. | 2445975. |
| CONTINGENCY COST,$ | | 1528735. | 1528735. | 1528735. | 1528735. | 1528735. |
| SUB TOTAL,$ | | 362?3629. | 362?3629. | 362?3629. | 362?3629. | 362?3629. |
| ESCALATION COST,$ | 12.5 | 21425533. | 2791557. | 3443447. | 43170?5. | 5416185. |
| INTREST DURING CONST,$ | 10.0 | 2865751. | 290678C. | 2947888. | 3002821. | 3C71683. |
| TOTAL CAPITALIZATION,$ | 18.0 | 41281912. | 419719654. | 42664963. | 4359352?. | 44761496. |
| COST OF ELEC-CAPITAL | | 14.97227 | 15.22254 | 15.47388 | 15.81C65 | 16.23426 |
| COST OF ELEC-FUEL | | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 |
| COST OF ELEC-OP & MAIN | | 2C.76495 | 2C.76495 | 2C.76495 | 2C.76495 | 2C.76495 |
| TOTAL COST OF ELEC | | 52.44074 | 52.69101 | 52.94235 | 53.27912 | 53.70273 |

**INT DURING CONST, PERCENT**

| ACCOUNT | RATE, PERCENT | 5.00 | 7.50 | 10.00 | 12.50 | 15.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 3C574693. | ?C574693. | 3C574693. | ?C574693. | ?C574693. |
| INDIRECT COST,$ | 8.0 | 1724226. | 1724226. | 1724226. | 1724226. | 1724226. |
| PROF & OWNER COSTS,$ | 5.0 | 2445975. | 2445975. | 2445975. | 2445975. | 2445975. |
| CONTINGENCY COST,$ | | 1528735. | 1528735. | 1528735. | 1528735. | 1528735. |
| SUB TOTAL,$ | | 362?3629. | 362?3629. | 362?3629. | 362?3629. | 362?3629. |
| ESCALATION COST,$ | 6.5 | 2791557. | 2791557. | 2791557. | 2791557. | 2791557. |
| INTREST DURING CONST,$ | 15.0 | 1745811. | 2326559. | 290678C. | 3631?6C. | 43552?4. |
| TOTAL CAPITALIZATION,$ | 18.0 | 40810996. | 41391745. | 419719654. | 42695546. | 4342C419. |
| COST OF ELEC-CAPITAL | | 14.8C14C | 15.C121C | 15.22254 | 15.43533 | 15.74787 |
| COST OF ELEC-FUEL | | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 | 16.7C352 |
| COST OF ELEC-OP & MAIN | | 2C.76495 | 2C.76495 | 2C.76495 | 2C.7649? | 2C.7649? |
| TOTAL COST OF ELEC | | 52.26995 | 52.48C57 | 52.69101 | 52.9538C | 53.21634 |

Table A 13.4.14 Continued

SOLID ELECTROLYTE FUEL CELL      COST OF ELECTRICITY, MILLS/KW.HR

PARAMETRIC POINT NO. 2

**FIXED CHARGE RATE, PCT**

| ACCOUNT | RATE, PERCENT | 10.00 | 14.40 | 18.00 | 21.60 | 25.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 30574693. | 30574693. | 30574693. | 30574693. | 30574693. |
| INDIRECT COST,$ | 8.0 | 1724226. | 1724226. | 1724226. | 1724226. | 1724226. |
| PROF & OWNER COSTS,$ | 5.0 | 2445975. | 2445975. | 2445975. | 2445975. | 2445975. |
| CONTINGENCY COST,$ | 5.0 | 1528735. | 1528735. | 1528735. | 1528735. | 1528735. |
| SUB TOTAL,$ | | 36273629. | 36273629. | 36273629. | 36273629. | 36273629. |
| ESCALATION COST,$ | 6.5 | 2791557. | 2791557. | 2791557. | 2791557. | 2791557. |
| INTREST DURING CONST,$ | 10.0 | 2906780. | 2906780. | 2906780. | 2906780. | 2906780. |
| TOTAL CAPITALIZATION,$ | 18.0 | 41971965. | 41971965. | 41971965. | 41971965. | 41971965. |
| COST OF ELEC-CAPITAL | | 8.45697 | 12.17803 | 15.22254 | 18.26705 | 21.14242 |
| COST OF ELEC-FUEL | | 16.70352 | 16.70352 | 16.70352 | 16.70352 | 16.70352 |
| COST OF ELEC-OP & MAIN | | 20.76495 | 20.76495 | 20.76495 | 20.76495 | 20.76495 |
| TOTAL COST OF ELEC | | 45.92544 | 49.64650 | 52.69101 | 55.73552 | 58.61089 |

**FUEL COST, $/10**6 BTU**

| ACCOUNT | RATE, PERCENT | 1.20 | 2.00 | 3.10 | 1.60 | 2.40 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 30574693. | 30574693. | 30574693. | 30574693. | 30574693. |
| INDIRECT COST,$ | 8.0 | 1724226. | 1724226. | 1724226. | 1724226. | 1724226. |
| PROF & OWNER COSTS,$ | 5.0 | 2445975. | 2445975. | 2445975. | 2445975. | 2445975. |
| CONTINGENCY COST,$ | 5.0 | 1528735. | 1528735. | 1528735. | 1528735. | 1528735. |
| SUB TOTAL,$ | | 36273629. | 36273629. | 36273629. | 36273629. | 36273629. |
| ESCALATION COST,$ | 6.5 | 2791557. | 2791557. | 2791557. | 2791557. | 2791557. |
| INTREST DURING CONST,$ | 10.0 | 2906780. | 2906780. | 2906780. | 2906780. | 2906780. |
| TOTAL CAPITALIZATION,$ | 18.0 | 41971965. | 41971965. | 41971965. | 41971965. | 41971965. |
| COST OF ELEC-CAPITAL | | 15.22254 | 15.22254 | 15.22254 | 15.22254 | 15.22254 |
| COST OF ELEC-FUEL | | 10.02211 | 16.70352 | 25.89045 | 13.36281 | 20.04422 |
| COST OF ELEC-OP & MAIN | | 20.76495 | 20.76495 | 20.76495 | 20.76495 | 20.76495 |
| TOTAL COST OF ELEC | | 46.00960 | 52.69101 | 61.87794 | 49.35031 | 56.03171 |

**CAPACITY FACTOR, PERCENT**

| ACCOUNT | RATE, PERCENT | 12.00 | 45.00 | 50.00 | 65.00 | 80.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 30574693. | 30574693. | 30574693. | 30574693. | 30574693. |
| INDIRECT COST,$ | 8.0 | 1724226. | 1724226. | 1724226. | 1724226. | 1724226. |
| PROF & OWNER COSTS,$ | 5.0 | 2445975. | 2445975. | 2445975. | 2445975. | 2445975. |
| CONTINGENCY COST,$ | 5.0 | 1528735. | 1528735. | 1528735. | 1528735. | 1528735. |
| SUB TOTAL,$ | | 36273629. | 36273629. | 36273629. | 36273629. | 36273629. |
| ESCALATION COST,$ | 6.5 | 2791557. | 2791557. | 2791557. | 2791557. | 2791557. |
| INTREST DURING CONST,$ | 10.0 | 2906780. | 2906780. | 2906780. | 2906780. | 2906780. |
| TOTAL CAPITALIZATION,$ | 18.0 | 41971965. | 41971965. | 41971965. | 41971965. | 41971965. |
| COST OF ELEC-CAPITAL | | 82.45543 | 21.98812 | 19.78930 | 15.22254 | 12.36831 |
| COST OF ELEC-FUEL | | 16.70352 | 16.70352 | 16.70352 | 16.70352 | 16.70352 |
| COST OF ELEC-OP & MAIN | | 25.74849 | 21.26644 | 21.10346 | 20.76495 | 20.55339 |
| TOTAL COST OF ELEC | | 124.90744 | 59.95807 | 57.59628 | 52.69101 | 49.62522 |

Table A 13.4.15

## SOLID ELECTROLYTE FUEL CELL

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT POW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 11 | .00000 | .00000 | 1680.00000 | 560000.00000 |
| 18 | | 100.00000 | .00000 | 560000.00000 |

TOTALS .43800
SOLID ELECTROLYTE FUEL CELL .43800 .50251

BASE CASE INPUT
NOMINAL POWER, MWE 87.6000 87.6000 NET POWER, MWE 87.1620
NOW HEAT RATE, BTU/KW-HR 8309.9998 8309.9998 NET HEAT RATE, BTU/KW-HR 8351.7584
ST TURB HEAT RATE CHANGE .0000

CONDENSER
DESIGN PRESSURE, IN HG A 2.0000 2.0000 NUMBER OF SHELLS .0000
NUMBER OF TUBES/SHELL .0000 TUBE LENGTH, FT .0000
U, BTU/HR-FT2-F .0000 TERMINAL TEMP DIFF, F .0000
HEAT REJECTION
DESIGN TEMP, F .0000 APPROACH, F .0000
RANGE, F .0000 OFF DESIGN TEMP, F .0000
OFF DESIGN PRES, IN HG A .0000 LP TURBINE BLADE LEN, IN .0000

| 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 87.600 | 2 | 2.000 | 3 | .000 | 4 | 8310.000 | 5 | 2.000 |
| 6 | .000 | 7 | .000 | 8 | .000 | 9 | .000 | 10 | .000 |
| 11 | .000 | 12 | .000 | 13 | .000 | 14 | 3.000 | 15 | .000 |
| 16 | .000 | 17 | .000 | 18 | .000 | 19 | .000 | 20 | .000 |
| 21 | .000 | 22 | .250 | 23 | 4.000 | 24 | .000 | 25 | .000 |
| 26 | .000 | 27 | 4050.000 | 28 | .000 | 29 | .000 | 30 | .000 |
| 31 | .000 | 32 | 5000.000 | 33 | .000 | 34 | .200 | 35 | .000 |
| 36 | 1.000 | 37 | 30.000 | 38 | .000 | 39 | .000 | 40 | 1.000 |
| 41 | 150000.000 | 42 | .000 | 43 | .000 | 44 | 1.000 | 45 | 280000.000 |
| 46 | 50000.000 | 47 | .000 | 48 | 3000.000 | 49 | 83000.000 | 50 | 50000.000 |
| 51 | .000 | 52 | 100000.000 | | | | 1.000 | | 6.000 |

| 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | .000 | 2 | 5.350 | 3 | .000 | 4 | 1.000 | 5 | .000 |
| 6 | .000 | 7 | .000 | 8 | .000 | 9 | .000 | 10 | .000 |
| 11 | .000 | 12 | .000 | 13 | .000 | 14 | .000 | 15 | .000 |
| 16 | .000 | 17 | .000 | 18 | .000 | 19 | .000 | 20 | .000 |
| 21 | .000 | 22 | .000 | 23 | .000 | 24 | 268000.000 | 25 | 200000.000 |
| 26 | .000 | 27 | .000 | 28 | .000 | 29 | 1580000.000 | 30 | 1000000.000 |
| 31 | .000 | 32 | .000 | 33 | .000 | 34 | 1.000 | 35 | .000 |
| 36 | 1.000 | 37 | 1.000 | 38 | .000 | 39 | 1910000.000 | 40 | 630000.000 |
| 41 | 247000.000 | 42 | 7000000.000 | 43 | .000 | 44 | 300000.000 | 45 | 1.000 |
| 46 | .000 | 47 | .000 | 48 | .000 | 49 | .000 | 50 | .000 |
| 51 | .000 | 52 | .000 | 53 | .000 | 54 | .000 | 55 | .000 |
| 56 | .200 | 57 | .000 | 58 | .000 | 59 | 1680.000 | 60 | 560000.000 |

Table A 13.4.16

## SOLID ELECTROLYTE FUEL CELL — ACCOUNT LISTING
### PARAMETRIC POINT NO. 4

| ACCOUNT NO. & NAME | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| SITE DEVELOPMENT | | | | | | |
| 1.1 LAND COST | ACRE | 30.0 | 1000.00 | .00 | 30000.00 | .00 |
| 1.2 CLEARING LAND | ACRE | 10.0 | .00 | 600.00 | .00 | 5999.40 |
| 1.3 GRADING LAND | ACRE | 30.0 | .00 | 3000.00 | .00 | 90000.00 |
| 1.4 ACCESS RAILROAD | MILE | 5.0 | 115000.00 | 110000.00 | 575000.00 | 550000.00 |
| 1.5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 70000.00 | .00 | .00 |
| 1.6 SIDING R R TRACK | MILE | .5 | 125000.00 | 80000.00 | 62500.00 | 40000.00 |
| 1.7 OTHER SITE COSTS | ACRE | | | | 72416.89 | 72416.89 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = .490 | | | | ACCOUNT TOTAL,$ | 739916.88 | 758416.28 |
| | | | | | | |
| EXCAVATION & PILING | | | | | | |
| 2.1 COMMON EXCAVATION | YD3 | 86700.0 | .00 | 3.00 | .00 | 260100.00 |
| 2.2 PILING | FT | .0 | 6.50 | 8.50 | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .085 | | | | ACCOUNT TOTAL,$ | .00 | 260100.00 |
| | | | | | | |
| PLANT ISLAND CONCRETE | | | | | | |
| 3.1 PLANT IS. CONCRETE | YD3 | 28900.0 | 70.00 | 80.00 | 2023000.00 | 2312000.00 |
| 3.2 SPECIAL STRUCTURES | YD3 | | | | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 1.919 | | | | ACCOUNT TOTAL,$ | 2023000.00 | 2312000.00 |
| | | | | | | |
| HEAT REJECTION SYSTEM | | | | | | |
| 4.1 COOLING TOWERS | EACH | 1.0 | .00 | .00 | 153500.00 | 76500.00 |
| 4.2 CIRCULATING H2O SYS | EACH | 1.0 | .00 | .00 | 637.12 | 854.29 |
| 4.3 SURFACE CONDENSER | FT2 | 232.5 | .00 | .00 | 283709.77 | 162.74 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .169 | | | | ACCOUNT TOTAL,$ | 437846.89 | 77517.03 |
| | | | | | | |
| STRUCTURAL FEATURES | | | | | | |
| 5.1 STAT. STRUCTURAL ST. | TON | .0 | 650.00 | 175.00 | .00 | .00 |
| 5.2 SILOS & BUNKERS | TPH | .0 | 1800.00 | 750.00 | .00 | .00 |
| 5.3 CHIMNEY | FT | .0 | | | | |
| 5.4 STRUCTURAL FEATURES | EACH | 1.0 | 942000.00 | 197000.00 | 942000.00 | 197000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = .373 | | | | ACCOUNT TOTAL,$ | 942000.00 | 197000.00 |
| | | | | | | |
| BUILDINGS | | | | | | |
| 6.1 STATION BUILDINGS | FT3 | .0 | .16 | .16 | .00 | .00 |
| 6.2 ADMINSTRATION | FT2 | 10000.0 | 16.00 | 14.00 | 160000.00 | 140000.00 |
| 6.3 WAREHOUSE & SHOP | FT2 | 15000.0 | 12.00 | 8.00 | 180000.00 | 120000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = .196 | | | | ACCOUNT TOTAL,$ | 340000.00 | 260000.00 |
| | | | | | | |
| FUEL HANDLING & STORAGE | | | | | | |
| 7.1 COAL HANDLING SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7.2 DOLOMITE HAND. SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7.3 FUEL OIL HAND. SYS | GAL | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = .000 | | | | ACCOUNT TOTAL,$ | .00 | .00 |

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Table A 13.4.16 Continued
SOLID ELECTROLYTE FUEL CELL
PARAMETRIC POINT NO. 4               ACCOUNT LISTING

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| FUEL PROCESSING | | | | | | |
| 9. 1 COAL GASIFIER | EACH | .0 | .00 | .00 | .00 | .00 |
| 9. 2 DESULFURIZER | EACH | .00 | .00 | .00 | .00 | .00 |
| 9. 3 VENTURI SCRUBBER | EACH | .00 | .00 | .00 | .00 | .00 |
| 8. 4 COAL PRETREATMENT | EACH | .00 | .00 | .00 | .00 | .00 |
| 8. 5 REFORMER | EACH | .00 | .00 | .00 | .00 | .00 |
| 9. 6 SHIFT CONVERTER | EACH | .0 | .00 | .00 | .00 | .00 |
| 3. 7 CO2 SCRUBBER | EACH | 1.0 | 2412000.00 | 1800000.00 | 2412000.00 | 1300000.00 |
| 3. 8 BLOWER | EACH | | 2412000.00 | | 2412000.00 | 1800000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 8 = 1.373 ACCOUNT TOTAL,$ | | | | | | |
| | | | | | | |
| FIRING SYSTEM | | | | | | |
| 9. 1 | | 9. = | .000 ACCOUNT TOTAL,$ | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 9 = | | | | | | |
| | | | | | | |
| VAPOR GENERATOR (FIRED) | | | | | | |
| 10. 1 | | 10. = | .000 ACCOUNT TOTAL,$ | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 10 = | | | | | | |
| | | | | | | |
| ENERGY CONVERTER | | | | | | |
| 11. 1 FUEL CELL SYSTEM | EACH | 1.0 | 14200000.00 | 9000000.00 | 14200000.00 | 9000000.00 |
| 11. 2 STM TURBINE GENERATOR | EA | 1.0 | 11518000.00 | 876934.13 | 11518000.00 | 876934.13 |
| 11. 3 OXYGEN PLANT | EACH | | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 11 =53.485 ACCOUNT TOTAL,$ 15351800.00 | | | | | | 9876934.12 |
| | | | | | | |
| COUPLING HEAT EXCHANGER | | | | | | |
| 12. 1 HEAT REC STEAM GEN | EACH | 1.0 | 15624000.00 | 6695000.00 | 15624000.00 | 6695000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 12 = 7.306 ACCOUNT TOTAL,$ 15624000.00 | | | | | | 6696000.00 |
| | | | | | | |
| HEAT RECOVERY HEAT EXCH. | | | | | | |
| 13. 1 RECUPERATOR | EACH | 1.0 | 18400000.00 | 6700000.00 | 18400000.00 | 6700000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 13 = 8.216 ACCOUNT TOTAL,$ 18400000.00 | | | | | | 6700000.00 |
| | | | | | | |
| WATER TREATMENT | | | | | | |
| 14. 1 DEMINERALIZER | GPM | 59.5 | 2500.00 | 700.00 | 148800.00 | 41664.00 |
| 14. 2 CONDENSATE POLISHING | KWE | 37200.0 | 1.25 | .30 | 465000.00 | 11160.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 14 = .251 ACCOUNT TOTAL,$ 613799.99 | | | | | | 153264.00 |
| | | | | | | |
| POWER CONDITIONING | | | | | | |
| 15. 1 POWER CONDITIONING EQ | EA | 1.0 | 59000000.00 | 27000000.00 | 59000000.00 | 27000000.00 |
| 15. 2 STD TRANSFORMER | KVA | | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 15 =20.196 ACCOUNT TOTAL,$ 59000000.00 | | | | | | 27000000.00 |
| | | | | | | |
| AUXILIARY MECH EQUIPMENT | | | | | | |
| 16. 1 BOILER FEED PUMP &DR. | KWE | 365280.4 | 1.67 | .10 | 610018.28 | 36528.04 |
| 16. 2 OTHER PUMPS | KWE | 571487.1 | .88 | .12 | 502908.64 | 68578.45 |
| 16. 3 MISC SERVICE SYS | KWE | 1142974.2 | 1.17 | .73 | 1337279.80 | 834371.15 |
| 16. 4 AUXILIARY BOILER | FPH | 0 | 4.00 | .80 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 16 = 1.110 ACCOUNT TOTAL,$ 2450206.72 | | | | | | 939477.63 |

## SOLID ELECTROLYTE FUEL CELL
### PARAMETRIC POINT NO. 4 — ACCOUNT LISTING

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **PIPE & FITTINGS** | | | | | | |
| 17. 1 CONVENTIONAL PIPING | TON | 845.0 | 3000.00 | 1800.00 | 2535000.00 | 1521000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = 1.328 ACCOUNT TOTAL:$ | | | | | 2535000.00 | 1521000.00 |
| | | | | | | |
| **AUXILIARY ELEC EQUIPMENT** | | | | | | |
| 18. 1 MISC MOTERS,ETC | KWE | 571487.1 | 1.40 | .17 | 800081.93 | 97152.81 |
| 18. 2 SWITCHGEAR & MCC PAN | KWE | 1142974.2 | 1.95 | .45 | 2228799.66 | 514338.38 |
| 18. 3 CONDUIT,CABLES,TRAYS | FT | 2198000.0 | 1.32 | 1.36 | 2901359.97 | 2989279.97 |
| 18. 4 ISOLATED PHASE BUS | FT | 300.0 | 510.00 | 450.00 | 153000.00 | 135000.00 |
| 18. 5 LIGHTING & COMMUN | KWE | 1142974.2 | .35 | .43 | 400090.96 | 491478.90 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 3.506 ACCOUNT TOTAL:$ | | | | | 6483282.44 | 4227250.00 |
| | | | | | | |
| **CONTROL, INSTRUMENTATION** | | | | | | |
| 19. 1 COMPUTER | EACH | 1.0 | 560000.00 | 150000.00 | 660000.00 | 150000.00 |
| 19. 2 OTHER CONTROLS | EACH | 1.0 | 775500.00 | 50000.00 | 775500.00 | 50000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = .491 ACCOUNT TOTAL:$ | | | | | 1435500.00 | 65000.00 |
| | | | | | | |
| **PROCESS WASTE SYSTEMS** | | | | | | |
| 20. 1 BOTTOM ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 2 DRY ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 3 WET SLURRY | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 4 ONSITE DISPOSAL | ACRE | .0 | 7676.49 | 11070.89 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = .000 ACCOUNT TOTAL:$ | | | | | .00 | .00 |
| | | | | | | |
| **STACK GAS CLEANING** | | | | | | |
| 21. 1 PRECIPITATOR | EACH | .0 | .00 | .00 | .00 | .00 |
| 21. 2 SCRUBBER | KWE | .0 | .00 | .00 | .00 | .00 |
| 21. 3 MISC STEEL & DUCTS | | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL:$ | | | | | .00 | .00 |
| | | | | | | |
| **TOTAL DIRECT COSTS:$** | | | | | 266954548.00 | 78543958.50 |

Table A 13.4.17
SOLID ELECTROLYTE FUEL CELL    COST OF ELECTRICITY, MILLS/KW.HR
PARAMETRIC POINT NO. 4

LABOR RATE, $/HR

| ACCOUNT | RATE, PERCENT | | | | | |
|---|---|---|---|---|---|---|
| | | 8.50 | 10.00 | 15.00 | 21.50 |
| TOTAL DIRECT COSTS, $ | | | | | |
| INDIRECT COST, $ | | | | | |
| PROF & OWNER COSTS, $ | | | | | |
| CONTINGENCY COST, $ | | | | | |
| SUB TOTAL, $ | | | | | |
| ESCALATION COST, $ | | | | | |
| INTREST DURING CONST, $ | | | | | |
| TOTAL CAPITALIZATION, $ | | | | | |
| COST OF ELEC-CAPITAL | | | | | |
| COST OF ELEC-FUEL | | | | | |
| COST OF ELEC-OP & MAIN | | | | | |
| TOTAL COST OF ELEC | | | | | |

CONTINGENCY, PERCENT

| ACCOUNT | RATE, PERCENT | | | | | |
|---|---|---|---|---|---|---|
| | | 3.00 | 5.00 | 20.00 | 30.00 |
| TOTAL DIRECT COSTS, $ | | | | | |
| INDIRECT COST, $ | | | | | |
| PROF & OWNER COSTS, $ | | | | | |
| CONTINGENCY COST, $ | | | | | |
| SUB TOTAL, $ | | | | | |
| ESCALATION COST, $ | | | | | |
| INTREST DURING CONST, $ | | | | | |
| TOTAL CAPITALIZATION, $ | | | | | |
| COST OF ELEC-CAPITAL | | | | | |
| COST OF ELEC-FUEL | | | | | |
| COST OF ELEC-OP & MAIN | | | | | |
| TOTAL COST OF ELEC | | | | | |

ESCALATION RATE, PERCENT

| ACCOUNT | RATE, PERCENT | | | | | |
|---|---|---|---|---|---|---|
| | | 6.50 | 10.00 | 12.50 | 18.00 |
| TOTAL DIRECT COSTS, $ | | | | | |
| INDIRECT COST, $ | | | | | |
| PROF & OWNER COSTS, $ | | | | | |
| CONTINGENCY COST, $ | | | | | |
| SUB TOTAL, $ | | | | | |
| ESCALATION COST, $ | | | | | |
| INTREST DURING CONST, $ | | | | | |
| TOTAL CAPITALIZATION, $ | | | | | |
| COST OF ELEC-CAPITAL | | | | | |
| COST OF ELEC-FUEL | | | | | |
| COST OF ELEC-OP & MAIN | | | | | |
| TOTAL COST OF ELEC | | | | | |

INT DURING CONST, PERCENT

| ACCOUNT | RATE, PERCENT | | | | | |
|---|---|---|---|---|---|---|
| | | 6.00 | 12.50 | 15.00 | 18.00 |
| TOTAL DIRECT COSTS, $ | | | | | |
| INDIRECT COST, $ | | | | | |
| PROF & OWNER COSTS, $ | | | | | |
| CONTINGENCY COST, $ | | | | | |
| SUB TOTAL, $ | | | | | |
| ESCALATION COST, $ | | | | | |
| INTREST DURING CONST, $ | | | | | |
| TOTAL CAPITALIZATION, $ | | | | | |
| COST OF ELEC-CAPITAL | | | | | |
| COST OF ELEC-FUEL | | | | | |
| COST OF ELEC-OP & MAIN | | | | | |
| TOTAL COST OF ELEC | | | | | |

Table A 13.4.17 Continued

SOLID ELECTROLYTE FUEL CELL    COST OF ELECTRICITY,MILLS/KW.HR

PARAMETRIC POINT NO. 4

**FIXED CHARGE RATE, PCT**

| ACCOUNT | RATE, PERCENT | 10.00 | 14.40 | 18.00 | 21.60 | 25.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 305498504. | 305498504. | 305498504. | 305498504. | 305498504. |
| INDIRECT COST,$ | 8.0 | 19657418. | 19657418. | 19657418. | 19657418. | 19657418. |
| PROF & OWNER COSTS,$ | 8.0 | 24439880. | 24439880. | 24439880. | 24439880. | 24439880. |
| CONTINGENCY COST,$ | 8.0 | 24439880. | 24439880. | 24439880. | 24439880. | 24439880. |
| SUB TOTAL,$ | .0 | 374035680. | 374035680. | 374035680. | 374035680. | 374035680. |
| ESCALATION COST,$ | 6.5 | 76685605. | 76685605. | 76685605. | 76685605. | 76685605. |
| INTREST DURING CONST,$ | 10.0 | 88332538. | 88332538. | 88332538. | 88332538. | 88332538. |
| TOTAL CAPITALIZATION,$ | 25.0 | 539053816. | 539053816. | 539053816. | 539053816. | 539053816. |
| COST OF ELEC-CAPITAL | .0 | 8.19103 | 11.79509 | 14.74386 | 17.69263 | 20.47755 |
| COST OF ELEC-FUEL | .0 | 11.34006 | 11.34006 | 11.34006 | 11.34006 | 11.34006 |
| COST OF ELEC-OP & MAIN | .0 | 14.15888 | 14.15888 | 14.15888 | 14.15888 | 14.15888 |
| TOTAL COST OF ELEC | .0 | 33.68998 | 37.29403 | 40.24281 | 43.19158 | 45.97653 |

**FUEL COST, $/10**6 BTU**

| ACCOUNT | RATE, PERCENT | 1.20 | 2.00 | 3.10 | 1.60 | 2.40 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 305498504. | 305498504. | 305498504. | 305498504. | 305498504. |
| INDIRECT COST,$ | 8.0 | 19657418. | 19657418. | 19657418. | 19657418. | 19657418. |
| PROF & OWNER COSTS,$ | 8.0 | 24439880. | 24439880. | 24439880. | 24439880. | 24439880. |
| CONTINGENCY COST,$ | 8.0 | 24439880. | 24439880. | 24439880. | 24439880. | 24439880. |
| SUB TOTAL,$ | .0 | 374035680. | 374035680. | 374035680. | 374035680. | 374035680. |
| ESCALATION COST,$ | 6.5 | 76685605. | 76685605. | 76685605. | 76685605. | 76685605. |
| INTREST DURING CONST,$ | 10.0 | 88332538. | 88332538. | 88332538. | 88332538. | 88332538. |
| TOTAL CAPITALIZATION,$ | 18.0 | 539053816. | 539053816. | 539053816. | 539053816. | 539053816. |
| COST OF ELEC-CAPITAL | .0 | 14.74386 | 14.74386 | 14.74386 | 14.74386 | 14.74386 |
| COST OF ELEC-FUEL | .0 | 6.80404 | 11.34006 | 17.57710 | 9.07205 | 13.60807 |
| COST OF ELEC-OP & MAIN | .0 | 14.15888 | 14.15888 | 14.15888 | 14.15888 | 14.15888 |
| TOTAL COST OF ELEC | .0 | 35.70678 | 40.24281 | 46.47984 | 37.97479 | 42.51082 |

**CAPACITY FACTOR, PERCENT**

| ACCOUNT | RATE, PERCENT | 12.00 | 45.00 | 50.00 | 65.00 | 80.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 305498504. | 305498504. | 305498504. | 305498504. | 305498504. |
| INDIRECT COST,$ | 8.0 | 19657418. | 19657418. | 19657418. | 19657418. | 19657418. |
| PROF & OWNER COSTS,$ | 8.0 | 24439880. | 24439880. | 24439880. | 24439880. | 24439880. |
| CONTINGENCY COST,$ | 8.0 | 24439880. | 24439880. | 24439880. | 24439880. | 24439880. |
| SUB TOTAL,$ | .0 | 374035680. | 374035680. | 374035680. | 374035680. | 374035680. |
| ESCALATION COST,$ | 6.5 | 76685605. | 76685605. | 76685605. | 76685605. | 76685605. |
| INTREST DURING CONST,$ | 10.0 | 88332538. | 88332538. | 88332538. | 88332538. | 88332538. |
| TOTAL CAPITALIZATION,$ | 18.0 | 539053816. | 539053816. | 539053816. | 539053816. | 539053816. |
| COST OF ELEC-CAPITAL | .0 | 79.86258 | 21.29669 | 19.16702 | 14.74386 | 11.97939 |
| COST OF ELEC-FUEL | .0 | 11.34006 | 11.34006 | 11.34006 | 11.34006 | 11.34006 |
| COST OF ELEC-OP & MAIN | .0 | 18.38695 | 14.58435 | 14.44607 | 14.15888 | 13.97939 |
| TOTAL COST OF ELEC | .0 | 109.58959 | 47.22110 | 44.95315 | 40.24281 | 37.29884 |

Table A 13.4.18

## SOLID ELECTROLYTE FUEL CELL

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT POW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 4 | .16603 | 2.02027 | .03101 | .8827 |
| 11 | .00000 | .00000 | 15100.00000 | 6300000.00000 |
| 14 | .00000 | .00000 | 6.43781 | .00000 |
| 16 | .00000 | .00000 | .00000 | .00000 |
| 18 | 8.05200 | 97.97973 | 15258.15442 | .00000 |
| TOTALS | 8.21803 | .71104 | 15258.15442 | 6300000.87500 |

SOLID ELECTROLYTE FUEL CELL

| | | BASE CASE INPUT | |
|---|---|---|---|
| NOMINAL POWER, MWE | 1154.0000 | NET POWER, MWE | 1155.7820 |
| NOM HEAT RATE, BTU/KW-HR | 5629.9998 | NET HEAT RATE, BTU/KW-HR | 5670.0311 |
| ST TURB HEAT RATE CHANGE | .9942 | | |

CONDENSER

| DESIGN PRESSURE, IN HG A | 2.0000 | NUMBER OF SHELLS | 2.0000 |
|---|---|---|---|
| NUMBER OF TUBES/SHELL | 5.9017 | TUBE LENGTH, FT | 75.2339 |
| U, BTU/HR-FT2-F | 608.8535 | TERMINAL TEMP DIFF, F | 5.0000 |

HEAT REJECTION

| DESIGN TEMP, F | 51.4000 | APPROACH, F | 21.6744 |
|---|---|---|---|
| RANGE, F | 23.0000 | OFF DESIGN TEMP, F | 77.0000 |
| OFF DESIGN PRES, IN HG A | 1.2126 | LP TURBINE BLADE LEN, IN | 25.0000 |

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 1164.000 | 2.000 | .000 | 1899195.000 | 5630.000 |
| 6 | 372.000 | | | | 2.000 |
| 11 | 1.000 | | | | 5.000 |
| 16 | 2.000 | .500 | 30.000 | 3.000 | |
| 21 | | | 28900.000 | 15000.000 | |
| 26 | | | 10000.000 | .500 | |
| 31 | 1.000 | | 845.000 | 1.000 | 1.000 |
| 36 | 21980.000 | | 300.000 | 15000.000 | 775500.000 |
| 41 | 197000.000 | | 660000.000 | 1.000 | 1.000 |
| 46 | | | .000 | | |
| 51 | | | 5.350 | | |

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 6 | | .000 | .000 | 1.000 | .000 |
| 11 | | | | | |
| 16 | | | | 2412000.000 | 1800000.000 |
| 21 | | | | 142000000.000 | 9000000.000 |
| 26 | 1.000 | 1.000 | | 1.000 | 1151800.000 |
| 31 | | | | 1840000.000 | 1562000.000 |
| 36 | 6696000.000 | | 5900000.000 | 2700000.000 | 6700000.000 |
| 41 | | | | | 1.000 |
| 46 | | | | | |
| 51 | | | | | 15100.000 |
| 56 | .400 | | | | 6300000.000 |

Table A 13.4.19

## SOLID ELECTROLYTE FUEL CELL
### PARAMETRIC POINT NO.18  ACCOUNT LISTING

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| SITE DEVELOPMENT | | | | | | |
| 1. 1 LAND COST | ACRE | 42.0 | 1000.00 | .00 | 42000.00 | .00 |
| 1. 2 CLEARING LAND | ACRE | 14.0 | .00 | 600.00 | .00 | 8399.15 |
| 1. 3 GRADING LAND | ACRE | 42.0 | .00 | 3000.00 | .00 | 126000.00 |
| 1. 4 ACCESS RAILROAD | MILE | 5.0 | 115000.00 | 110000.00 | 575000.00 | 550000.00 |
| 1. 5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 76000.00 | .00 | .00 |
| 1. 6 SIDING R R TRACK | MILE | 1.5 | 125000.00 | 80000.00 | 187500.00 | 120000.00 |
| 1. 7 OTHER SITE COSTS | ACRE | .0 | .00 | .00 | 100130.62 | 100130.62 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = 1.376 ACCOUNT TOTAL,$ | | | | | 904630.62 | 904529.77 |
| EXCAVATION & PILING | | | | | | |
| 2. 1 COMMON EXCAVATION | YD3 | 36450.0 | .00 | 3.00 | .00 | 109350.00 |
| 2. 2 PILING | FT | .0 | 6.50 | 8.50 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .083 ACCOUNT TOTAL,$ | | | | | .00 | 109350.00 |
| PLANT ISLAND CONCRETE | | | | | | |
| 3. 1 PLANT IS. CONCRETE | YD3 | 12150.0 | 70.00 | 80.00 | 850500.00 | 972000.00 |
| 3. 2 SPECIAL STRUCTURES | YD3 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 1.386 ACCOUNT TOTAL,$ | | | | | 850500.00 | 972000.00 |
| HEAT REJECTION SYSTEM | | | | | | |
| 4. 1 COOLING TOWERS | EACH | .0 | .00 | .00 | .00 | .00 |
| 4. 2 CIRCULATING H2O SYS | EACH | 1.0 | .00 | .00 | .00 | .00 |
| 4. 3 SURFACE CONDENSER | FT2 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| STRUCTURAL FEATURES | | | | | | |
| 5. 1 STR. STRUCTURAL ST. | TON | .0 | 650.00 | 175.00 | .00 | .00 |
| 5. 2 SILOS & BUNKERS | TPH | 64.7 | 180.00 | 750.00 | 116381.81 | 43492.42 |
| 5. 3 CHIMNEY | FT | .0 | .00 | .00 | .00 | .00 |
| 5. 4 STRUCTURAL FEATURES | EACH | 1.0 | 330000.00 | 70000.00 | 330000.00 | 70000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = .430 ACCOUNT TOTAL,$ | | | | | 446381.81 | 118492.42 |
| BUILDINGS | | | | | | |
| 6. 1 STATION BUILDINGS | FT3 | 10000.0 | .00 | .16 | .00 | 140000.00 |
| 6. 2 ADMINSTRATION | FT2 | 10000.0 | 16.00 | 14.00 | 160000.00 | 80000.00 |
| 6. 3 WAREHOUSE & SHOP | FT2 | 10000.0 | 12.00 | 8.00 | 120000.00 | 220000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = .380 ACCOUNT TOTAL,$ | | | | | 280000.00 | 220000.00 |
| FUEL HANDLING & STORAGE | | | | | | |
| 7. 1 COAL HANDLING SYS | TPH | 64.7 | .00 | .00 | 1083565.48 | 586629.56 |
| 7. 2 DOLOMITE HAND. SYS | TPH | 34.2 | .00 | .00 | 610490.90 | 358623.95 |
| 7. 3 FUEL OIL HAND. SYS | GAL | 25000.0 | .00 | .00 | 6727.20 | 5526.17 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = 2.017 ACCOUNT TOTAL,$ | | | | | 1700783.56 | 950779.67 |

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Table A 13.4.19 Continued

SOLID ELECTROLYTE FUEL CELL
PARAMETRIC POINT NO. 18

ACCOUNT LISTING

| ACCOUNT NO. & NAME | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| FUEL PROCESSING | | | | | | |
| 8-- 1 COAL GASIFIER | EACH | 1.0 | 4200000.00 | 1540000.00 | 4200000.00 | 15400000.00 |
| 8-- 2 DESULFURIZER | EACH | 1.0 | 5000000.00 | 1250000.00 | 5000000.00 | 12500000.00 |
| 8-- 3 DESULFURIZER | EACH | 1.0 | 1910000.00 | 480000.00 | 1910000.00 | 4800000.00 |
| 8-- 4 VENTURI SCRUBBER | EACH | 1.0 | 1110000.00 | 280000.00 | 1110000.00 | 2800000.00 |
| 8-- 5 COAL PRETREATMENT | EACH | | .00 | .00 | .00 | .00 |
| 8-- 6 REFORMER | EACH | | .00 | .00 | .00 | .00 |
| 8-- 7 SHIFT CONVERTER | EACH | | .00 | .00 | .00 | .00 |
| 8-- 8 CO2 SCRUBBER | EACH | | .00 | .00 | .00 | .00 |
| 8-- 8 BLOWER | EACH | 1.0 | 2340000.00 | 1000000.00 | 2340000.00 | 10000000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 8 =52.839 ACCOUNT TOTAL,$ | | | | | 5236000C.00 | 18410000.00 |
| FIRING SYSTEM | | | | | | |
| 9-- 1 PERCENT TOTAL DIRECT COST IN ACCOUNT 9 = .000 ACCOUNT TOTAL,$ | | | .00 | .00 | .00 | .00 |
| VAPOR GENERATOR (FIRED) | | | | | | |
| 10-- 1 PERCENT TOTAL DIRECT COST IN ACCOUNT 10 = .000 ACCOUNT TOTAL,$ | | | .00 | .00 | .00 | .00 |
| ENERGY CONVERTER | | | | | | |
| 11-- 1 FUEL CELL SYSTEM | EACH | 1.0 | 1980000.00 | 250000.00 | 1380000C.00 | 2500000.00 |
| 11-- 2 STM TURBINE GENERATOR | EA | | .00 | .00 | .00 | .00 |
| 11-- 3 OXYGEN PLANT | EACH | | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 11 =16.204 ACCOUNT TOTAL,$ | | | | | 1080000C.00 | 2500000.00 |
| COUPLING HEAT EXCHANGER | | | | | | |
| 12-- 1 HEAT REC STEAM GEN | EACH | 1.0 | 211000.00 | 90000.00 | 211000.00 | 90000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 12 = .229 ACCOUNT TOTAL,$ | | | | | 211000.00 | 90000.00 |
| HEAT RECOVERY HEAT EXCH. | | | | | | |
| 13-- 1 RECUPERATOR | EACH | 1.0 | 420000C.00 | 1530000.00 | 420000C.00 | 1530000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 13 = 4.359 ACCOUNT TOTAL,$ | | | | | 420000C.00 | 1530000.00 |
| WATER TREATMENT | | | | | | |
| 14-- 1 DEMINERALIZER | GPM | .0 | 2500.00 | 700.00 | .00 | .00 |
| 14-- 2 CONDENSATE POLISHING | KWE | .0 | 1.25 | .30 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 14 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |
| POWER CONDITIONING | | | | | | |
| 15-- 1 POWER CONDITIONING EQ | EA | 1.0 | 1750000.00 | 750000.00 | 1750000.00 | 750000.00 |
| 15-- 2 STD TRANSFORMER | KVA | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 15 =13.884 ACCOUNT TOTAL,$ | | | | | 1750000.00 | 750000.00 |
| AUXILIARY MECH EQUIPMENT | | | | | | |
| 16-- 1 BOILER FEED PUMP &DR.KWE | KWE | .0 | .55 | .04 | .00 | .00 |
| 16-- 2 OTHER PUMPS | KWE | .0 | .88 | .12 | .00 | .00 |
| 16-- 3 MISC SERVICE SYS | KWE | 279325.9 | 1.17 | .73 | 326812.52 | 203903.67 |
| 16-- 4 AUXILIARY BOILER | FPH | .0 | 4.00 | .80 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 16 = .404 ACCOUNT TOTAL,$ | | | | | 326812.52 | 203903.67 |

Table A 13.4.19 Continued

SOLID ELECTROLYTE FUEL CELL     ACCOUNT LISTING

PARAMETRIC POINT NO.18

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| PIPE & FITTINGS | | | | | | |
| 17. 1 CONVENTIONAL PIPING | TON | 60.0 | 3000.00 | 1800.00 | 180000.00 | 108000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = .219 ACCOUNT TOTAL,$ | | | | | 180000.00 | 108000.00 |
| | | | | | | |
| AUXILIARY ELEC EQUIPMENT | | | | | | |
| 18. 1 MISC MOTERS,ETC | KWE | 83798.1 | 1.40 | .17 | 117317.32 | 14295.67 |
| 18. 2 SWITCHGEAR & MCC PAN | KWE | 279326.9 | 1.95 | .45 | 544687.54 | 125697.12 |
| 18. 3 CONDUIT,CABLES,TRAYS | FT | 400000.0 | 1.32 | 1.36 | 527999.99 | 543999.99 |
| 18. 4 ISOLATED PHASE BUS | FT | .0 | 510.00 | 450.00 | .00 | .00 |
| 18. 5 LIGHTING & COMMUN | KWE | 279326.9 | .35 | .43 | 97764.43 | 120110.59 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 1.591 ACCOUNT TOTAL,$ | | | | | 1287769.27 | 804053.37 |
| | | | | | | |
| CONTROL, INSTRUMENTATION | | | | | | |
| 19. 1 COMPUTER | EACH | 1.0 | 200000.00 | 6000.00 | 200000.00 | 6000.00 |
| 19. 2 OTHER CONTROLS | EACH | 1.0 | 166000.00 | 100000.00 | 166000.00 | 100000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = .359 ACCOUNT TOTAL,$ | | | | | 366000.00 | 106000.00 |
| | | | | | | |
| PROCESS WASTE SYSTEMS | | | | | | |
| 20. 1 BOTTOM ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 2 DRY ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 3 WET SLURRY | TPH | 34.2 | 1036072.06 | 259018.02 | 1036072.06 | 259018.02 |
| 20. 4 ONSITE DISPOSAL | ACRE | 174.4 | 6875.64 | 10105.84 | 1198916.50 | 1762170.44 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = 3.238 ACCOUNT TOTAL,$ | | | | | 2234988.56 | 2021188.45 |
| | | | | | | |
| STACK GAS CLEANING | | | | | | |
| 21. 1 PRECIPITATOR | EACH | .0 | 1782899.77 | 1158884.84 | .00 | .00 |
| 21. 2 SCRUBBER | KWE | .0 | .00 | .00 | .00 | .00 |
| 21. 3 MISC STEEL & DUCTS | | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

TOTAL DIRECT COSTS,$     101648864.00     29798301.75

Table A 13.4.20

SOLID ELECTROLYTE FUEL CELL    COST OF ELECTRICITY, MILLS/KW.HR
PARAMETRIC POINT NO.19

**LABOR RATE, $/HR**

| ACCOUNT | RATE, PERCENT |
|---|---|

- TOTAL DIRECT COSTS,$
- INDIRECT COST,$
- PROF & OWNER COSTS,$
- CONTINGENCY COST,$
- SUB TOTAL,$
- ESCALATION COST,$
- INTREST DURING CONST,$
- TOTAL CAPITALIZATION,$
- COST OF ELEC-CAPITAL
- COST OF ELEC-FUEL
- COST OF ELEC-OP & MAIN
- TOTAL COST OF ELEC

**CONTINGENCY, PERCENT**

| ACCOUNT | RATE, PERCENT |
|---|---|

- TOTAL DIRECT COSTS,$
- INDIRECT COST,$
- PROF & OWNER COSTS,$
- CONTINGENCY COST,$
- SUB TOTAL,$
- ESCALATION COST,$
- INTREST DURING CONST,$
- TOTAL CAPITALIZATION,$
- COST OF ELEC-CAPITAL
- COST OF ELEC-FUEL
- COST OF ELEC-OP & MAIN
- TOTAL COST OF ELEC

**ESCALATION RATE, PERCENT**

| ACCOUNT | RATE, PERCENT |
|---|---|

- TOTAL DIRECT COSTS,$
- INDIRECT COST,$
- PROF & OWNER COSTS,$
- CONTINGENCY COST,$
- SUB TOTAL,$
- ESCALATION COST,$
- INTREST DURING CONST,$
- TOTAL CAPITALIZATION,$
- COST OF ELEC-CAPITAL
- COST OF ELEC-FUEL
- COST OF ELEC-OP & MAIN
- TOTAL COST OF ELEC

**INT DURING CONST, PERCENT**

| ACCOUNT | RATE, PERCENT |
|---|---|

- TOTAL DIRECT COSTS,$
- INDIRECT COST,$
- PROF & OWNER COSTS,$
- CONTINGENCY COST,$
- SUB TOTAL,$
- ESCALATION COST,$
- INTREST DURING CONST,$
- TOTAL CAPITALIZATION,$
- COST OF ELEC-CAPITAL
- COST OF ELEC-FUEL
- COST OF ELEC-OP & MAIN
- TOTAL COST OF ELEC

Table A 13.4.20 Continued
SOLID ELECTROLYTE FUEL CELL     COST OF ELECTRICITY, MILLS/KW-HR
PARAMETRIC POINT NO.18

**FIXED CHARGE RATE, PCT**

| ACCOUNT | RATE, PERCENT | 10.00 | 14.40 | 18.00 | 21.60 | 25.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 131447165. | 131447165. | 131447165. | 131447165. | 131447165. |
| INDIRECT COST,$ | | 15197133. | 15197133. | 15197133. | 15197133. | 15197133. |
| PROF & OWNER COSTS,$ | 8.0 | 105515773. | 105515773. | 105515773. | 105515773. | 105515773. |
| CONTINGENCY COST,$ | 6.0 | 7886830. | 7886830. | 7886830. | 7886830. | 7886830. |
| SUB TOTAL,$ | | 165046898. | 165046898. | 165046898. | 165046898. | 165046898. |
| ESCALATION COST,$ | 6.5 | 19457089. | 19457089. | 19457089. | 19457089. | 19457089. |
| INTREST DURING CONST,$ | 10.0 | 20953113. | 20953113. | 20953113. | 20953113. | 20953113. |
| TOTAL CAPITALIZATION,$ | | 205457098. | 205457098. | 205457098. | 205457098. | 205457098. |
| COST OF ELEC-CAPITAL | 25.0 | 16.65449 | 23.98247 | 29.97809 | 35.97371 | 41.63623 |
| COST OF ELEC-FUEL | | 5.47306 | 5.47306 | 5.47306 | 5.47306 | 5.47306 |
| COST OF ELEC-OP & MAIN | | 12.24773 | 12.24773 | 12.24773 | 12.24773 | 12.24773 |
| TOTAL COST OF ELEC | | 34.37529 | 41.70326 | 47.69888 | 53.69450 | 59.35703 |

**FUEL COST, $/10**6 BTU**

| ACCOUNT | RATE, PERCENT | .50 | .85 | 1.00 | 1.50 | 2.50 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 51.0 | 131447165. | 131447165. | 131447165. | 131447165. | 131447165. |
| INDIRECT COST,$ | | 15197133. | 15197133. | 15197133. | 15197133. | 15197133. |
| PROF & OWNER COSTS,$ | 8.0 | 105515773. | 105515773. | 105515773. | 105515773. | 105515773. |
| CONTINGENCY COST,$ | 6.0 | 7886830. | 7886830. | 7886830. | 7886830. | 7886830. |
| SUB TOTAL,$ | | 165046898. | 165046898. | 165046898. | 165046898. | 165046898. |
| ESCALATION COST,$ | 6.5 | 19457089. | 19457089. | 19457089. | 19457089. | 19457089. |
| INTREST DURING CONST,$ | 10.0 | 20953113. | 20953113. | 20953113. | 20953113. | 20953113. |
| TOTAL CAPITALIZATION,$ | | 205457098. | 205457098. | 205457098. | 205457098. | 205457098. |
| COST OF ELEC-CAPITAL | 18.0 | 29.97809 | 29.97809 | 29.97809 | 29.97809 | 29.97809 |
| COST OF ELEC-FUEL | | 3.21945 | 5.47306 | 6.56834 | 9.65834 | 16.09723 |
| COST OF ELEC-OP & MAIN | | 12.24773 | 12.24773 | 12.24773 | 12.24773 | 12.24773 |
| TOTAL COST OF ELEC | | 45.44527 | 47.69888 | 51.88416 | 58.32306 | 48.79349 |

**CAPACITY FACTOR, PERCENT**

| ACCOUNT | RATE, PERCENT | 45.00 | 50.00 | 65.00 | 80.00 |
|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | 12.00 | 131447165. | 131447165. | 131447165. | 131447165. |
| INDIRECT COST,$ | 51.0 | 15197133. | 15197133. | 15197133. | 15197133. |
| PROF & OWNER COSTS,$ | 8.0 | 105515773. | 105515773. | 105515773. | 105515773. |
| CONTINGENCY COST,$ | 6.0 | 7886830. | 7886830. | 7886830. | 7886830. |
| SUB TOTAL,$ | | 165046898. | 165046898. | 165046898. | 165046898. |
| ESCALATION COST,$ | 6.5 | 19457089. | 19457089. | 19457089. | 19457089. |
| INTREST DURING CONST,$ | 10.0 | 20953113. | 20953113. | 20953113. | 20953113. |
| TOTAL CAPITALIZATION,$ | | 205457098. | 205457098. | 205457098. | 205457098. |
| COST OF ELEC-CAPITAL | 18.0 | 43.30168 | 38.97151 | 29.97809 | 24.35720 |
| COST OF ELEC-FUEL | | 5.47306 | 5.47306 | 5.47306 | 5.47306 |
| COST OF ELEC-OP & MAIN | | 16.53716 | 12.69447 | 12.54928 | 12.05927 |
| TOTAL COST OF ELEC | | 184.54152 | 61.46921 | 55.99385 | 41.88952 |

Table A 13.4.21

## SOLID ELECTROLYTE FUEL CELL

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT POW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 7 | .94372 | 40.27445 | 183.02236 | .00000 |
| 8 | .08405 | 3.58707 | .00000 | .00000 |
| 11 | .00000 | .00000 | 2150.00000 | .00000 |
| 18 | 1.09500 | 46.73031 | .00000 | 1240000.00000 |
| 20 | .22096 | 9.40817 | 1.13303 | .00000 |

TOTALS
SOLID ELECTROLYTE FUEL CELL   2.34323   1.08154   2435.78137   1240000.000000

BASE CASE INPUT
NOMINAL POWER, MWE        219.0000          NET POWER, MWE              216.6568
NOM HEAT RATE, BTU/KW-HR  6369.9998         NET HEAT RATE, BTU/KW-HR    6438.8939
ST TURB HEAT RATE CHANGE  .0000

CONDENSER
DESIGN PRESSURE, IN HG A   2.0000           NUMBER OF SHELLS            2.0000
NUMBER OF TUBES/SHELL      .0000             TUBE LENGTH, FT             .0000
U, BTU/HR-FT2-F            608.8535          TERMINAL TEMP DIFF, F       .0000

HEAT REJECTION
DESIGN TEMP, F             .0000             APPROACH, F                 .0000
RANGE, F                   .0000             OFF DESIGN TEMP, F          .0000
OFF DESIGN PRES, IN HG A   .0000             LP TURBINE BLADE LEN, IN    25.0000

| 1 | 219.000 | 2 | 2.000 | 3 | .000 | 4 | .000 | 5 | 6370.000 | |
| 6 | .000 | 7 | .000 | 8 | .000 | 9 | .000 | 10 | .000 | |
| 11 | .000 | 12 | .000 | 13 | .000 | 14 | 1.000 | 15 | .000 | |
| 16 | .000 | 17 | 42.000 | 18 | .000 | 19 | 3.000 | 20 | 5.000 | |
| 21 | 1.500 | 22 | 12150.000 | 23 | .000 | 24 | .000 | 25 | .000 | |
| 26 | .000 | 27 | 10000.000 | 28 | .000 | 29 | 10000.000 | 30 | 25000.000 | |
| 31 | 1.000 | 32 | 60.000 | 33 | .000 | 34 | 1.000 | 35 | 1.000 | |
| 36 | 400000.000 | 37 | .000 | 38 | .000 | 39 | 1.000 | 40 | 330000.000 | |
| 41 | 70000.000 | 42 | 200000.000 | 43 | .000 | 44 | 6000.000 | 45 | 166000.000 | 100000.000 |
| 46 | .000 | 47 | .000 | 48 | .000 | 49 | 1.000 | 50 | 6.000 | |
| 51 | .529 | 52 | 5.350 | 53 | .000 | 54 | .000 | 55 | .000 | |

| 1 | 1.000 | 2 | 1.000 | 3 | 1.000 | 4 | 1.000 | 5 | 1.000 | |
| 6 | 5000000.000 | 7 | 1250000.000 | 8 | .000 | 9 | .000 | 10 | 4200000.000 | 1540000.000 |
| 11 | 280000.000 | 12 | .000 | 13 | .000 | 14 | .000 | 15 | 480000.000 | 110000.000 |
| 16 | .000 | 17 | .000 | 18 | .000 | 19 | .000 | 20 | .000 | |
| 21 | .000 | 22 | .000 | 23 | 2340000.000 | 24 | 1000000.000 | 25 | .000 | |
| 26 | .000 | 27 | .000 | 28 | 18800000.000 | 29 | 2500000.000 | 30 | 211000.000 | 1.000 |
| 31 | .000 | 32 | .000 | 33 | .000 | 34 | .000 | 35 | .000 | |
| 36 | 90000.000 | 37 | 1.000 | 38 | 4200000.000 | 39 | 1530000.000 | 40 | 1.000 | |
| 41 | .000 | 42 | .000 | 43 | 750000.000 | 44 | .000 | 45 | .000 | |
| 46 | .000 | 47 | .000 | 48 | .000 | 49 | 1.000 | 50 | .000 | |
| 51 | .000 | 52 | .000 | 53 | .000 | 54 | 2150.000 | 55 | 1240000.000 | |
| 56 | .400 | 57 | .000 | 58 | .000 | 59 | .000 | 60 | .000 | |

Table A 13.4.22

MOLTEN CARBONATE FUEL CELL SYSTEM      ACCOUNT LISTING

PARAMETRIC POINT NO. 4

| ACCOUNT NO. & NAME | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST,$ | INS COST,$ |
|---|---|---|---|---|---|---|
| **SITE DEVELOPMENT** | | | | | | |
| 1. 1 LAND COST | ACRE | 50.0 | 1000.00 | 500.00 | 5000.00 | .00 |
| 1. 2 CLEARING LAND | ACRE | 16.7 | .00 | .00 | .00 | 9999.00 |
| 1. 3 GRADING LAND | ACRE | 50.0 | .00 | 3000.00 | .00 | 150000.00 |
| 1. 4 ACCESS RAILROAD | MILE | 5.0 | 115000.00 | 110000.00 | 575000.00 | 55000.00 |
| 1. 5 LOOP RAILROAD TRACK | MILE | .0 | 120000.00 | 70000.00 | .00 | .00 |
| 1. 6 SIDING R R TRACK | MILE | .5 | 125000.00 | 80000.00 | 62500.00 | 40000.00 |
| 1. 7 OTHER SITE COSTS | ACRE | .0 | .00 | .00 | 118248.90 | 118248.90 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 1 = .514 ACCOUNT TOTAL,$ | | | | | 805748.89 | 963247.88 |
| **EXCAVATION & PILING** | | | | | | |
| 2. 1 COMMON EXCAVATION | YD3 | 185100.0 | .00 | 3.00 | .00 | 555300.00 |
| 2. 2 PILING | FT | .0 | 6.50 | 8.50 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 2 = .171 ACCOUNT TOTAL,$ | | | | | .00 | 555300.00 |
| **PLANT ISLAND CONCRETE** | | | | | | |
| 3. 1 PLANT IS. CONCRETE | YD3 | 51700.0 | 80.00 | 70.00 | 4319000.00 | 4936000.00 |
| 3. 2 SPECIAL STRUCTURES | YD3 | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 3 = 2.843 ACCOUNT TOTAL,$ | | | | | 4319000.00 | 4936000.00 |
| **HEAT REJECTION SYSTEM** | | | | | | |
| 4. 1 COOLING TOWERS | EACH | 1.0 | 153500.00 | .00 | 153500.00 | 76500.00 |
| 4. 2 CIRCULATING H2O SYS | EACH | 1.0 | 640.55 | .00 | 640.55 | 858.90 |
| 4. 3 SURFACE CONDENSER | FT2 | 233.7 | 283714.13 | .00 | 283714.13 | 163.62 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 4 = .158 ACCOUNT TOTAL,$ | | | | | 437854.68 | 77522.51 |
| **STRUCTURAL FEATURES** | | | | | | |
| 5. 1 STAT. STRUCTURAL ST. | TON | .0 | 650.00 | 175.00 | .00 | .00 |
| 5. 2 SILOS & BUNKERS | TPH | .0 | 1800.00 | 750.00 | .00 | .00 |
| 5. 3 CHIMNEY | FT | .0 | .00 | .00 | .00 | .00 |
| 5. 4 STRUCTURAL FEATURES | EACH | 1.0 | 982000.00 | 217000.00 | 982000.00 | 217000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 5 = .368 ACCOUNT TOTAL,$ | | | | | 982000.00 | 217000.00 |
| **BUILDINGS** | | | | | | |
| 6. 1 STATION BUILDING | FT3 | 10000.0 | 16.00 | 14.15 | 160000.00 | 140000.00 |
| 6. 2 ADMINSTRATION | FT2 | 10000.0 | 16.00 | 12.00 | 160000.00 | 120000.00 |
| 6. 3 WAREHOUSE & SHOP | FT2 | 15000.0 | 12.00 | 8.00 | 180000.00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 6 = .184 ACCOUNT TOTAL,$ | | | | | 340000.00 | 260000.00 |
| **FUEL HANDLING & STORAGE** | | | | | | |
| 7. 1 COAL HANDLING SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7. 2 DOLOMITE HAND. SYS | TPH | .0 | .00 | .00 | .00 | .00 |
| 7. 3 FUEL OIL HAND. SYS | GAL | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 7 = .000 ACCOUNT TOTAL,$ | | | | | .00 | .00 |

Table A 13.4.22 Continued

MOLTEN CARBONATE FUEL CELL SYSTEM    ACCOUNT LISTING

PARAMETRIC POINT NO. 4

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST.$ | INS COST.$ |
|---|---|---|---|---|---|---|

FUEL PROCESSING
1. COAL GASIFIER          EACH
2. DESULFURIZER           EACH
3. VENTURI SCRUBBER       EACH
4. COAL PRETREATMENT      EACH
5. REFORMER/CONVERTER     EACH
6. SHIFT CONVERTER        EACH
7. CO2 CONVERTER          EACH
8. BLOWER                 EACH
PERCENT TOTAL DIRECT COST IN ACCOUNT  8 = .777 ACCOUNT TOTAL.$

FIRING SYSTEM
9.
PERCENT TOTAL DIRECT COST IN ACCOUNT  9 = .000 ACCOUNT TOTAL.$

VAPOR GENERATOR (FIRED)
10.
PERCENT TOTAL DIRECT COST IN ACCOUNT 10 = .000 ACCOUNT TOTAL.$

ENERGY CONVERTER
11. 1 FUEL CELL SYSTEM     EACH
11. 2 STM TURBINE GENERATOR EA
11. 3 OXYGEN PLANT         EACH
PERCENT TOTAL DIRECT COST IN ACCOUNT 11 = 56.552 ACCOUNT TOTAL.$

COUPLING HEAT EXCHANGER
12. 1 HEAT REC STEAM GEN   EACH
PERCENT TOTAL DIRECT COST IN ACCOUNT 12 = 7.445 ACCOUNT TOTAL.$

HEAT RECOVERY HEAT EXCH.
13. 1 RECUPERATOR          EACH
PERCENT TOTAL DIRECT COST IN ACCOUNT 13 = 5.417 ACCOUNT TOTAL.$

WATER TREATMENT
14. 1 DEMINERALIZER        GPM
14. 2 CONDENSATE POLISHING KWE
PERCENT TOTAL DIRECT COST IN ACCOUNT 14 = .256 ACCOUNT TOTAL.$

POWER CONDITIONING
15. 1 POWER CONDITIONING   EA
15. 2 STD TRANSFORMER      KVA
PERCENT TOTAL DIRECT COST IN ACCOUNT 15 = 19.296 ACCOUNT TOTAL.$

AUXILIARY MECH EQUIPMENT
16. 1 BOILER FEED PUMP     BFR.KWE      1.67
16. 2 OTHER PUMPS          KWE          .88
16. 3 MISC SERVICE SYS     KWE         1.17
16. 4 AUXILIARY BOILER     PPH         4.00
PERCENT TOTAL DIRECT COST IN ACCOUNT 16 = 1.032 ACCOUNT TOTAL.$

Table A 13.4.22 Continued

MOLTEN CARBONATE FUEL CELL SYSTEM  ACCOUNT LISTING
PARAMETRIC POINT NO. 4

| ACCOUNT NO. & NAME. | UNIT | AMOUNT | MAT $/UNIT | INS $/UNIT | MAT COST.$ | INS COST.$ |
|---|---|---|---|---|---|---|
| **PIPE & FITTINGS** | | | | | | |
| 17. 1 CONVENTIONAL PIPING | TON | 770.0 | 3000.00 | 1300.00 | 2310000.00 | 1386000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 17 = 1.135 ACCOUNT TOTAL.$ | | | | | 2310000.00 | 1386000.00 |
| | | | | | | |
| **AUXILIARY ELEC EQUIPMENT** | | | | | | |
| 18. 1 MISC MOTERS,ETC | | 586838.1 | 1.40 | .17 | 821573.29 | 99762.47 |
| 18. 2 SWITCHGEAR & MCC PAN | KWE | 1173676.1 | 1.95 | .45 | 2288668.44 | 528154.25 |
| 18. 3 CONDUIT,CABLES,TRAYS | FT | 2358000.0 | 1.32 | 1.36 | 3112559.97 | 3206879.97 |
| 18. 4 ISOLATED PHASE BUS | FT | 300.0 | 510.00 | 450.00 | 153000.00 | 135000.00 |
| 18. 5 LIGHTING & COMMUN | KWE | 1173676.1 | .35 | .43 | 410786.64 | 504680.73 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 18 = 3.459 ACCOUNT TOTAL.$ | | | | | 6786588.31 | 4474477.37 |
| | | | | | | |
| **CONTROL, INSTRUMENTATION** | | | | | | |
| 19. 1 COMPUTER | EACH | 1.0 | 560000.00 | 435000.00 | 560000.00 | 435000.00 |
| 19. 2 OTHER CONTROLS | EACH | 1.0 | 722000.00 | 450000.00 | 722000.00 | 450000.00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 19 = .563 ACCOUNT TOTAL.$ | | | | | 1382000.00 | |
| | | | | | | |
| **PROCESS WASTE SYSTEMS** | | | | | | |
| 20. 1 BOTTOM ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 2 DRY ASH | TPH | .0 | .00 | .00 | .00 | .00 |
| 20. 3 WET SLURRY | TPH | .0 | 7676.49 | 11070.89 | | |
| 20. 4 ONSITE DISPOSAL | ACRE | .0 | | | | |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 20 = .000 ACCOUNT TOTAL.$ | | | | | | |
| | | | | | | |
| **STACK GAS CLEANING** | | | | | | |
| 21. 1 PRECIPITATOR | EACH | .0 | .00 | .00 | .00 | .00 |
| 21. 2 SCRUBBER | KWE | .0 | .00 | .00 | .00 | .00 |
| 21. 3 MISC STEEL & DUCTS | | .0 | .00 | .00 | .00 | .00 |
| PERCENT TOTAL DIRECT COST IN ACCOUNT 21 = .000 ACCOUNT TOTAL.$ | | | | | | |
| | | | | | | |
| **TOTAL DIRECT COSTS.$** | | | | | 290771955.00 | 34817045.00 |

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Table A 13.4.23

MOLTEN CARBONATE FUEL CELL SYSTEM    COST OF ELECTRICITY,MILLS/KWH.HR
PARAMETRIC POINT NO. 4

ACCOUNT

TOTAL DIRECT COST,$
INDIRECT COST,$
PERCENT OWNER COST,$
CONTINGENCY COST,$
SUB TOTAL,$
ESCALATION DURING CONST,$
TOTAL,$
INTREST DURING CONST,$
TOTAL CAPITALIZATION,$
TOTAL CAPITAL
COST OF ELEC-CAPITAL
COST OF ELEC-FUEL
COST OF ELEC-OP + MAIN
TOTAL COST OF ELEC

Table A 13.4.23 Continued

MOLTEN CARBONATE FUEL CELL SYSTEM    COST OF ELECTRICITY,MILLS/KW.HR
PARAMETRIC POINT NO. 4

### ACCOUNT — FIXED CHARGE RATE, PCT

| ACCOUNT | RATE, PERCENT | 10.00 | 14.40 | 18.00 | 21.60 | 25.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | .0 | 325589000. | 325589000. | 325589000. | 325589000. | 325589000. |
| INDIRECT COST,$ | 51.0 | 177566692. | 177566692. | 177566692. | 177566692. | 177566692. |
| PROF & OWNER COSTS,$ | 8.0 | 260047120. | 260047120. | 260047120. | 260047120. | 260047120. |
| CONTINGENCY COST,$ | 8.0 | 260047120. | 260047120. | 260047120. | 260047120. | 260047120. |
| SUB TOTAL,$ | .0 | 395439932. | 395439932. | 395439932. | 395439932. | 395439932. |
| ESCALATION COST,$ | 6.5 | 810739951. | 810739951. | 810739951. | 810739951. | 810739951. |
| INTREST DURING CONST,$ | 10.0 | 933873382. | 933873382. | 933873382. | 933873382. | 933873382. |
| TOTAL CAPITALIZATION,$ | 25.0 | 5699012256. | 5699012256. | 5699012256. | 5699012256. | 5699012256. |
| COST OF ELEC-CAPITAL | | 8.47155 | 12.19990 | 15.24880 | 18.29856 | 21.17889 |
| COST OF ELEC-FUEL | | 12.55007 | 12.55007 | 12.55007 | 12.55007 | 12.55007 |
| COST OF ELEC-OP & MAIN | | 16.05295 | 16.05295 | 16.05295 | 16.05295 | 16.05295 |
| TOTAL COST OF ELEC | | 37.07457 | 40.80205 | 43.85181 | 46.90157 | 49.78190 |

### ACCOUNT — FUEL COST, $/10**6 BTU

| ACCOUNT | RATE, PERCENT | 1.20 | 2.00 | 3.10 | 1.60 | 2.40 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | .0 | 325589000. | 325589000. | 325589000. | 325589000. | 325589000. |
| INDIRECT COST,$ | 51.0 | 177566692. | 177566692. | 177566692. | 177566692. | 177566692. |
| PROF & OWNER COSTS,$ | 8.0 | 260047120. | 260047120. | 260047120. | 260047120. | 260047120. |
| CONTINGENCY COST,$ | 8.0 | 260047120. | 260047120. | 260047120. | 260047120. | 260047120. |
| SUB TOTAL,$ | .0 | 395439932. | 395439932. | 395439932. | 395439932. | 395439932. |
| ESCALATION COST,$ | 6.5 | 810739951. | 810739951. | 810739951. | 810739951. | 810739951. |
| INTREST DURING CONST,$ | 10.0 | 933873382. | 933873382. | 933873382. | 933873382. | 933873382. |
| TOTAL CAPITALIZATION,$ | 18.0 | 5699012256. | 5699012256. | 5699012256. | 5699012256. | 5699012256. |
| COST OF ELEC-CAPITAL | | 15.24880 | 15.24880 | 15.24880 | 15.24880 | 15.24880 |
| COST OF ELEC-FUEL | | 7.53004 | 12.55007 | 19.45260 | 10.04005 | 15.06008 |
| COST OF ELEC-OP & MAIN | | 16.05295 | 16.05295 | 16.05295 | 16.05295 | 16.05295 |
| TOTAL COST OF ELEC | | 38.83179 | 43.85181 | 50.75435 | 41.34180 | 46.36182 |

### ACCOUNT — CAPACITY FACTOR, PERCENT

| ACCOUNT | RATE, PERCENT | 12.00 | 45.00 | 50.00 | 65.00 | 80.00 |
|---|---|---|---|---|---|---|
| TOTAL DIRECT COSTS,$ | .0 | 325589000. | 325589000. | 325589000. | 325589000. | 325589000. |
| INDIRECT COST,$ | 51.0 | 177566692. | 177566692. | 177566692. | 177566692. | 177566692. |
| PROF & OWNER COSTS,$ | 8.0 | 260047120. | 260047120. | 260047120. | 260047120. | 260047120. |
| CONTINGENCY COST,$ | 8.0 | 260047120. | 260047120. | 260047120. | 260047120. | 260047120. |
| SUB TOTAL,$ | .0 | 395439932. | 395439932. | 395439932. | 395439932. | 395439932. |
| ESCALATION COST,$ | 6.5 | 810739951. | 810739951. | 810739951. | 810739951. | 810739951. |
| INTREST DURING CONST,$ | 10.0 | 933873382. | 933873382. | 933873382. | 933873382. | 933873382. |
| TOTAL CAPITALIZATION,$ | 18.0 | 5699012256. | 5699012256. | 5699012256. | 5699012256. | 5699012256. |
| COST OF ELEC-CAPITAL | | 82.59766 | 22.02604 | 19.82344 | 15.24880 | 12.39965 |
| COST OF ELEC-FUEL | | 12.55007 | 12.55007 | 12.55007 | 12.55007 | 12.55007 |
| COST OF ELEC-OP & MAIN | | 19.74202 | 16.42418 | 16.30353 | 16.05295 | 15.89634 |
| TOTAL COST OF ELEC | | 114.88975 | 51.00028 | 48.67703 | 43.85181 | 40.83605 |

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Table A 13.4.24

## MOLTEN CARBONATE FUEL CELL SYSTEM

| ACCOUNT NO | AUX POWER,MWE | PERC PLANT FOW | OPERATION COST | MAINTENANCE COST |
|---|---|---|---|---|
| 4 | .16605 | 1.94434 | .03117 | .88250 |
| 11 | .00000 | .00000 | 17820.00000 | 5619000.00000 |
| 14 | .00000 | .00000 | 6.99160 | .00000 |
| 18 | 8.37400 | 98.05566 | .00000 | .00000 |
| | 8.54005 | .72234 | 17979.08740 | 5619000.87500 |

TOTALS

### MOLTEN CARBONATE FUEL CELL SYSTEM

NOMINAL POWER, MWE          1190.0000     BASE CASE INPUT     1181.4600
NOM HEAT RATE, BTU/KW-HR    6229.9998     NET POWER, MWE      6275.0325
ST TURB HEAT RATE CHANGE    .9941         NET HEAT RATE, BTU/KW-HR

CONDENSER
DESIGN PRESSURE, IN HG A    2.0000        NUMBER OF SHELLS        2.0000
NUMBER OF TUBES/SHELL       5.9336        TUBE LENGTH, FT        75.2339
U, BTU/HR-FT2-F             608.8535      TERMINAL TEMP DIFF, F   5.0000

HEAT REJECTION
DESIGN TEMP, F              51.4000       APPROACH, F            21.6744
RANGE, F                    23.0000       OFF DESIGN TEMP, F     77.0000
OFF DESIGN PRES, IN HG A    1.2145        LP TURBINE BLADE LEN, IN  25.0000

| | | | | |
|---|---|---|---|---|
| 1 | 1190.000 | 2 | .000 | 3 | 4 | 6230.000 | 5 | 5.000 |
| 6 | 404.000 | 7 | 2.000 | 8 | 1909430.000 | 9 | 2.000 | 10 | 1.000 |
| 11 | 1.000 | 12 | .000 | 13 | .000 | 14 | 3.000 | 15 | .000 |
| 16 | 2.000 | 17 | .000 | 18 | .000 | 19 | .000 | 20 | .000 |
| 21 | .500 | 22 | 61700.000 | 23 | 15000.000 | 24 | .000 | 25 | .500 |
| 26 | .000 | 27 | 10000.000 | 28 | .000 | 29 | .500 | 30 | .000 |
| 31 | 1.000 | 32 | 770.000 | 33 | .000 | 34 | .000 | 35 | 1.000 |
| 36 | 2358000.000 | 37 | 300.000 | 38 | 1.000 | 39 | 1.000 | 40 | .000 |
| 41 | 217000.000 | 42 | 660000.000 | 43 | .000 | 44 | 722000.000 | 45 | 982000.000 |
| 46 | .000 | 47 | .000 | 48 | 1500.000 | 49 | 1.000 | 50 | 4350000.000 |
| 51 | .000 | 52 | 5.350 | 53 | 3.000 | | | 6.000 |

| | | | | |
|---|---|---|---|---|
| 1 | .000 | 2 | .000 | 3 | 4 | 1.000 | 5 | .000 |
| 6 | .000 | 7 | .000 | 8 | 1.000 | 9 | .000 | 10 | .000 |
| 11 | .000 | 12 | .000 | 13 | .000 | 14 | .000 | 15 | .000 |
| 16 | .000 | 17 | .000 | 18 | .000 | 19 | .000 | 20 | 1.000 |
| 21 | .000 | 22 | 2300000.000 | 23 | 2300000.000 | 24 | 230000.000 | 25 | 11723000.000 |
| 26 | 1.000 | 27 | 171000000.000 | 28 | .000 | 29 | 720000.000 | 30 | 20200000.000 |
| 31 | .000 | 32 | .000 | 33 | .000 | 34 | 1.000 | 35 | .000 |
| 36 | 4090000.000 | 37 | 4838000.000 | 38 | 1.000 | 39 | 6289000.000 | 40 | 1.000 |
| 41 | 1.000 | 42 | 2700000.000 | 43 | .000 | 44 | .000 | 45 | .000 |
| 46 | 1.000 | 47 | .000 | 48 | .000 | 49 | .000 | 50 | .000 |
| 51 | .000 | 52 | .000 | 53 | .000 | 54 | .000 | 55 | .000 |
| 56 | .400 | 57 | | 58 | | 59 | 17820.000 | 60 | 5619000.000 |

| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .355 | .351 | .351 | .348 | .296 | .355 | .355 | .355 |
| OVERALL ENERGY EFF | .236 | .236 | .236 | .293 | .199 | .239 | .239 | .239 |
| CAP COST MILLION $ | 10.438 | 39.516 | 37.614 | 357.206 | 15.955 | 10.436 | 10.436 | 10.436 |
| CAPITAL COST,$/KWE | 448.243 | 428.885 | 426.778 | 446.395 | 833.006 | 448.243 | 448.243 | 448.243 |
| COE CAPITAL | 14.170 | 13.558 | 12.397 | 13.922 | 26.333 | 14.170 | 14.170 | 14.170 |
| COE FUEL | 25.012 | 25.268 | 25.268 | 19.590 | 29.946 | 25.012 | 25.012 | 25.012 |
| COE OP & MAIN | 10.893 | 10.910 | 10.793 | 10.464 | 9.919 | 4.580 | 3.291 | 2.346 |
| COST OF ELECTRIC | 50.076 | 49.736 | 49.458 | 43.976 | 66.198 | 43.762 | 42.473 | 41.529 |
| EST TIME OF CONST | 1.500 | 2.000 | 2.500 | 4.000 | 1.500 | 1.500 | 1.500 | 1.500 |

| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .355 | .355 | .355 | .355 | .355 | .358 | .360 | .299 |
| OVERALL ENERGY EFF | .239 | .239 | .239 | .239 | .239 | .249 | .242 | .201 |
| CAP COST MILLION $ | 10.788 | 8.771 | 7.900 | 8.642 | 8.064 | 10.904 | 10.236 | 116.549 |
| CAPITAL COST,$/KWE | 463.336 | 376.725 | 336.306 | 371.160 | 346.364 | 468.337 | 439.640 | 554.590 |
| COE CAPITAL | 14.647 | 11.909 | 10.725 | 11.733 | 10.949 | 14.805 | 13.898 | 18.796 |
| COE FUEL | 25.012 | 25.012 | 25.012 | 25.012 | 25.012 | 25.752 | 24.659 | 29.692 |
| COE OP & MAIN | 2.437 | 7.973 | 6.469 | 9.863 | 9.562 | 10.991 | 10.833 | 9.244 |
| COST OF ELECTRIC | 42.096 | 44.894 | 42.208 | 46.608 | 45.523 | 51.548 | 49.390 | 57.732 |
| EST TIME OF CONST | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 2.500 |

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| OVERALL ENERGY EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| CAP COST MILLION $ | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| CAPITAL COST,$/KWE | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE CAPITAL | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE FUEL | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE OP & MAIN | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COST OF ELECTRIC | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| EST TIME OF CONST | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |

Table A 13.4.26  PARAMETRIC TYPE FUEL CELL SYSTEM  SUMMARY PLANT RESULTS

Table A 13.4.27   PHOSPHORIC ACID FUEL CELL SYSTEM   NATURAL RESOURCE REQUIREMENTS

| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | 1.32491 | 1.33847 | 1.33847 | 1.08042 | 1.58623 | 1.32491 | 1.32491 | 1.32491 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL LAND ACRES/100MWE | 6.44 | 4.88 | 3.91 | 3.60 | 13.05 | 6.44 | 6.44 | 6.44 |
| MAIN PLANT | 6.44 | 4.88 | 7.91 | 3.60 | 13.05 | 6.44 | 6.44 | 6.44 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | 1.32431 | 1.32491 | 1.32491 | 1.32491 | 1.32491 | 1.26844 | 1.30622 | 1.57281 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL LAND ACRES/100MWE | 6.44 | 6.44 | 4.29 | 6.44 | 6.44 | 10.74 | 6.44 | 7.65 |
| MAIN PLANT | 6.44 | 6.44 | 4.29 | 6.44 | 6.44 | 10.74 | 6.44 | 7.65 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SORBANT OR SEED, LB/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| TOTAL WATER, GAL/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| TOTAL LAND ACRES/100MWE | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| MAIN PLANT | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

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| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .381 | .377 | .377 | .366 | .318 | .381 | .381 | .381 |
| OVERALL ENERGY EFF | .256 | .254 | .254 | .307 | .214 | .256 | .256 | .256 |
| CAP COST MILLION $ | 13.577 | 51.872 | 129.826 | 536.268 | 16.649 | 13.577 | 13.577 | 13.577 |
| CAPITAL COST-$/KWE | 620.243 | 599.230 | 598.525 | 699.952 | 890.038 | 620.243 | 620.243 | 620.243 |
| COE CAPITAL | 19.607 | 18.943 | 18.921 | 22.127 | 28.136 | 19.607 | 19.607 | 19.607 |
| COE FUEL | 23.311 | 23.552 | 23.552 | 18.665 | 27.871 | 23.311 | 23.311 | 23.311 |
| COE OP & MAIN | 17.837 | 17.936 | 17.939 | 18.077 | 11.179 | 7.193 | 5.046 | 3.447 |
| COST OF ELECTRIC | 60.756 | 60.430 | 60.412 | 58.869 | 67.186 | 50.111 | 47.964 | 46.365 |
| EST TIME OF CONST | 1.500 | 2.000 | 2.500 | 4.000 | 1.500 | 1.500 | 1.500 | 1.500 |

| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .381 | .381 | .381 | .381 | .381 | .381 | .381 | .383 |
| OVERALL ENERGY EFF | .256 | .256 | .256 | .256 | .256 | .256 | .256 | .258 |
| CAP COST MILLION $ | 13.929 | 10.941 | 9.812 | 11.569 | 11.318 | 13.577 | 13.452 | 13.577 |
| CAPITAL COST-$/KWE | 636.297 | 499.840 | 448.239 | 528.507 | 517.040 | 620.243 | 614.509 | 620.243 |
| COE CAPITAL | 20.115 | 15.801 | 14.170 | 16.707 | 16.345 | 19.607 | 19.426 | 19.607 |
| COE FUEL | 23.311 | 23.311 | 23.311 | 23.311 | 23.311 | 23.311 | 23.311 | 23.167 |
| COE OP & MAIN | 3.559 | 11.442 | 8.701 | 16.467 | 16.467 | 17.837 | 17.380 | 17.837 |
| COST OF ELECTRIC | 46.985 | 50.554 | 46.182 | 56.485 | 56.123 | 60.756 | 60.118 | 60.612 |
| EST TIME OF CONST | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 |

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| OVERALL ENERGY EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| CAP COST MILLION $ | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| CAPITAL COST-$/KWE | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE CAPITAL | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE FUEL | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE OP & MAIN | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COST OF ELECTRIC | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| EST TIME OF CONST | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |

Table A 13.4.29 ALKALINE FUEL CELL SYSTEM

SUMMARY PLANT RESULTS

## PARAMETRIC POINT

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL CAPITAL COST | ,M$ | 13.03 | 61.87 | 129.83 | 536.27 | 10.61 | 12.49 | 13.58 | 15.52 |
| FUEL PROCESSING EQUIPMENT | ,M$ | 1.396 | 4.716 | 10.610 | 47.450 | 2.976 | 1.236 | 1.396 | 1.396 |
| FUEL CELL SYSTEM | ,M$ | 5.000 | 0.000 | 50.010 | 100.000 | 2.500 | 5.000 | 5.000 | 5.000 |
| STEAM TURBINE GENERATOR | ,M$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| OXYGEN PLANT | ,M$ | 0.000 | 0.000 | 0.000 | 0.000 | 3.400 | 0.000 | 0.000 | 0.000 |
| HEAT REC STEAM GENERATOR | ,M$ | 0.074 | 0.210 | 0.390 | 1.800 | 0.074 | 0.074 | 0.074 | 0.074 |
| RECUPERATOR | ,M$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| POWER CONDITIONING | ,M$ | 1.380 | 7.000 | 17.500 | 53.000 | 1.380 | 1.330 | 1.390 | 1.380 |
| TOT MAJOR COMPONENT COST | ,$/KWE | 7.850 | 11.926 | 78.700 | 268.250 | 8.350 | 7.350 | 7.850 | 7.850 |
| TOT MAJOR COMPONENT COST | ,$/KWE | 358.512 | 353.010 | 362.823 | 376.232 | 45.312 | 358.611 | 358.611 | 353.611 |
| BALANCE OF PLANT COST | ,$/KWE | 49.092 | 49.256 | 35.642 | 15.420 | 62.947 | 49.092 | 49.092 | 49.092 |
| SITE LABOR | ,$/KWE | 48.9C6 | 44.964 | 39.957 | 15.495 | 139.236 | 62.947 | 53.952 | 53.962 |
| TOTAL DIRECT COST | ,$/KWE | 467.465 | 447.663 | 434.432 | 435.140 | 49.495 | 467.0C5 | 467.466 | 467.456 |
| INDIRECT COSTS | ,$/KWE | 30.071 | 30.040 | 30.333 | 22.182 | 70.501 | 30.071 | 30.071 | 30.071 |
| PROF & OWNER COSTS | ,$/KWE | 37.037 | 35.677 | 35.715 | 34.812 | 51.720 | 37.037 | 37.037 | 37.037 |
| CONTINGENCY COST | ,$/KWE | 21.036 | 21.060 | 23.179 | 22.460 | 23.092 | 21.036 | 21.036 | 21.036 |
| ESCALATION COST | ,$/KWE | 31.757 | 31.550 | 31.437 | 0.904 | 46.570 | 31.757 | 31.757 | 31.757 |
| INT DURING CONSTRUCTION | ,$/KWE | 32.515 | 31.216 | 31.525 | 695.952 | 630.C38 | 32.515 | 32.516 | 32.515 |
| TOTAL OF CAPITALIZATION | ,$/KWE | 620.240 | 618.270 | 618.921 | 22.107 | 226.107 | 620.243 | 620.243 | 620.243 |
| COST OF ELEC-CAPITAL | ,MILLS/KWE | 19.607 | 19.607 | 18.552 | 18.665 | 27.371 | 19.607 | 19.607 | 19.607 |
| COST OF ELEC-FUEL | ,MILLS/KWE | 23.311 | 23.311 | 17.939 | 18.077 | 14.179 | 23.311 | 23.311 | 23.311 |
| COST OF ELEC-OP&MAIN | ,MILLS/KWE | 17.877 | 17.877 | 66.013 | 5.869 | 67.186 | 7.193 | 5.046 | 3.447 |
| COE 0.5 CAP. FACTOR | ,MILLS/KWE | 67.042 | 67.042 | 64.196 | 54.450 | 61.665 | 56.111 | 47.364 | 45.365 |
| COE 0.8 CAP. FACTOR | ,MILLS/KWE | 56.826 | 56.533 | 55.122 | 63.235 | 72.914 | 54.835 | 54.035 | 52.652 |
| COE 1.2XCAP. COST | ,MILLS/KWE | 64.677 | 64.196 | 55.122 | 57.602 | 72.761 | 54.774 | 54.224 | 50.287 |
| COE 1.2XFUEL COST | ,MILLS/KWE | 60.413 | 60.413 | 55.532 | 57.590 | 68.16C | 54.37C | 52.622 | 51.628 |
| COE (CONTINGENCY=0) | ,MILLS/KWE | 61.725 | 61.689 | 61.997 | 61.312 | 68.577 | 51.081 | 48.633 | 47.335 |

## PARAMETRIC POINT

| | | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL CAPITAL COST | ,M$ | 13.90 | 10.94 | 9.34 | 11.57 | 11.32 | 13.58 | 13.45 | 17.58 |
| FUEL PROCESSING EQUIPMENT | ,M$ | 5.000 | 10.390 | 1.396 | 1.396 | 1.396 | 1.396 | 1.390 | 1.396 |
| FUEL CELL SYSTEM | ,M$ | 5.000 | 2.900 | 2.000 | 3.400 | 3.200 | 5.000 | 4.900 | 5.000 |
| STEAM TURBINE GENERATOR | ,M$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| OXYGEN PLANT | ,M$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| HEAT REC STEAM GENERATOR | ,M$ | 0.074 | 0.074 | 0.074 | 0.074 | 0.074 | 0.074 | 0.074 | 0.074 |
| RECUPERATOR | ,M$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| POWER CONDITIONING | ,M$ | 1.660 | 1.380 | 1.330 | 1.380 | 1.380 | 1.380 | 1.780 | 1.330 |
| TOT MAJOR COMPONENT COST | ,$/KWE | 371.402 | 262.677 | 221.562 | 205.518 | 276.382 | 357.350 | 354.043 | 356.611 |
| TOT MAJOR COMPONENT COST | ,$/KWE | 43.832 | 49.892 | 58.892 | 49.892 | 49.892 | 49.892 | 49.892 | 49.892 |
| BALANCE OF PLANT COST | ,$/KWE | 58.962 | 58.962 | 58.962 | 58.962 | 58.962 | 58.962 | 58.962 | 58.962 |
| SITE LABOR | ,$/KWE | 48C.257 | 371.532 | 330.417 | 394.373 | 385.236 | 467.466 | 462.398 | 467.466 |
| TOTAL DIRECT COST | ,$/KWE | 30.071 | 30.071 | 26.433 | 30.071 | 30.071 | 37.037 | 30.071 | 30.071 |
| INDIRECT COSTS | ,$/KWE | 36.421 | 29.723 | 26.433 | 31.550 | 30.319 | 37.037 | 37.032 | 37.397 |
| PROF & OWNER COSTS | ,$/KWE | 32.612 | 16.719 | 19.860 | 17.747 | 26.473 | 21.036 | 31.036 | 21.036 |
| CONTINGENCY COST | ,$/KWE | 32.579 | 16.592 | 22.950 | 27.7C0 | 26.473 | 31.757 | 31.463 | 31.757 |
| ESCALATION COST | ,$/KWE | 33.358 | 26.204 | 23.499 | 27.1C0 | 27.1C0 | 32.515 | 32.216 | 32.516 |
| INT DURING CONSTRUCTION | ,$/KWE | 636.297 | 499.801 | 418.239 | 528.507 | 517.C50 | 626.240 | 614.509 | 620.243 |
| COST OF ELEC-CAPITAL | ,MILLS/KWE | 20.115 | 15.801 | 14.170 | 16.707 | 16.345 | 19.607 | 19.426 | 19.607 |
| COST OF ELEC-FUEL | ,MILLS/KWE | 23.311 | 23.311 | 23.311 | 23.311 | 23.311 | 23.311 | 23.380 | 23.311 |
| COST OF ELEC-OP&MAIN | ,MILLS/KWE | 3.559 | 11.442 | 8.701 | 16.467 | 16.467 | 17.837 | 17.877 | 17.877 |
| COE 0.5 CAP. FACTOR | ,MILLS/KWE | 46.335 | 50.554 | 46.182 | 56.485 | 56.123 | 67.042 | 60.118 | 60.612 |
| COE 0.8 CAP. FACTOR | ,MILLS/KWE | 42.94C | 47.698 | 50.277 | 61.962 | 61.43C | 56.826 | 56.35C | 66.898 |
| COE 1.2XCAP. COST | ,MILLS/KWE | 51.008 | 47.338 | 49.016 | 53.100 | 61.8C5 | 56.826 | 56.822 | 56.683 |
| COE 1.2XFUEL COST | ,MILLS/KWE | 51.647 | 53.714 | 53.272 | 59.827 | 59.392 | 64.677 | 64.C03 | 64.533 |
| COE (CONTINGENCY=0) | ,MILLS/KWE | 46.223 | 49.964 | 49.657 | 51.147 | 55.859 | 65.413 | 64.790 | 65.245 |
| COE (ESCALATION=0) | ,MILLS/KWE | 47.979 | 51.335 | 46.892 | 57.311 | 55.931 | 61.725 | 61.078 | 61.581 |

## Table A 13.4.30 ALKALINE FUEL CELL SYSTEM

### NATURAL RESOURCE REQUIREMENTS

| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | 1.23480 | 1.24753 | 1.24753 | 1.02943 | 1.47633 | 1.23480 | 1.23480 | 1.23480 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | 6.85 | 5.20 | 4.15 | 3.92 | 13.36 | 6.85 | 6.85 | 6.85 |
| TOTAL LAND ACRES/100MWE | 6.85 | 5.20 | 4.15 | 3.92 | 13.36 | 6.85 | 6.85 | 6.85 |
| MAIN PLANT | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | | | | | | | | |

| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | 1.23480 | 1.23480 | 1.23480 | 1.23480 | 1.23480 | 1.23480 | 1.23480 | 1.22718 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 |
| TOTAL LAND ACRES/100MWE | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 | 6.85 |
| MAIN PLANT | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | | | | | | | | |

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| TOTAL LAND ACRES/100MWE | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| MAIN PLANT | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | | | | | | | | |

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Table A 13.4.31

## MOLTEN CARBONATE FUEL CELL SYSTEM     SUMMARY PLANT RESULTS

| PARAMETER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .488 | .480 | .480 | .544 | .488 | .488 | .488 | .488 |
| OVERALL ENERGY EFF | .329 | .323 | .323 | .457 | .329 | .329 | .329 | .329 |
| CAP COST MILLION $ | 11.516 | 44.954 | 113.868 | 559.901 | 19.871 | 11.871 | 11.516 | 11.516 |
| CAPITAL COST-$/KWE | 514.413 | 504.804 | 511.350 | 432.370 | 887.615 | 514.413 | 514.413 | 514.413 |
| COE CAPITAL | 16.262 | 15.953 | 16.165 | 15.249 | 28.059 | 16.262 | 16.262 | 16.262 |
| COE FUEL | 18.169 | 18.469 | 18.469 | 12.550 | 18.169 | 18.169 | 18.169 | 18.169 |
| COE OP & MAIN | 23.378 | 23.512 | 23.610 | 16.053 | 20.801 | 8.638 | 5.690 | 3.501 |
| COST OF ELECTRIC | 57.809 | 57.939 | 58.244 | 43.852 | 67.029 | 43.068 | 40.120 | 37.931 |
| EST TIME OF CONST | 1.500 | 2.000 | 2.500 | 45.000 | 1.500 | 1.500 | 1.500 | 1.500 |

| PARAMETER | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .488 | .488 | .488 | .488 | .488 | .364 | .448 | .488 |
| OVERALL ENERGY EFF | .329 | .329 | .329 | .329 | .329 | .306 | .312 | .329 |
| CAP COST MILLION $ | 11.860 | 14.624 | 10.573 | 11.486 | 11.450 | 11.876 | 11.778 | 11.423 |
| CAPITAL COST-$/KWE | 529.773 | 653.233 | 476.727 | 513.067 | 511.447 | 540.085 | 528.435 | 510.244 |
| COE CAPITAL | 16.747 | 20.650 | 15.070 | 16.219 | 16.168 | 17.073 | 16.705 | 16.130 |
| COE FUEL | 18.169 | 18.169 | 18.169 | 18.169 | 18.169 | 18.750 | 20.588 | 18.169 |
| COE OP & MAIN | 3.611 | 30.748 | 18.956 | 23.289 | 23.110 | 23.889 | 23.528 | 23.065 |
| COST OF ELECTRIC | 38.527 | 69.567 | 52.195 | 57.677 | 57.447 | 59.712 | 60.821 | 57.364 |
| EST TIME OF CONST | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 |

| PARAMETER | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| THERMODYNAMIC EFF | .480 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .323 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| OVERALL ENERGY EFF | 149.979 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| CAP COST MILLION $ | 673.514 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| CAPITAL COST-$/KWE | 21.291 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE CAPITAL | 18.465 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE FUEL | 18.933 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE OP & MAIN | 58.694 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COST OF ELECTRIC | 2.500 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| EST TIME OF CONST | | | | | | | | |

Table A 13.4.32

SUMMARY PLANT RESULTS

MOLTEN CARBONATE FUEL CELL SYSTEM

PARAMETRIC POINT

TOTAL CAPITAL COST, EQUIPMENT, M$
  FUEL PROCESSING SYSTEM, $/KWE
  FUEL CELL SYSTEM GENERATOR
  STEAM TURBINE GENERATOR
  OXYGEN PLANT
  HEAT RECUPERATOR STEAM GENERATOR
  RECUPERATOR
  POWER CONDITIONING

TOT MAJOR COMPONENT COST, M$
TOT MAJOR COMPONENT COST, $/KWE
BALANCE OF PLANT COST, $/KWE
SITE LABOR, $/KWE
TOTAL DIRECT COST, $/KWE
INDIRECT COSTS, $/KWE
PROF & OWNER COSTS, $/KWE
CONTINGENCY COST, $/KWE
ESCALATION DURING CONSTRUCTION, $/KWE
TOTAL CAPITALIZATION, $/KWE
COST OF ELEC-CAPITAL, MILLS/KWE
COST OF ELEC-OP&MAIN, MILLS/KWE
COST OF ELEC-FUEL, MILLS/KWE
TOTAL COST OF ELEC, MILLS/KWE
COE 0.5 CAP. FACTOR, MILLS/KWE
COE 0.8 CAP. FACTOR, MILLS/KWE
COE 1.2XCAP. COST, MILLS/KWE
COE 1.2XFUEL COST, MILLS/KWE
COE (CONTINGENCY=0), MILLS/KWE
COE (ESCALATION=0), MILLS/KWE

PARAMETRIC POINT

TOTAL CAPITAL COST, EQUIPMENT, M$
  FUEL PROCESSING SYSTEM, $/KWE
  FUEL CELL SYSTEM GENERATOR
  STEAM TURBINE GENERATOR
  OXYGEN PLANT
  HEAT RECUPERATOR STEAM GENERATOR
  RECUPERATOR
  POWER CONDITIONING

TOT MAJOR COMPONENT COST, M$
TOT MAJOR COMPONENT COST, $/KWE
BALANCE OF PLANT COST, $/KWE
SITE LABOR, $/KWE
TOTAL DIRECT COST, $/KWE
INDIRECT COSTS, $/KWE
PROF & OWNER COSTS, $/KWE
CONTINGENCY COST, $/KWE
ESCALATION DURING CONSTRUCTION, $/KWE
TOTAL CAPITALIZATION, $/KWE
COST OF ELEC-CAPITAL, MILLS/KWE
COST OF ELEC-OP&MAIN, MILLS/KWE
COST OF ELEC-FUEL, MILLS/KWE
TOTAL COST OF ELEC, MILLS/KWE
COE 0.5 CAP. FACTOR, MILLS/KWE
COE 0.8 CAP. FACTOR, MILLS/KWE
COE 1.2XCAP. COST, MILLS/KWE
COE 1.2XFUEL COST, MILLS/KWE
COE (CONTINGENCY=0), MILLS/KWE
COE (ESCALATION=0), MILLS/KWE

Table A 13.4.32 Continued
MOLTEN CARBONATE FUEL CELL SYSTEM

SUMMARY PLANT RESULTS

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| TOTAL CAPITAL COST ,M$ | 149.98 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| FUEL PROCESSING EQUIPMENT ,M$ | 31.29C | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| FUEL CELL SYSTEM ,M$ | 31.7C0 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| STEAM TURBINE GENERATOR ,M$ | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| OXYGEN PLANT ,M$ | 27.660 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| HEAT REC STEAM GENERATOR ,M$ | 2.950 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| RECUPERATOR ,M$ | 1.344 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER CONDITIONING ,M$ | 17.500 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| TOT MAJOR COMPONENT COST ,M$ | 81.444 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| TOT MAJOR COMPONENT COST,$/KWE | 365.743 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| BALANCE OF PLANT COST ,$/KWE | 27.144 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| SITE LABOR ,$/KWE | 70.069 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| TOTAL DIRECT COST ,$/KWE | 462.957 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| INDIRECT COSTS ,$/KWE | 35.735 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| PROF & OWNER COSTS ,$/KWE | 37.037 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| CONTINGENCY COST ,$/KWE | 25.463 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| ESCALATION COST ,$/KWE | 54.554 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| INT DURING CONSTRUCTION ,$/KWE | 57.769 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| TOTAL CAPITALIZATION ,$/KWE | 673.514 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COST OF ELEC-CAPITAL,MILLS/KWE | 21.291 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COST OF ELEC-FUEL ,MILLS/KWE | 18.469 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COST OF ELEC-OP&MAIN,MILLS/KWE | 18.933 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| TOTAL COST OF ELEC ,MILLS/KWE | 58.694 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE 0.5 CAP. FACTOR ,MILLS/KWE | 66.176 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE 0.8 CAP. FACTOR ,MILLS/KWE | 54.018 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE 1.2XCAP. COST ,MILLS/KWE | 62.952 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE 1.2XFUEL COST ,MILLS/KWE | 62.388 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE (CONTINGENCY=0) ,MILLS/KWE | 57.728 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COE (ESCALATION=0) ,MILLS/KWE | 60.478 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |

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Table A 13.4.33

## MOLTEN CARBONATE FUEL CELL SYSTEM — NATURAL RESOURCE REQUIREMENTS

| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .96240 | .97832 | .37832 | .69216 | .96240 | .96240 | .96240 | .96240 |
| SORBANT OR SEED,LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .197 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .19704 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL LAND ACRES/100MWE | 6.70 | 5.05 | 4.04 | 5.77 | 11.17 | 6.70 | 6.70 | 6.70 |
| MAIN PLANT | 6.70 | 5.05 | 4.04 | 4.23 | 11.17 | 6.70 | 6.70 | 6.70 |
| DISPOSAL LAND | .00 | .00 | .00 | 1.54 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .96240 | .96240 | .96240 | .96240 | .96240 | 1.03909 | 1.01409 | .96240 |
| SORBANT OR SEED,LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL LAND ACRES/100MWE | 6.70 | 6.70 | 6.70 | 6.70 | 6.70 | 6.82 | 11.22 | 6.70 |
| MAIN PLANT | 6.70 | 6.70 | 6.70 | 6.70 | 6.70 | 6.82 | 11.22 | 6.70 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .97832 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SORBANT OR SEED,LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL LAND ACRES/100MWE | 7.19 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| MAIN PLANT | 7.19 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

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Table A 13.4.34

SOLID ELECTROLYTE FUEL CELL

SUMMARY PLANT RESULTS

| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .697 | .409 | .409 | .602 | .397 | .416 | .416 | .416 |
| OVERALL ENERGY EFF | .469 | .343 | .343 | .506 | .333 | .350 | .350 | .350 |
| CAP COST MILLION $ | 9.670 | 41.972 | 105.249 | 539.054 | 17.699 | 10.666 | 10.666 | 10.666 |
| CAPITAL COST.$/KWE | 424.390 | 481.540 | 487.595 | 466.397 | 972.033 | 480.714 | 480.714 | 480.714 |
| COE CAPITAL | 13.416 | 15.223 | 15.414 | 14.744 | 30.728 | 15.196 | 15.196 | 15.196 |
| COE FUEL | 12.726 | 15.704 | 16.704 | 11.340 | 17.206 | 16.402 | 16.402 | 16.402 |
| COE OP & MAIN | 16.002 | 20.765 | 21.123 | 14.159 | 24.222 | 7.881 | 5.312 | 3.419 |
| COST OF ELECTRIC | 42.143 | 52.691 | 53.240 | 40.243 | 72.156 | 39.479 | 36.910 | 35.017 |
| EST TIME OF CONST | 1.500 | 2.000 | 2.500 | 5.000 | 1.500 | 1.500 | 1.500 | 1.500 |

| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .416 | .371 | .320 | .423 | .416 | .403 | .416 | .347 |
| OVERALL ENERGY EFF | .350 | .312 | .269 | .355 | .350 | .339 | .350 | .292 |
| CAP COST MILLION $ | 11.013 | 9.633 | 9.276 | 10.511 | 10.666 | 10.722 | 9.035 | 11.889 |
| CAPITAL COST.$/KWE | 496.325 | 434.166 | 418.057 | 473.716 | 480.714 | 483.273 | 407.181 | 535.834 |
| COE CAPITAL | 15.690 | 13.725 | 13.216 | 14.975 | 15.196 | 15.276 | 12.872 | 16.939 |
| COE FUEL | 16.402 | 18.392 | 21.307 | 16.141 | 16.402 | 16.945 | 16.402 | 19.658 |
| COE OP & MAIN | 3.530 | 16.176 | 14.460 | 20.176 | 20.635 | 21.101 | 20.635 | 24.304 |
| COST OF ELECTRIC | 35.622 | 48.292 | 48.982 | 51.292 | 52.233 | 53.322 | 49.909 | 60.901 |
| EST TIME OF CONST | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 |

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| THERMODYNAMIC EFF | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| POWER PLANT EFF | .485 | .530 | .457 | .567 | .000 | .000 | .000 | .000 |
| OVERALL ENERGY EFF | .408 | .530 | .478 | .382 | .000 | .000 | .000 | .000 |
| CAP COST MILLION $ | 9.799 | 205.457 | 893.285 | 7.668 | .000 | .000 | .000 | .000 |
| CAPITAL COST.$/KWE | 441.604 | 948.307 | 858.698 | 339.517 | .000 | .000 | .000 | .000 |
| COE CAPITAL | 13.960 | 29.978 | 27.145 | 10.733 | .000 | .000 | .000 | .000 |
| COE FUEL | 14.070 | 5.473 | 6.346 | 15.652 | .000 | .000 | .000 | .000 |
| CCE OP & MAIN | 17.899 | 12.248 | 18.398 | 10.911 | .000 | .000 | .000 | .000 |
| COST OF ELECTRIC | 45.930 | 47.699 | 51.890 | 37.297 | .000 | .000 | .000 | .000 |
| EST TIME OF CONST | 1.500 | 3.000 | 5.500 | 1.500 | .000 | .000 | .000 | .000 |

Table A 13.4.35

SOLID ELECTROLYTE FUEL CELL

SUMMARY PLANT RESULTS

PARAMETRIC POINT

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| TOTAL CAPITAL COST ,M$ | | | | | | | | |
| FUEL PROCESSING EQUIPMENT ,M$ | | | | | | | | |
| FUEL CELL SYSTEM ,M$ | | | | | | | | |
| STEAM TURBINE GENERATOR ,M$ | | | | | | | | |
| OXYGEN PLANT ,M$ | | | | | | | | |
| HEAT REC STEAM GENERATOR ,M$ | | | | | | | | |
| RECUPERATOR ,M$ | | | | | | | | |
| POWER CONDITIONING ,M$ | | | | | | | | |
| TOT MAJOR COMPONENT COST ,$/KWE | | | | | | | | |
| TCT MAJOR COMPONENT COST ,$/KWE | | | | | | | | |
| BALANCE OF PLANT COST ,$/KWE | | | | | | | | |
| SITE LABOR ,$/KWE | | | | | | | | |
| TOTAL DIRECT COST ,$/KWE | | | | | | | | |
| INDIRECT COSTS ,$/KWE | | | | | | | | |
| PROF & OWNER COSTS ,$/KWE | | | | | | | | |
| CONTINGENCY COST ,$/KWE | | | | | | | | |
| ESCALATION COST ,$/KWE | | | | | | | | |
| INT DURING CONSTRUCTION ,$/KWE | | | | | | | | |
| TOTAL CAPITALIZATION ,$/KWE | | | | | | | | |
| COST OF ELEC-CAPITAL ,MILLS/KWE | | | | | | | | |
| COST OF ELEC-FUEL ,MILLS/KWE | | | | | | | | |
| COST OF ELEC-OP&MAIN ,MILLS/KWE | | | | | | | | |
| TOTAL COST OF ELEC ,MILLS/KWE | | | | | | | | |
| COE 0.5 CAP. FACTOR ,MILLS/KWE | | | | | | | | |
| COE 0.8 CAP. FACTOR ,MILLS/KWE | | | | | | | | |
| COE 1.2XCAP. COST ,MILLS/KWE | | | | | | | | |
| COE 1.2XFUEL COST ,MILLS/KWE | | | | | | | | |
| COE (CONTINGENCY=0) ,MILLS/KWE | | | | | | | | |
| COE (ESCALATION=0) ,MILLS/KWE | | | | | | | | |

PARAMETRIC POINT

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 15 |
|---|---|---|---|---|---|---|---|---|
| TOTAL CAPITAL COST ,M$ | | | | | | | | |
| FUEL PROCESSING EQUIPMENT ,M$ | | | | | | | | |
| FUEL CELL SYSTEM ,M$ | | | | | | | | |
| STEAM TURBINE GENERATOR ,M$ | | | | | | | | |
| OXYGEN PLANT ,M$ | | | | | | | | |
| HEAT REC STEAM GENERATOR ,M$ | | | | | | | | |
| RECUPERATOR ,M$ | | | | | | | | |
| POWER CONDITIONING ,M$ | | | | | | | | |
| TOT MAJOR COMPONENT COST ,$/KWE | | | | | | | | |
| TCT MAJOR COMPONENT COST ,$/KWE | | | | | | | | |
| BALANCE OF PLANT COST ,$/KWE | | | | | | | | |
| SITE LABOR ,$/KWE | | | | | | | | |
| TOTAL DIRECT COST ,$/KWE | | | | | | | | |
| INDIRECT COSTS ,$/KWE | | | | | | | | |
| PROF & OWNER COSTS ,$/KWE | | | | | | | | |
| CONTINGENCY COST ,$/KWE | | | | | | | | |
| ESCALATION COST ,$/KWE | | | | | | | | |
| INT DURING CONSTRUCTION ,$/KWE | | | | | | | | |
| TOTAL CAPITALIZATION ,$/KWE | | | | | | | | |
| COST OF ELEC-CAPITAL ,MILLS/KWE | | | | | | | | |
| COST OF ELEC-FUEL ,MILLS/KWE | | | | | | | | |
| COST OF ELEC-OP&MAIN ,MILLS/KWE | | | | | | | | |
| TOTAL COST OF ELEC ,MILLS/KWE | | | | | | | | |
| COE 0.5 CAP. FACTOR ,MILLS/KWE | | | | | | | | |
| COE 0.8 CAP. FACTOR ,MILLS/KWE | | | | | | | | |
| COE 1.2XCAP. COST ,MILLS/KWE | | | | | | | | |
| COE 1.2XFUEL COST ,MILLS/KWE | | | | | | | | |
| COE (CONTINGENCY=0) ,MILLS/KWE | | | | | | | | |
| COE (ESCALATION=0) ,MILLS/KWE | | | | | | | | |

Table A 13.4.35 Continued

SOLID ELECTROLYTE FUEL CELL      SUMMARY PLANT RESULTS

| PARAMETRIC POINT | | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL CAPITAL COST | ,M$ | 9.80 | 205.46 | 893.28 | 7.67 | .00 | .00 | .00 | .00 |
| FUEL PROCESSING EQUIPMENT | ,M$ | .067 | 52.360 | 75.372 | .067 | .000 | .000 | .000 | .000 |
| FUEL CELL SYSTEM | ,M$ | 3.400 | 18.800 | 167.000 | 1.900 | .000 | .000 | .000 | .000 |
| STEAM TURBINE GENERATOR | ,M$ | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| OXYGEN PLANT | ,M$ | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| HEAT REC STEAM GENERATOR | ,M$ | .105 | .211 | 11.802 | .084 | .000 | .000 | .000 | .000 |
| RECUPERATOR | ,M$ | .500 | 4.200 | 28.000 | .440 | .000 | .000 | .000 | .000 |
| POWER CONDITIONING | ,M$ | 1.380 | 17.500 | 59.000 | 1.380 | .000 | .000 | .000 | .000 |
| TOT MAJOR COMPONENT COST | ,M$ | 5.452 | 93.071 | 341.174 | 3.871 | .000 | .000 | .000 | .000 |
| TOT MAJOR COMPONENT COST,$/KWE | | 245.717 | 429.578 | 327.964 | 171.386 | .000 | .000 | .000 | .000 |
| BALANCE OF PLANT COST | ,$/KWE | 37.604 | 39.592 | 36.982 | 37.390 | .000 | .000 | .000 | .000 |
| SITE LABOR | ,$/KWE | 47.163 | 137.537 | 89.083 | 42.484 | .000 | .000 | .000 | .000 |
| TOTAL DIRECT COST | ,$/KWE | 330.480 | 606.707 | 454.030 | 251.260 | .000 | .000 | .000 | .000 |
| INDIRECT COSTS | ,$/KWE | 24.053 | 70.144 | 45.432 | 21.667 | .000 | .000 | .000 | .000 |
| PROF & OWNER COSTS | ,$/KWE | 26.438 | 48.537 | 36.322 | 20.101 | .000 | .000 | .000 | .000 |
| CONTINGENCY COST | ,$/KWE | 14.872 | 36.402 | 38.593 | 11.307 | .000 | .000 | .000 | .000 |
| ESCALATION COST | ,$/KWE | 22.610 | 39.806 | 130.936 | 17.383 | .000 | .000 | .000 | .000 |
| INT DURING CONSTRUCTION | ,$/KWE | 23.151 | 96.711 | 153.384 | 17.799 | .000 | .000 | .000 | .000 |
| TOTAL CAPITALIZATION | ,$/KWE | 441.604 | 948.307 | 858.698 | 339.517 | .000 | .000 | .000 | .000 |
| COST OF ELEC-CAPITAL,MILLS/KWE | | 13.960 | 29.978 | 27.145 | 10.753 | .000 | .000 | .000 | .000 |
| COST OF ELEC-FUEL | ,MILLS/KWE | 14.070 | 5.473 | 6.346 | 15.652 | .000 | .000 | .000 | .000 |
| COST OF ELEC-OP&MAIN,MILLS/KWE | | 17.899 | 12.248 | 18.398 | 10.911 | .000 | .000 | .000 | .000 |
| TOTAL COST OF ELEC | ,MILLS/KWE | 45.930 | 47.699 | 51.890 | 37.297 | .000 | .000 | .000 | .000 |
| COE 0.5 CAP. FACTOR | ,MILLS/KWE | 50.403 | 56.994 | 60.337 | 40.785 | .000 | .000 | .000 | .000 |
| COE 0.8 CAP. FACTOR | ,MILLS/KWE | 43.134 | 41.890 | 46.610 | 35.116 | .000 | .000 | .000 | .000 |
| COE 1.2XCAP. COST | ,MILLS/KWE | 48.722 | 53.694 | 57.319 | 39.443 | .000 | .000 | .000 | .000 |
| COE 1.2XFUEL COST | ,MILLS/KWE | 48.744 | 48.793 | 53.159 | 40.427 | .000 | .000 | .000 | .000 |
| COE (CONTINGENCY=0) | ,MILLS/KWE | 45.405 | 46.266 | 50.066 | 36.898 | .000 | .000 | .000 | .000 |
| COE (ESCALATION=0) | ,MILLS/KWE | 46.620 | 50.738 | 57.154 | 37.827 | .000 | .000 | .000 | .000 |

Table A 13.4.36

## SOLID ELECTROLYTE FUEL CELL

NATURAL RESOURCE REQUIREMENTS

| PARAMETRIC POINT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .67408 | .92123 | .92123 | .62543 | .94895 | .90460 | .90460 | .90460 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .186 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .18547 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | 6.58 | 2.58 | 2.07 | 4.17 | 8.24 | 3.38 | 3.38 | 3.38 |
| TOTAL LAND ACRES/100MWE | 6.58 | 2.58 | 2.07 | 2.60 | 8.24 | 3.38 | 3.38 | 3.38 |
| MAIN PLANT | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | .00 | 1.57 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | | | | | | | | |

| PARAMETRIC POINT | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .90460 | 1.01435 | 1.17510 | .89019 | .90460 | .93453 | .90460 | 1.08419 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .08000 |
| TOTAL WATER, GAL/KW-HR | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .00000 | .00000 | .00000 | .08000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | 3.38 | 6.76 | 6.76 | 3.38 | 3.38 | 3.38 | 3.38 | 3.38 |
| TOTAL LAND ACRES/100MWE | 3.38 | 6.76 | 6.76 | 3.38 | 3.38 | 3.38 | 3.38 | 3.38 |
| MAIN PLANT | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | | | | | | | | |

| PARAMETRIC POINT | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| COAL, LB/KW-HR | .77601 | .59686 | 1.03604 | .82910 | .00000 | .00000 | .00000 | .00000 |
| SORBANT OR SEED, LB/KW-HR | .00000 | .31580 | .09882 | .00000 | .00000 | .00000 | .00000 | .00000 |
| TOTAL WATER, GAL/KW-HR | .000 | .101 | .268 | .000 | .000 | .000 | .000 | .000 |
| COOLING WATER | .00000 | .00000 | .03891 | .00000 | .00000 | .00000 | .00000 | .00000 |
| GASIFIER PROCESS H2O | .00000 | .00000 | .15565 | .00000 | .00000 | .00000 | .00000 | .00000 |
| CONDENSATE MAKE UP | .00000 | .0654 | .0338 | .00000 | .00000 | .00000 | .00000 | .00000 |
| WASTE HANDLING SLURRY | .00000 | .03581 | .03937 | .00000 | .00000 | .00000 | .00000 | .00000 |
| SCRUBBER WASTE WATER | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 |
| NOX SUPPRESSION | 3.38 | 99.87 | 50.72 | 6.64 | .00 | .00 | .00 | .00 |
| TOTAL LAND ACRES/100MWE | 3.38 | 19.39 | 11.82 | 6.64 | .00 | .00 | .00 | .00 |
| MAIN PLANT | .00 | 80.48 | 37.15 | .00 | .00 | .00 | .00 | .00 |
| DISPOSAL LAND | .00 | .00 | 1.75 | .00 | .00 | .00 | .00 | .00 |
| LAND FOR ACCESS RR | | | | | | | | |

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