JPL NO. 9950 - 789

PSI TR-360

ADVANCED COAL GASIFIER-FUEL CELL POWER PLANT SYSTEMS DESIGN

FINAL REPORT

Martin E. Heller

January 1983

Prepared for

California Institute of Technology
JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, CA 91103

Under Prime Contract NAS7-918
(Subcontract No. 956332)

PHYSICAL SCIENCES INC.

RESEARCH PARK, ANDOVER, MA 01810

PSI TR-360

ADVANCED COAL GASIFIER-FUEL CELL POWER PLANT SYSTEMS DESIGN

FINAL REPORT

Martin E. Heller

January 1983

Prepared for

California Institute of Technology
JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, CA 91103

Under Prime Contract NAS7-918
(Subcontract No. 956332)

Prepared by

Physical Sciences Inc.
Research Park
Andover, MA 01810

"This work was performed for the Jet Propulsion Laboratory, California Institute of Technology sponsored by U.S. Department of Energy through an agreement with the National Aeronautics and Space Administration."

ABSTRACT

Two advanced coal-powered power plants utilizing fuel cells have been designed. Both plants incorporate the TRW Catalytic Hydrogen Process fluidized bed gasifier and regenerator. The phosphoric acid fuel cell power plant has a 48% efficiency, a heat rate of 7100 Btu/kWh, a capital cost of $1155/kW, and a cost of electricity (calculated on a ten year levelized basis at 65% availability) of $0.072/kWh. The molten carbonate fuel cell power plant has a 52% efficiency, a heat rate of 6600 Btu/kWh, a capital cost of $1210/kW, and a cost of electricity of $0.078/kWh.

It is recommended that the phosphoric acid fuel cell power plant design be refined, and that technical questions relevant to the feasibility of the design be investigated experimentally. It is recommended that this study lead to the construction of a pilot demonstration unit of approximately 300 kW capacity.

TABLE OF CONTENTS

1.0 SUMMARY

Two advanced, high efficiency coal-fired power plants have been designed, one utilizing a phosphoric acid fuel cell (Fig. 1) and one utilizing a molten carbonate fuel cell (Fig. 2). Both incorporate a TRW Catalytic Hydrogen Process gasifier and regenerator (Fig. 3). Both plants operate without an oxygen plant and without requiring water feed; they, instead, require makeup dolomite. Neither plant requires a shift converter; neither plant has heat exchangers operating above 1250°F.

Both plants have attractive efficiencies and costs. While the molten carbonate version has a higher (52%) efficiency than the phosphoric acid version (48%), it also has a higher ($0.078/kWh versus $0.072/kWh) ten-year levelized cost of electricity. The phosphoric acid fuel cell power plant is probably feasible to build in the near term: questions about the TRW process need to be answered experimentally, such as whether it can operate on caking coals, and how effective the catalyzed carbon-dioxide acceptor will be at pilot scale, both in removing carbon dioxide and in removing sulfur from the gasifier.

Another question that needs to be addressed experimentally is the chemistry of the interaction of sulfur compounds with phosphoric acid fuel cells. Historically, the sulfur tolerance of phosphoric acid fuel cell power plants has been limited to a few parts per million by low temperature shift catalysts; it is believed that the fuel cells themselves can tolerate on the order of 100 parts per million of sulfur in the form of H_2S. This is within a factor of three of the sulfur level reported from the Conoco CO_2 Acceptor Process (a similar process that has operated at pilot plant scale) gasifier; it would be an advantage to be able to operate the plant without any sulfur removal process other than that occurring in the fluidized bed.

The power plant has been designed to produce 675 MW. It appears feasible to design a commercial version as small as 50 MW that would still be economically attractive. We would propose to test this by designing, building, and operating a pilot demonstration unit to produce 300 kW.

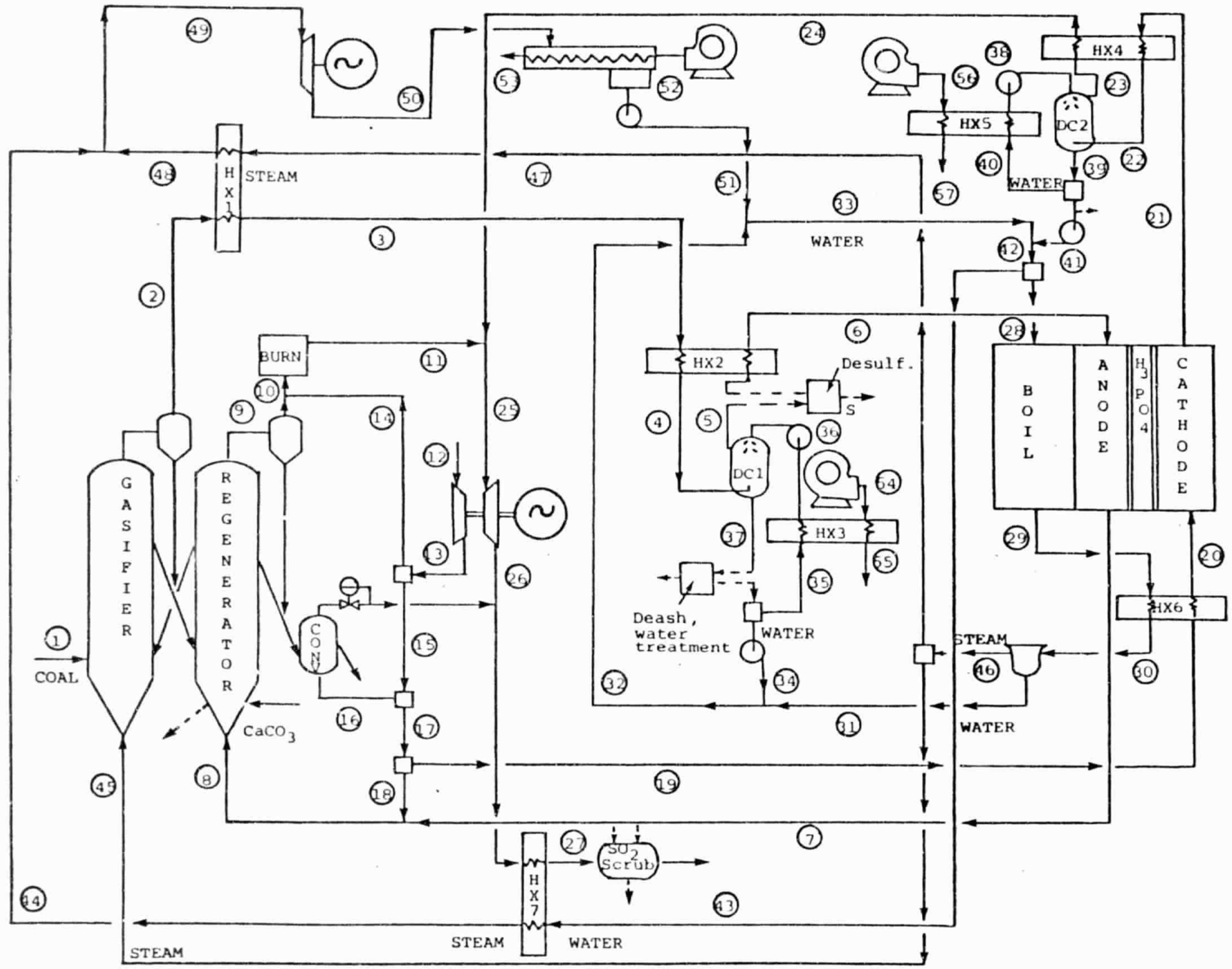


Fig. 1 Phosphoric acid fuel cell power plant with TRW catalytic hydrogen process.

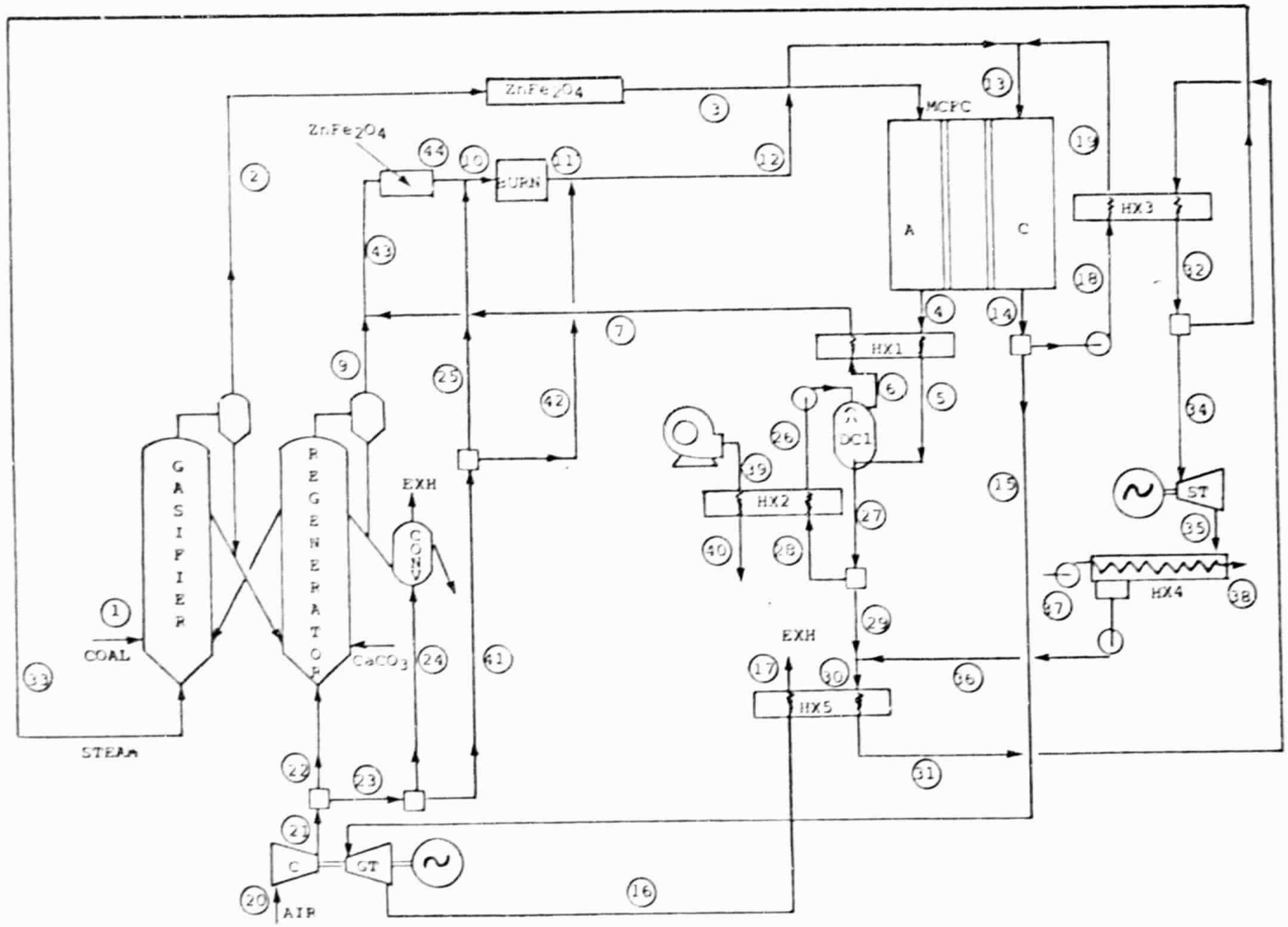
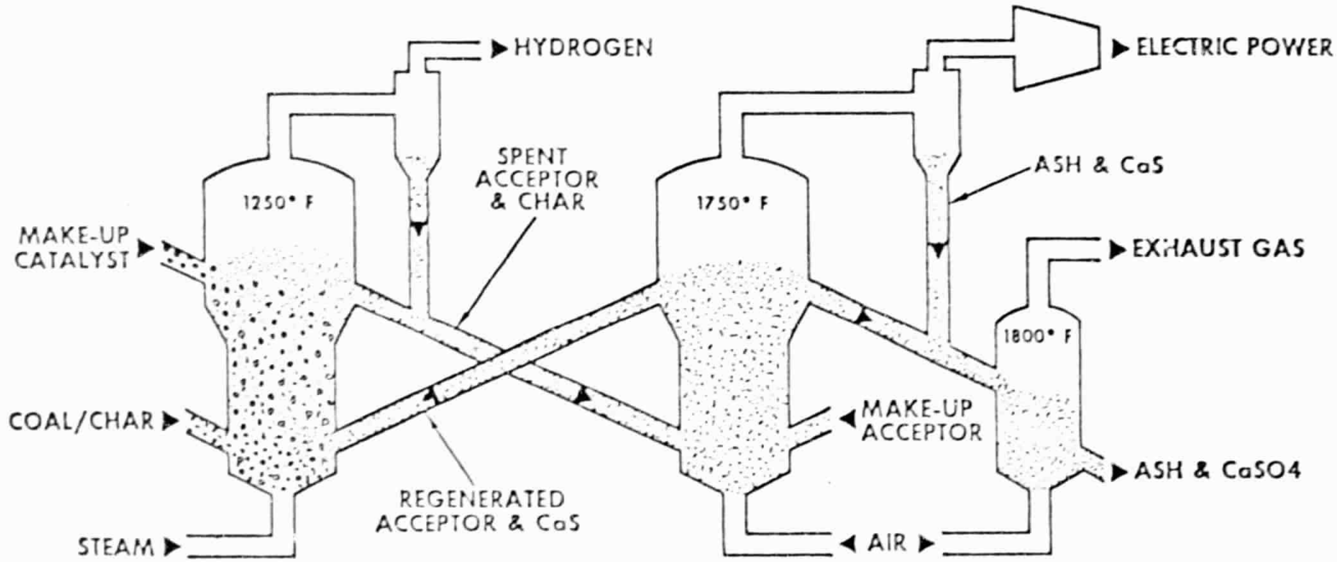


Fig. 2 Molten carbonate fuel cell with TRW catalytic hydrogen process.



FUEL GAS PRODUCTION

$C + H_2O \xrightarrow[CAT]{} H_2 + CO$

$CO + H_2O \xrightarrow[CAT]{} H_2 + CO_2$

$CO + 3H_2 \xrightarrow[CAT]{} CH_4 + H_2O$

$CO_2 + CaO \longrightarrow CaCO_3$

$H_2S + CaO \longrightarrow CaS + H_2O$

ACCEPTOR REGENERATION

$C + \frac{1}{2}O_2 \longrightarrow CO$

$CaCO_3 \longrightarrow CO_2 + CaO$

WASTE SOLIDS CONVERSION

$CaS + 2O_2 \longrightarrow CaSO_4$

Fig. 3 Catalytic hydrogen production.

2.0 INTRODUCTION

The object of this program is to analytically synthesize at least two coal-fired fuel cell power plant configurations which represent a significant advance over the current state of the art. The measure of success of these systems is reduction in capital cost and cost of electricity and improvement in power plant efficiency.

Another design goal is to simplify the systems to as great a degree as possible. For example, a prime candidate for elimination from conventional designs is the liquid oxygen subsystem, since it is expensive in capital as well as efficiency. Another example of a subsystem that is too complex in conventional designs is the gas cleanup train.

The importance of thermal integration to a power plant's efficiency cannot be overemphasized. Poor thermal integration of components always implies heat losses; heat lost is unavailable for power generation or fuel conversion, and the power plant consequently has poor efficiency.

The scope of this study also includes the definition of areas where technological research is required, and the potential payoff of that research. For example, if a new gasification technology could eliminate the requirement for shift conversion of the raw gas, or could reduce the sulfur levels in the raw gas so that further desulfurization were not required, there would be a clear payoff in both cost and efficiency for the power plant.

The computer code used for thermodynamic systems analysis of the power plant flow sheets developed in this study is PSI/S3E. This code is a product of PSI/Systems and runs on microcomputers. The interactive nature of the code allowed many flowsheets to be evaluated quickly, which greatly facilitated the progress of this study.

The author wishes to thank David Bloomfield for his astute support and guidance in this program. In addition, he would like to thank Joseph Ferrall of Jet Propulsion Laboratory for his active involvement in the program, which extended even to identifying the TRW gasifier as the catalyzed acceptor process we were seeking in the early stages of the project.

3.0 TECHNICAL DISCUSSION

3.1 Acid Fuel Cell Characteristics

The phosphoric acid fuel cell is an efficient device for converting hydrogen and oxygen into water and electricity. Its performance depends directly on hydrogen pressure at the anode, oxygen pressure at the cathode, and operating temperature, and depends inversely on carbon monoxide partial pressure. Sulfur and chlorine bearing contaminants can decrease the performance of the cell as well as shortening the cell operating lifetime.

The fuel cell efficiency is proportional to operating voltage, but current density is inversely proportional to operating voltage; thus there is a tradeoff in fuel cell power plants between cell size and cell efficiency. Practical limits such as electrode corrosion at high temperatures and potentials circumscribe the achievable operating regimes, as do water balance considerations.

3.2 TRW Gasifier

In our initial search for a gasifier that would integrate well with a fuel cell in an efficient coal-fired power plant, we looked at the major characteristics of many coal gasifiers, eventually examining in more detail 19 gasifiers either commercially available or proven in pilot plants (see Table 1). Of these, two processes, the Conoco Carbon Dioxide Acceptor Process and the Battelle Ash Agglomerating Process, show the characteristic of producing medium-Btu gas from coal with good efficiency and without requiring an oxygen plant. The intrinsic disadvantage of both of these processes is that hot solids flow between gasification and combustion beds, which can cause engineering and maintenance problems. We were willing to accept this disadvantage based on the satisfactory performance of the pilot plants for these processes.

Of these processes, the Conoco method seemed to have more potential for integration with a fuel cell, since the dolomite used as a carbon dioxide acceptor also removes sulfur. However, the process is limited to highly reactive lignites and subbituminous coals, since the acceptor reaction is thermodynamically unfavored at temperatures above 1550°F. We investigated the

TABLE 1 - COAL GASIFICATION PROCESS

PROCESS	BED	COALS	tpt GAS	tpt STEAM	P (atm)	T (°F)	Cold Gas Effic. (%)	Typical mol % H_2	Typical mol % CH_4	Typical mol % CO_2	Typical mol % CO	Gas HHV Btu/SCF	
British gas	fixed	all	0.52 O_2	0.28	5-26	~2300	68.3	28	7.6	2.5	61	381	
Lurgi, Dry Ash	fixed	all	0.6 O_2	3.2	25-35	1800-2500	63	39	9	32	17	285-302	
Wellman-Galusha	fixed	all	3.5 air	0.4-0.7	~1	~2400	75	15.0	2.7	3.4	28.6	168	
WD/GI	fixed	non-caking	2.3 air	0.25	1	2200	77	17.0	2.7	4.5	28.3	175	
			O_2					38.4	3.5	18.00	37.5	280	
Battelle	fluidized	all	air	0.8-1.2	6-8	$\frac{2000}{1200}$	?	48-66	1-6	3-28	0-39	300-350	separate burner + gasifier
CO_2 Acceptor	fluidized	lignite subbituminous	2.3 air	1.1	10	$\frac{1850}{1500}$	77	58.8	13.7	9.1	15.5	380	dolomite regeneration
COGAS	fluidized	all	~5 air	~1	1-4	$\frac{1600}{3500}$	$\frac{48^{*}}{70-75^{+}}$	57.9	4.0	6.6	31.2	355	*based on char +forecast
HYGAS	fluidized	all	0.25 O_2	1-1.2	~80	~1760	~70[x]	30.2	18.6	24.5	23.8	370	[x]thermal
Synthane	fluidized	all	<0.35 O_2	< 1.5	~40	1500-1800	$\frac{48^{a}}{70^{b}}$	32.3	15.0	36.2	13.2	335	[a]Braun report [b]Overall thermal
			air					21.5	5.6	17.9	10.1		
Tri-Gas (BCR)	fluidized	all	3.59 air	0.11	~15	1200-2000	88	15.80	---	0.48	31.23	150	3 stages

Table 1 - COAL GASIFICATION PROCESS (Cont.)

PROCESS	BED	COALS	tpt GAS	tpt STEAM	P (atm)	T (°F)	Cold Gas Effic. (%)	Typical mol % H_2	CH_4	CO_2	CO	Gas HHV (Btu/SCF)	
U-Gas	fluidized	all	2.8-3.3 air (also O_2)	0.2-0.6	3-30 (6)	~1900		17.5	3.4	9.9	19.6	154	
							79	35.8	5.9	16.1	41.4	320	
Westinghouse	fluidized	all	2.2-2.8 air	0.2-0.4	15-20	1600/2000	94*	14.4	2.7	9.3	19.2	135	*thermal
Winkler	fluidized	low rank	0.35-0.6 O_2	0.4-0.7	1	1800-2100	69	40	2	14	38	290	
			1.7-3.0 air					12	0.7	10	22	118	
Babcock & Wilcox	entrained	all	0.8-1.0 O_2	< 0.05	1-20	3400	74	27.9	---	5.0	65.3	301	
			air					8.4	---	4.6	23.3	102	
Bi-GAS	entrained	all	0.5 O_2	0.4	30-100	2300-3000/1700	69	32.0	15.7	21.5	29.3	356	
CE	entrained	all	4.5 air	recycled	1	3000/1800	60	10.6	0.0	4.0	24.7	112	
Foster Wheeler	entrained	all	2.9 air	0.17	23	2200/1900	75	14.2	3.4	3.3	29.1	160	
Koppers-Totzek	entrained	all	0.7-0.9 O_2	< 0.3	1.1	3500/2700	75	36	---	10	52.5	286	
Texaco	entrained	all	0.84 O_2	0.44	10-40	~3000	66-73	39	0.5	20.8	37.6	253	typical
	entrained	all	0.84 O_2	0.44	40	2450 exit	77	28.8	0.08	8.7	42.5		REFERENCE

possibility of catalyzing this process, and discovered that this had been done successfully in the laboratory by TRW Energy Systems Division, as the TRW Catalytic Hydrogen Process (CHP).

The CHP (Fig. 3) incorporates fluidized beds for coal gasification and acceptor regeneration, recycling of acceptor and catalyst, and a solids converter to transform the sulfur and ash to environmentally acceptable forms. The catalyzed gasifier operates at 1250°F, the regenerator at 1750°F, and the solids converter at 1800°F. The product gas (from char) is 95-97% hydrogen by volume on a dry basis, with the remaining fraction made up of carbon dioxide, carbon monoxide, methane, nitrogen, and sulfur compounds. The full CHP schematic includes steps to dry the gas and remove the sulfur.

Based on Conoco's experience, we expect the sulfur level in the raw gas stream to be on the order of 300 ppm, and the acceptor recycle rate to be of the order of seven tons per ton of coal feed. As the acceptor is deactivated in time by grain growth, we expect to need roughly 1/4 ton of makeup acceptor feed per ton of coal feed. Based on TRW's studies of catalyst life, which show that calcium sulfate poisons the catalyst in a few cycles, we expect to run the regenerator in a slightly reducing atmosphere. An option not considered in this study, which has been demonstrated as feasible by Conoco, is the reactivation of spent acceptor. This option would probably decrease the efficiency of our power plants by ~ 2%, while reducing drastically the cost of acceptor feed and disposal.

The CHP has not been tried at pilot plant scale. However, the similar Conoco process has run successfully as a pilot plant, and the catalytic work special to the CHP has been successfully completed at bench scale. While there is substantial work to be done before the CHP is brought to commercial availability, there is adequate evidence that this can be done successfully and that the process will prove feasible.

3.3 Sulfur Cleanup Options for the PATRW

While the full CHP uses a Stretford process to remove and recover sulfur from the raw hydrogen stream, it is not necessary for us to do so when designing an integrated phosphoric acid fuel cell power plant. First, we are not producing pipeline gas. Second, we have no reformer or shift converter catalysts or methanators to limit the sulfur tolerance of our system. Third, the tolerance of an acid fuel cell for sulfur depends on the gas composition and the chemical form of the sulfur. As little as a few ppm of sulfur may be intolerable in systems running on hydrogen-poor gases with substantial CO or COS content, but as much as a few hundred ppm of sulfur may be tolerable in systems running on nearly pure hydrogen where the sulfur is almost entirely H_2S.

Our acid fuel cell power plant design, with 97% hydrogen content in the gas stream (dry basis) and less than 1% CO, should allow a tolerance of about 100 ppm of H_2S at the fuel cell anode. It should be noted, however, that the fuel cell anode's response to sulfur is complex, and, in fact, not particularly well understood.

Limestone and dolomite are moderately effective sulfur sorbents. In the gasifier and regenerator beds much of the sulfur present in the coal is captured as CaS; in the solids converter it is roasted to the more acceptable $CaSO_4$. If the remaining sulfur constitutes less than 100 ppm of the gas stream, then no further sulfur cleanup may be necessary except for the plant exhaust stream conditioning. If further sulfur cleanup is necessary, there are three options available. The choice of these depends on the gasifier effluent sulfur concentration, and the required anode inlet concentration.

A conventional ZnO bed may be placed immediately before the fuel cell anode in the system diagram. The advantage of this is that no sulfur will pass into the fuel cell; the disadvantage is that the bed is not regenerable and could be very large. Alternatively, a bed of zinc ferrite may be placed immediately after the cyclones at the outlet of the gasifier. This has the advantage of being regenerable, but is a newer and less proven process. It is especially attractive for molten carbonate fuel cell systems, since it operates at the same temperature as the fuel cell. (Note that the $ZnFe_2O_4$ will not remove other contaminants in the gas streams.) The third alternative is to use a sulfur removal process on cold dried gas; several processes are available, of which an amine process might be appropriate for this application.

An amine process would be easy to integrate with the PATRW flowsheet. It has been shown in Fig. 1 in dotted lines to indicate that it is an option, but has not been included in the economic analysis. A reasonable temperature and composition exists at the point shown for the correct operation of the process. In addition, there is water for raising steam available at no significant cost or efficiency penalty from DC2, and heat available for raising steam, again at no significant cost or efficiency penalty, in the power plant exhaust stream.

3.4 Phosphoric Acid Fuel Cell Power Plant Operational Description

The power plant we have designed is extremely efficient without requiring oxygen enrichment or water feed. It is efficient because: the fuel cell is efficient (57%); the fuel cell anode exhaust is utilized in the regenerator; the gasifier's product can be made suitable for input to the fuel cell in a thermally efficient way; and, heat generated by the fuel cell and other parts of the system is utilized to drive turbines and generate additional electricity. In this configuration, the overall efficiency is 48%, with a heat rate of slightly over 7100 Btu/kWh. To produce a net power of 675 MW, slightly over 550 MW must be produced by the fuel cell. There are roughly 14 MW of electrical power coming from the gas turbine-air compressor turbocharging system. The steam turbine (Rankine topping cycle) will produce slightly under 124 MW; and, finally, the plant will require slightly under 14 MW of parasite power. These numbers may be adjusted slightly in further revisions of the design, but the overall efficiency should be correct to within one or two percent.

Figure 1 shows the Phosphoric Acid Fuel Cell Power Plant with TRW Catalytic Hydrogen Process; the case is designated PATRW. In the following section we will trace the major flows through the power plant, making reference to node numbers (designated 1-57), line numbers in the S3E Basic language model of the power plant (designated 3000-4999), and component names (such as HX1 for heat exchanger #1). This discussion will be most conveniently followed while referring to the system schematic (Fig. 1) and the program listing (Appendix 1).

Coal and catalyst are fed to the gasifier at node 1, and steam at node 45 (lines 3054-5,3066). Heat of gasification is supplied by the carbon dioxide acceptor from the regenerator. In the gasifier, the coal is pyrolyzed and approximately 70% of the char is gasified. Catalytic action helps to drive the gasification reactions to completion, and the carbon dioxide evolved combines with the acceptor.

The major reactions occurring in the gasifier are:

1.	$C + H_2O \rightarrow H_2 + CO$	Gasification
2.	$CO + H_2O \rightarrow H_2 + CO_2$	Shift Conversion
3.	$CO + 3H_2 \rightarrow CH_4 + H_2O$	Methanation
4.	$CO_2 + CaO \rightarrow CaCO_3$	Acceptor
5.	$H_2S + CaO \rightarrow CaS + H_2O$	Sulfidization

In addition, there is pyrolysis of the coal, formation of ammonia from nitrogen and hydrogen, formation of water from oxygen and hydrogen, and other less important reactions. One must realize that reactions 1-3 are catalyzed and that the effectiveness of reaction 4 drives the equilibrium so that the primary reaction product is hydrogen.

Spent acceptor is recycled to the regenerator along with catalyst and sulfided acceptor; unutilized steam and nearly pure hydrogen are produced at node 2 (4200-4219). Coal fines are removed by cyclones and returned to the regenerator. Figure 3 shows the reactions in the gasifier and regenerator in more detail.

The hot hydrogen and steam are cooled, by saturated steam from the fuel cell boiler, in HX1 (4220). They are cooled further in the regenerative heat exchanger for the water removal process, HX2 (4225). The gases, cooled to just above dew point, are then quenched with a water spray in DC1 (4230-5). Excess water is removed in DC1, as is ammonia, HCl, and any remaining ash.

A point for consideration in subsequent design studies is the formation of ammonium chloride in the hot gas stream, which may deposit in the heat exchangers as the gases are cooled, and require filtration or regeneration. HCl will probably be completely neutralized and not present a problem; excess ammonia will eventually be burnt in the regenerator, and ash can be removed by centrifuge or filtration before the water is recycled. Some deionization and polishing of water will be necessary; however, the excess ammonia in the water may neutralize most of the corrosive acids (such as phosphoric acid from the fuel cell in the cathode exhaust stream) and eliminate much of the need for water treatment. However, dissolved CO_2, and O_2 in the cathode condensers may also present a corrosion problem that will need to be addressed.

The dried, cooled gas exiting DC1 at node 5 is desulfurized (refer to other options, above) and regeneratively reheated (4240) before passing to the fuel cell anode (4250), where most of the hydrogen is utilized to produce electricity. Anode exhaust at node 7 is mixed with compressed air (4265) and burned along with the remaining 30% of the coal char in the regenerator (4270). This combustion is maintained in a slightly reducing environment in order to allow multiple-pass recycling of the gasification catalyst.

Regenerator fines are removed in cyclones and hot, partially oxidized gases leave the regenerator at node 9. Makeup limestone or dolomite is fed to the regenerator, and a percentage of the used carbonate is removed from the bed for use in exhaust gas sulfur cleanup. CaS and ash pass to the solids converter where the sulfur is roasted to the environmentally more acceptable $CaSO_4$. The regenerator exhaust is mixed with air at node 10 (4280) and burned (4285). A mass balance at the gasifier and regenerator is given in Table 2.

Ambient air at node 12 is compressed (4305-10) and split among the regenerator, converter, burner, and fuel cell (4315-25). Air destined for the fuel cell cathode is first cooled to the fuel cell operating temperature by low-quality steam from the fuel cell boiler in HX6 (4330), and the cooled air at node 20 is utilized by the fuel cell to produce electricity (4045). The reaction in the fuel cell produces water at the cathode; steam-bearing cathode exhaust at node 21 is cooled in HX4 (4400-5) and quenched in DC2 (4410-15) before being regeneratively reheated (4420), mixed with the burner exhaust at node 25 (4505), and expanded through the gas turbine (4510). The expanded gas is further cooled when it boils water in HX7 (4440-4455) and when it is quenched by a carbonate-water slurry at node 27 to remove all sulfur oxides before being exhausted to the atmosphere.

TABLE 2

PATRW gasifier-regenerator species balance

(lb-mol/h)

Node	H_2	H_2O	CH_4	CO	CO_2	O_2	N_2	C	TOTAL
1	9769	894	0	0	0	1149	469	21261	34155
2	35877	13533	298	177	115	0	235	0	50233
7	3588	1028	298	177	115	0	235	0	5440
18	0	0	0	0	0	7966	30060	0	38026
8	3588	1028	298	177	115	7966	30529	6374	50075
9	247	4965	0	1524	19737	0	30529	0	57001
45	0	39342	0	0	0	0	0	0	39342

Node	H_2	H_2O	CH_4	CO	CO_2	O_2	N_2	C
1+45+7+18	13357	41264	298	177	115	9115	30764	21261

<u>H_2"atoms"</u>: $13357 + 41264 + 2 \times 298 = \underline{55217}$

<u>O-atoms</u>: $41264 + 177 + 2 \times 115 + 2 \times 9115 = \underline{59901}$

<u>C-atoms</u>: $298 + 177 + 115 + 21261 = \underline{21851}$

Node	H_2	H_2O	CH_4	CO	CO_2	O_2	N_2	C
2+9	36124	18498	298	1701	19852	0	30764	0

<u>H_2"atoms"</u>: $36124 + 18498 + 2 \times 298 = \underline{55218}$ $\quad \Delta = \frac{1}{55217}$

<u>O-atoms</u>: $18498 + 1701 + 2 \times 19852 = \underline{59903}$ $\quad \Delta = \frac{2}{59903}$

<u>C-atoms</u>: $298 + 1701 + 19852 = \underline{21851}$ $\quad \Delta = 0$

The fuel cell is cooled by water entering at node 28, which exits the fuel cell boiler at approximately 50% steam quality (4620-50). The quality of this steam is increased in HX6 (4655-62). This stream is split into its steam and water components (4668-72); the water is mixed with other water streams and recycled. The pure saturated steam at node 46 is split between the gasifier at node 45 and the steam turbine (4672); the steam destined for the turbine is first superheated in HX1 (4676) by hot hydrogen and steam coming from the gasifier. It is mixed with the superheated steam raised in HX7 (4678, 4440-99), and the combined steam drives the steam turbine (4680-2). The turbine expands the steam to 0.2 atmospheres; it is then condensed at 140°F, pumped back to loop pressure, and recycled. This and the other water sources are mixed (4687-94) and returned to the fuel cell boiler and HX7.

The amount of water removed from the gasifier and cathode outlet streams is controlled by the direct-contact cooler spray temperatures. There is excess water available which may be removed at node 41, for instance for use in the SO_2 cleanup system, as long as the DC2 spray temperature is lowered by increasing the air flow across HX5. Water not removed in DC1 passes through the fuel cell anode and into the regenerator, through the burner, and out through the gas turbine. Water not removed in DC2 is combined with the burner outlet stream and passes out through the gas turbine.

The amount of water passing through HX7 determines the steam temperature at node 44 and affects the temperature at node 49. This water flow is limited on the upper end by the heat capacity of the gas turbine outlet stream and on the lower end by efficiency considerations. Water to supply this cycle can be taken from DC2 condensate at power plant startup, but is completely recycled with the power plant operating at steady state. An overall plant energy balance is given in Table 3.

To summarize: The power plant converts coal by gasification to hydrogen, which is converted to electricity by the fuel cell. Waste fuel cell and gasifier heat powers a steam turbine which also produces electricity. The

TABLE 3

Overall energy balance for PATRW

	DESCRIPTION	NODE	ENTHALPY MM Btu
Inlets	Coal	1	-54.155
	Air	12	569.290
	Parasite Power		46.075
	Total In		561.210
Outlets	Fuel Cell		1929.74
	Net Turbine Power		470.646
	Cond In	50	-6255.6
	Cond Out	-51	7452.1
	HX3 In	35	-17260.0
	HX3 Out	-36	17508.0
	HX5 In	40	-57840.0
	HX5 Out	-38	58367.0
	Exhaust	27	-3826.9
	Total Out		554.984
	Total In		561.210
Difference			-6.227
Percent error			-1.1%

power plant turbocharging system is unbalanced and produces additional electricity. Waste heat in the gas turbine exhaust stream is used to raise additional superheated steam for the steam turbine. Water is completely recycled using direct contact cooling and a simple regeneration scheme, and there is capacity to produce excess water. Additional feeds of dolomite or limestone and a catalyst are required, and ash, calcium sulfate, and ammonium chloride are produced. The overall efficiency for producing electrical power from coal is 48%, amounting to a heat rate of 7108 Btu/kWh.

3.5 Molten Carbonate Fuel Cell Characteristics

The molten carbonate fuel cell generally operates at a temperature of 1200°F. It converts hydrogen and carbon monoxide at its anode and oxygen at its cathode to electricity; in addition, it transports carbon dioxide from cathode to anode. Hydrogen at the anode is used directly, with water and electricity being produced. Carbon monoxide at the anode combined with water undergoes a shift conversion reaction to produce hydrogen, which is then used by the fuel cell.

The molten carbonate fuel cell generally utilizes a porous nickel anode and a nickel oxide cathode. These catalysts can be poisoned by small quantities of sulfur compounds, and can be clogged by carbon deposited by the reactants. Carbon dioxide, which is required at the cathode as a reactant, also degrades the cathode. In addition, the binary or ternary melts of the molten carbonate electrolyte can form hot spots where the melt dissociates, causing crossover failure of the fuel cell.

For these reasons, the molten carbonate fuel cell is still an experimental device. However, it has long-term attractions: it has very high inherent efficiency; it can utilize carbon monoxide; versions of the molten carbonate fuel cell can utilize methane and other hydrocarbons by internal reforming reactions.

3.6 Molten Carbonate Fuel Cell Power Plant Operational Description

The molten carbonate fuel cell power plant we have designed is even more efficient than the phosphoric acid fuel cell power plant. This is primarily because the fuel cell itself is more efficient. However, this plant is not quite so well thermally integrated: large temperature changes are required, for instance, to condense water from the anode exhaust stream for recycling.

In this configuration, the overall efficiency is 52%, with a heat rate of slightly under 6600 Btu/kWh. To produce a net power of 675 MW, slightly over 572 MW must be produced by the fuel cell. There are roughly 52 MW of electrical power coming from the gas turbine-air compressor turbocharging system. The steam turbine (Rankine topping cycle) will produce slightly over 69 MW; and, finally, the plant will require slightly under 14 MW of parasite power. These numbers may be adjusted slightly in further revisions of the design, but the overall efficiency should be correct to within one or two percent.

Figure 2 shows the Molten Carbonate Fuel Cell Power Plant with TRW Catalytic Hydrogen Process; the case is designated MCTRW. In the following section we will trace the major flows through the power plant, making reference as before to anode numbers (designated 1-44), line numbers in the PSI/S3E Basic language model of the power plant (designated 3000-4999), and component names (such as HX1 for heat exchanger #1). This discussion will be most conveniently followed while referring to the system schematic (Fig. 2) and the program listing (Appendix 1).

Coal and catalyst are fed to the gasifier at node 1, and steam at node 33 (lines 3054-5,3066). Heat of gasification is supplied by the carbon dioxide acceptor from the regenerator, and some sensible heat by the 1100°F steam. In the gasifier, the coal is pyrolyzed and approximately 70% of the char is gasified. As in case PATRW, catalytic action helps to drive the gasification reactions to completion, and the carbon dioxide evolved combines with the acceptor.

Spent acceptor is recycled to the regenerator along with catalyst and sulfided acceptor; unutilized steam and nearly pure hydrogen are produced at node 2 (4200-4219). Coal fines are removed by cyclones and returned to the regenerator. Figure 3 shows the reactions in the gasifier and regenerator in more detail.

The gas exiting the gasifier at node 2 is desulfurized in a zinc ferrite bed before passing to the fuel cell anode (4030), where most of the hydrogen is utilized to produce electricity. The zinc ferrite should reduce the hydrogen sulfide level in the fuel gas from 300 ppm to less than 1 ppm, and can be regenerated. It is possible that further hot gas cleanup systems would be required in series with the zinc ferrite bed: ammonia and chlorides are the other principal contaminants that should be removed from the hydrogen before it is utilized by the fuel cell, but many other contaminants exist in the coal gas which may affect molten carbonate fuel cell performance and lifetime.

The anode exhaust gas, which includes the water formed by the fuel cell reactions and carbon dioxide transported from the fuel cell cathode, is cooled in HX1, quenched in DC1, and reheated in HX1 (4400-4435). The dried gas is mixed with regenerator exhaust. The water removed from the anode exhaust gas is mixed with Rankine cycle condensate and heated by the turbine exhaust in HX5. The quench water is cooled by air in HX2 and recycled to DC1.

In the regenerator, char is burned to recalcine the limestone or dolomite acceptor. Air to support partial oxidation enters at node 22. This combustion is maintained in a slightly reducing environment in order to allow multiple-pass recycling of the gasification catalyst.

Regenerator fines are removed in cyclones and hot, partially oxidized gases leave the regenerator at node 9. Makeup limestone or dolomite is fed to the regenerator, and a percentage of the used carbonate is removed from the bed for use in exhaust gas sulfur cleanup. CaS and ash pass to the solids converter where the sulfur is roasted to the environmentally more acceptable $CaSO_4$. The regenerator exhaust is mixed with anode exhaust at node 43, air at node 10, and burned (4280-4299).

Burner exhaust at node 11 is mixed with air at node 12 and cathode recycle gases at node 13. This mix is utilized by the fuel cell cathode (4045-4050). The fuel cell is cooled by a cathode recycle scheme; the cathode recycle flow is adjusted so that the gas stream enters the fuel cell at 1000°F and leaves at 1200°F (4440-4449). The cathode exhaust stream is expanded in the gas turbine and exhausted through HX5 (4500-4549). A wet scrubber is used to clean the SO_2 from the exhaust gas.

Ambient air at node 20 is compressed (4305-10) and split among the regenerator, converter, burner, and fuel cell (4315-25). Water recovered from the fuel cell anode exhaust at node 29 is mixed with water condensed in the Rankine bottoming cycle at node 30. This water is heated or boiled by exhaust gas heat in HX5, and then boiled and superheated by fuel cell heat in HX3 (4620-4699). This 1100°F steam is split between the gasifier and the steam turbine; the steam expanded through the turbine is condensed in HX4 and mixed with water condensed from the anode exhaust.

The amount of water removed from the anode outlet stream is controlled by the direct-contact cooler spray temperature. There is excess water available which may be removed at node 29, for instance, for use in the SO_2 cleanup system, as long as the DC1 spray temperature is lowered by increasing the air flow across HX2. Water not removed in DC1 passes through the burner, through the fuel cell cathode, and out through the gas turbine.

The amount of water passing through HX5 determines the steam temperature at node 31 and affects the temperature at node 32. This water flow is limited on the upper end by the heat capacity of the gas turbine outlet stream and on the lower end by efficiency considerations. Water to supply this cycle can be taken from DC1 condensate at power plant startup, but is completely recycled with the power plant operating at steady state.

To summarize: the power plant converts coal by gasification to hydrogen, which is converted to electricity by the fuel cell. Waste fuel cell and exhaust stream heat powers a steam turbine which also produces electricity. The power plant turbocharging system is unbalanced and produces additional electricity. Water is completely recycled using direct contact cooling and a simple regeneration scheme, and there is capacity to produce excess water. Additional feeds of dolomite or limestone and a catalyst are required, and ash, calcium sulfate, and ammonium chloride, are produced. The overall efficiency for producing electrical power from coal is 52%, amounting to a heat rate of 6555 Btu/kWh.

3.7 Economic Analyses

3.7.1 Phosphoric Acid Fuel Cell Power Plant Economics

Heat exchanger cost estimates

	area k ft^2	$\$/ft^2$	cost ($MM)
HX1	15	16	0.24
HX2	17	16	0.27
HX3	32	13	0.42
HX4	48	16	0.77
HX5	45	13	0.59
HX6	15	16	0.24
HX7	20	16	0.32
Condenser	257	9	2.31
DC1			0.25
DC2			0.75
Total	449		6.15

PLANT CAPITAL COST ESTIMATE

UNIT	SIZE	EXPONENT	W/O CONT *MM$	CONSTRUCTED MM$	PROC. CONT. MM$	PROJ. CONT. MM$	TOTAL MM$	$/kW
Coal handling	4597	0.78	12.33	18.98	0.00	5.69	24.68	36.56
Gasification	4597	0.6	59.65	59.65	23.86	17.89	101.40	150.22
Turbines	226	1	56.99	87.77	0.00	26.33	114.10	169.04
	124	1	31.27	48.16	0.00	14.45	62.61	92.75
Compressor	212	1	53.46	82.33	0.00	24.70	107.03	158.57
Thermal management	449	1	24.62	24.62	0.00	7.38	32.00	47.41
Inverters	554	1	36.29	55.89	5.59	16.77	78.25	115.92
Fuel cell	565	1	45.18	101.71	30.51	30.51	162.74	241.09
Other electric	675	1	18.30	28.18	0.00	8.45	36.64	54.28
Subtotal				507.29	59.96	152.19	719.44	1065.84
General facilities				46.12		13.84	59.95	88.82
Total cost				553.41	59.96	166.02	779.39	1154.66

*Basis scaled cost: 1976 dollars: coal handling, turbines, compressor, inverter, other electric
Manufactured: fuel cell (UTC)
Installed: gasification, thermal management (TRW)

OPERATING COSTS -- MM$/YEAR

Variable costs at 65% capacity

Fuel	4597	TPD	$1.65/MMBtu	44.04
Ash disposal	0.096	TPT	$ 5/ton	0.52
Dolomite	0.25	TPT	$12.7/ton	3.46
Catalyst	0.0077	TPT	$92.8/ton	0.78
Solids disposal	0.2577	TPT	$ 2/ton	0.56
Total variable costs	MM$/year			49.36

Fixed costs

Operating labor	3.74
Maintenance	14.98
Overhead	2.92
Total fixed costs MM$/year	21.94
Total fixed and variable costs	71.00 MM$/year

Calculate fuel cell replacement as cost of electricity increment

Fuel cell	3,012,000 ft^2	@ $15	45.18	1981
Replace	5 yrs	i=0.085	45.29	1986
	note: credit 1/3 for Pt catalyst			
Replace	10 yrs	i=0.085	68.10	1991

Annual sinking fund	$10.95 MM (10 year levelized)
Plus process contingency	3.29
Plus project contingency	3.29
Total	$17.53 MM/year

As COE: $0.0054/kW-h of F. C. power

COST OF ELECTRICITY FOR PHOSPHORIC ACID FUEL CELL POWER PLANT

Total plant cost (1.1)				TPC
Process costs (on-site)		461.17		
General facilities		46.12		
Engineering and home office		46.12		
Process contingency		59.96		
Project contingency		166.02		
Total		779.39		TPC
Allowance for funds during construction (1.2)				AFDC
AFDC	0.0373	29.07		
Prepaid royalties (1.3)				
	0.005	3.60		
Startup costs (1.4)				
Month fixed oper. costs		1.80		
Month var. oper. costs		6.33		
Month cap. fuel * 0.25		1.41		
TPC*2%		15.59		
Total		25.13		
Inventory capital (1.5)				
60 days supplies @ full capacity			12.61	
Initial catalyst and chemical charge (1.6)				
Based on TRW estimate		1.04		
Land (1.07)	164	5500	0.90	
Total capital requirement (1.08)			851.35MM	
Variable operating costs (2.0)			49.36	
Fixed operating costs (3.0)			21.64	
Fuel cell replacement (4.0)			17.53	

CALCULATE SHORT TERM 10 YEAR, LEVELIZED COE (5.0)

	1981 Cost	Interest Rate	Real Escalation	Inflation Rate	Apparent Escalation Level	Levelizing Factor	Levelized Expenditures
Fixed	21.64	0.125	0	0.085	0.085	1.4878	32.20
Var-Coal	44.04	0.125	0.007	0.085	0.092595	1.5434	67.96
-Other	5.33	0.125	0	0.085	0.085	1.4878	7.93
Fuel cell	17.53	0.125	0	0.085	0.085	NA	17.53
Total							125.61

Levelized revenue requirement for first 10 years

	MM$/year	%	
	153.24	54.95	Capital related changes
	32.20	11.55	Fixed operating costs
	67.96	24.37	Variable operating costs - Coal
	7.93	2.84	Variable operating costs - Other
	17.53	6.29	Fuel cell replacement expense
Total	278.86	100.00	

Phosphoric acid fuel cell power plant

COE $0.0725 per kWh

3.7.2 Molten Carbonate Fuel Cell Power Plant Economics

Heat exchanger cost estimates

	area k ft^2	\$/ft^2	cost (\$MM)
HX1	100	16	1.60
HX2	32	13	0.42
HX3	50	16	0.80
HX5	20	16	0.32
Condenser	257	9	2.31
DC1			0.75
Total	459		6.20

PLANT CAPITAL COST ESTIMATE

UNIT	SIZE	EXPONENT	W/O CONT *MM$	CONSTRUCTED MM$	PROC. CONT. MM$	PROJ. CONT. MM$	TOTAL MM$	$/kW
Coal handling	4255	0.78	11.61	17.87	0.00	5.36	23.23	36.42
Gasification	4255	0.6	56.94	56.94	22.78	17.08	98.80	143.41
Zinc ferrite	122358	0.65	11.08	11.08	1.66	3.32	16.07	23.80
Turbines	254	1	64.06	98.65	0.00	29.59	128.24	189.99
	70	1	17.65	27.19	0.00	8.16	35.34	52.36
Compressor	201	1	50.69	78.06	0.00	23.42	101.48	150.34
Thermal management	459	1	24.80	24.80	0.00	7.44	32.23	47.76
Inverters	572	1	37.47	57.71	5.77	17.31	80.79	119.69
Fuel cell	584	1	55.75	114.11	57.06	34.23	205.40	304.30
Other electric	675	1	18.30	28.18	0.00	8.45	36.64	54.28
Subtotal				514.59	87.27	154.38	756.28	1120.34
General facilities				46.78		14.03	60.82	90.10
Total cost				561.37	87.27	168.41	817.05	1210.44

*Basis scaled cost: 1976 dollars: coal handling, turbines, compressor, inverter, other electric
Manufactured: fuel cell (UTC)
Installed: gasification, thermal management (TRW)

OPERATING COSTS MM$YEAR

Variable costs at 65% capacity

Fuel	4255	TPD	$1.65/MMBtu	40.76
Ash disposal	0.096	TPT	$ 5/ton	0.48
Dolomite	0.25	TPT	$12.7/ton	3.21
Catalyst	0.0077	TPT	$92.8/ton	0.72
Solids disposal	0.2577	TPT	$ 2/ton	0.52
Total variable costs	MM$/year			45.69

Fixed costs

Operating labor		3.74
Maintenance		14.76
Overhead		2.89
Total fixed costs	MM$/year	21.40

Total fixed + variable costs 67.09 MM$/year

Calculate fuel cell replacement expense as cost of electricity

Fuel cell	4,099,000 ft^2	@$13.6	55.75	1981
Replace	5 yr	i=0.085	83.82	1986
Replace	10 yr	i=0.085	126.04	1991

Annual sinking fund	$20.75 MM (10 year levelized)
Plus process contingency	10.37
Plus project contingency	6.22
Total	37.35MM/year

As COE: $ 0.0112/kW-h of F.C. power

COST OF ELECTRICITY FOR MOLTEN CARBONATE FUEL CELL POWER PLANT

Total plant cost (1.1)				TPC
Process costs (On-site)		467.81		
General facilities		46.78		
Engineering and home office		46.78		
Process contingency		87.27		
Project contingency		168.41		
Total		817.05		TPC
Allowance for funds during construction (1.2)				AFDC
AFDC	0.0373	30.48		
Prepaid royalties (1.3)				
	0.005	3.78		
Startup costs (1.4)				
Month fixed oper. costs		1.78		
Month var. oper. costs		5.86		
Month cap. fuel * 0.25		1.31		
TPC*2%		16.34		
Total		25.29		
Inventory capital (1.5)				
60 days supplies @ full capacity			11.30	
Initial catalyst and chemical charge (1.6)				
based on TRW estimate		0.97		
Land (1.7)	164	5500	0.90	
Total capital requirement (1.8)			889.76MM	
Variable operating costs (2.0)			45.69	
Fixed operating costs (3.0)			21.40	
Fuel cell replacement (4.0)			37.35	

CALCULATE SHORT TERM 10 YEAR, LEVELIZED COE (5.0)

	1981 Cost	Interest Rate	Real Escalation	Inflation Rate	Apparent Escalation Level	Levelizing Factor	Levelized Expenditures
Fixed	21.40	0.125	0	0.085	0.085	1.4878	31.84
Var-Coal	40.76	0.125	0.007	0.085	0.092595	1.5434	62.91
-Other	4.93	0.125	0	0.085	0.085	1.4878	7.34
Fuel cell	37.35	0.125	0	0.085	0.085	NA	37.35
Total							139.43

Levelized revenue requirement for first 10 years

	MM$/year	%	
	160.16	53.46	Capital related changes
	31.84	10.63	Fixed operating costs
	62.91	21.00	Variable operating costs - Coal
	7.34	2.45	Variable operating costs - Other
	37.35	12.47	Fuel cell replacement expense
Total	299.58	100.00	

Molten carbonate fuel cell power plant

COE $0.0779 per kWh

4.0 CONCLUSIONS

Two coal gasification-based fuel cell power plants have been designed. Both are thermodynamically and economically attractive. The molten carbonate fuel cell power plant is 52% efficient and shows a ten-year levelized cost of electricity of $0.078/kWh. The phosphoric acid fuel cell power plant is 48% efficient, shows a cost of electricity of $0.072/kWh, and should be feasible to build in the near term.

The phosphoric acid fuel cell power plant designed here has the highest projected efficiency reported, and the lowest projected cost of electricity. It contains no oxygen plant. It requires no water feed. And, it has the potential for minimal gas cleanup requirements.

The power plant cost estimates were done using conservative assumptions. The fuel cell performance assumed is below that demonstrated by United Technologies. Realistic estimates were used of industrial equipment performance. The gasification concept used has substantial experimental support, and a high probability of success.

This plant should be built. In the next section we present a program for bringing the power plant to the demonstration stage.

5.0 RECOMMENDATIONS

We recommend that the feasibility of our phosphoric acid fuel cell power plant design be demonstrated, and the plant brought to commercial reality. In support of this goal, we recommend that the following technical issues be addressed.

1. The TRW gasifier must be demonstrated on coals, including eastern agglomerating coals and high sulfur coals.
2. The tolerance of a phosphoric acid fuel cell to sulfur compounds must be determined.
3. The sensitivity of the plant design to major parameters must be studied.
4. The gasifier-regenerator system must be shown to be controllable and thermodynamically sound.
5. The economic scaling of the plant must be refined.
6. The water treatment needs of the plant must be determined.
7. The feasibility and cost of the various sulfur cleanup options must be studied.
8. The off-design and upset behavior of the plant must be investigated.
9. Pressure balances in the plant must be determined.
10. Operation of a phosphoric acid fuel cell at 12 atmospheres must be demonstrated.

6.0 REFERENCES

1. D. Bloomfield and M. Heller, "Systems Analysis of On-site Integrated Energy Systems," PSI TR-345, Sept. 1982.

2. "Base Case Reference Design and Economic Assumptions for a Coal-Based Fuel Cell Power Plant," Jet Propulsion Laboratory, Aug. 1982.

3. "Economics for Base Case Reference Design," Jet Propulsion Laboratory, Oct. 1982.

4. A. Gelb and G. Wilemski, "Modeling of Long-Term Decay in Molten Carbonate Fuel Cell," EPRI EM-2596, PSI TR-285, Sept. 1982.

5. "Technical Assessment Guide," EPRI P-2410-SR, May 1982.

6. "Assessment of a Coal Gasification Fuel Cell System for Utility Application, EPRI EM-2387, Kinetics Technology International Corporation, May 1982.

7. Coal Gasification Processes, ed. Perry Nowacki, Noyes Data Corporation, 1981.

8. Keenan and Keyes, Thermodynamic Properties of Steam, John Wiley and Sons, 1936.

9. Roger Detman, Factored Estimates for Western Coal Commercial Concepts, C.F. Braun & Co., Oct. 1976.

10. J.A. Starkovich et al., "Catalytic Conversion of Coal Energy to Hydrogen," DOE contract ET-78-C-01-2855, TRW, 1977, 1978, 1979, 1980.

11. Brahm Prasher, "An Assessment of Catalytic Gasification," USDOE, METC, Jan. 1979.

12. T. L. Bonds et al., "Fuel Cell Power Plant Integrated Systems Evaluation," EPRI EM-1670, General Electric Company, Jan. 1981.

13. J. M. King, "Energy Conversion Alternatives Study," NASA CR 134955, FCR-0237, United Technologies Phase II Final Report, Oct. 1976.

14. W. Spackman et al., "Characteristics of American Coals in Relation to their Conversion into Clean Energy Fuels," Penn State, ERDA FE-2030-3, May 1976.

15. "CO_2 Acceptor Process Gasification Pilot Plant," DOE FE-1734-45 and -46, Conoco Coal Development Co. and Stearns-Rogers Corp., 1977.

16. "An Economic Comparison of Molten Carbonate Fuel Cells and Gas Turbines in Coal Gasification-Based Power Plants," EPRI AP-1543, Fluor Engineers and Constructors, Sept. 1980.

17. "Economic Studies of Coal Gasification Combined Cycle Systems for Electric Power Generation," EPRI AF-642, Fluor Engineers and Constructors, Jan. 1978.

18. "Coal Conversion 1979 Technical Report," USDOE/FE-0010, Sept. 1980.

19. "Coal Conversion 1977 Technical Report," USDOE/ET-0061/1, June 1978.

20. "Advanced Technology Fuel Cell Program," EPRI EM-956, United Technologies Corporation, Dec. 1978.

21. D. Bloomfield, H. Piperopoulou, N. Kemp, "Fuel Processor Gasification and Gas Stream Cleaup Processes Modeling and System Studies," PSI TR-275, July 1981.

22. G. Wilemski et al., "Performance Model for Molten Carbonate Fuel Cells," PSI TR-190, Aug. 1979.

23. D. Bloomfield, A. Gelb, S. Guberman, P. Lewis, "Interaction of Trace Species with the Molten Carbonate Fuel Cell," PSI TR-192, Nov. 1979.

24. A. Gelb, D. Ham, P. Lewis, G. Lord, and G. Simons, "Hot Gas Cleanup for Molten Carbonate Fuel Cells - Dechlorination and Soot Formation," PSI TR-315, Nov. 1982.

25. Thermopak Documentation, ©1980-1982 PSI/Systems, Research Park, Andover, MA, 01810

26. Mathpak Documentation, ©1980-1982 PSI/Systems, Research Park, Andover, MA 01810

27. S3E PAK Documentation, ©1980-1982 PSI/Systems, Research Park, Andover, MA 01810

28. FCPAK Documentation, ©1980-1982 PSI/Systems, Research Park, Andover, MA 01810

29. Reacpak Documentation, ©1980-1982 PSI/Systems, Research Park, Andover, MA 01810

30. Fluidpak Documentation, ©1980-1982 PSI/Systems, Research Park, Andover, MA 01810

31. D. P. Bloomfield, "Steady State Systems Engineering Model -- PSI/S3E©," Physical Sciences Inc., TR-221, June 1980.

7.0 APPENDIX 1 -- Program Listings

PATRW11/BAS

SYSM11/TRW

DATABL11/TRW

MCTRW7/BAS

SYSMC7/TRW

DATABLMC/TRW

```
4000 REM PAFC WITH TRW CATALYTIC HYDROGEN PROCESS,REV.11D
4005 POKE 16425,1 '
     MODEL III LINES PRINTED
4010 CLS:
     PRINT " GET PARAMETERS AND CALCULATE FEEDS"
4015 GOSUB 3000
4020 CLS:
     PRINT " TRACK COAL GAS":
     IC=0
4025 GOSUB 4200
4027 X=UC:
     Y=HD/H(1):
     Y0=0:
     J5=10:
     GOSUB 440:
     UC=X:
     IF K(J5)<>0
     THEN PRINT "NEW UC=";
     UC:
     GOSUB 3050:
     GOTO 4020 '
     HEAT BALANCE,GAS.+REG.
4028 LPRINT "HEAT BALANCE GIVES UC=";
     UC
4030 CLS:
     PRINT " TRACK AIR"
4035 GOSUB 4300
4040 CLS:
     PRINT " FUEL CELL"
4045 IP=L4:
     P(IP)=P(L8):
     OP=L4+1:
     GOSUB 950:
     GOSUB 1200:
     LPRINT"V0=";
     V0,"AF=";
     AF
4047 Z9= ABS((A(1,L8)-A(1,L8+1))/(A(6,L4)-A(6,L4+1))-2):
     IF Z9>.001
     THEN PRINT Z9:
     STOP
4050 CLS:
     PRINT " CATHODE EXIT STREAM"
4055 GOSUB 4400
4060 CLS:
     GOSUB 4600 '
     CLOSE WATER LOOP AT DC2
4065 GOSUB 4500:
     GOSUB 4620 '
     TURBINES AND STEAM LOOP
4072 GOSUB 4515 '
     NET TURBINE POWER
4077 IF ABS(PF-PN)/PN>0.001
     THEN LPRINT"***** ITERATING ON TURBINE POWER *****":
```

```
     PT=PT*PG/(PF+PP):
     GOSUB 3050:
     GOTO 4020
4080 CLS:
     PRINT " CALCULATE EFFICIENCIES AND PRINT SUMMARIES"
4085 GOSUB 3200
4090 CLS:
     PRINT " PRINT NODE ARRAY"
4095 LPRINT CHR$(12):
     LPRINT CHR$(27);
     CHR$(20):
      GOSUB 1800:
      LPRINT CHR$(27);
     CHR$(19)
4100 REM SIZE HEAT EXCHANGERS AND CONDENSERS
4105 STOP
4110 CLS:
     PRINT "SAVE NODE ARRAY":
     GOSUB 6000:
     STOP
4115 CLS:
     PRINT "GET NODE ARRAY":
     GOSUB 6040:
     STOP
4200 'TRACK COAL GAS
4201 PRINT"GASIFIER",C9
4202 I9=L3:
     J9=45:
     K9=L3+1:
     N=K9:
     GOSUB 410:
     IF UZ<=0 OR UZ>1
     THEN UZ=0.98
4204 A(2,N)=A(2,I9)+A(2,J9):
     A(1,N)=A(1,I9)+UC*A(8,I9):
     A(4,N)=UC*A(8,I9):
     A(2,N)=A(2,N)-UC*A(8,I9) '
     DIRECT AND GASIFICATION
4206 A(5,N)=UZ*A(4,N):
     A(4,N)=A(4,N)-A(5,N):
     A(2,N)=A(2,N)-A(5,N):
     A(1,N)=A(1,N)+A(5,N) '
     SHIFT CONVERSION TO COMPLETION FOR UZ OF CO
4208 A(3,N)=A(4,N):
     A(4,N)=0:
     A(1,N)=A(1,N)-3*A(3,N):
     A(2,N)=A(2,N)+A(3,N):
     A(3,N)=A(3,N)+A(3,I9) '
     METHANATION AND DIRECT METHANE
4210 A(2,N)=A(2,N)+2*A(6,I9):
     A(1,N)=A(1,N)-2*A(6,I9) '
     O2+2H2-->2H20
4212 A(7,N)=A(7,I9)/2 '
     N2+S (APPROXIMATION !)
```

```
4214 A(5,N)=(1-UZ)*A(5,N) '
     CO2 ACCEPTOR
4216 P(N)=P:
     T(N)=TG:
     GOSUB 5:
     GOSUB 550:
     GOSUB 5 '
     SHIFT EQUIL + THERMO
4218 D9=C9:
     C9=C9*HY/A(1,N):
     IF ABS(C9-D9)>1.E-5
     THEN GOSUB 3050:
     GOTO 4200
4219 PRINT"HYDROGEN",A(1,N);
     HY
4220 IP=N:
     OP=N+1:
     GOSUB 600:
     T(OP)=TC+50:
     N=OP:
     GOSUB 10:
     PRINT "HX1":
     GOSUB 7
4225 GOSUB 6:
     N=OP:
     NV=5:
     GOSUB 2420:
     T(N)=TB+5:
     GOSUB 10:
     PRINT"HX2 HOT SIDE":
     GOSUB 7
4230 D1%=36:
     D2%=4:
     D3%=5:
     D4%=37:
     TX=10:
     T(D1%)=150:
     A(2,D1%)=3*A(0,D2%):
     N=D1%:
     LQ=1:
     GOSUB 5:
     PRINT"SET UP DC1"
4235 GOSUB 11050:
     PRINT"DC1"
4240 GOSUB 4342 '
     HX2
4250 IP=L8:
     OP=IP+1:
     GOSUB 990 :
     PRINT"ANODE"
4255 N=34:
     A(2,N)=A(2,D4%)-A(2,D1%):
     LQ=1:
     T(N)=T(D4%):
```

```
     GOSUB 5:
     PRINT "WATER CONDENSED"
4260 N=35:
     A(2,N)=A(2,D1%):
     LQ=1:
     T(N)=T(D4%):
     GOSUB 5
4262 N=18:
     A(6,N)=RP*(A(8,L3)*(1-UC)+A(1,L8+1)/2+2*A(3,L8+1)+A(4,L8+1)/2):
     A(7,N)=A(6,N)*3.7733:
     T(N)=T(L2+1):
     GOSUB 5:
     PRINT "COMPUTE AIR FOR REGENERATOR"
4265 I9=N:
     J9=7:
     K9=8:
     GOSUB 910:
     PRINT "MIX AIR AND ANODE EXHAUST INTO REGENERATOR"
4270 N=K9:
     A(8,N)=(1-UC)*A(8,L3):
     A(7,N)=A(7,N)+A(7,L3)-A(7,L3+1):
     GOSUB 5:
     IP=N:
     OP=N+1:
     XN=1:
     XM=0:
     GOSUB 1100:
     PRINT"PO GAS AND CARBON"
4272 A(5,N)=A(5,N)+UZ*(A(5,L3+1)+A(4,L3+1))/(1-UZ):
     T(N)=TR:
     GOSUB 5:
     GOSUB 550:
     GOSUB 5 '
     REGENERATE CaO AND EVOLVE CO2
4275 HD=H(1)+H(45)+H(7)+H(18)-H(2)-H(9):
     PRINT "ENTHALPY BALANCE IS";
     HD '
     ENTHALPY BALANCE WITH GASIFIER
4280 A(6,14)=BE*(A(1,N)/2+2*A(3,N)+A(4,N)/2+A(8,N)):
     A(7,14)=A(6,14)*3.7733:
     N=14:
     T(N)=T(L2+1):
     GOSUB 5:
     I9=9:
     J9=14:
     K9=10:
     GOSUB 910 :
     PRINT "MIX WITH AIR"
4285 IP=10:
     OP=11:
     GOSUB 1100:
     GOSUB 1132 '
     BURN EXHAUST
4290 'A(6,16)=? 'SOLIDS CONVERTER AIR REQUIREMENT
```

```
4299 RETURN
4300 'TRACK AIR
4305 T(L2)=75:
     A(6,L2)=A(6,L4)+A(6,18)+A(6,16)+A(6,14):
     A(7,L2)=A(6,L2)*3.7733:
     N=L2:
     GOSUB 5:
     PRINT"TOTAL AIR REQUIREMENT"
4310 IP=L2:
     OP=L2+1:
     RC=P:
     GOSUB 800:
     LPRINT"AIR COMPRESSOR WORK";
     WC
4315 I9=OP:
     J9=14:
     K9=15:
     F=A(6,J9)/A(6,I9):
     GOSUB 880:
     PRINT"SPLIT 1"
4320 I9=15:
     J9=16:
     K9=17:
     F=A(6,J9)/A(6,I9):
     GOSUB 880:
     PRINT"SPLIT 2"
4325 I9=17:
     J9=18:
     K9=19:
     F=A(6,J9)/A(6,I9):
     GOSUB 880:
     PRINT"SPLIT 3":
     IF ABS(A(6,K9)-A(6,L4))>1
     THEN PRINT "AIR BALANCE ERROR";
     A(6,K9);
     A(6,L4):
     STOP
4330 IP=K9:
     OP=L4:
     GOSUB 600:
     T(OP)=TC:
     N=OP:
     GOSUB 10:
     PRINT "HX6 HOT SIDE":
     GOSUB 7
4332 RETURN
4340 REM HEAT EXCHANGER SETUPS
4341 J5=1:
     I7=2:
     J7=3:
     I8=47:
     J8=48:
     GOTO 4380 '
     HX1
```

```
4342 J5=2:
     I7=3:
     J7=4:
     I8=5:
     J8=6:
     GOTO 4380 '
     HX2
4343 J5=3:
     I7=35:
     J7=36:
     I8=51:
     J8=52:
     GOTO 4360 '
     HX3
4344 J5=4:
     I7=21:
     J7=22:
     I8=23:
     J8=24:
     GOTO 4380 '
     HX4
4345 J5=5:
     I7=40:
     J7=38:
     I8=53:
     J8=54:
     GOTO 4360 '
     HX5
4346 J5=6:
     I7=19:
     J7=20:
     I8=29:
     J8=30:
     GOTO 4370 '
     HX6
4347 J5=7:
     I7=26:
     J7=27:
     I8=43:
     J8=44:
     GOTO 4380 '
     HX7
4350 GOSUB 4390 '
     ENSURE CONTINUITY
4352 IF IC=1
     THEN PRINT @531,"HX";
     J5;
     "G/G";

     ELSE IF K(J5)=0 PRINT "HX";
     J5
4355 GOSUB 1300:
     IF K(J5)<>0
     THEN 4352
```

```
     ELSE RETURN '
     HX GAS/GAS
4360 GOSUB 4390 '
     ENSURE CONTINUITY
4362 IF IC=1
     THEN PRINT "531,"HX";
     J5;
     "G/L"
     ELSE IF K(J5)=0 PRINT "HX";
     J5
4365 GOSUB 5810:
     IF K(J5)<>0
     THEN 4362
     ELSE RETURN '
     HX GAS/LIQ
4370 GOSUB 4390:
     H(J8)=H(I8)+H(I7)-H(J7):
     IF IC<>1
     THEN PRINT "HX";
     J5;
     "H BALANCE":
     RETURN
     ELSE RETURN
4380 GOSUB 4370:
     N=J8:
     NH=2:
     GOSUB 10:
     RETURN '
     H BAL+GAS TEMP
4390 A5=J5:
     N!=N!(J5)
4392 IF A(0,J7)<>A(0,I7)
     THEN IP=I7:
     OP=J7:
     T=T(OP):
     GOSUB 600:
     IF T<>0
     THEN T(OP)=T:
     N=OP:
     GOSUB 10
4394 IF A(0,J8)<>A(0,I8)
     THEN IP=I8:
     OP=J8:
     GOSUB 600
4395 P(J7)=P(I7)-DP:
     P(J8)=P(I8)-DP '
     PRESSURE DROPS
4399 RETURN
4400 N=L4+1:
     GOSUB 5'
     CATHODE EXIT STREAM
4405 OP=N:
     GOSUB 6:
     N=OP:
```

```
     NV=5:
     GOSUB 2420:
     T(N)=TB+5:
     GOSUB 10:
     PRINT"HX4 HOT SIDE":
     GOSUB 7
4410 D1%=38:
     D2%=OP:
     D3%=OP+1:
     D4%=D1%+1:
     TX=10:
     A(2,D1%)=4*A(0,D2%):
     N=D1%:
     LQ=1:
     IF T(D1%)=0
     THEN T(D1%)=180:
     GOSUB 5
     ELSE GOSUB 5'
     WATER TO DC2
4415 GOSUB 11050:
     IF IC<>1
     THEN PRINT "DC2"
4420 GOSUB 4344 '
     HX4
4425 N=41:
     A(2,N)=A(2,D4%)-A(2,D1%):
     LQ=1:
     T(N)=T(D4%):
     GOSUB 5'
     WATER CONDENSED
4430 N=40:
     A(2,N)=A(2,D1%):
     LQ=1:
     T(N)=T(D4%):
     GOSUB 5
4435 RETURN
4440 REM BOIL WATER TO USE EXCESS HEAT OF GAS TURBINE (HX7)
4445 T(43)=T(L6-1):
     P(43)=P(L6):
     IF A(2,43)<=0
     THEN A(2,43)=10*PN  '
     WATER INTO HX7
4447 N=43:
     LQ=1:
     GOSUB 5:
     IP=26:
     OP=27:
     GOSUB 600:
     T(OP)=T(N)+20:
     N=OP:
     GOSUB 10 '
     DETERMINE THREE LEGS OF HX7
4450 GOSUB 4347:
     PRINT"A(2,44),T(44):
```

```
     ";
     A(2,44);
     T(44) '
     HX7
4455 J5=16:
     X=A(2,43):
     Y=T(44):
     Y0=T(26)-20:
     EE=.001:
     GOSUB 440 '
     SECANT ON WATER FLOW
4457 IF X<=0
     THEN PRINT "NEGATIVE FLOW AT HX7";
     X:
      STOP
4458 IF K(J5)<>0
     THEN A(2,43)=X:
     N=43:
     LQ=1:
     GOSUB 5:
     GOTO 4450'
     ADJUST FLOW AND LOOP
4460 I9=44:
     J9=48:
     K9=49:
     GOSUB 910 '
     MIX HX7 AND HX1 OUTPUTS
4499 RETURN
4500 ' OUT THROUGH TURBINE
4505 I9=24:
     J9=11:
     K9=25:
     GOSUB 910:
     PRINT "MIX"
4510 IP=25:
     OP=IP+1:
     RT=P(IP)/(1+DP):
     GOSUB 820:
     LPRINT "GAS TURBINE WORK IS";
     WT
4512 W1=WT:
     RETURN
4515 W2=W1+WT-WC:
     LPRINT "NET TURBINE WORK IS";
     W2;
     "BTU/HR"
4520 PT=W2*EG*2.93E-7:
     LPRINT "WITH A GENERATOR EFFICIENCY OF";
     EG;
     ",THE NET TURBINE POWER IS";
     PT;
     "MW"
4525 PF=PS+PT-PP:
     LPRINT "POWER PLANT OUTPUT IS";
```

```
     PF;
     "MW"
4549 RETURN
4600 IF A(2,34)+.95*A(2,22)<A(2,45)
     THEN 4610 '
     CHECK FOR ADEQUATE WATER
4602 A5=8:
     IC=1:
     PRINT @530,"CLOSE WATER LOOP,X=T(SPRAY),Y=WATER OUT";
4605 X=T(D1%):
     Y=A(2,41)+A(2,34):
     Y0=A(2,45):
     J5=8:
     GOSUB 440 '
     SECANT
4607 IF K(J5)=0
     THEN RETURN
     ELSE T(D1%)=X:
     N=D1%:
     LQ=1:
     GOSUB 10:
     GOSUB 4415:
     GOTO 4602 '
     ADJUST DC2 SPRAY TEMP
4610 T(D1%)=140:
     N=D1%:
     LQ=1:
     GOSUB 10:
     GOSUB 4415 '
     SET DC2 TO MIN T
4612 N=41:
     DW=A(2,45)-A(2,34)-A(2,N):
     A(2,N)=A(2,N)+DW:
     LQ=1:
     GOSUB 5 '
     ADD MAKEUP WATER
4614 LPRINT DW;
     "LB MOL/HR OF MAKEUP WATER ADDED AT NODE";
4616 RETURN
4620 CLS:
     IC=0:
     PRINT"RAISE STEAM FROM CONDENSED WATER"
4625 QS=H(L8)-H(L8+1)+H(L4)-H(L4+1)-3.413E6*PS '
     CELL HEAT
4630 N=L6-1:
     A(2,N)=QS/8500:
     IF T(N)=0
     THEN T(N)=270:
     LQ=1:
     GOSUB 5
     ELSE LQ=1:
     GOSUB 5
4632 PRINT "WATER REQUIREMENTS"
4635 IP=N:
```

```
     OP=60:
     GOSUB 600:
     OP=0:
     GOSUB 600:
     TB=TC-30:
     T(60)=TB:
     T(0)=TB:
     N=0:
     NV=2:
     GOSUB 2420:
     P(0)=PW:
     P(60)=PW:
     PRINT"TB=";
     TB;
     " PW=";
     PW
4637 N=60:
     LQ=1:
     GOSUB 10:
     N=0:
     LQ=0:
     GOSUB 10:
     PRINT"WATER AND STEAM ENTHALPIES";
     H(60);
     H(0)
4650 IP=L6-1:
     OP=L6:
     GOSUB 600:
     H(OP)=H(IP)+QS:
     PRINT"FUEL CELL HEAT"
4655 N=L6:
     GOSUB 4665:
     P(N)=P(0):
     GOSUB 4346 '
     HX6
4662 N=J8:
     GOSUB 4665:
     P(N)=P(0):
     GOTO 4668
4665 IF H(N)>H(60) AND H(N)<H(0)
     THEN T(N)=T(0):
     PRINT"PARTIAL BOILING"
     ELSE IF H(N)<H(60)
     THEN LQ=1:
     NH=2:
     GOSUB 10:
     PRINT"NO BOILING"
     ELSE LQ=0:
     NH=2:
     GOSUB 10:
     PRINT"STEAM"
4667 RETURN
4668 QU=(H(N)-H(60))/(H(0)-H(60)):
     N=46:
```

```
     A(2,N)=QU*A(2,L6):
     T(N)=T(0):
     P(N)=P(0):
     GOSUB 5:
     N=31:
     A(2,N)=(1-QU)*A(2,L6):
     LQ=1:
     T(N)=T(0):
     P(N)=P(0):
     GOSUB 5:
     PRINT"STEAM SEPARATOR, QUALITY="QU
4669 IF QU>1 OR QU<0
     THEN STOP
     ELSE IF ABS(A(2,31)+A(2,46)-A(2,30))>1
     THEN PRINT "WATER IMBALANCE":
     STOP
     ELSE IF ABS(H(31)+H(46)-H(30))/H(30)>1E-3
     THEN PRINT "H IMBALANCE":
     STOP
4672 I9=46:
     J9=45:
     K9=47:
     F=A(2,J9)/A(2,I9):
     GOSUB 880 '
     SPLIT STEAM
4676 GOSUB 4341 '
     HX1
4678 GOSUB 4440 '
     HX7 AND MIX
4680 IP=K9:
     OP=IP+1:
     RT=P(IP)/0.2
4682 GOSUB 820 '
     STEAM TURBINE
4685 GOSUB 6:
     T(OP)=140:
     P(OP)=P(L6):
     N=OP:
     LQ=1:
     GOSUB 10 '
     COND
4687 P(34)=P(L6):
     P(41)=P(L6):
     P(L6-1)=P(L6) '
     PUMPS
4688 I9=34:
     J9=31:
     K9=32:
     GOSUB 912:
     I9=51:
     J9=32:
     K9=33:
     GOSUB 912:
     I9=K9:
```

```
     J9=41:
     K9=42:
     GOSUB 912:
     PRINT "MIX WATER"
4691 IF ABS(T(42)-T(28))>1
     THEN PRINT T(42);
     T(28);
     "T INTO BOILER":
     T(28)=(3*T(42)+T(28))/4:
     GOTO 4650
4694 IF ABS(A(0,42)-A(0,28)-A(0,43))>1
     THEN PRINT "WATER BALANCE ERROR ":
     STOP
4699 LPRINT "STEAM TURBINE WORK";
     WT:
     LPRINT "QUALITY AT STEAM SEPARATOR";
     QU:
     RETURN
4900 REM COMPUTE HHV OF COAL
4905 CF=A(8,L3)*12/WF(3) '
     COAL FEED IN POUNDS
4910 N=58:
     A(2,N)=A(2,L3)+A(1,L3):
     A(5,N)=A(8,L3):
     A(7,N)=A(7,L3):
     T(N)=T(L3):
     LQ=1:
     GOSUB 5 '
     OXIDIZED PRODUCT
4915 N=57:
     A(6,N)=A(1,L3)/2+A(8,L3)-A(6,L3):
     T(N)=T(L3):
     GOSUB 5 '
     O2 FOR TOTAL COMBUSTION
4920 I9=L3:
     J9=57:
     K9=56:
     GOSUB 912 '
     UNBURNED MIX
4925 HHV=(H(56)-H(58))/CF:
     '
     LPRINT "COAL FEED (LBS)";
     CF;
     "HHV(BTU/LB)";
     HHV
4999 RETURN
```

```
3000 REV$="11D":
     REM SYSM,PAFC + TRW CATALYTIC HYDROGEN PROCESS
3003 DATA 12,1,20,29,6
3005 READ L2,L3,L4,L6,L8
3010 DATA 675,.72,.70,.98,.2,1.03,1.2,.9,12,1250,1750,1800,
     405,.9,.7,.72,135,13.5,.98,.92,.85,.98,.096,.042,.666,.051,
     .096,.049
3020 READ PN,UC,US,UZ,DP,C9,BE,RP,P,TG,TR,TV,TC,UH,UO,V0,PT
     ,PP,EI,ET,EC,EG,WF(1),WF(2),WF(3),WF(4),WF(5),WF(6)
3030 GOSUB 3100 '
     LIST VARS
3040 INPUT "UPDATE VARIABLES";
     U$:
     U$=LEFT$(U$,1):
     IF U$="Y" OR U$="y"
     THEN GOSUB 3150:
     GOTO 3030
     ELSE IF U$="N" OR U$="n"
     THEN GOSUB 3045:
     GOTO 3050
     ELSE PRINT "ANSWER YES OR NO":
     GOTO 3040
3045 X=PEEK(14312):
     IF X=60
     THEN DEFUSR=473:
     X=USR(X):
     RETURN
     ELSE RETURN  '
     JKL IF PRINTER OK
3050 'CALCULATE MAJOR FLOWS IN PLANT FROM POWER AND EFFICIE
     NCY
3052 PG=PN+PP:
     PS=PG-PT:
     ES=V0/1.2527:
     HY=41.12*PS/(V0*UH*EI):
     A(1,L8)=HY:
     N=L8:
     T(N)=TC:
     GOSUB 5 '
     HYDROGEN NEEDED AT ANODE
3054 A(8,L3)=C9*HY/(6*WF(4)/WF(3)+2*UC*.97-.75*WF(5)/WF(3)):
     A(1,L3)=A(8,L3)*6*WF(4)/WF(3):
     A(2,L3)=A(8,L3)*(2/3)*WF(2)/WF(3):
     A(6,L3)=A(8,L3)*.375*WF(5)/WF(3):
     A(7,L3)=A(8,L3)*.3*WF(6)/WF(3)'
     COAL FEED
3055 N=L3:
     GOSUB 400:
     A(0,N)=A(0,N)+A(8,N)*.2*WF(1)/WF(3):
     T(N)=75:
     GOSUB 3410:
     LQ=1:
     GOSUB 10 :
     GOSUB 4900 '
```

PAGE 54 INTENTIONALLY BLANK

```
     SUM WITH ASH
3056 N=L4:
     A(6,N)=HY*UH/(2*UO):
     A(7,N)=3.7733*A(6,N):
     T(N)=TC:
     GOSUB 5 '
     AIR NEEDED AT CATHODE
3066 N=45:
     A(2,N)=2*UC*A(8,L3)/US-A(2,L3)-2*A(6,L3):
     T(N)=TC-30:
     GOSUB 5 '
     STEAM NEEDED AT GASIFIER
3070 FOR I=0 TO NM:
     P(I)=P:
     NEXT I '
     SET PRESSURES
3072 P(L2)=1:
     FOR I=52 TO 57:
     P(I)=1:
     NEXT I '
     BLOWER PRESSURES
3075 T(L2)=75:
     A(6,L2)=1:
     A(7,L2)=3.7733:
     N=L2:
     GOSUB 5:
     IP=L2:
     OP=L2+1:
     RC=P:
     GOSUB 800 '
     TEMP OF AIR FROM COMPRESSOR
3099 RETURN
3100 CLS:
     PRINT TAB(20) "POWER PLANT VARIABLES":
      PRINT TAB(10) "REV.";
     REV$;
     TAB(40) TIME$"
3103 PRINT "PN  ";
     PN;
      "MW";
     TAB(21) "UC  ";
     UC ;
     TAB(41) "US  ";
     US
3104 PRINT "UZ  ";
     UZ;
      TAB(21) "DP  ";
     DP;
     "ATM";
      TAB(41) "C9  ";
     C9
3106 PRINT "BE  ";
     BE  ;
     TAB(21) "RP  ";
```

```
     RP ;
     TAB(41) "PRES";
     P;
     "ATM"
3109 PRINT "TGAS";
     TG;
     "F";
     TAB(21) "TREG";
     TR;
     "F";
     TAB(41) "TCVT";
     TV;
     "F"
3112 PRINT "TCEL";
     TC;
     "F";
     TAB(21) "UH  ";
     UH;
     TAB(41) "UO";
     UO
3115 PRINT "V0  ";
     V0;
     "V";
     TAB(21) "PT  ";
     PT;
     "MW";
3118 PRINT TAB(41) "PP  ";
     PP;
     "MW":
     PRINT "EI  ";
     EI;
     TAB(21) "ET  ";
     ET;
3121 PRINT TAB(41) "EC  ";
     EC:
     PRINT "EG  ";
     EG;
     TAB(21) "COAL FRACTIONS:
3130 PRINT "ASH ";
     WF(1);
     "TPT";
     TAB(21) "H2O ";
     WF(2);
     "TPT";
     TAB(41) "C   ";
     WF(3);
     "TPT"
3133 PRINT "H2  ";
     WF(4);
     "TPT";
     TAB(21) "O2  ";
     WF(5);
     "TPT";
     TAB(41) "N2+S";
```

```
     WF(6);
     "TPT"
3136 PRINT "FUEL SPECIES IS ";
     A$(8);
     TAB(30) "PERFORMANCE IS FOR ";
     C1$
3149 RETURN
3150 PRINT "PN ";
     PN;
     :
     INPUT PN:
     PRINT "UC  ";
     UC ;
     :
     INPUT UC :
     PRINT "US ";
     US ;
     :
      INPUT US
3151 PRINT "UZ GASIFIER ";
     UZ;
     :
     INPUT UZ:
     PRINT "DP PER COMPONENT";
   . DP;
     :
     INPUT DP:
     PRINT "C9 SHIFT CORRECTION";
     C9;
     :
     INPUT C9
3153 PRINT "BE  ";
     BE  ;
     :
     INPUT BE  :
     PRINT "RP  ";
     RP ;
     :
     INPUT RP :
     PRINT"PRES";
     P;
     :
     INPUT P
3156 PRINT "TGASIFIER";
     TG;
     :
     INPUT TG:
     PRINT "TREGENERATOR";
     TR;
     :
     INPUT TR:
     PRINT "TCONVERTER";
     TV;
     :
```

```
     INPUT TV
3159 PRINT "TCELL";
     TC;
     :
     INPUT TC:
     PRINT "UH";
     UH;
     :
     INPUT UH:
     PRINT "UO";
     UO;
     :
     INPUT UO
3162 PRINT "V0";
     V0;
     :
     INPUT V0:
     PRINT "TURBINE NET POWER";
     PT;
     :
     INPUT PT
3165 PRINT "PARASITE POWER";
     PP;
     :
     INPUT PP:
     PRINT "EI";
     EI;
     :
     INPUT EI:
     PRINT "ET";
     ET;
     :
     INPUT ET
3168 PRINT "EC";
     EC;
     :
     INPUT EC:
     PRINT "EG";
     EG;
     :
     INPUT EG
3177 PRINT "ASH IN COAL";
     WF(1);
     :
     INPUT WF(1):
     PRINT "WATER IN COAL";
     WF(2);
     :
     INPUT WF(2):
     PRINT "CARBON IN COAL";
     WF(3);
     :
     INPUT WF(3)
3180 PRINT "HYDROGEN IN COAL";
```

```
     WF(4);
     :
     INPUT WF(4):
     PRINT "OXYGEN IN COAL";
     WF(5);
     :
     INPUT WF(5):
     PRINT "N2 AND SULFUR IN COAL";
     WF(6);
     :
     INPUT WF(6)
3199 RETURN
```

```
3200 LPRINT CHR$(12);TAB(20) "POWER PLANT DATA":
     LPRINT TAB(10) "REV.";
     REV$;
     TAB(40) ;
     TIME$'
     DATABLOC
3205 EO=PF*3.413E6/(CF*HHV) '
     CALCULATE OVERALL EFFICIENCY
3207 HR=CF*HHV*1E-3/PF '
     CALCULATE HEAT RATE
3210 AR=PS*1E6/(V0*AF) '
     CALCULATE FUEL CELL AREA
3215 FD(1)=CF*24/2000:
     FD(2)=A(2,45)*24/(111.111*FD(1)):
     FD(3)=A(0,L2)*24/(69.4*FD(1)) '
     CALCULATE FEEDS IN TONS PER DAY OR TONS PER TON
3217 FD(4)=FD(3)*A(0,18)/A(0,L2)
3220 LPRINT "OVERALL EFFICIENCY IS ";
      EO ;
     " USING A COAL HHV OF ";
     HHV;
     "BTU/LB" '
     PRINT RESULTS
3222 LPRINT "FUEL CELL EFFICIENCY IS ";
      ES
3225 LPRINT "FUEL CELL AREA REQUIRED IS";
     AR;
     " SQUARE FEET"
3230 LPRINT "COAL FEED REQUIRED IS";
     FD(1);
     " TONS PER DAY"
3235 LPRINT "STEAM RECYCLED AT GASIFIER IS";
      FD(2);
     " TONS PER TON OF COAL"
3240 LPRINT "OVERALL AIR FEED IS";
      FD(3);
     " TONS PER TON OF COAL"
3245 LPRINT "REGENERATOR AIR FEED IS";
      FD(4);
     " TONS PER TON OF COAL"
3250 LPRINT "HEAT RATE IS";
     HR;
     "BTU/KWH"
3255 LPRINT TAB(20) "POWER (MW)"
3257 A$="####.#"
3260 LPRINT "GROSS";
     TAB(30)USING A$;
      PF+PP
3265 LPRINT "FUEL CELL";
     TAB(30)USING A$;
      PS
3270 LPRINT"COMPRESSOR MECHANICAL";
     TAB(30)USING A$;
     -WC*2.93E-7
```

```
3275 LPRINT"GAS TURBINE MECHANICAL";
     TAB(30)USING A$;
     W1*2.93E-7
3280 LPRINT"STEAM TURBINE MECHANICAL";
     TAB(30)USING A$;
     WT*2.93E-7
3282 LPRINT"NET TURBINE ELECTRICAL";
     TAB(30)USING A$;
     PT
3285 LPRINT "PARASITE";
     TAB(30)USING A$;
      -PP
3290 LPRINT "NET";
     TAB(30)USING A$;
      PF
3399 RETURN
```

```
4000 REM MCFC WITH TRW CATALYTIC HYDROGEN PROCESS,REV.7
4005 POKE 16425,1 '
     MODEL III LINES PRINTED
4007 N!(1)=1.5
4008 E1=5E-4:
     E3=1E-5:
     E7=.05:
     E4=5E-5:
     AA=.014:
     AC=7.8E-4:
     RP=2.5E-4:
     K0!=34.5:
     E2=2918:
     Z0=.2714 '
     MCFC PERF DATA FOR ECAS CELL
4010 CLS:
     PRINT " GET PARAMETERS AND CALCULATE FEEDS"
4015 GOSUB 3000
4020 CLS:
     PRINT " GASIFIER AND REGENERATOR":
     IC=0
4025 GOSUB 4200
4027 X=UC:
     Y=HD/H(1):
     Y0=0:
     J5=10:
     GOSUB 440:
     UC=X:
     IF K(J5)<>0
     THEN PRINT "NEW UC=";
     UC:
     GOSUB 3050:
     GOTO 4025 '
     HEAT BALANCE,GAS.+REG.
4028 LPRINT "HEAT BALANCE GIVES UC=";
     UC
4030 CLS:
     IP=2:
     OP=3:
     GOSUB 600:
     IP=NA(1):
     OP=NA(2):
     PRINT "ANODE":
     GOSUB 9000
4035 N=OP:
     T(N)=TC:
     GOSUB 550:
     GOSUB 10:
     GOSUB 4400:
     GOSUB 4600 '
     ANODE EXIT
4040 CLS:
     PRINT "CATHODE INLET PREP":
     GOSUB 4280
```

```
4045 IP=12:
     OP=13:
     GOSUB 600:
     IP=NA(3):
     OP=NA(4):
     GOSUB 9100:
     PRINT"CATHODE"
4050 CLS:
     PRINT"CATHODE RECYCLE AND MCFC INITIALIZATION":
     GOSUB 4440
4055 PRINT"MCFC PERFORMANCE":
     GOSUB 4550
4060 CLS:
     PRINT"GAS TURBINE AND AIR COMPRESSOR":
     GOSUB 4300:
     GOSUB 4500
4065 CLS:
     PRINT"STEAM LOOP":
     GOSUB 4620
4070 GOSUB 4515 '
     SUM TURBINES
4075 'IC=2 :
      GOSUB 1070 :
      STOP
4077 'IF ABS(PF-PN)/PN>0.001
     THEN LPRINT"***** ITERATING ON TURBINE POWER *****":
     PT=PT*PN/PF:
     GOSUB 3050:
     GOTO 4020
4080 CLS:
     PRINT " CALCULATE EFFICIENCIES AND PRINT SUMMARIES"
4085 GOSUB 3200
4090 CLS:
     PRINT " PRINT NODE ARRAY"
4095 LPRINT CHR$(12):
     LPRINT CHR$(27);
     CHR$(20):
      GOSUB 1800:
      LPRINT CHR$(27);
     CHR$(19)
4100 REM SIZE HEAT EXCHANGERS AND CONDENSERS
4105 STOP
4110 CLS:
     PRINT "SAVE NODE ARRAY":
     GOSUB 6000:
     STOP
4115 CLS:
     PRINT "GET NODE ARRAY":
     GOSUB 6040:
     STOP
4200 'TRACK COAL GAS
4202 I9=L3:
     J9=L6:
     K9=L3+1:
```

```
     N=K9:
     GOSUB 410:
     IF UZ<=0 OR UZ>1
     THEN UZ=0.98
4204 A(2,N)=A(2,I9)+A(2,J9):
     A(1,N)=A(1,I9)+UC*A(8,I9):
     A(4,N)=UC*A(8,I9):
     A(2,N)=A(2,N)-UC*A(8,I9) '
     DIRECT AND GASIFICATION
4206 A(5,N)=UZ*A(4,N):
     A(4,N)=A(4,N)-A(5,N):
     A(2,N)=A(2,N)-A(5,N):
     A(1,N)=A(1,N)+A(5,N) '
     SHIFT CONVERSION TO COMPLETION FOR UZ OF CO
4208 A(3,N)=A(4,N):
     A(4,N)=0:
     A(1,N)=A(1,N)-3*A(3,N):
     A(2,N)=A(2,N)+A(3,N):
     A(3,N)=A(3,N)+A(3,I9) '
     METHANATION AND DIRECT METHANE
4210 A(2,N)=A(2,N)+2*A(6,I9):
     A(1,N)=A(1,N)-2*A(6,I9) '
     O2+2H2-->2H2O
4212 A(7,N)=A(7,I9)/2 '
     N2+S (APPROXIMATION !)
4214 A(5,N)=(1-UZ)*A(5,N) '
     CO2 ACCEPTOR
4216 P(N)=P:
     T(N)=TG:
     GOSUB 5:
     GOSUB 550:
     GOSUB 5 '
     SHIFT EQUIL + THERMO
4219 PRINT"HYDROGEN",A(1,N);
     HY
4262 N=22:
     A(6,N)=RZ*(A(8,L3)*(1-UC)+.5*A(1,7)+2*A(3,7)+.5*A(4,7)):
     A(7,N)=A(6,N)*3.7733:
     T(N)=T(L2+1):
     GOSUB 5:
     PRINT "COMPUTE AIR FOR REGENERATOR"
4270 IP=22:
     OP=49:
     GOSUB 600:
     N=OP:
     A(8,N)=(1-UC)*A(8,L3):
     A(7,N)=A(7,N)+A(7,L3)-A(7,L3+1):
     GOSUB 5:
     IP=N:
     OP=9:
     XN=1:
     XM=0:
     GOSUB 1100:
     PRINT"PO GAS AND CARBON"
```

```
4272 A(5,N)=A(5,N)+UZ*(A(5,L3+1)+A(4,L3+1))/(1-UZ):
     T(N)=TR:
     GOSUB 5:
     GOSUB 550:
     GOSUB 5 '
     REGENERATE CaO AND EVOLVE CO2
4275 HD=H(L3)+H(L6)+H(22)-H(L3+1)-H(9):
     PRINT "ENTHALPY BALANCE IS";
     HD '
     ENTHALPY BALANCE WITH GASIFIER
4277 RETURN
4280 I9=9:
     J9=7:
     K9=43:
     GOSUB 910:
     IP=43:
     OP=44:
     GOSUB 600:
     PRINT"MIX REGEN AND ANODE EXH, DESULFURIZE"
4282 A(6,25)=BE*(.5*A(1,OP)+2*A(3,OP)+A(4,OP)-A(6,OP)):
     A(7,25)=3.7733*A(6,25):
     N=25:
     T(N)=T(L2+1):
     GOSUB 5:
     I9=OP:
     J9=N:
     K9=10:
     GOSUB 910:
     PRINT"MIX WITH AIR"
4285 IP=10:
     OP=11:
     GOSUB 1100:
     GOSUB 1132:
     PRINT"BURN REGENERATOR EXHAUST, T(11)=";
     T(11)
4290 A(6,42)=.04112*PG/(VC*2*UO)-A(6,11):
     A(7,42)=3.7733*A(6,42):
     N=42:
     T(N)=T(L2+1):
     GOSUB 5:
     I9=42:
     J9=11:
     K9=12:
     GOSUB 910
4295 PRINT"MIX WITH AIR,T(12)=";
     T(12)
4299 RETURN
4300 'TRACK AIR
4305 T(L2)=75:
     A(6,L2)=A(6,22)+A(6,24)+A(6,25)+A(6,42):
     A(7,L2)=A(6,L2)*3.7733:
     N=L2:
     GOSUB 5:
     PRINT"TOTAL AIR REQUIREMENT"
```

```
4310 IP=L2:
     OP=L2+1:
     RC=P:
     GOSUB 800:
     LPRINT"AIR COMPRESSOR WORK";
     WC
4315 I9=OP:
     J9=22:
     K9=23:
     F=A(6,J9)/A(6,I9):
     GOSUB 880:
     PRINT"SPLIT 1"
4320 I9=23:
     J9=24:
     K9=41:
     F=A(6,J9)/A(6,I9):
     GOSUB 880:
     PRINT"SPLIT 2"
4325 IF A(0,25)+A(0,42)-A(0,41)>1
     THEN PRINT"AIR IMBALANCE":
     STOP
4332 RETURN
4340 REM HEAT EXCHANGER SETUPS
4341 J5=1:
     I7=4:
     J7=5:
     I8=6:
     J8=7:
     GOTO 4350 '
     HX1
4343 J5=3:
     I7=18:
     J7=19:
     I8=31:
     J8=32:
     GOTO 4370 '
     HX3
4344 'HX4 IS COND
4345 J5=5:
     I7=16:
     J7=17:
     I8=30:
     J8=31:
     GOTO 4370 '
     HX5
4350 GOSUB 4390 '
     ENSURE CONTINUITY
4352 IF IC=1
     THEN PRINT @531,"HX";
     J5;
     "G/G";

     ELSE IF K(J5)=0 PRINT "HX";
     J5
```

```
4355 GOSUB 1300:
     IF K(J5)<>0
     THEN 4352
     ELSE RETURN '
     HX GAS/GAS
4360 GOSUB 4390 '
     ENSURE CONTINUITY
4362 IF IC=1
     THEN PRINT "531,"HX";
     J5;
     "G/L"
     ELSE IF K(J5)=0 PRINT "HX";
     J5
4365 GOSUB 5810:
     IF K(J5)<>0
     THEN 4362
     ELSE RETURN '
     HX GAS/LIQ
4370 GOSUB 4390:
     H(J8)=H(I8)+H(I7)-H(J7):
     IF IC<>1
     THEN PRINT "HX";
     J5;
     "H BALANCE":
     RETURN
     ELSE RETURN
4380 GOSUB 4370:
     N=J8:
     NH=2:
     GOSUB 10:
     RETURN '
     H BAL+GAS TEMP
4390 A5=J5:
     N!=N!(J5)
4392 IF A(0,J7)<>A(0,I7)
     THEN IP=I7:
     OP=J7:
     T=T(OP):
     GOSUB 600:
     IF T<>0
     THEN T(OP)=T:
     N=OP:
     GOSUB 10
4394 IF A(0,J8)<>A(0,I8)
     THEN IP=I8:
     OP=J8:
     GOSUB 600
4396 RETURN
4400 'ANODE EXIT STREAM
4405 OP=NA(2):
     T=T(OP+1):
     GOSUB 6:
     N=OP:
     IF T=0
```

```
     THEN NV=5:
     GOSUB 2420:
     T(N)=TB+5:
     GOSUB 10:
     PRINT"HX1 HOT SIDE TO SAT"
     ELSE T(N)=T:
     GOSUB 10:
     PRINT "HX1 HOT SIDE CONTINUITY"
4410 D1%=26:
     D2%=OP:
     D3%=OP+1:
     D4%=D1%+1:
     TX=10:
     A(2,D1%)=4*A(0,D2%):
     N=D1%:
     LQ=1:
     IF T(D1%)=0
     THEN T(D1%)=207:
     GOSUB 5
     ELSE GOSUB 5'
     WATER TO DC1
4415 GOSUB 11050:
     IF IC<>1
     THEN PRINT "DC1"
4420 GOSUB 4341 '
     HX1
4425 N=29:
     A(2,N)=A(2,D4%)-A(2,D1%):
     LQ=1:
     T(N)=T(D4%):
     GOSUB 5'
     WATER CONDENSED
4430 N=28:
     A(2,N)=A(2,D1%):
     LQ=1:
     T(N)=T(D4%):
     GOSUB 5
4435 RETURN
4440 REM CATHODE RECYCLE AND MCFC INITIALIZATION
4445 IC=1:
     A5=17:
     IF FM=0
     THEN FM=2.1:
     TZ=400:
     GOTO 4455
     ELSE GOTO 4455
4450 FOR I=0 TO 8:
     A(I,OP)=F*A(I,IP):
     FR(I,OP)=FR(I,IP):
     NEXT I:
     H(OP)=F*H(IP):
     P(OP)=P(IP):
     T(OP)=T(IP):
     RETURN
```

```
4455 IP=NA(4):
     OP=IP:
     F=FM*A(7,12)/A(7,IP):
     GOSUB 4450:
     I9=IP:
     J9=IP+1:
     K9=18:
     F=A(7,12)/A(7,IP):
     GOSUB 880 '
     MASS FEEDBACK,N2 IS INERT
4460 IP=18:
     OP=19:
     GOSUB 600:
     T(OP)=TZ:
     N=OP:
     GOSUB 10:
     I9=12:
     J9=N:
     K9=NA(3):
     GOSUB 910 '
     TEMP CONTROL AND MIX
4465 J5=16:
     X=TZ:
     Y=T(NA(3)):
     Y0=TC-200:
     GOSUB 440:
     TZ=X:
     IF K(J5)<>0
     THEN 4460 '
     LOOP ON INPUT TEMP
4470 GOSUB 9620 '
     MCINIT
4472 IF IC=1 AND A5=17
     THEN PRINT @532,"X=FLOW MULTIPLIER,Y=T OUT";
4475 J5=17:
     X=FM:
     Y=T(NA(4)):
     Y0=TC:
     GOSUB 440:
     FM=X:
     IF K(J5)<>0
     THEN 4455 '
     LOOP ON OUTPUT TEMP
4480 UO=(A(6,12)-A(6,15))/A(6,12) '
     THIS SHOULD BE AS DESIGNED
4485 PRINT "UF,UO,FM,F";
     UF;
     UO;
     FM;
4499 RETURN
4500 ' OUT THROUGH TURBINE
4510 IP=15:
     OP=IP+1:
     RT=P:
```

```
     GOSUB 820:
     LPRINT "GAS TURBINE WORK IS";
     WT
4511 GOSUB 6:
     T(OP)=360:
     N=OP:
     GOSUB 10 '
     HX5 HOTSIDE
4512 W1=WT:
     RETURN
4515 W2=W1+WT-WC:
     LPRINT "NET TURBINE WORK IS";
     W2;
     "BTU/HR"
4520 PT=W2*EG*2.93E-7:
     LPRINT "WITH A GENERATOR EFFICIENCY OF";
     EG;
     ",THE NET TURBINE POWER IS";
     PT;
     "MW"
4522 PS=PG*EI/1000 '
     CELL STACK INVERTED OUTPUT IN MW
4525 PF=PS+PT-PP:
     LPRINT "POWER PLANT OUTPUT IS";
     PF;
     "MW"
4549 RETURN
4550 'MCFC PERFORMANCE
4555 GOSUB 9350
4560 LPRINT "MCFC PERFORMANCE:
      CURRENT DENSITY";
     AF;
     "AMPS/CM2";
     "  CELL VOLTAGE";
     VC;
     "V"
4599 RETURN
4600 A5=8:
     IC=1:
     PRINT @530,"CLOSE WATER LOOP,X=T(SPRAY),Y=WATER OUT";
4605 X=T(D1%):
     Y=A(2,29):
     Y0=A(2,L6):
     J5=8:
     GOSUB 440 '
     SECANT
4610 IF K(J5)=0
     THEN RETURN
4615 T(D1%)=X:
     N=D1%:
     LQ=1:
     IC=0:
     PRINT@0,;
     :
```

```
     GOSUB 10:
     GOSUB 4415:
     GOTO 4300 '
     ADJUST DC1 SPRAY TEMP
4620 'STEAM LOOP
4622 IF A(2,36)=0
     THEN A(2,36)=A(2,29)/1.5
4625 N=36:
     LQ=1:
     T(N)=140:
     GOSUB 5:
     I9=36:
     J9=29:
     K9=30:
     GOSUB 912:
     PRINT"MIX WATER,A(2,36),A(2,29),T(30):
     ";
     A(2,36);
     A(2,29);
     T(30)
4630 P(30)=P+10:
     PRINT"PUMP"
4635 IP=K9:
     OP=50:
     GOSUB 600:
     OP=0:
     GOSUB 600:
     N=0:
     NV=5:
     GOSUB 2420:
     T(0)=TB:
     T(50)=TB:
     PRINT"TB=";
     TB;
     " PW=";
     PW
4637 N=50:
     LQ=1:
     GOSUB 10:
     N=0:
     LQ=0:
     GOSUB 10:
     PRINT"WATER AND STEAM ENTHALPIES";
     H(50);
     H(0)
4640 IC=0:
     GOSUB 4345:
     N=J8:
     GOSUB 4665:
     GOSUB 4343:
     N=J8:
     GOSUB 4665 '
     HX5,HX3
4645 'ADJUST COND FLOW FOR T(32)=T(33)
```

```
4650 PRINT"T(32),T(33),K(18):
     ";
     T(32);
     T(33);
     K(18)
4652 IF K(18)=0
     THEN IF T(32)>T(18)
     THEN A(2,36)=1.5*A(2,36):
     GOTO 4625
     ELSE IF T(32)<=TB
     THEN A(2,36)=.5*A(2,36):
     GOTO 4625
4655 X=A(2,36):
     Y=T(32):
     Y0=T(L6):
     J5=18:
     EE=.005:
     GOSUB 440:
     A(2,36)=X:
     IF K(J5)<>0
     THEN 4625
4660 GOTO 4672
4665 IF H(N)>H(50) AND H(N)<H(0)
     THEN T(N)=T(0):
     PRINT"PARTIAL BOILING"
     ELSE IF H(N)<H(50)
     THEN LQ=1:
     NH=2:
     GOSUB 10:
     PRINT"NO BOILING"
     ELSE LQ=0:
     NH=2:
     GOSUB 10:
     PRINT"STEAM"
4667 RETURN
4672 I9=32:
     J9=33:
     K9=34:
     F=A(2,J9)/A(2,I9):
     GOSUB 880:
     PRINT"SPLIT STEAM"
4680 IP=K9:
     OP=IP+1:
     RT=P(IP)/0.2
4682 GOSUB 820 '
     STEAM TURBINE
4699 LPRINT "STEAM TURBINE WORK";
     WT:
     RETURN
4900 REM COMPUTE HHV OF COAL
4905 CF=A(8,L3)*12/WF(3) '
     COAL FEED IN POUNDS
4910 N=48:
     A(2,N)=A(2,L3)+A(1,L3):
```

```
     A(5,N)=A(8,L3):
     A(7,N)=A(7,L3):
     T(N)=T(L3):
     LQ=1:
     GOSUB 5 '
     OXIDIZED PRODUCT
4915 N=47:
     A(6,N)=A(1,L3)/2+A(8,L3)-A(6,L3):
     T(N)=T(L3):
     GOSUB 5 '
     O2 FOR TOTAL COMBUSTION
4920 I9=L3:
     J9=47:
     K9=46:
     GOSUB 912 '
     UNBURNED MIX
4925 HHV=(H(46)-H(48))/CF:
     '
     LPRINT "COAL FEED (LBS/HR)";
     CF;
     "HHV(BTU/LB)";
     HHV
4999 RETURN
```

```
3000 REV$="7":
     REM SYSM,MCFC + TRW CATALYTIC HYDROGEN PROCESS
3003 DATA 20,1,33,3,4,13,14
3005 READ L2,L3,L6,NA(1),NA(2),NA(3),NA(4)
3010 DATA 675,.70,.70,1.2,.95,12,1250,1750,1800,1200,.75,.6
     0,.95,116,13.5,.98,.92,.88,.98,.096,.042,.666,.051,.096,.049
3020 READ PN,UC,US,BE,RZ,P,TG,TR,TV,TC,UF,UO,VC,PT,PP,EI,ET
     ,EC,EG,WF(1),WF(2),WF(3),WF(4),WF(5),WF(6)
3030 GOSUB 3100 '
     LIST VARS
3040 INPUT "UPDATE VARIABLES";
     U$:
     U$=LEFT$(U$,1):
     IF U$="Y" OR U$="y"
     THEN GOSUB 3150:
     GOTO 3030
     ELSE IF U$="N" OR U$="n"
     THEN GOSUB 3045:
     GOTO 3050
     ELSE PRINT "ANSWER YES OR NO":
     GOTO 3040
3045 X=PEEK(14312):
     IF X=60
     THEN DEFUSR=473:
     X=USR(X):
     RETURN
     ELSE RETURN  '
     JKL IF PRINTER OK
3050 'CALCULATE MAJOR FLOWS IN PLANT FROM POWER AND EFFICIE
     NCY
3052 PG=1000*(PN+PP-PT)/EI:
     HY=.04112*PG/(VC*UF):
     A(1,NA(1))=HY:
     N=NA(1):
     T(N)=TC:
     GOSUB 5 '
     HYDROGEN NEEDED AT ANODE
3054 A(8,L3)=HY/(6*WF(4)/WF(3)+2*UC*.97-.75*WF(5)/WF(3)):
     A(1,L3)=A(8,L3)*6*WF(4)/WF(3):
     A(2,L3)=A(8,L3)*(2/3)*WF(2)/WF(3):
     A(6,L3)=A(8,L3)*.375*WF(5)/WF(3):
     A(7,L3)=A(8,L3)*.3*WF(6)/WF(3)'
     COAL FEED
3055 N=L3:
     GOSUB 400:
     A(0,N)=A(0,N)+A(8,N)*.2*WF(1)/WF(3):
     T(N)=75:
     GOSUB 3410:
     LQ=1:
     GOSUB 10 :
     GOSUB 4900 '
     SUM WITH ASH
3066 N=L6:
     A(2,N)=2*UC*A(8,L3)/US-A(2,L3)-2*A(6,L3):
```

```
     T(N)=TC-100:
     GOSUB 5 '
     STEAM NEEDED AT GASIFIER
3070 FOR I=0 TO NM:
     P(I)=P:
     NEXT I '
     SET PRESSURES
3072 P(L2)=1:
     FOR I=37 TO 40:
     P(I)=1:
     NEXT I '
     BLOWER PRESSURES
3075 T(L2)=75:
     A(6,L2)=1:
     A(7,L2)=3.7733:
     N=L2:
     GOSUB 5:
     IP=L2:
     OP=L2+1:
     RC=P:
     GOSUB 800 '
     TEMP OF AIR FROM COMPRESSOR
3099 RETURN
3100 CLS:
     PRINT TAB(20) "POWER PLANT VARIABLES":
      PRINT TAB(10) "REV.";
     REV$;
     TAB(40) TIME$"
3103 PRINT "PN  ";
     PN;
      "MW";
     TAB(21) "UC  ";
     UC ;
     TAB(41) "US  ";
     US
3106 PRINT "BE  ";
     BE  ;
     TAB(21) "RZ  ";
     RZ ;
     TAB(41) "PRES";
     P;
     "ATM"
3109 PRINT "TGAS";
     TG;
     "F";
     TAB(21) "TREG";
     TR;
     "F";
     TAB(41) "TCVT";
     TV;
     "F"
3112 PRINT "TCEL";
     TC;
     "F";
```

```
     TAB(21) "UF  ";
     UF;
     TAB(41) "UO";
     UO
3115 PRINT "VC  ";
     VC;
     "V";
     TAB(21) "PT  ";
     PT;
     "MW";
3118 PRINT TAB(41) "PP  ";
     PP;
     "MW":
     PRINT "EI  ";
     EI;
     TAB(21) "ET  ";
     ET;
3121 PRINT TAB(41) "EC  ";
     EC:
     PRINT "EG  ";
     EG;
     TAB(21) "COAL FRACTIONS:
3130 PRINT "ASH ";
     WF(1);
     "TPT";
     TAB(21) "H2O ";
     WF(2);
     "TPT";
     TAB(41) "C   ";
     WF(3);
     "TPT"
3133 PRINT "H2  ";
     WF(4);
     "TPT";
     TAB(21) "O2  ";
     WF(5);
     "TPT";
     TAB(41) "N2+S";
     WF(6);
     "TPT"
3136 PRINT "FUEL SPECIES IS ";
     A$(8);
     TAB(30) "PERFORMANCE IS FOR MCFC"
3149 RETURN
3150 PRINT "PN ";
     PN;
     :
     INPUT PN:
     PRINT "UC  ";
     UC ;
     :
     INPUT UC :
     PRINT "US ";
     US ;
```

```
     :
      INPUT US
3153 PRINT "BE  ";
     BE  ;
     :
     INPUT BE  :
     PRINT "RZ  ";
     RZ ;
     :
     INPUT RZ :
     PRINT"PRES";
     P;
     :
     INPUT P
3156 PRINT "TGASIFIER";
     TG;
     :
     INPUT TG:
     PRINT "TREGENERATOR";
     TR;
     :
     INPUT TR:
     PRINT "TCONVERTER";
     TV;
     :
     INPUT TV
3159 PRINT "TCELL";
     TC;
     :
     INPUT TC:
     PRINT "UF";
     UF;
     :
     INPUT UF:
     PRINT "UO";
     UO;
     :
     INPUT UO
3162 PRINT "VC";
     VC;
     :
     INPUT VC:
     PRINT "TURBINE NET POWER";
     PT;
     :
     INPUT PT
3165 PRINT "PARASITE POWER";
     PP;
     :
     INPUT PP:
     PRINT "EI";
     EI;
     :
     INPUT EI:
```

```
     PRINT "ET";
     ET;
     :
     INPUT ET
3168 PRINT "EC";
     EC;
     :
     INPUT EC:
     PRINT "EG";
     EG;
     :
     INPUT EG
3177 PRINT "ASH IN COAL";
     WF(1);
     :
     INPUT WF(1):
     PRINT "WATER IN COAL";
     WF(2);
     :
     INPUT WF(2):
     PRINT "CARBON IN COAL";
     WF(3);
     :
     INPUT WF(3)
3180 PRINT "HYDROGEN IN COAL";
     WF(4);
     :
     INPUT WF(4):
     PRINT "OXYGEN IN COAL";
     WF(5);
     :
     INPUT WF(5):
     PRINT "N2 AND SULFUR IN COAL";
     WF(6);
     :
     INPUT WF(6)
3199 RETURN
```

```
3200 LPRINT CHR$(12);TAB(20) "POWER PLANT DATA":
     LPRINT TAB(10) "REV.";
     REV$;
     TAB(40) ;
     TIME$'
     DATABLOC
3205 EO=PF*3.413E6/(CF*HHV) '
     CALCULATE OVERALL EFFICIENCY
3207 HR=CF*HHV*1E-3/PF '
     CALCULATE HEAT RATE
3210 AR=1000*PG/(VC*AF*929.03) '
     CALCULATE FUEL CELL AREA
3215 FD(1)=CF*24/2000:
     FD(2)=A(2,L6)*24/(111.111*FD(1)):
     FD(3)=A(0,L2)*24/(69.4*FD(1)) '
     CALCULATE FEEDS IN TONS PER DAY OR TONS PER TON
3217 FD(4)=FD(3)*A(0,22)/A(0,L2)
3220 LPRINT "OVERALL EFFICIENCY IS ";
      EO ;
     " USING A COAL HHV OF ";
     HHV;
     "BTU/LB" '
     PRINT RESULTS
3225 LPRINT "FUEL CELL AREA REQUIRED IS";
     AR;
     " SQUARE FEET"
3230 LPRINT "COAL FEED REQUIRED IS";
     FD(1);
     " TONS PER DAY"
3235 LPRINT "STEAM RECYCLED AT GASIFIER IS";
      FD(2);
     " TONS PER TON OF COAL"
3240 LPRINT "OVERALL AIR FEED IS";
      FD(3);
     " TONS PER TON OF COAL"
3245 LPRINT "REGENERATOR AIR FEED IS";
      FD(4);
     " TONS PER TON OF COAL"
3250 LPRINT "HEAT RATE IS";
     HR;
     "BTU/KWH"
3255 LPRINT TAB(20) "POWER (MW)"
3257 A$="####.#"
3260 LPRINT "GROSS";
     TAB(30)USING A$;
      PF+PP
3265 LPRINT "FUEL CELL";
     TAB(30)USING A$;
      PS
3270 LPRINT"COMPRESSOR MECHANICAL";
     TAB(30)USING A$;
     -WC*2.93E-7
3275 LPRINT"GAS TURBINE MECHANICAL";
     TAB(30)USING A$;
```

```
     W1*2.93E-7
3280 LPRINT"STEAM TURBINE MECHANICAL";
     TAB(30)USING A$;
     WT*2.93E-7
3282 LPRINT"NET TURBINE ELECTRICAL";
     TAB(30)USING A$;
     PT
3285 LPRINT "PARASITE";
     TAB(30)USING A$;
      -PP
3290 LPRINT "NET";
     TAB(30)USING A$;
      PF
3399 RETURN
```

7.0 APPENDIX 2 -- PATRW Thermodynamics

POWER PLANT VARIABLES

PN	675 MW	UC	0.72	US	0.7
UZ	0.98	DP	0.2 atm	C9	1.03
BE	1.2	RP	0.9	PRES	12 atm
TGAS	1250°F	TREG	1750°F	TCVT	1800°F
TCEL	405°F	UH	0.9	UO	0.7
V0	0.72 V	PT	110 MW	PP	13.5 MW
EI	0.98	ET	0.92	EC	0.85
EG	0.98	COAL FRACTIONS:			
ASH	0.096 TPT	H2O	0.042 TPT	C	0.666 TPT
H2	0.051 TPT	O2	0.096 TPT	N2+S	0.049 TPT

FUEL SPECIES IS CARBON   PERFORMANCE IS FOR UTC
UPDATE VARIABLES? N

```
HEAT BALANCE GIVES UC = 0.700207
AIR COMPRESSOR WORK 7.56524E+08
V0 = 0.72
AF = 255.46
GAS TURBINE WORK IS 8.05548E+08
STEAM TURBINE WORK 4.39822E+08
QUALITY AT STEAM SEPARATOR 0.500279
NET TURBINE WORK IS 4.88845E+08 Btu/h
WITH A GENERATOR EFFICIENCY OF 0.98, THE NET TURBINE POWER IS 140.367 MW
POWER PLANT OUTPUT IS 705.367 MW
***** ITERATING ON TUBBINE POWER *****
HEAT BALANCE GIVES UC = 0.700207
AIR COMPRESSOR WORK 7.24566E+08
V0 = 0.72
AF = 255.459
GAS TURBINE WORK IS 7.71519E+08
STEAM TURBINE WORK 4.23404E+08
QUALITY AT STEAM SEPARATOR 0.502777
NET TURBINE WORK IS 4.70356E+08 Btu/h
WITH A GENERATOR EFFICIENCY OF 0.98, THE NET TURBINE POWER IS 135.058 MW
POWER PLANT OUTPUT IS 675.621 MW
```

POWER PLANT DATA

OVERALL EFFICIENCY IS 0.480183 USING A COAL HHV OF 12535.5 Btu/lb
FUEL CELL EFFICIENCY IS 0.574759
FUEL CELL AREA REQUIRED IS 3.01235E+06 SQUARE FEET
COAL FEED REQUIRED IS 4596.97 TONS PER DAY
STEAM RECYCLED AT GASIFIER IS 1.84859 TONS PER TON OF COAL
OVERALL AIR FEED IS 11.5238 TONS PER TON OF COAL
REGENERATOR AIR FEED IS 2.86064 TONS PER TON OF COAL
HEAT RATE IS 7107.71 Btu/kWh

	POWER (MW)
GROSS	689.1
FUEL CELL	554.1
COMPRESSOR MECHANICAL	-212.3
GAS TURBINE MECHANICAL	226.1
STEAM TURBINE MECHANICAL	124.1
NET TURBINE ELECTRICAL	135.1
PARASITE	-13.5
NET	675.6

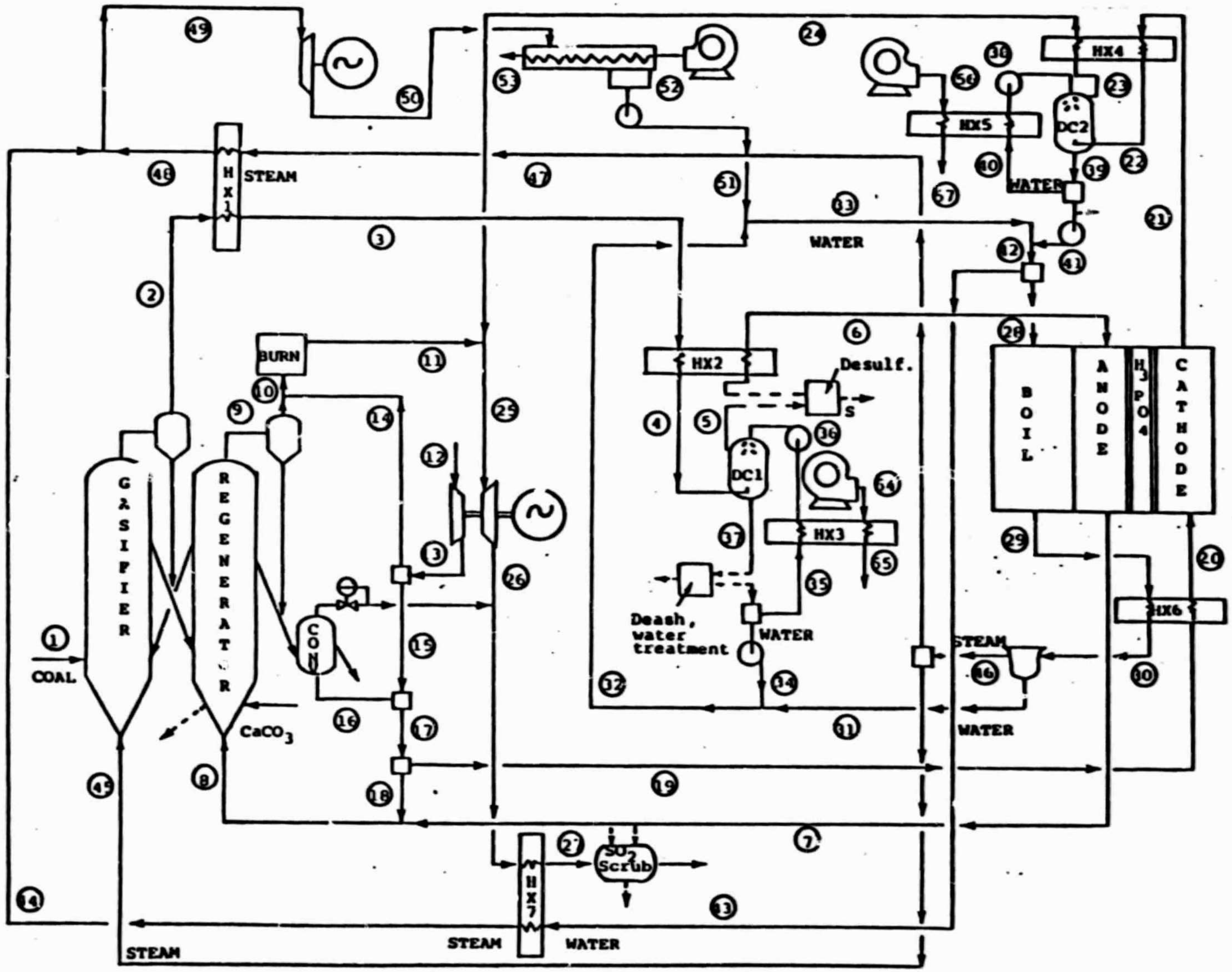


Fig. 1 Phosphoric acid fuel cell power plant with TRW catalytic hydrogen process.

PSI/S3E NODE ARRAY

	MOLAR FLOW RATES - lb mole/hr									Press	Temp	Enthalpy	
NODE	H2	H2O	CH4	CO	CO2	O2	N2	FUEL	TOT	ATM	Deg-F	BTU/hr	NODE
1	9769	894	0	0	0	1149	469	21261	34155	12.0	75	-5.4155E+07	1
2	35877	13533	298	177	115	0	235	0	50233	12.0	1250	-7.9134E+08	2
3	35877	13533	298	177	115	0	235	0	50233	11.8	455	-1.0971E+09	3
4	35877	13533	298	177	115	0	235	0	50233	11.6	281	-1.1613E+09	4
5	35877	1028	298	177	115	0	235	0	37729	11.4	160	1.7906E+07	5
6	35877	1028	298	177	115	0	235	0	37729	11.2	402	8.2181E+07	6
7	3588	1028	298	177	115	0	235	0	5440	11.0	405	-1.0855E+08	7
8	3588	1028	298	177	115	7966	30529	6374	50075	11.5	694	2.3021E+08	8
9	247	4965	0	1524	19737	0	30529	0	57001	11.5	1750	-2.8310E+09	9
10	247	4965	0	1524	19737	1062	34537	0	62072	11.8	1685	-2.7882E+09	10
11	0	5211	0	0	21261	177	34537	0	61186	11.8	2021	-2.7882E+09	11
12	0	0	0	0	0	32092	121093	0	153185	1.0	75	5.6929E+08	12
13	0	0	0	0	0	32092	121093	0	153185	12.0	737	1.2939E+09	13
14	0	0	0	0	0	1062	4008	0	5070	12.0	737	4.2824E+07	14
15	0	0	0	0	0	31030	117085	0	148115	12.0	737	1.2510E+09	15
16	0	0	0	0	0	0	0	0	0	12.0	737	0.0000E+00	16
17	0	0	0	0	0	31030	117085	0	148115	12.0	737	1.2510E+09	17
18	0	0	0	0	0	7966	30060	0	38026	12.0	737	3.2118E+08	18
19	0	0	0	0	0	23064	87026	0	110089	12.0	737	9.2985E+08	19
20	0	0	0	0	0	23064	87026	0	110089	11.8	405	6.6410E+08	20
21	0	32289	0	0	0	6919	87026	0	126233	11.0	405	-2.5289E+09	21
22	0	32289	0	0	0	6919	87026	0	126233	10.8	274	-2.6508E+09	22
23	0	5451	0	0	0	6919	87026	0	99396	10.6	189	-1.0867E+08	23
24	0	5451	0	0	0	6919	87026	0	99396	10.4	362	1.3158E+07	24
25	0	10662	0	0	21261	7096	121563	0	160582	11.1	1114	-2.7750E+09	25

ORIGINAL PAGE IS
OF POOR QUALITY

PSI/S3E NODE ARRAY (Continued)

	MOLAR FLOW RATES - lb mole/hr									Press	Temp	Enthalpy	
NODE	H2	H2O	CH4	CO	CO2	O2	N2	FUEL	TOT	ATM	Deg-F	BTU/hr	NODE
26	0	10662	0	0	21261	7096	121563	0	160582	1.2	521	-3.5465E+09	26
27	0	10662	0	0	21261	7096	121563	0	160582	1.0	292	-3.8269E+09	27
28	0	175618	0	0	0	0	0	0	175618	12.6	272	-1.9956E+10	28
29	0	175618	0	0	0	0	0	0	175618	12.6	375	-1.8463E+10	29
30	0	175618	0	0	0	0	0	0	175618	12.6	375	-1.8198E+10	30
31	0	87321	0	0	0	0	0	0	87321	12.6	375	-9.7123E+09	31
32	0	99826	0	0	0	0	0	0	99826	12.6	358	-1.1144E+10	32
33	0	163861	0	0	0	0	0	0	163861	12.6	278	-1.8596E+10	33
34	0	12504	0	0	0	0	0	0	12504	12.6	232	-1.4318E+09	34
35	0	150700	0	0	0	0	0	0	150700	12.0	232	-1.7255E+10	35
36	0	150700	0	0	0	0	0	0	150700	12.0	150	-1.7508E+10	36
37	0	163204	0	0	0	0	0	0	16[illegible]04	11.8	232	-1.8687E+10	37
38	0	504934	0	0	0	0	0	0	50[illegible]34	12.0	179	-5.8367E+10	38
39	0	531772	0	0	0	0	0	0	531772	11.8	230	-6.0909E+10	39
40	0	504934	0	0	0	0	0	0	504934	12.0	230	-5.7835E+10	40
41	0	26838	0	0	0	0	0	0	26838	12.6	230	-3.0740E+09	41
42	0	190699	0	0	0	0	0	0	190699	12.6	272	-2.1670E+10	42
43	0	15081	0	0	0	0	0	0	15081	12.6	272	-1.7137E+09	43
44	0	15081	0	0	0	0	0	0	15081	12.4	501	-1.4333E+09	44
45	0	39342	0	0	0	0	0	0	39342	12.6	375	-3.7809E+09	45
46	0	88297	0	0	0	0	0	0	88297	12.6	375	-8.4855E+09	46
47	0	48954	0	0	0	0	0	0	48954	12.6	375	-4.7046E+09	47
48	0	48954	0	0	0	0	0	0	48954	12.4	1080	-4.3988E+09	48
49	0	64035	0	0	0	0	0	0	64035	12.4	949	-5.8322E+09	49
50	0	64035	0	0	0	0	0	0	64035	0.2	182	-6.2556E+09	50
51	0	64035	0	0	0	0	0	0	64035	12.6	140	-7.4521E+09	51

7.0 APPENDIX 3 -- MCTRW Thermodynamics

PRECEDING PAGE BLANK NOT FILMED

PAGE 90 INTENTIONALLY BLANK

POWER PLANT VARIABLES

PN	675 MW	UC	0.7	US	0.7
BE	1.2	RZ	0.95	PRES	12 atm
TGAS	1250°F	TREG	1750°F	TCVT	1800°F
TCEL	1200°F	UF	0.75	UO	0.6
VC	0.95 V	PT	116 MW	PP	13.5 MW
EI	0.98	ET	0.92	EC	0.88
EG	0.98	COAL	FRACTIONS:		
ASH	0.096 TPT	H2O	0.042 TPT	C	0.666 TPT
H2	0.051 TPT	O2	0.096 TPT	N2+S	0.049 TPT

FUEL SPECIES IS CARBON   PERFORMANCE IS FOR MCFC
UPDATE VARIABLES? N

HEAT BALANCE GIVES UC = 0.701803
MCFC PERFORMANCE: CURRENT DENSITY 0.161472 AMPS/CM2 CELL VOLTAGE 0.95 V
AIR COMPRESSOR WORK 6.87607E+08
GAS TURBINE WORK IS 8.65758E+08
STEAM TURBINE WORK 2.37183E+08
NET TURBINE WORK IS 4.15334E+08 Btu/h
WITH A GENERATOR EFFICIENCY OF 0.98, THE NET TURBINE POWER IS 119.259 MW
POWER PLANT OUTPUT IS 678.259 MW

POWER PLANT DATA

OVERALL EFFICIENCY IS 0.520696 USING A COAL HHV OF 12535.5 Btu/lb
FUEL CCELL AREA REQUIRED IS 4.09921E+06 SQUARE FEET
COAL FEED REQUIRED IS 4255.86 TONS PER DAY
STEAM RECYCLED AT GASIFIER IS 1.85315 TONS PER TON OF COAL
OVERALL AIR FEED IS 12.2449 TONS PER TON OF COAL
REGENERATOR AIR FEED IS 2.16276 TONS PER TON OF COAL

POWER (MW)

GROSS	691.8
FUEL CELL	572.5
COMPRESSOR MECHANICAL	-201.6
GAS TURBINE MECHANICAL	253.7
STEAM TURBINE MECHANICAL	69.5
NET TURBINE ELECTRICAL	119.3
PARASITE	-13.5
NET	678.3

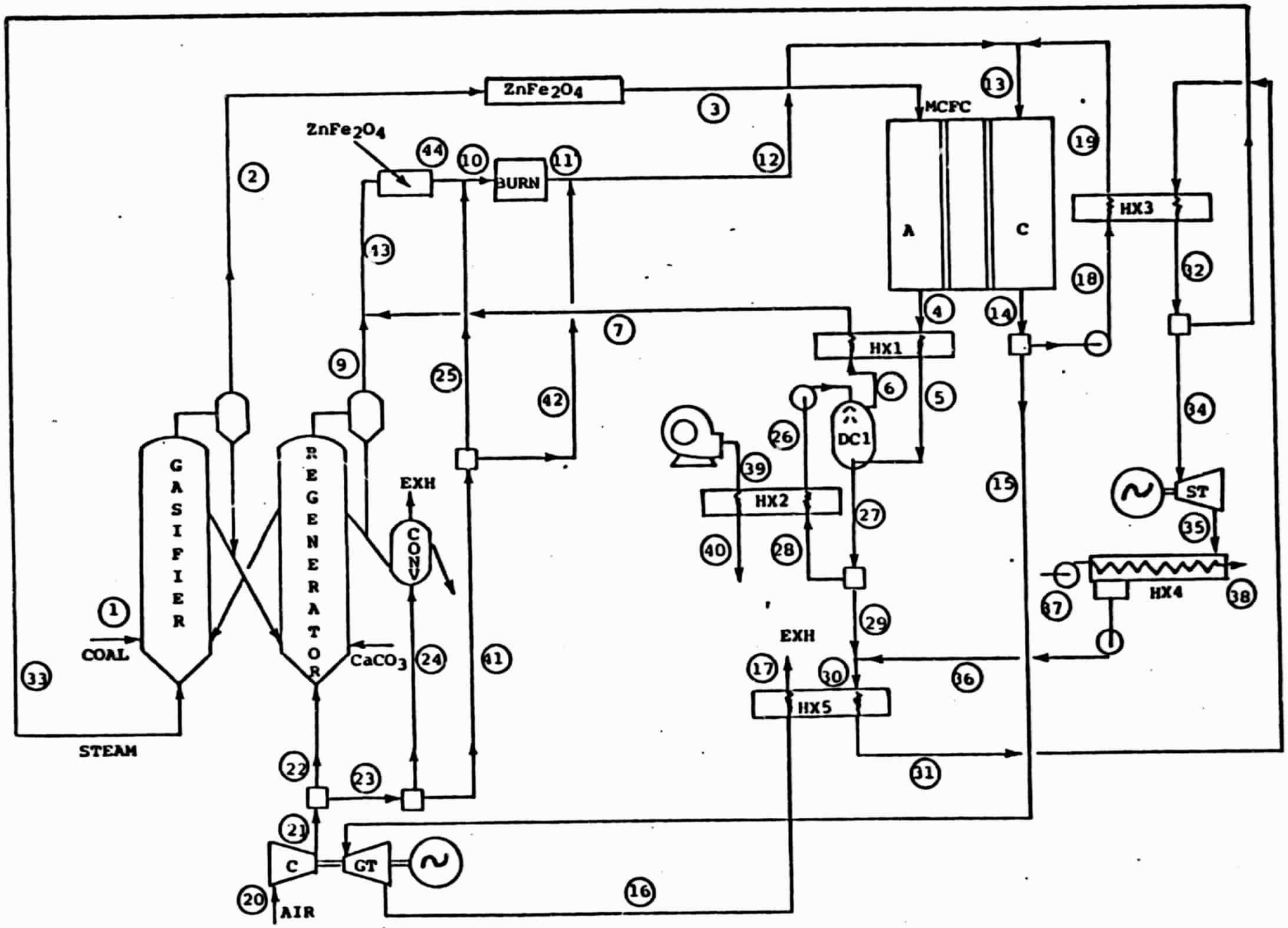


Fig. 2 Molten carbonate fuel cell with TRW catalytic hydrogen process.

PSI/S3E NODE ARRAY

	MOLAR FLOW RATES - lb mole/hr									Press	Temp	Enthalpy	
NODE	H2	H2O	CH4	CO	CO2	O2	N2	FUEL	TOT	ATM	Deg-F	BTU/hr	NODE
1	9044	828	0	0	0	1064	434	19683	31620	12.0	75	-5.0136E+07	1
2	33274	12557	276	164	107	0	217	0	46596	12.0	1250	-7.3448E+08	2
3	33274	12557	276	164	107	0	217	0	46596	12.0	1250	-7.3448E+08	3
4	6253	39578	276	1900	23657	0	217	0	71881	12.0	1200	-7.1185E+09	4
5	6253	39578	276	1900	23657	0	217	0	71881	12.0	876	-7.3550E+09	5
6	6253	3066	276	1900	23657	0	217	0	35369	12.0	218	-4.2341E+09	6
7	6253	3066	276	1900	23657	0	217	0	35369	12.0	895	-3.9977E+09	7
8	0	0	0	0	0	0	0	0	0	12.0	0	0.0000E+00	8
9	-0	0	0	587	18549	0	21257	0	40394	12.0	1750	-2.3693E+09	9
10	6253	3066	276	2486	42206	7399	49391	0	111078	12.0	1183	-6.0742E+09	10
11	0	9871	0	0	44969	2476	49391	0	106708	12.0	2130	-6.0742E+09	11
12	0	9871	0	0	44969	21072	119557	0	195469	12.0	1598	-5.3386E+09	12
13	0	22605	0	0	70361	31945	273788	0	398699	12.0	1000	-9.7823E+09	13
14	0	22605	0	0	45075	19302	273788	0	360770	12.0	1200	-5.3922E+09	14
15	0	9871	0	0	19683	8429	119557	0	157540	12.0	1201	-2.3534E+09	15
16	0	9871	0	0	19683	8429	119557	0	157540	1.0	523	-3.2192E+09	16
17	0	9871	0	0	19683	8429	119557	0	157540	1.0	360	-3.4158E+09	17
18	0	12734	0	0	25392	10873	154231	0	203230	12.0	1201	-3.0360E+09	18
19	0	12734	0	0	25392	10873	154231	0	203230	12.0	336	-4.4438E+09	19
20	0	0	0	0	0	31570	119123	0	150692	1.0	75	5.6002E+08	20
21	0	0	0	0	0	31570	119123	0	150692	12.0	715	1.2476E+09	21
22	0	0	0	0	0	5576	21040	0	26616	12.0	715	2.2036E+08	22
23	0	0	0	0	0	25994	98083	0	124076	12.0	715	1.0273E+09	23
24	0	0	0	0	0	0	0	0	0	12.0	715	0.0000E+00	24
25	0	0	0	0	0	7399	27917	0	35316	12.0	715	2.9239E+08	25

PSI/S3E NODE ARRAY (Continued)

	MOLAR FLOW RATES - lb mole/hr									Press	Temp	Enthalpy	
NODE	H2	H2O	CH4	CO	CO2	O2	N2	FUEL	TOT	ATM	Deg-F	BTU/hr	NODE
26	0	287526	0	0	0	0	0	0	287526	12.0	208	-3.3063E+10	26
27	0	324039	0	0	0	0	0	0	324039	12.0	357	-3.6184E+10	27
28	0	287526	0	0	0	0	0	0	287526	12.0	357	-3.2107E+10	28
29	0	36513	0	0	0	0	0	0	36513	12.0	357	-4.0772E+09	29
30	0	66522	0	0	0	0	0	0	66522	22.0	265	-7.5695E+09	30
31	0	66522	0	0	0	0	0	0	66522	22.0	391	-7.3729E+09	31
32	0	66522	0	0	0	0	0	0	66522	22.0	1100	-5.9650E+09	32
33	0	36513	0	0	0	0	0	0	36513	22.0	1100	-3.2740E+09	33
34	0	30009	0	0	0	0	0	0	30009	22.0	1100	-2.6909E+09	34
35	0	30009	0	0	0	0	0	0	30009	0.2	196	-2.9281E+09	35
36	0	30009	0	0	0	0	0	0	30009	12.0	140	-3.4924E+09	36
37	0	0	0	0	0	0	0	0	0	1.0	0	0.0000E+00	37
38	0	0	0	0	0	0	0	0	0	1.0	0	0.0000E+00	38
39	0	0	0	0	0	0	0	0	0	1.0	0	0.0000E+00	39
40	0	0	0	0	0	0	0	0	0	1.0	0	0.0000E+00	40
41	0	0	0	0	0	25994	98083	0	124076	12.0	715	1.0273E+09	41
42	0	0	0	0	0	18595	70166	0	88761	12.0	715	7.3488E+08	42
43	6253	3066	276	2486	42206	0	21474	0	75762	12.0	1338	-6.3668E+09	43
44	6253	3066	276	2486	42206	0	21474	0	75762	12.0	1338	-6.3668E+09	44
45	0	0	0	0	0	0	0	0	0	12.0	0	0.0000E+00	45
46	9044	828	0	0	0	24205	434	19683	54762	12.0	75	3.5861E+07	46
47	0	0	0	0	0	23141	0	0	23141	12.0	75	8.5952E+07	47
48	0	9871	0	0	19683	0	434	0	29989	12.0	75	-4.4099E+09	48
49	0	0	0	0	0	5576	21257	5870	32703	12.0	715	2.3711E+08	49
50	0	66522	0	0	0	0	0	0	66522	22.0	424	-7.3153E+09	50