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THIN FILM BATTERY/FUEL CELL POWER GENERATION SYSTEM

Topical Report Covering Task 5: The Design, Cost and Benefit of an Industrial Cogeneration System, Using a High Temperature Solid Oxide Electrolyte (HTSOE) Fuel Cell Generator

February 25, 1981

Work Performed Under Contract No. AC02-76ET11305

Westinghouse Electric Corporation
Research and Development Center
Pittsburgh, Pennsylvania

U. S. DEPARTMENT OF ENERGY

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GENERATION SYSTEM

TOPICAL REPORT COVERING TASK 5:
THE DESIGN, COST AND BENEFIT OF AN INDUSTRIAL
COGENERATION SYSTEM, USING A HIGH TEMPERATURE
SOLID OXIDE ELECTROLYTE (HTSOE) FUEL CELL
GENERATOR

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February 25, 1981

Prepared for the United States Department of Energy
Under Continuation Contract No. DE-AC-0379ET11305
(Formerly Contract EY-76-03-1197)

By

Research and Development Center
Westinghouse Electric Corporation
Pittsburgh, PA 15235

FOREWORD

For the first year of the two year continuation program (DOE Contract DE-AC-0379ET11305) the Department of Energy Program Manager was Mr. R. F. Dudley, Jr. For the second year, the program was technically and financially managed at Argonne National Laboratories/DOE, under Dr. J. P. Ackerman, with Dr. A. V. Fraioli, as his Deputy Assistant Manager. Mr. O. S. Merrill of the Department of Energy was responsible for the administration of the program. Their assistance and guidance in program planning, program interaction and in direct contract-related matters is gratefully acknowledged.

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1.0 PREFATORY NOTE

The purpose of this task was to provide a preliminary examination of a promising industrial process where the HTSOE fuel cell could be utilized in a cogeneration mode to achieve energy (and thereby economic) savings. This study does not suggest that the application that was chosen will ultimately be used in the form analyzed, or even for the specific application selected. Rather, the purpose of this study was to ascertain whether or not anticipated progress in the HTSOE fuel cell program can lead to technically and economically viable application(s). Also, the sensitivity to the many assumptions of future scenarios must be determined.

We selected an application where the reject heat of an HTSOE fuel cell generation or cogeneration system could be completely used, to provide thermal or electrical energy, or both. After reviewing the rather extensive data already available in the literature for the most propitious electrical/thermal match potential, we determined that an integrated aluminum production plant would be among the best. Specifically, we selected the Reynolds facility near Corpus Christi, Texas. The cogeneration system was designed to the degree necessary to provide a preliminary analysis of economic and technical viability when compared with the use of conventional energy sources in the year 1990. The system was not optimized, nor was it compared with other "non-conventional" methods of providing the energy needs. Also, no change in the process of producing aluminum was considered.

Assuming development of the HTSOE fuel cell as scheduled, the next step in evaluation of its application to the aluminum industry is a more detailed design, optimization of the system

and comparison with other, potentially competitive, methods and processes. If, indeed, the HTSOE fuel cell will find widespread application in the favorable aluminum industry, search for additional markets should be made and detailed analyses of institutional, environmental and materials availability will be appropriate.

2.0 ABSTRACT

A literature search and review of the studies analyzing the relationship between thermal and electrical energy demand for various industries and applications resulted in several applications affording reasonable correlation to the thermal and electrical output of the HTSOE fuel cell. One of the best matches was in the aluminum industry, specifically, the Reynolds Aluminum Production Complex near Corpus Christi, Texas. Therefore, a preliminary design of three variations of a cogeneration system for this plant was effected. The designs were not optimized, nor were alternate methods of providing energy compared with the HTSOE cogeneration systems. The designs were developed to the extent necessary to determine technical practicality and economic viability, when compared with alternate conventional fuel (gas and electric) prices in the year 1990.

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3.0 CONCLUSIONS

At projected 1990 fuel prices, all of the variations in cogeneration system preliminary designs that incorporated the HTSOE fuel cell generator resulted in approximately 30% net cash flow savings for the plant. Sensitivity of this result to an initial 50% variation in HTSOE capital cost estimates is small; this is because, by 1990, the overriding importance of energy costs favors high efficiency energy supply systems. Sensitivity to projected fuel costs is most important, particularly to the cost of electricity. Methods of depreciation, moderate tax credits, assumptions for inflation and discount rates are not of major impact.

Preliminary considerations do not reveal any environmental or material availability problems with the HTSOE fuel cell, although further detailed study is suggested. The positive aspects include the use of abundant fuel and the reduction in projected incremental energy costs for the aluminum industry.

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4.0 TASK 5

THE DESIGN, COST AND BENEFIT OF AN INDUSTRIAL COGENERATION SYSTEM USING AN HTSOE FUEL CELL

In September 1979 Task 5 was added to the program. The objective of Task 5 was to select a promising industrial application for "commercial-size" HTSOE fuel cell modules, so that a conceptual design could be envisaged, to the extent necessary to estimate the economic viability of the system. Three major efforts were:

- 1) selection of a specific cogeneration application
- 2) preparation of a preliminary system design that identified all components and performance capability
- 3) use of the above design to estimate cost, environment, and conservation benefits.

4.1 Subtask 5A - Select a Promising Industrial Cogeneration System Using the HTSOE Fuel Cell, and Subtask 5B - Identify Several Cogeneration Applications

The mutual objective of these subtasks was to select a specific industrial cogeneration application for the solid-oxide electrolyte (HTSOE) fuel cell so that the system costs and public benefits could be quantified. To this end, a supply of clean coal gas, pipelined from a central, large coal gasification facility, such as the proposed Exxon East Texas plant or the TVA 20,000 ton/day middle south project, was assumed. Also, a requirement for a substantial block of DC power, as well as process steam, was desirable for the selected application.

We chose an integrated aluminum production application. A modular installation of HTSOE fuel cells to provide: 1) 220 MW_e DC, plus 100% process steam as the product of the HTSOE waste heat, or 2) 220 MW_e DC plus AC power from an extraction steam turbogenerator, along with extraction steam, or 3) 220 MW_e DC plus 100% AC power as the product of the waste heat. The 220 MW_e DC output matches the Reynolds Aluminum plant near Corpus Christi, Texas, an integrated bauxite processing and Hall cell electrolytic aluminum producing facility that requires steam and AC power in addition to DC power. Data for this plant were taken from a TRW review⁽¹⁾ of cogeneration applications for UTC's 4.8 MW phosphorus fuel cell power generating facility. The substantial capability of the 800°C effluent gas from the HTSOE fuel cell modules to produce steam and AC power was investigated. In addition to cost estimates for the HTSOE fuel cell, commercially available equipment was quoted for every major element of the system. Investment costs and system efficiencies were estimated, and these costs and efficiencies were then used as the basis for an analysis of system benefits.

Selection of the aluminum facility was based on a literature search and several investigations of cogeneration applications for fuel cells that have been performed by IGT, TRW and others. These investigations indicated, in general, that application of the HTSOE fuel cell to the chlor-alkali and aluminum industries could be of substantial economic benefit if life expectancy and sufficiently low cost fuel stacks can be produced. The large amount of DC power required by such industries obviates the need for power inversion, requiring only modest DC control, and the requirement for process steam permits a potentially large cost and energy savings if the steam can be provided from the fuel cell waste heat.

A review with IGT of their Gas Research Institute funded effort to identify cogeneration applications for molten carbonate fuel cells was made at their offices on January 22, 1980. This review included, as well, many industries that did not use DC power, such as the petrochemical, pulp and paper, and metallurgical industries. This review, along with the TRW study made in conjunction with Reynolds Aluminum, as referenced earlier, permitted us to choose the Reynolds Sherwin Alumina/San Patricia Reduction collocated plants as a basis for the cogeneration review. The fuel savings potential offered by the ability of the HTSOE waste heat utilization system to meet the principal recommendation of TRW ("to operate the fuel cell at higher temperature to permit the utilization of the waste heat") is fully realized in the Sherwin Alumina plant.

4.2 Subtask 5C - Prepare a Conceptual Design of the Selected System and Its Mode of Operation

Three modes of operation for the selected HTSOE cogeneration system were designed to the extent necessary to determine technical and economic viability.

A generalized flow diagram of the HTSOE fuel cell auxiliary subsystems, as presented in the proposal to DOE for the Task 5 work, is shown in Figure 1. A coal gas supply system (not shown and not part of this study) will deliver clean, pipeline coal gas to the cogeneration system. Given design parameters and fuel cell performance, characteristics are the following:

Fig. 1—Auxiliary subsystems in a cogeneration system having an HTSOE fuel cell generator

1. Fuel Gas Composition:

<u>Component</u>	<u>% by Volume</u>
H ₂	34.4
CO	61.9
CH ₄	1.89
H ₂ S	.01
H ₂ O	.8
CO ₂	<u>1.0</u>
	100.0

2. Fuel cell voltage = 0.66 VDC

3. Fuel cell temperature = 900°C inlet
1100°C outlet
1000°C nominal

4. Fuel preheat temperature = 700°C

5. Air preheat temperature = 700°C (initial flowsheet)
= variable (later flowsheets)

6. Fuel utilization = 90% (of CO + H₂)

7. Power Conditioning Efficiency = 95%

8. Oxygen concentration, stack exit = 5% min.

9. Gas enthalpies from JANAF Tables⁽²⁾

Several conceptual designs were prepared during the initial phases of process optimization and cogeneration application selection. The initial plant arrangement, as presented in Figure 1, was first modified to reduce fresh air feed and increase thermal efficiency by recycling a portion of the spent air leaving the fuel cells. Subsequently, this arrangement was abandoned due to inevitable fuel and air mixing in the fuel cell exhaust. A revised arrangement was prepared, employing a regenerative air preheater and a waste heat steam bottoming cycle. Plant capacity was increased from a nominal 50 MW_e AC rating to 220 MW_e DC to match the requirements of the Reynolds Texas aluminum plants. Then conceptual designs were prepared for three cogeneration arrangements:

- Bottoming cycle cogenerating AC power and process steam.
- Bottoming cycle producing all AC electric power.
- Bottoming cycle producing all process steam.

Cogeneration of AC power and process steam, under likely fuel and electric cost assumptions, was selected as an efficient design and was chosen for preliminary design and cost estimating. A detailed description of this design, along with conceptual designs for a steam bottoming cycle and an all electric system, follow.

4.3 Subtask 5D - Prepare Preliminary Designs of the System

Modification of the basic cogeneration concept shown in Figure 1 was made to incorporate ceramic heat exchangers and a spent fuel and spent air mixing combustor. This modification also included a hot spent air recirculator. A diagram incorporating these concepts

was included in the HTSOE Final Report, covering the period April 1, 1978, to March 31, 1980.⁽³⁾ That report includes the statement in reference to the modification that, "a more reliable, potentially more economical, cell module could be constructed if the spent fuel did not have to be isolated from the spent air." This report uses that "more reliable, potentially more economical" approach shown in Figure 2. It is based on the requirements of the Reynolds Texas plant and utilizes the cogeneration scheme incorporating a back pressure steam turbogenerator to most efficiently produce both AC electric power and process steam for the alumina processing system. All of the process steam is used directly in the alumina plant and no condensate is returned to the fuel cell plant. Pretreated make-up water at 20°C is provided from existing water conditioning equipment.

Additional changes from the previous flowsheet have been made to reflect actual equipment performance characteristics as supplied by the vendors. The feedwater temperature entering the economizer has been increased to 120°C, requiring the addition of a deaerating feedwater heater. The FW heater consumes 108,000 pounds per hour of exhaust steam, or 15% of the total exhaust flow of 710,000 pounds per hour. The steam turbine-generator efficiency has been assumed at 80% of theoretical, as estimated by the Westinghouse-Canada steam turbine division.

To summarize, this final cogeneration design is as follows:

Clean coal gas is delivered to the power plant from a gas pipeline at 20°C and 1.1 bar. The fuel gas has a medium BTU heat

Fig. 2—Reynolds, Texas, Aluminum plant-auxiliary systems flowsheet (cogeneration)

content (HHV = 330 BTU per SCF) and contains less than 100 ppm of sulfur. The fuel is preheated by hot fuel cell exhaust gas to a temperature of 700°C before entering the HTSOE fuel cell power generator.

Ambient air is drawn through a forced draft fan and heated in a regenerative air heater to 200°C before entering the post-cell combustion chamber. In the after burner, the air is indirectly heated to 700°C. Before entering the air electrode, it is further heated by ceramic heat exchangers (integral to the fuel cell stacks) to 900°C.

The 700°C fuel and 900°C air react in the HTSOE fuel cell to deliver 220 MW_e DC electric power and produce waste heat. The nominal fuel cell temperature is 1000°C and a cell voltage of 0.66V is obtained with a current density of 400 mA/cm². Ninety percent of the H₂ and CO in the fuel gas are reacted in the fuel cell and the spent fuel and spent air exit to a post-cell combustion chamber at 1100°C. The combustion chamber serves as an after burner for the unreacted H₂, CO and CH₄. In addition, sensible heat is transferred from the combustion gases to indirectly preheat the fresh air from 220°C to 700°C.

The fuel cell exhaust gas exits the after burner at 800°C and flows in parallel to the fuel preheater and a waste heat boiler. Approximately 11% is utilized in the fuel preheater where it is cooled to 150°C before being discharged with other exhaust gas out of the stack at 123°C. The remaining 89% of the exhaust gas is used to generate superheated steam in a waste heat boiler. The gas temperature is lowered to 350°C in the boiler/superheater section and further lowered to 300°C as it leaves the economizer. The remaining recoverable waste heat is removed in a regenerative air preheater, resulting in a 120°C exhaust gas exit temperature.

The steam cycle consists of a back-pressure steam turbine-generator, a deaerating feedwater heater, a boiler feed pump and the waste heat boiler/economizer. Superheated steam leaves the

superheater at 1500 psig/950°F and is expanded to 150 psig/445°F in the turbine, thereby matching the process steam conditions, as specified for Reynolds Alumina process.

The generator output is 41.8 MW_e AC. Fifteen percent of the exhaust steam is returned to the cycle to preheat the make-up water to 120°C. Make-up water is delivered from existing water conditioning equipment at 20°C. The remaining exhaust steam, 602,000 pounds per hour, is used as process steam in the aluminum plant. The auxiliary power requirements, primarily for the forced draft fan and the boiler feedpump, are 6500 KW_e, resulting in a net AC power output of 35.3 MW_e AC. The overall thermal utilization of the system, based on an output of 220 MW_e DC, 35.3 MW_e AC and 602,000 lbs. per hr. of process steam, is 81%.

To parametrically evaluate the cogeneration options, two other conceptual plant designs were prepared:

- Steam bottoming cycle used to produce electric power exclusively.
- Steam bottoming cycle used to produce process steam (165 psia).

The processing flowsheet for the All Electric Power option is shown in Figure 3. The 800°C exhaust gas is divided into two parallel streams and used to preheat the cold fuel gas and to generate steam in a waste heat boiler. Approximately 11% of the exhaust gas is required for fuel gas preheating. A regenerative air preheater is located at the waste heat boiler exhaust to recover additional sensible heat from the exhaust gas and to preheat the make-up air from ambient temperature to the post-combustor inlet temperature of 200°C.

Steam produced in the waste heat boiler is expanded in a condensing steam turbine to produce AC electric power. Calculations were made to determine the preferred throttle steam conditions. Steam throttle pressure was varied from 300 psig to 1500 psig while maintaining 150-200°C superheat. The steam cycle is based on a

Fig. 3—All electric power cogeneration, using the HTSOE fuel cell generator

condenser vacuum of 1.5 in. Hg and a single feedwater heater utilizing extraction steam at 17 psia. Based on these calculations, superheated steam conditions of 1500 psig and 950°C were chosen. This results in a throttle steam flow of 693,000 pounds per hour and a generator output of 92.5 MW_e AC. The overall plant heat rate, based on the production of 220 MW_e DC and 86 MW_e AC (again, allowing for 6500 KW_e for forced draft fan and feedwater pump) net, is 6450 BTU per kilowatt-hour.

The All Process Steam option is shown in Figure 4. The general arrangement is similar to the previous option, except for the deletion of the steam turbine cycle. The waste heat boiler produces 755,000 pounds per hour of 150 psig/466°C process steam. This represents about 40% of the Reynolds Texas plants process steam requirements. The overall thermal efficiency of this option, based on an output of 220 MW_e DC electric power and 258 MW_t thermal energy, is 83%.

The all electric option, while possessing an attractive heat rate, does not provide any of the steam presently being generated by using expensive oil/natural gas at the Reynolds plant. The all steam option produces only about 150,000 lbs. per hour of additional steam, when compared with the cogeneration design, but at the expense of 35.3 MW_e of AC power. For most installations, the generation of that much power would require at least 250,000 lbs. per hour of steam, so that it appears (from a thermodynamic viewpoint) that the cogeneration mode, Figure 2, is superior. However, the saving in fuel must be balanced against the cost of the generation equipment. To provide quantification of that assessment, we have obtained quotations of the equipment shown in Figure 2 and have estimated the total installed investment cost, based on installation factors derived from a commercial cogeneration system design. In addition, we have factored equipment cost data for Figure 2 to the equipment sizes shown in Figures 3 and 4 so that approximate investment costs are available for both options. These data have been summarized in the following section.

Fig. 4—DC power and process steam cogeneration, using the HTSOE fuel cell generator

4.3.1. EQUIPMENT DESCRIPTIONS AND COSTS

Refer to Base Case, Figure 2, for the equipment to be described.

Fuel Preheater

The fuel preheater has the following design requirements:

Heat Duty = 143×10^6 BTU/h

Cold Fluid = Coal Synthesis Gas

Flowrate = 100,000 SCFM

300,000 lbs./h

$T_{in} = 20^\circ\text{C}$

$T_{out} = 700^\circ\text{C}$

Hot Fluid = Fuel Cell Exhaust Gas

Flowrate = 97,000 SCFM

450,000 lbs./h

$T_{in} = 800^\circ\text{C}$

$T_{out} = 150^\circ\text{C}$

Due to the large capacity, the fuel preheater consists of three (3) heat exchangers arranged in parallel. Each unit is 40' 40' L x 30' H x 15' W. The proposed design is of the type built by Coaltech Farrier and utilizes a tubular arrangement encased in a carbon steel casing. The tubes are constructed of a stainless steel alloy and the casing is refractory-lined. The tubes are cold-rolled, finned type U-tubes and are free-hanging with the only connections being at a tubesheet on the top of the unit. The cold fluid

(i.e., fuel gas) is passed through the tubes while the hot gas flows through the shell-side.

Waste Heat Boiler

The waste heat boiler produces 710,000 pounds per hour of superheated steam at 1500 psig and 950°C. The hot gas flow of 3,550,000 pounds per hour enters the boiler at 800°C and exits the economizer at 300°C. Feedwater temperature entering the economizer is 120°C.

The unit is an extended surface type, field erected boiler. It consists of a boiler, superheater and economizer. The approximate size is 20'3" W x 50' H x 12' D. The total shipping weight is 2,400,000 pounds. The total draft loss for the boiler with superheater and economizer is 6.0" w.g.

Air Preheater

The air preheater consists of a Ljungstrom rotary regenerative air preheater. It is designed to heat 3,700,000 pounds per hour of ambient air from 20°C to 200°C. The exhaust gas leaving the economizer enters at 300°C and leaves at 120°C. The air preheater has the approximate dimensions of 46' W x 44' L x 19' H and weighs 1,074,000 pounds.

Back Pressure Steam Turbine

The back pressure steam turbine/generator produces 41.8 MW_e AC from 710,000 pounds per hour of superheated steam. The throttle conditions are 1500 psig/950°C and the exhaust conditions are 150 psig/445°C. The design is of the Westinghouse-Canada type and includes a totally enclosed water-air heat exchanger, voltage regulator and lube oil console.

Forced-draft Fan

The design conditions for the forced-draft fan are 860,000 ACFM and a static pressure of 40" w.g. The fan consists of a centrifugal airfoil fan with a double width, double inlet arrangement. Operating speed is 880 RPM and fan brake horsepower equals 6520.

Boiler Feedwater System

The boiler feedwater system consists of a deaerating feedwater heater and a boiler feed pump. The feedwater heater is of the direct-contact, deaerating type utilizing 108,000 pounds per hour of exhaust steam (150 psig/445°C) to heat 602,000 pounds of pretreated make-up water from 20°C to 120°C. The feedwater pump is a centrifugal pump with 12% chrome contact parts, a forced-feed lub system and a Kingbury thrust bearing. It is designed to deliver 1420 gpm at 1600 psig. Pump speed is 3500 rpm and brake horsepower is 1580.

Start-up Burner and Blower

A start-up burner and blower system is supplied for plant start-up. The blower delivers approximately 100,000 ACFM to the burner/combustion chamber where coal gas is burned to produce hot exhaust gas for the start-up of the fuel preheater. The start-up system consists of the blower, combustor with burners, interconnecting ducts with dampers and associated controls.

4.3.2 BASE CASE (FIGURE 2) COSTS

Preliminary cost estimates were prepared for the auxiliary equipment of the HTSOE fuel cell power plant. This includes the preheating and waste heat recovery equipment but does not include the HTSOE fuel cells themselves or the ceramic heat exchangers and after-burner which are integral to the fuel cells. Vendor quotes were obtained for all major pieces of equipment and are shown in Table 1. Total capital investment for the auxiliary equipment was obtained by applying build-up factors from Table 53, cost breakdown for the steam cycle in TVA's report to EPA No. 600/7-77-126, November, 1977, to the major process equipment costs. The individual cost items and total capital investment is shown in Table 2. Based on an electrical output of 220 MW_e DC and 35.3 MW_e AC (net), and neglecting any credit for the process steam, the total capital investment represents a cost of 189/KW.

Table 3 summarizes the equipment costs and total costs for Figure 3, All Electric, and Figure 4, All Steam, options. These options, due to the size and service factoring method of estimating equipment costs, have less accurate costs than the base case. We estimate 20% accuracy for the base case and 30% for the two options.

TABLE 1

Major Auxiliary Equipment List for DC and AC
Power and Steam Cogeneration System

<u>Item</u>	<u>Description</u>	<u>Estimate Source</u>	<u>Cost</u>
Fuel Preheater	3 HX in parallel 33,000 SCFM each 40' L x 30' H x 15' W	Coal Tech 7/31/80	\$1,500,000
Waste Heat Boiler	700,000 #/h @ 1500 psi/950°C Extended Surface 20' W x 50' H x 12' D 2,400,000 #	Zurn 8/8/80	\$4,490,000 (plus \$2,450,000 Field Labor)
Air Preheater	3,700,000 #/h air 46' W x 44' L x 19' H 1,074,000 lbs	CE Air Preheater 7/21/81	\$1,200,000
Back Pressure Steam Turbine	Totally Enclosed Water-Air Hx Voltage Regulator Lube Oil Console	W Canada 7/24/80	\$4,600,000
Forced-draft Fan	Double width 4000 series Centrifugal with aerfoil blades 860,000 ACFM, 40" H ₂ O	W Sturtevant 8/15/80	\$ 226,000
Boiler Feed Pump	1420 gpm/1500 psi 12% chrome contact parts Forced Feed lub/Kingsburg	Ingersoll-Rand 8/14/80	\$ 130,000
Feed Pump Drive	1700 HP/3600 RPM	Estimate (\$20/HP)	\$ 34,000
Feedwater Heater	Deaerating heater 710,000 lbs/h	Estimate	\$ 100,000
Start-up Burner and Blower	100,000 CFM gas	Estimate	\$ 50,000
F.D. Fan Drive	7000 HP	Estimate (\$20/HP)	<u>\$ 140,000</u>
TOTAL			\$12,470,000

TABLE 2
Cogeneration System (DC and AC Power and Steam)
Cost Estimate (220 MWe DC HTSOE Fuel Cell Generator)

<u>Item</u>	<u>Cost (10³\$)</u>	<u>Percent of Major Equipment Cost¹</u>	<u>Percent of Total Capital Investment</u>
Major Process Equipment (excluding fuel cells)	12,470	100	26
Direct Site Labor	5,642	45	12
BOP and Materials (pipe, steel, concrete, etc.)	7,856	63	16
<hr/>			
Subtotal Direct Investment	25,968	208	54
Indirect Field Costs	4,489	36	9
Home Office Engineering and Fee	2,494	20	5
Contingency @ 20%	6,484	52	14
Interest during construction (10% per year on 50% of investment)	8,854	71	18
<hr/>			
Total Capital Investment	48,289	387	100

¹Power plant build-up factors per EPA/TVA Study⁽⁴⁾

TABLE 3
Capital Investment Costs

a) All Electric Cogeneration Option (Figure 3)

<u>Item</u>	<u>Cost (10³\$)</u>
Major Process Equipment (excluding fuel cells)	16,951
Direct Site Labor	7,628
BOP and Materials (pipe, steel, concrete, etc.)	10,679
<hr/>	
Subtotal Direct Investment	35,258
Indirect Field Costs	6,102
Home Office Engineering and Fee	3,390
Contingency @ 20%	8,814
Interest during construction (10% per year on 50% of investment)	12,086
<hr/>	
Total Capital Investment	65,600

b) All Steam Cogeneration Option (Figure 4)

Major Process Equipment (excluding fuel cells)	6,848
Direct Site Labor	3,081
BOP and Materials (pipe, steel, concrete, etc.)	4,314
<hr/>	
Subtotal Direct Investment	14,243
Indirect Field Costs	2,465
Home Office Engineering and Fee	1,370
Contingency @ 20%	3,561
Interest during construction (10% per year on 50% of investment)	4,861
<hr/>	
Total Capital Investment	26,500

4.3.3 AREAS OF INVESTIGATION FOR FUTURE SYSTEMS

No serious technical problems appear to exist with the auxiliary equipment portion of the HTSOE fuel cell power plant. All major process equipment used in the study was representative of existing equipment designs that have operated successfully in similar applications. The piece of equipment of greatest concern is the high temperature gas-to-gas heat exchanger used to preheat the fuel gas. The outlet temperature of 700°C (1292°F), large capacity (100,000 SCFM total; 33,000 SCFM per heater) and nature of heated fluid (coal gas) make this a difficult application. However, Coaltech-Farrier has successfully built similar heat exchangers (e.g., air heaters for foundry cupolas) of up to 40,000 SCFM capacity and outlet temperatures of 1400°C. In addition, Combustion Engineering offered a recuperative heater for this application that utilized rectangular metallic tubes (5" x 1"), demonstrating an alternate solution.

An area that may require further investigation is the feedwater heating system. A single feedwater heater utilizing exhaust steam and pretreated make-up water was assumed. Water conditioning requirements of the boiler should be investigated to insure that the feedwater has sufficiently low oxygen and chemical concentrations. A second feedwater heater might also increase the steam cycle efficiency slightly.

Also, a more careful investigation of fuel cell pressure drop should be conducted. The forced-draft fan was sized based on a 28" w.g. pressure drop through the HTSOE fuel cell and associated ceramic heat exchanger. This was based on calculating the fuel-side ΔP for the flow through a 4' long, 1/2" ID tube, and then assuming that the air-side ΔP was equal to the fuel-side ΔP . More precise calculations, or actual testing, should be conducted.

4.4 Subtask 5E - Conduct Preliminary Cost, Environmental and Conservation Benefit Analyses of the Selected Cogeneration System

This subtask considered the economic viability of the HTSOE cogeneration system for a variety of economic assumptions and determined sensitivity to projected energy costs and HTSOE capital costs estimates. It also treated, briefly, the environmental and fuel conservation aspects.

4.4.1 Economic Evaluation

The following procedure was used in the economic analysis:

1. Establish a base case of projected fuel costs, HTSOE fuel cell capital and operating costs and general economic assumptions.
2. A cash flow analysis of the HTSOE fuel cell systems versus conventional energy purchase.
3. Determine sensitivity to general economic assumptions.
4. Determine sensitivity to projected 1990 alternate energy (gas, electric) fuel costs and escalation, and initial HTSOE fuel cell cost estimates.
5. Present conclusions based on the above analyses.

All costs are given in 1980 dollars.

Variables

Variables associated with the HTSOE fuel cell economic evaluation include electric and gas prices, projected escalation at the time of installation (1990), HTSOE fuel cell initial cost and life, depreciation rate and annual system operating costs. General economic factors include the inflation rate, discount rate, projected taxes and investment tax credit.

Table 4 lists the materials needed per kilowatt for the HTSOE fuel cell and the estimated labor add-on. A one third factor is estimated for profit and installation. The conventional equipment is added to the HTSOE installed price to reach the initial capital cost of the three systems covered in the BASE CASE shown in Table 5. The 2% escalation cost for electricity versus 0% for gas was projected for the BASE CASE because plant replacement for electric generation will continue far beyond 1990, whereas gasification plants will be new and likely not rise beyond inflation. However, we depict sensitivity to variations in this assumption, as well as others, in the data that follows.

Cash Flow Analysis

A cash flow analysis for the base case for System (1) (HTSOE + Thermal) is shown in Table 6A. Cash flow for purchase of conventional fuel is compared with all costs of the system for a 20 year period. The initial cost of the HTSOE system by 1990 (in 1990 dollars) is 215 million and replacement of the HTSOE is started, annually, after 5 years, with 20% salvage. (Table 6B completely replaces the HTSOE fuel cell generator portion every five years, it can be seen that the method of replacement calculation does not affect the results to any degree). Net Cash Flow is a calculation of the difference between conventional and the HTSOE fuel cell generator system. Present value of the sum of the cash

Table 4

PROJECTED MATERIALS AND COSTS FOR THE HTSOE FUEL CELL GENERATOR

In_2O_3 - Indium Oxide	0.120 kg/kw	600 \$/kg*	72.0 \$/kw
Y_2O_3 - Yttrium Oxide	0.032	160	5.1
La_2O_3 - Lanthanum Oxide	0.018	36	0.7
Cr_2O_3 - Chromium Oxide	0.006	29	0.2
ZrO_2 - Zirconium Oxide	4.800	4	19.2
Al_2O_3 - Aluminum Oxide	4.000	4	16.0
NiO - Nickel Oxide	0.150	172	25.8
PrO_2 - Praseodymium Oxide	<u>0.024</u>	240	<u>5.8</u>
	9.150		144.8

a) \$145 for generator materials/kw

b) 15 for generator housing (10% of material cost)

c) 160 raw materials

160 labor (50% of total)

320 total cost/kw

*prices are 1980 catalog

Table 5

BASE CASE COSTS (1990 COSTS IN 1980 DOLLARS)

\$.05/kwh electric, 2% escalation over inflation

\$6/10⁶ BTU gas, 0% escalation over inflation, thermal value: \$6/10⁶ BTU

Capital Cost:

- 1) HTSOE Fuel Cell Generator + Thermal = \$120 x 10⁶
- 2) HTSOE Fuel Cell Generator + AC Electric + Thermal = \$146 x 10⁶
- 3) HTSOE Fuel Cell Generator + All Electric = \$166 x 10⁶

Output:

- 1) 220 MW_e, 885 x 10⁶ BTU/hr Thermal
- 2) 261 MW_e, 731 x 10⁶ BTU/hr Thermal
- 3) 312 MW_e, 0

5Y Life - 20 Y Plant Operation

6% Inflation, 10% Discount Rate

15% Investment Tax Credit

$$\text{Viability Ratio} = \frac{\text{Present Value Fuel Cell System Cash Flow}}{\text{Present Value Fuel Purchase Cash Flow}}$$

Table 6A.

ECONOMIC EVALUATION, SYSTEM 1, HTSOE FUEL CELL GENERATOR + THERMAL

INITIAL ELEC PRIC: \$0.05 * GAS ESCALATION OVER INFL: 0%

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
COST OF PURCH GAS (\$/MBTU)	10.7	11.4	12.1	12.8	13.6	14.4	15.2	16.2	17.1	18.2	19.2	20.4	21.6	22.9	24.3	25.8	27.3	28.9	30.7	32.5
COST OF PURCH ELEC (\$/KWH)	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.19	0.20	0.22	0.23	0.25	0.27	0.29	0.32	0.34	0.37	0.40	0.43	0.47
CONVENTIONAL SYSTEM																				
BTU USAGE/HR (MIL)	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881
BTU COST BEF TAXES (\$MIL)	75	79	84	89	94	100	106	112	119	126	134	142	150	159	169	179	190	201	213	226
KW USAGE/HR (000)	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
KW COST BEF TAXES (\$MIL)	187	202	218	236	255	275	297	321	347	374	404	437	471	509	550	594	641	693	748	808
SYSTEM COST BEFORE TAXES	262	281	302	325	349	375	403	433	466	500	538	578	622	668	719	773	831	894	961	1034
COST AFTER TAXES	141	152	163	175	188	202	218	234	251	270	290	312	336	361	388	417	449	483	519	558
CASH FLOW AFTER TAXES	-141	-152	-163	-175	-188	-202	-218	-234	-251	-270	-290	-312	-336	-361	-388	-417	-449	-483	-519	-558
FUEL CELL COSTS																				
BTU USAGE/HR	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976
BTU COST	167	177	188	199	211	224	237	252	267	283	300	318	337	357	378	401	425	451	478	506
INVESTMENTS	215					43	46	48	51	54	58	61	65	69	73	77	82	87	92	98
TAX CREDITS	32					6	7	7	8	8	9	9	10	10	11	12	12	13	14	15
OPERATING COST	12	13	13	14	15	16	17	18	19	20	21	22	24	25	27	28	30	32	34	36
DEPRECIATION (SYD)	72	57	43	29	14	14	27	37	45	51	54	57	60	64	68	72	76	81	85	90
COST BEFORE TAXES	251	247	244	242	241	254	281	306	331	353	374	397	421	446	473	501	531	563	597	633
COST AFTER TAXES	103	134	132	131	130	131	145	158	171	183	194	205	217	231	244	259	275	291	309	327
CASH FLOW AFTER TAXES	-246	-76	-89	-102	-116	-160	-164	-170	-177	-187	-198	-210	-222	-236	-250	-265	-281	-297	-315	-334
FUEL CELL SALVAGE																				
REVENUE FROM SALVAGE																				
REVENUE AFTER TAXES																				
TOTAL FUEL CELL SYSTEM																				
SYSTEM IAT	-103	-134	-132	-131	-130	-131	-145	-158	-171	-183	-194	-205	-217	-231	-244	-259	-275	-291	-309	-327
SYSTEM CASH FLOW	-246	-76	-89	-102	-116	-160	-164	-170	-177	-187	-198	-210	-222	-236	-250	-265	-281	-297	-315	-334
PAYBACK ANALYSIS																				
FUEL CELL SYS DEBT (JAN 1)	215	117	47	-24	-99	-177	-230	-296	-376	-470	-579	-703	-844	-1003	-1183	-1385	-1613	-1868	-2154	-2474
NET CASH FLOW	-117	69	72	75	78	52	66	80	94	109	124	141	159	180	202	227	255	286	320	358
CUMULATIVE NET CASH FLOW	-117	-47	24	99	177	230	296	376	470	579	703	844	1003	1183	1385	1613	1868	2154	2474	2832
6% DISCOUNT	-117	-51	13	75	137	176	223	276	336	400	469	543	622	707	796	891	992	1098	1210	1328
10% DISCOUNT	-117	-54	6	62	115	148	185	226	270	316	364	414	464	516	570	624	680	736	794	852

PRESENT VALUES:

IAT FOR CONVENTL SYSTEM	-917
IAT FOR FUEL CELL SYSTEM	-616
CASH FLOW FOR CONV SYSTEM	-917
CASH FLOW FOR F.C. SYST	-642
RATIO FC-TO-CONV CASH FLOW	0.70

* ASSUMPTIONS:

INITIAL GAS PRICE (1980\$)	6.00	DISCOUNT RATE (%)	10.0
INITIAL ELEC PRICE	0.05	TAX RATE	46.0
GAS ESCALATION OVER INFL		TAX CREDIT	15.0
ELEC ESCALATION OVER INFL	2.00	SALVAGE RATE	20.0
INFLATION RATE (%)	6.00	DEPRECIABLE LIFE (YRS)	5.0

Table 6B.

HTSOE ECONOMIC EVALUATION

HTSOE FUEL CELL GENERATOR REPLACEMENT EVERY FIVE YEARS: GESC = 0% * INIT COST ELEC = \$0.05

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
COST OF PURCH GAS (\$/MBTU)	10.7	11.4	12.1	12.8	13.6	14.4	15.2	16.2	17.1	18.2	19.2	20.4	21.6	22.9	24.3	25.8	27.3	28.9	30.7	32.5	34.5
COST OF PURCH ELEC (\$/KWH)	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.19	0.20	0.22	0.23	0.25	0.27	0.29	0.32	0.34	0.37	0.40	0.43	0.47	0.50
CONVENTIONAL SYSTEM																					
BTU USAGE/HR (MIL)	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881	881
BTU COST BEF TAXES (\$MIL)	75	79	84	89	94	100	106	112	119	126	134	142	150	159	169	179	190	201	213	226	239
KW USAGE/HR (000)	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
KW COST BEF TAXES (\$MIL)	187	202	218	236	255	275	297	321	347	374	404	437	471	509	550	594	641	693	748	808	873
SYSTEM COST BEFORE TAXES	262	281	302	325	349	375	403	433	466	500	538	578	622	668	719	773	831	894	961	1034	1112
COST AFTER TAXES	141	152	163	175	188	202	218	234	251	270	290	312	336	361	388	417	449	483	519	558	600
CASH FLOW AFTER TAXES	-141	-152	-163	-175	-188	-202	-218	-234	-251	-270	-290	-312	-336	-361	-388	-417	-449	-483	-519	-558	-600
FUEL CELL COSTS																					
BTU USAGE/HR	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976	1976
BTU COST	167	177	188	199	211	224	237	252	267	283	300	318	337	357	378	401	425	451	478	506	537
INVESTMENTS	215					204					273					365					
TAX CREDITS	32					31					41					55					
OPERATING COST	12	13	13	14	15	16	17	18	19	20	21	22	24	25	27	28	30	32	34	36	38
DEPRECIATION (SYD)	72	57	43	29	14	68	54	41	27	14	91	73	55	36	18	122	97	73	49	24	
COST BEFORE TAXES	251	247	244	242	241	308	309	310	313	316	412	413	415	419	423	551	553	556	560	567	575
COST AFTER TAXES	103	134	132	131	130	136	167	168	169	171	181	223	224	226	229	243	298	300	302	306	310
CASH FLOW AFTER TAXES	-246	-76	-89	-102	-116	-271	-112	-127	-142	-157	-363	-150	-170	-190	-210	-486	-201	-227	-254	-282	-310
FUEL CELL SALVAGE																					
REVENUE FROM SALVAGE						20					27					36					69
REVENUE AFTER TAXES						11					15					20					37
TOTAL FUEL CELL SYSTEM																					
SYSTEM IAT	-103	-134	-132	-131	-130	-125	-167	-168	-169	-171	-167	-223	-224	-226	-229	-223	-298	-300	-302	-306	-273
SYSTEM CASH FLOW	-246	76	-89	-102	-116	-260	-112	-127	-142	-157	-349	-150	-170	-190	-210	-466	-201	-227	-254	-282	-273
PAYBACK ANALYSIS																					
FUEL CELL SYS DEBT (JAN 1)	215	117	47	-24	-99	-177	-129	-241	-361	-490	-630	-606	-800	-1010	-1235	-1480	-1511	-1840	-2195	-2578	-2994
NET CASH FLOW	-117	69	72	75	78	-48	112	120	129	139	-24	195	209	226	244	31	329	355	384	416	489
CUMULATIVE NET CASH FLOW	-117	-47	24	99	177	129	241	361	490	630	606	800	1010	1235	1480	1511	1840	2195	2578	2994	3483
6% DISCOUNT	-117	-51	13	75	137	101	180	260	341	424	410	513	617	723	831	843	973	1105	1239	1377	1529
10% DISCOUNT	-117	-54	6	62	115	85	148	210	270	329	320	388	455	520	585	592	664	734	803	871	944
PRESENT VALUES:																					
IAT FOR CONVENTL SYSTEM	-917																				
IAT FOR FUEL CELL SYSTEM	-614																				
CASH FLOW FOR CONV SYSTEM	-917																				
CASH FLOW FOR F.C. SYST	-637																				
RATIO FC-TO-CONV CASH FLOW	0.69																				
*ASSUMPTIONS:																					
INITIAL GAS PRICE (1980\$)											6.00									10.00	
INITIAL ELEC PRICE											0.05									46.00	
GAS ESCALATION OVER INFL																				15.00	
ELEC ESCALATION OVER INFL											2.00									10.00	
INFLATION RATE (%/%)											6.00									5.00	
DISCOUNT RATE (%/%)																					
TAX RATE																					
TAX CREDIT																					
SALVAGE RATE																					
DEPRECIABLE LIFE (YRS)																					

flow over the twenty year period is compared in the Ratio. A value less than 1 is a saving, the degree of saving is 1 minus the ratio value.

Economic Assumptions

Table 7 shows the effect of various general economic assumptions. The Viability Ratio is only modestly altered by changes in the discount rate, projected inflation rate, or investment tax credit. These ratios are calculated in the same manner as illustrated in Tables 6A and 6B but only the answer--i.e., the Viability Ratio--is shown. This same procedure is used for the Sensitivity analysis to follow; hundreds of cash flow runs have been made with only the results printed. This allows for a thorough and inexpensive analysis.

4.4.1.1 Sensitivity to Fuel Cost, Escalation Rates and Fuel Cell Generator Costs

This section will deal with the sensitivity of the BASE CASE results to changes in fuel cost, fuel escalation, and estimates of HTSOE fuel cell generator initial costs. Of the three variations in the cogeneration systems analyzed, System 1 (all steam option) was chosen for extensive sensitivity analysis. Table 8 shows the variation for a limited sensitivity analysis for all three systems. The rectangle indicates the closeness of all three for the base case.

Table 9 shows the Viability Ratios for the indicated 1990 fuel costs (in 1980 dollars) with 0 and 2% escalation with the HTSOE fuel cell generator initial price as estimated in the BASE CASE, as well as for a 1.5 increase in the estimated initial cost and a 0.67 decrease in that cost.

Since interpreting sensitivity from so many numbers is hard to visualize, we have prepared a series of curves (Figures 5 through 15) that should simplify sensitivity evaluation. Figure 5

Table 7

ECONOMIC VARIATIONS

BASE CASE = 0.70 Viability Ratio

HTSOE Replacement Every Five Years = 0.69

No Investment Tax Credit = 0.73

15% Discount Rate = 0.73

10% Inflation, 15% Discount Rate = 0.72

\$4/10⁶ BTU Thermal Value = 0.76

Table 8.

COMPARISON OF THE THREE COGENERATION SYSTEMS

(Effect on Viability Ratio)

<u>ELECTRIC</u>			<u>GAS</u>			
\$/kwh	Esc. (%)	Esc. (%)	\$4/10 ⁶ BTU		\$6/10 ⁶ BTU	
			0	2	0	2
.03	0	S	1.06	1.21	1.24	1.40
		C	1.02	1.20	1.22	1.42
		E	1.19	1.55	1.62	2.16
.03	2	S	.83	.98	1.00	1.16
		C	.78	.94	.96	1.15
		E	.84	1.09	1.13	1.51
.05	0	S	.74	.88	.90	1.07
		C	.69	.83	.86	1.04
		E	.72	.93	.97	1.29
.05	2	S	.56	.68	.70	.85
		C	.51	.63	.65	.80
		E	.50	.65	.68	.91

S = Electric HTSOE + All Thermal Reject Heat Utilization

C = Electric HTSOE + Thermal Electric Generation and Reject Heat Utilization

E = All Electric System - HTSOE + Thermal Electric Generation

Table 9

INITIAL COST VARIATIONS

(Effect on Viability Ratio)

a) 1.0 x Initial HTSOE Fuel Cell Generator Cost Estimate

<u>ELECTRIC</u>			<u>GAS</u>					
\$/kwh	Esc. (%)	Esc. (%)	\$4/10 ⁶ BTU		\$6/10 ⁶ BTU		\$8/10 ⁶ BTU	
			0	2	0	2	0	2
.03	0		1.06	1.21	1.24	1.40	1.37	1.52
.03	2		0.83	0.98	1.00	1.16	1.13	1.30
.05	0		0.74	0.88	0.90	1.07	1.03	1.21
.05	2		0.56	0.68	0.70	0.85	0.82	0.99
.07	0		0.57	0.69	0.71	0.86	0.83	1.00
.07	2		0.42	0.52	0.54	0.67	0.64	0.79

b) 0.67 x Initial HTSOE Fuel Cell Generator Cost Estimate

.03	0		0.99	1.16	1.18	1.35	1.32	1.48
.03	2		0.78	0.93	0.95	1.13	1.09	1.27
.05	0		0.69	0.84	0.86	1.03	1.00	1.17
.05	2		0.52	0.65	0.67	0.82	0.79	0.96
.07	0		0.53	0.66	0.68	0.83	0.80	0.97
.07	2		0.40	0.50	0.51	0.65	0.62	0.77

c) 1.5 x Initial HTSOE Fuel Cell Generator Cost Estimate

.03	0		1.16	1.30	1.32	1.47	1.44	1.58
.03	2		0.91	1.05	1.07	1.22	1.19	1.36
.05	0		0.81	0.94	0.96	1.12	1.09	1.25
.05	2		0.61	0.73	0.75	0.89	0.86	1.02
.07	0		0.62	0.74	0.76	0.90	0.88	1.04
.07	2		0.46	0.56	0.58	0.70	0.68	0.82

Curve 725526-A

Fig. 5—Effect of HTSOE fuel cell generator cost and electricity cost on the viability ratio

is a plot of Viability Ratio versus initial HTSOE fuel cell generator cost estimate and electric price change under the other conditions of the BASE CASE. One can see that the change in the Viability Ratio is moderate for initial HTSOE fuel cell generator cost changes, whereas the sensitivity to changes in electric rate are considerably greater. The center dot represents the BASE CASE for all variables.

Figures 6 to 9 superimpose various changes in BASE CASE assumptions over the BASE CASE. The effect of an increase in gas price or gas price escalation is shown in Figure 6; Figure 7 shows a reduction in gas price with and without a price escalation. Figure 8 shows the effect of removal of the 2% electric escalation from the base case. Finally, Figure 9 in this series shows the extreme of \$8/106 BTU gas and 2% escalation on the Viability Ratio.

Since the effect of variation in the initial HTSOE fuel cell generator cost is minimal, Figures 10 to 13 plot variation of the Viability Ratio versus gas and electric price changes for the BASE CASE using the estimated HTSOE fuel cell generator cost. Figure 10 shows an expanded range of gas and electric costs, relative to those used to establish the base shown in Figure 11. The overlays in Figure 12 show the minor effect of a 1.5 increase in the initial HTSOE fuel cell generator cost estimate and the greater effect of a 2% gas price escalation. Figure 13 is interesting in that it shows that the 2% electric price escalation pays for the cost of the HTSOE cogeneration system.

Figures 14 and 15 summarize the sensitivity analysis. Each is a superimposed set of curves, one relating electric prices to gas prices, the other to variation of the HTSOE fuel cell generator system initial price estimate. Figure 14 is for the 2% electric escalation used for the BASE CASE; Figure 15 is for 0% electric escalation. The "slope" of the initial fuel cell cost curve for any electric rate is an indication of the sensitivity of the Viability Ratio to initial cost for that electric rate with the other variables corresponding to the BASE CASE. The "slope"

Fig. 6—Effect of gas price and gas price escalation on the viability ratio

Fig. 7—Effect of reduction in gas price, with and without escalation, on the viability ratio

Fig. 8—Effect of no electric cost escalation on the viability ratio. Base case = 2% escalation

Fig. 9—Effect of increased gas cost and escalation on the viability ratio

Fig. 10—Effect of cost of gas and electricity on the viability ratio

Curve 725527-A

Fig. 11—Base case - effect of gas and electricity costs on the viability ratio

Fig. 12—Effect of 1.5 × cost increase for the HTSOE fuel cell generator and a 2% gas escalation cost on the viability ratio

Fig. 13—Effect of 2% electric price escalation (the base case) with respect to the cost of the HTSOE fuel cell generator system

Fig. 14—The effect of electric, gas and HTSOE fuel cell generator costs on the viability ratio

Fig. 15—Effect of electric, gas and HTSOE fuel cell generator costs on the viability ratio

of the gas curve indicates the greater sensitivity to the gas price. The negative "slope" of the electric curve for either the gas or initial cost curves indicate the even greater sensitivity to electric prices.

4.4.1.2 Conclusion - Economic Evaluation

The main conclusion of the preliminary economic evaluation is that an HTSOE cogeneration system can effect substantial savings for the conditions projected for the BASE CASE. This is in comparison with use of conventional fuel for the selected specific existing application in the aluminum industry when considered in the year 1990. It should be noted that if conventional energy sources are used, the cost of aluminum will escalate beyond inflation but that use of the HTSOE fuel cell cogeneration system will modify this escalation. The sensitivity analysis indicates that major modification of this result will depend upon future electricity prices.

4.4.2 Environmental and Conservation Benefit

The high efficiency of energy utilization by the HTSOE fuel cell cogeneration systems result in a substantial conservation benefit. Further, the use of gasified coal to produce both electric and thermal energy results in the use of one of our countries abundant fuels in a clean process. Preliminary analysis also indicates there will be no environmental problems of consequence and that there is no problem of materials availability, even with substantial utilization of the HTSOE fuel cell generator. This aspect should be investigated further in the next phase of HTSOE development.

5.0 Suggested Future Effort

The preliminary analysis performed indicates that the use of the HTSOE fuel cell generator, as anticipated in this project, will

result in substantial economic savings and fuel conservation relative to conventional methods for a specific application in the aluminum industry. As covered in the Prefatory Note, the Task 5 study was limited and considerably greater detailed analysis and scope is warranted, given the positive results of this report.

As technical development of the HTSOE fuel cell proceeds, detailed design and evaluation of the HTSOE system and its application, optimization of the system and comparison to alternate methods and processes will be needed. Also, determination of other applications, impact on the national energy picture and a more comprehensive study of the institutional and materials availability aspects will have to be carefully appraised.

The following is a very brief outline of a suggested program for the next phase:

- Verification that the aluminum industry is indeed an appropriate first application.
- Design a detailed, comprehensive, optimized system.
- Compare with other methods and changed processes.
- Further consideration of environmental and institutional aspects.
- A detailed examination of materials availability, costs and environmental problems if the HTSOE fuel cell is widely applied.
- A search for all available applications and an order of and plan for implementation.
- Projection of the total market and evaluation of the HTSOE fuel cell generator impact on the energy economy.

6.0 REFERENCES

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4. TVA/EPA Report No. 600/7-77-126, November 1977.