1 of 1

**An Economic Feasibility Analysis of Distributed Electric Power
Generation Based Upon the Natural Gas-Fired Fuel Cell
A Model of the Operations Cost**

Topical Report

**Staff,
Manes Associates, Incorporated**

June 30, 1993

Work Performed Under Cooperative Agreement No.: DE-FC21-92MC29227

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Southern California Gas Company
Los Angeles, California

MASTER

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for

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ABSTRACT

The "Operations Model of a Natural Gas-Fired, Fuel Cell-Based Central Utilities Plant" is the sixth topical report of the program for an "Economic Feasibility Analysis of Distributed Electric Power Generation Based Upon the Natural Gas-Fired Fuel Cell." This model of the operations of central utilities plant system definition details the major sources and uses of operating funds to sustain the operation of the plant and to provide the data for a computation of the cost of ownership of the plant.

The operational scenarios with appropriate expenses, revenues and incentives to ownership and operation are modeled for classes of users. The model enables the analyst to examine several different scenarios depending upon the class and circumstance of ownership chosen and the user class specified in the Central Utilities Plant Model.

This model description establishes the revenues, expenses incentives and avoided costs of Operation of a Natural Gas-Fired Fuel Cell-Based. Fuel is the major element of the cost of operation of a natural gas-fired fuel cell. Forecasts of the change in the price of this commodity are an important consideration in the ownership of an energy conversion system. Differences between forecasts, the interests of the forecaster or geographical areas can all have significant effects on imputed fuel costs. There is less affect on the judgments made on the feasibility of an energy conversion system since changes in fuel price can be affect the cost of operation of the alternatives to the fuel cell in a similar fashion. The forecasts used in this model are only intended to provide the potential owner or operator with the means to examine alternate future scenarios.

The operations model computes operating costs of a system suitable for a large condominium complex or a residential institution such as a hotel, boarding school or prison. The user may also select large office buildings that are characterized by 12 to 16 hours per day of operation or industrial users with a steady demand for thermal and electrical energy around the clock.

Keywords: Fuel Cell, Economic Analysis, Fuel Cell Operations, Fuel Cell Operating Revenues Fuel Cell Operating Costs Distributed Power Generation, Feasibility Analysis

FOREWORD

This report was prepared under cooperative agreement No. DE-FC21-92MC29227, among the US Department of Energy, Fossil Energy, Morgantown Energy Technology Center, The Southern California Gas Company, The Brooklyn Union Gas Company and the Manes Associates, Incorporated. The participants are sponsoring an investigation by the Manes Associates, of the "Economic Feasibility of Distributed Electric Power Generation Based Upon the Natural Gas-Fired Fuel Cell."

This report, An Operations Model of a Natural Gas-Fired Fuel Cell-Based Central Utilities Plant, is the sixth fourth deliverable report of the contract. It is submitted in accord with Attachment B, Paragraph B of the "Financial Assistance Reporting Requirements Checklist."

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EXECUTIVE SUMMARY

The natural gas fired-fuel cell produces electrical and thermal energy in an electrochemical reaction between natural gas fuel and oxygen from the air. The currently available phosphoric acid electrolyte cell produces about half of its energy in the form of hot (~ 175° F) water. Central Utilities Plant Design for important classes of users can exploit the "free energy," that is normally provided by fuel combustion. The avoided fuel costs are an important source of "revenue" for those users.

The fuel cell energy conversion process is inherently more efficient than any commercial chemical to electrical energy conversion process. The electrical energy conversion efficiency of the fuel cell is 44%. This represents a 10% reduction in fuel costs from any of the state-of-the-art central generating processes (and many of those proposed for distant future applications.)

- Fuel cell-based central utility plant systems, sized to meet the peak electrical demand of an application with duty cycles as low as 75%, can have a lower cost of ownership than a purchased power alternate. However, off-peak excess fuel cell capacity cannot be profitably sold to the local utility. Their buy-back rates are frequently based upon the suppliers cost of fuel and a modest energy charge. The energy charge is significant only if the power offered is dispatchable¹.
- The variation in an application's demand for thermal energy is readily manageable. Excess thermal energy produced during off-peak hours can be saved and used to meet peak consumption demands. Thermal energy production considerations should not drive fuel cell sizing considerations.

Potential applications that use or plan to use a hydronic system for space conditioning are most likely to fully utilize the energy conversion capacity of the fuel cell. This system will make the best use of all of the energy produced and ensure uninterrupted service in the event of unscheduled fuel cell-based central plant down time include a four-pipe hydronic thermal energy distribution system.

A second important use of the thermal energy from the fuel cell is air-conditioning that utilizes an absorption chiller in association with the hydronic distribution system. The economy-of-scale of larger absorption systems, combined with their lower operating costs, can make absorption chilling the most economical space conditioning system and improve the economics of the fuel cell.

¹The electrical utilities' standard offer contract include a capital recovery allowance for "dispatchable" capacity that is paid whether there is any production or not. A user plant that is sized for his own peak demand will not have extra "dispatchable" capacity. Therefore the energy charge is much lower than any practical capital recovery scenario.

The operations plant model;

- Computes fuel costs consistent with the application demand and seasonal price variations
- Computes the benefit of the avoided cost of purchasing electricity from the local utility at a price schedule that is consistent with the applications demand and daily and seasonal price variations.

Estimates the present and planned incentives to fuel cell ownership

- Provides the user with a choice of fuel cost growth forecasts to examine a variety of possible future operating scenarios.
- Develops the required cost and revenue streams that are needed as input to the Cost-of-Ownership Model.

ECONOMIC FEASIBILITY ANALYSIS OVERVIEW

This report is a description of an Operations Model of a Natural Gas-Fired Fuel Cell-Based Central Utilities Plant² that is an element of the cost of ownership model being developed for the project for "An Economic Feasibility Analysis of **"Distributed Electric Power Generation Based upon the Natural Gas-Fired Fuel Cell"**". The project is further comprised of a survey of energy users, and numeric models of an energy distribution system, capital cost of the hardware elements and an operations model. The models' output is combined with a series of ownership scenarios to drive a model of the cost of ownership of a fuel cell-based power generation system. Figure No. 1. is a diagram of the relationship among the project elements.

Figure No. 1, Elements of An Economic Feasibility Analysis of Fuel Cell-Based Power Generation

Operations Model

The business operations model computes fuel cell operating expenses based upon gas price forecasts or an input parameter. The maintenance expenses include periodic fuel cell stack refurbishment and the purchase of back-up electric power and additional space heating boiler fuel while the cell is out of service.

The revenue streams are imputed from the avoided cost of purchasing electric and thermal energy at rates appropriate to the ownership class, time of day and season. The power and thermal energy production rates are computed by the Central Utility Plant Model. An additional revenue stream is derived from investment credit, utility displacement credits or RECLAIM² permit sales or other incentives to ownership of

²RECLAIM is the recently announced program of the South Coast Air Quality Management District to create a trading market for emission permits. The emissions of a fuel cell is below the most stringent limits proposed for the year 2010. A fuel cell

the fuel cell that are under consideration to limit emissions of NO_x, SO_x and ever CO₂. In some cases the enabling legislation or regulation to support these incentives does not yet exist. Recently (especially in Southern California) these regulations have become more comprehensive and made the operation of stationary emission sources more costly. Provisions have been included in the operations model to enable the prospective owner to account for this potentially important source of revenue and public good-will.

Central Plant Utility Model

This report describes the central plant utility model and its relationship to the other elements of the project. The relationship is further illustrated by shading the appropriate portion of Figure No. 1. The central plant model sizes a fuel cell for one of several user-chosen electrical demand profiles. The thermal energy produced is a dependent variable of the electric energy computed by a model of fuel cell performance and gas consumption. The model computes the thermal energy required for space conditioning and other uses to size an absorption chiller, boiler, thermal accumulator tank and system pumps. The report on this model is complete and has been provided under separate cover.

Combined Use Energy Survey

A survey of the extensive literature on energy consumption among a variety of user classes was conducted to establish the consumption rates and the relationship between consumption of thermal and electrical energy. The literature survey was supplemented with data on consumption history contributed by 15 industrial energy users in the Southern California area. The data fell into categories of demand profiles by industry and end-use that were non-dimensionalized by peak use. The profiles were used to model the fuel cell-based utility plant that could satisfy the demand and a distribution system to deliver the thermal energy to the point of use. The survey report is complete and was submitted under separate cover.

Thermal Energy Distribution System Model

The report describes several types of thermal energy distribution systems that are suitable for the distribution of thermal energy to multiple points of use. The primary conclusion drawn from the work is that a four-pipe, hydronic distribution system is most suitable for adaptation of the fuel cell based central plant. The report on the model is complete and was submitted under separate cover.

Capital Cost Model

The model computes the capital cost of the ancillary elements of the central utility plant by scaling cost data from the R.S. Means Co.'s "Means Mechanical Cost Data, 1992" with a series of scaling relationships developed by multiple linear regression. The capacity or size of each element of the utility plant varies as a dependent variable of demand profile and user specified space conditioning loads. The capital cost of the fuel cell varies with a manufacturing learning expression. The initial value of fuel cell cost (the starting point on the learning curve) is one of the parameters of the feasibility analysis. The report on this model is complete and was submitted under separate cover.

owner should be able to sell all of their annual permit allowances on the open market. Similar programs have already been established at the federal level and will likely be emulated in other non-compliant areas of the country.

Ownership Scenarios

The treatment of revenues, expenses and incentives are dependent on the owners contractual and regulatory status with respect to the utility companies in the service area and the owner's customers for the energy produced by the fuel cell. The capital recovery period and the requisite return on investment will also vary by the class of owner, their industry and regulation.

Cost of Ownership Model

A model of the cost of fuel cell ownership is the final product of the series of models represented in Figure No. 1. The model combines the product of the capital cost model, ownership scenarios and the operations model cash flows to compute the cost of ownership. The form of the output is user selectable from a menu that includes cash flow curves, net present value as a function of capital cost and fuel cost or the internal rate of return on investment.

CENTRAL UTILITY PLANT MODEL

Introduction

The term "central utility plant" refers to the centrally located equipment of a building or set of buildings whose functions are to supply or distribute (a) electrical energy; (b) domestic hot water; (c) space heating; (d) air-conditioning; or (e) process heat. Since the fuel cell can supply some or all of the energy for these functions, it is considered part of the central plant. This model of operations of a central utilities plant computes the sources and uses of funds for the operation of a large, centrally-located plant for a modern residential complex, residential institution or industrial user. The user class is specified by the model user as part of the input for the "Central Utility Plant" that sizes the capacity of the plant to match the demand of the user.

This model accounts for the sources or avoided costs and uses of funds for the operation of the plant. The benefits (costs) of each stream of material or energy that enters or leaves the plant are computed from the capacity information computed by the Central Plant Model. Figure No. 3 is a schematic representation of the plant configuration considered. The following description of the plant is offered to clarify the model representations of cash streams. The descriptions of the associated plant functions is keyed to the nomenclature used in the schematic.

Central Utility Plant Design Description

The design of a fuel cell-based central utility plant is similar to a conventional plant design. Both systems are designed to deliver hot and chilled water to a hydronic, four pipe thermal distribution system. Figure No. 3 is a schematic of the fuel cell-based plant represented by this model of plant operations. The important features of the plant design considered include 1.) the fuel cell 2.) a large hot water storage tank 3.) a gas-fired absorption chiller for air conditioning and 4.) an additional heat transfer loop to supply hot water or steam to the chiller. 5.) An auxiliary boiler to supply additional thermal capacity beyond the capacity of the fuel cell or serve as a back-up supply for space heat in the event of an unplanned fuel cell outage.

The principle of operation and the basis for the model of cash streams described in the following paragraphs are keyed to the item numbers shown on Figure No. 3.. Other items of plant equipment that are not unique to the fuel cell system are not numbered on the schematic or represented in the model.

Figure No. 2, Fuel Cell-Based Central Utility Plant

Item 1. Fuel Cell

There are several different fuel cell technologies³ now in hardware development or entering the early stage of commercialization. The principle of operation is the same for each type of fuel cell. A natural or synthetic gaseous fuel comprised mainly of methane is reformed over a catalyst with high temperature steam to produce hydrogen and carbon monoxide. The carbon monoxide is further reacted with steam to produce additional hydrogen and carbon dioxide. The hydrogen is reacted with oxygen from the air in an electrolyte to produce an electron flow, hot water or steam and carbon dioxide. The principle of operation of each type of cell is the same. They differ only in electrolyte material and operating conditions.

³There are three types of fuel cells being considered for stationary power generating applications. The fuel cell types are designated by the electrolyte that is used for the electrochemical reaction that produces electric power and hot water or steam. The phosphoric acid electrolyte cell was recently introduced to commercial markets by ONSI Corp. A fuel cell that uses molten carbonate salts as an electrolyte is in development by a consortium, MC-Power. The first pilot plant application of this technology is under construction in the PG&E service area. The more advanced solid oxide electrolyte cell is being developed by several firms in the United States and Japan under the sponsorship of commercial interests, the Department of Energy and public utilities.

The fuel cell streams that are represented in the operations model are fueled by natural gas, produce electricity and thermal energy in the form of hot water. Cooling water is also supplied under abnormal operations. The value of the cooling stream is not modeled other than to provide for back-up electricity connections charges and the purchase of stand-by energy for space heating by the operations model

Item 2. Water Storage Tank

The fuel cell-based central utility plant design includes two water storage tanks. The potable water system provides hot water for cooking and sanitation and a second tank acts as a "thermal accumulator" for the system. The accumulator is used to smooth thermal demand peaks in residential applications. In these applications there are large surges in thermal energy (hot water) demand for bathing and cooking early in the morning and late in the evening. The tank should store the difference between the average and the peak thermal energy consumption. The average to peak ratio for residential applications is about 0.7.

Item 3. Absorption Chiller

The economic viability of the fuel cell is dependent upon productive use of the thermal energy produced by the power plant. The potential fuel cell owner should exploit the availability of the "free" thermal energy in the design of the central utility plant. The equipment in the analysis of the fuel cell-based central utility plant design includes absorption cooling for larger applications. A 200 kW phosphoric acid fuel cell produces 850,000 Btu / hr in the form of hot (~75 °C) water. This will supply 70 % of the energy required to power a 100 Ton absorption chiller.

Item 4. Heat Transfer Loop

An extra heat transfer loop transfers energy from the fuel cell hot water output and supplies the heated water to pre heat the boiler feed water. The fuel cell output temperature is too low to "fire" absorption chiller and must be boosted by the boiler. The model computes the value of the thermal energy as the cost of a quantity of natural gas to raise water to the same temperature. It also amortizes the cost of a boiler with suitable capacity over the life of the plant.

Item 5. Auxiliary Boiler

The fuel cell is used as a boiler preheater, as reflected in Figure No 3. The boiler is sized to deliver all of the thermal energy required by the application, including that normally supplied by the fuel cell. This redundancy is important in colder climates where there are health and safety issues associated with the loss of space heat (due to an unplanned outage of the fuel cell). The boiler is also used to raise the 75 °C fuel cell exit temperature to the level required in the absorption chiller concentrator loop. In very large cooling applications (over 400 tons) the fuel cell output could be used as the first stage in a multi stage absorption chiller. Later fuel cell technologies will not require the temperature boost for absorber operation.

Item 6. Cooling Tower

The cooling tower would not normally be considered unique to a fuel cell based central utilities plant installation. It is included in the model as a substitute for a coolant to air heat exchanger used in current installations. It is used to allow full electrical power production with installations that do not use the thermal energy produced by the fuel cell.

CENTRAL UTILITIES PLANT OPERATIONS MODEL

The central utility plant model computes the capacity each plant element. This includes the capacity for fuel cell production of electrical and thermal energy developed from user selected demand schedules and scaled to the appropriate load by peak demand. Thermal energy produced and natural gas consumed by the fuel cell are calculated from their relationship to electric power produced. The capacity of the ancillary equipment is also computed. Figure No. 4. is a schematic of the model logic. The titles of the model discussion sections are shown on the schematic in shadowed boxes to assist in establishing the relationship of the text to the model logic.

Figure No. 3, Central Plant Operations Model Logic

Central Utility Plant Operations Model Input

The model user has an opportunity to examine the default energy rates and forecasts. The user is asked to select from the available rate schedules and the forecast best suited to their operating situation. In the event the user wishes to change the rates or forecasts They may choose the "input New Rates" or Input

New Forecast options. The rates are entered as prices in \$ per kW for each hour of a summer day. A second set of rates for winter is also input. If the user chooses to input a different forecast they will be presented with an input screen and prompted to enter a non-dimensional growth⁴ for each year, referenced to the present rates for purchase and sale of electricity and natural gas. Table No. 2 is a copy of the model input sheet. The required user input is entered on the shaded areas. Other parameters may be changed if desired.

Table No. 2, Central Utility Plant Operations Model Input Sheet

Operations Model User Input Parameters		
The user may modify the default parameters or accept the sample values		
Parameter	Variable Name	Value
Electricity Purchase Prices		
Southern California Industrial Rates, \$ /kW hr	Industrial_Electricity_Rates	1
Southern California Residential User Rates, \$ / kWhr	Residential_Electricity_Rates	2
User Input Electrical Rates	Input_Electricity_Rates	3
Select one of the three choices, and enter it as the Electricity Rate	Electricity_Rate	1
Operations Costs and Benefits Calculated using Southern California Industrial Rates		
Electricity Rate Growth Forecast Input		
For Department of Energy Forecast, Select Electric Rate Growth = 1		
For Gas Research Institute Forecast, Select Electric Rate Growth = 2		
To Input your Own Forecast, Select Electric Rate Growth = 3		
For Constant Future Electricity Rates, Select Electric Rate Growth = 4		
Select one of the four choices, and enter it as the Electricity Rate Growth	Electricity_Rate_Growth	4
Operations Costs and Benefits Calculated Assuming No Change in Electricity Rates		
Natural Gas Prices and Growth Forecast Input		
Current Natural Gas Price, \$ / mcf	Gas_Price	\$2.50
Natural Gas Transportation Fee, \$ / mcf	Gas_Xport	\$1.20
Gas Research Institute Forecast	GRI_Gas_Forecast	1
User Forecast	User_Input_Gas_Forecast	2
Constant Future Gas Prices	Constant_Gas_Rates	3
Select one of the three choices, and enter it as the Gas Price Forecast	Gas_Price_Growth	1
Operations Costs and Benefits Calculated using GRI Gas Price Forecast		
Incentive Benefit Input		
Emission Mitigation cost, \$ / ton of NOx	NOx_Price	\$24,500
Emission Mitigation cost, \$ / ton of SOx	SOx_Price	\$18,300
Emission Mitigation cost, \$ / ton of Reactive Organic compounds	ROG_Price	\$17,500
Emission Mitigation cost, \$ / ton of PM10	PM10_Price	\$5,300
Allowable Boiler NOx Emission, lb / mmBtu Input	Boiler_NOx	0.05
Electric Utility's Allowable NOx Emission, lb / MWhr output	UEG_NOx	0.76
Electric Utility's Allowable SOx Emission, lb / MWhr output	UEG_SOx	0.00
Operating and Maintenance Cost Input		
Operating time at design capacity before major overhaul, hr	MTBO	43800
Fuel Cell Overhaul cost as fraction of capital replacement costs, DML	Overhaul	0.5
Routine maintenance as fraction of capital replacement costs, DML	O_and_M	0.05

⁴ For example if the rate growth were expected to be a constant 1.0 % per year the entry for each year would be 1.01.

Central Utility Plant Energy Supply Benefits (Avoided Costs)

The benefit of electrical power produced is the avoided cost of purchasing an equivalent amount of power at the appropriate rates. . The electricity produced by the fuel cell as a function of the time-of-day and the time of year is computed by the Central Utility Plant Model as two arrays, Winter_Power_Produced and Summer_Power_Produced. The benefit is computed as the product of the user input (or default) electrical rate and the arrays of power produced. Table No. 3 is a sample of the model output calculation of avoided costs

Table No. 3, Model Output Avoided Costs

Fuel Cell Operations Costs and Benefits Output		
Parameter	Variable Name	Value
Electricity Production		
Electricity Produced in Summer (peak rates), kWh	Summer_Power	561,987
Avoided Cost of Electricity Produced in Summer (peak rates), \$	Summer_Power_Value	\$58,594
Electricity Produced in Winter (off-peak rates), kWh	Winter_Power	1,161,755
Avoided Cost of Electricity Produced in Winter (off-peak rates), \$	Winter_Power_Value	\$115,272
Electricity Produced in Summer for Sale, MWhr	Summer_Sale_Power	0
Value of Electricity Produced in Summer for Sale, \$	Summer_Power_Sales	0
Electricity Produced in Winter for Sale, MWhr	Winter_Sale_Power	0
Value of Electricity Produced in Winter for Sale, \$	Winter_Power_Sales	0
Annual Electricity Production, MWhr	Annual_Power	1,723,742
Annual Avoided Cost of Electricity Production, \$ / yr	Annual_Power_Value	\$173,866
Thermal Energy Production		
Fuel Cell Thermal Energy Produced in Summer, mmBtu	Summer_Thermal	2,360
Combustion Thermal Energy Produced in Summer, mmBtu	Summer_Boiler_Thermal	4,389
Fuel Cell Thermal Energy Produced in Winter, mmBtu	Winter_Thermal	4,879
Combustion Thermal Energy Produced in Winter, mmBtu	Winter_Boiler_Thermal	954
Boiler Equipment Value, \$ / mmBtu	Daily_Boiler_Value	\$2.49
Avoided Cost of Thermal Energy Produced in Summer, \$	Summer_Thermal_Value	\$14,613
Cost of Combustion Thermal Energy Produced in Summer	Summer_Boiler_Thermal_Value	27,173
Avoided Cost of Thermal Energy Produced in Summer, \$	Winter_Thermal_Value	\$6,195
Avoided Cost of Thermal Energy Produced in Winter, \$	Winter_Boiler_Thermal_Value	\$31,672
Annual Thermal Energy Produced, Btu X 10 ⁶	Annual_Thermal	43,300
Annual Avoided Cost of Thermal Energy Produced, \$	Annual_Thermal_Value	\$79,654
Operations Incentive Benefits		
NOx Utility Displacement Credit (UDC)		
Utility Displacement Credit Power, MWhr	UDC_Power	1724
Utility allowable NOx Emission, Annual lb / MWhr Produced	UEG_NOx	0.76
Fuel Cell NOx Emission, Annual lb / MWhr	Fuel_Cell_Emission	0.19
NOx Production Avoided, lb / yr	UDC_NOx	983
Fuel Cell Utility Displacement NOx Credit, \$ / yr	NOx_UDC	\$12,036
NOx Emission Reduction Credit (ERC)		
Fuel Cell NOx Output, lb / yr as a boiler	Annual_Emission	175
Rule 1146 allowable NOx Output	Annual_1146_Emission	439
Fuel Cell Emission Reduction Credit (ERC)	NOx_ERC	\$3,223
Emission Reduction Incentive, \$	Annual_Incentives	\$15,259
Operations Benefits Summary		
Electricity Purchase Avoided, \$	Annual_Power_Value	\$173,866
Thermal Energy Purchase Avoided, \$	Annual_Thermal_Value	\$79,654
Operations Incentive Benefits, \$	Annual_Incentives	\$15,259

The thermal energy benefit is computed as the cost of purchasing sufficient natural gas to fire a boiler that will produce the equivalent energy in the form of hot water. The cost of the natural gas is either user input (or default). The purchase cost of a boiler to produce hot water at the necessary rate is included as part of

the avoided cost of the thermal energy produced by the fuel cell. The thermal energy purchase avoided is computed by the central utility plant model as the sum of the product of Daily Thermal energy produced and the number of Winter Days and Daily Thermal produced times the number of Summer Days. An account of seasonal production is maintained because of the variation in gas prices from winter to summer. Figure No. 4 is a sample of the model operations costs.

Table No. 4, Model Output Operations Costs

Fuel Cell Operations Costs		
Natural Gas Purchase		
Fuel Cell Summer Natural Gas Consumption, MCF	Summer_Cell_Gas	5,156
Fuel Cell Winter Natural Gas Consumption, MCF	Winter_Cell_Gas	10,659
Annual Quantity of Gas Purchased, for Fuel Cell, MCF	Annual_Cell_Gas	15,815
Auxillary Boiler Summer Fuel Consumption, MCF	Summer_Boiler_Fuel	4,651
Auxillary Boiler Winter Fuel Consumption, MCF	Winter_Boiler_Fuel	1,496
Annual Quantity of Gas Purchased, for Fuel Cell, MCF	Annual_Boiler_Fuel	6,147
Backup Purchase to provide uninterruptible wintertime space heat, M	Backup_Gas	498
Summer Natural Gas Purchase, MCF	Summer_Gas_Purchase	9,807
Winter Natural Gas Purchase, MCF	Winter_Gas_Purchase	12,653
Cost of Summer Gas Purchase, \$	Summer_Gas_Cost	\$24,517
Cost of Winter Gas Purchase	Winter_Gas_Cost	\$35,429
Annual cost of Natural Gas Purchases	Annual_Gas_Cost	\$59,947
Electricity Purchase		
Load Leveling Purchase, kWhr	Load_Level	\$0
Backup Electricity Purchase, kWhr	Backup_Power	258,561
Total Purchased Power, kWhr	Purchased_Power	258,561
Purchased Power Cost, \$	Purchased_Power_Cost	26,080
Annual Grid Connection Charge, \$	Grid_Standby_Connection	\$600
Total Purchased Power Costs, \$	Annual_Power_Costs	\$26,680
Operating and Maintenance Costs		
Routine repairs and consumables replacement, \$	Routine	\$33,770
Fuel Cell Stack Overhaul Costs	Cell_Stack	\$41,531
Operating and Maintenance Costs	Maintenance	\$75,301
Operations Costs Summary		
Natural Gas Purchases, \$	Annual_Gas_Cost	\$59,947
Electricity Purchases, \$	Annual_Power_Costs	\$26,680
Maintenance, \$	Maintenance	\$75,301
Annual Operating Costs, \$	Annual_Operating_Costs	\$161,927

Central Utility Plant Operating Costs

The operating costs of the central plant include natural gas purchased as fuel for the fuel cell and to power the utility boiler. The boiler boosts the absorption chiller input temperature and supplies back-up space heat in the event of an unplanned fuel cell outage. Air conditioning is assumed to be unavailable during a fuel cell failure. Space heat in the winter and year round back-up electrical power is provided as a health & safety measure.

The quantity of gas consumed by the fuel cell is computed by the Central Utility Plant Model as a function of the electricity produced by the fuel cell. The boiler fuel is calculated as the difference between the winter and summer demand and fuel cell production. The winter demand is for space heat and sanitary or process heat. The summer demand is for air conditioning (absorption chiller fuel) and sanitary or process heat. Back-up fuel is computed as the ratio of winter days per year times the fuel cell availability. Fuel cell outage hours are subtracted from the number of winter operating hours and added to the number of calendar hours of fuel cell stack operation between overhaul. The fuel cost is computed separately for summer and winter using the appropriate seasonal gas purchase rate.

The utility plant electrical purchase is for emergency backup, for the absorption chiller and other system pumps. The power consumed by the chiller was reduced from data supplied by the Trane Corp⁵ by a linear regression of power as a function of chilling capacity. The power required to drive the other pumps is assumed to be directly proportional to the volumetric capacity of the pumps. The number and capacity of the pumps required is computed by the central utility plant model.

The durability of the fuel cell remains an important development objective. The operations model includes provisions for parametric studies of the effect of differences in the MTBO⁶ and the MTBF⁷ and the maintenance expenses on the cost of operation of the fuel cell. The fuel cell maintenance labor expense is assumed to be a fraction of the benefits of the electrical power produced (hours of operation). The cost of maintenance materials are assumed to be 6% of the original capital purchase price. The cost of periodic major overhaul is expressed as a function of the original cell purchase price. The cost is reduced over time as additional fuel cells are produced and the effect of manufacturing "learning" reduces the cost of the overhaul. The maintenance fraction, initial cost of an overhaul, MTBO and MTBF are all input values.

Central Plant Utility Plant Incentives (Permits, Credits)

Fuel cell technology has been established for over 30 years. Despite a solid foundation of development it has not yet become a commercial alternative to electric supply by central generating stations based on rotating machinery. Further, the technology has not been considered by air quality regulators. The South

⁵Single Stage Absorption Cold Generator, 101 to 1660 Tons, The Trane Corp.

⁶MTBO is the Mean Time Between major Overhauls

⁷MTBF is the Mean Time Between Failures or the average number of hours of operation before a failure can be expected. It is also the time before about half of a large mature population is expected to fail.

Coast Air Quality Management District (SCAQMD)⁸ does not regulate emissions from fuel cells or boilers with a thermal input less than 2 million Btu. The heat input of a 200 kW fuel cells is 1.9 million Btu.

Under Rule 1134 the regulatory threshold for combined cycle turbine engines is 300 kW. The combined cycle output of a 200 kW cell is 449 kW. A combined-cycle turbine of this capacity would be allowed to emit 25 ppm NO_x or approximately 680 LB of NO_x per year. Although the technology has not yet been restricted by regulations or included as a candidate for emission credits, it is well within the range of sizes that have been addressed by regulators. The Operations model user may elect to include a stream of benefits due to emission credits for NO_x, SO_x and ROG⁹ to evaluate the effect on the economics of the enactment of regulation covering fuel cell technology.

The potentially available credits include:

Utility Displacement Credits (UDC) a utility displacement credit may be assigned to a facility that installs fuel cell which displaces the need for operation of a portion the utility company's generating capacity. The amount of the credit is based upon the emission limits of that fraction of the generating capacity. Under Rule 1135 the Southern California Edison Company is currently restricted to .76 lb NO_x/ MeW hr. This limit drops about 9% per year until 2000 when the limit will be .15 lb NO_x/ MeW hr. Under this rule a facility that installed a 1 MeW plant could initially emit 3.3 tons of NO_x from other sources. This credit is not transferable or marketable. However, using the CPUC value for a ton of NO_x the credit is potentially worth \$88,213. Similar values have been used by the SCAQMD as an upper limit for the cost of installation of equipment to remove that quantity of NO_x.

The model computes the value of the credit by multiplying the current year's utility permitted emission in lb per MeW hr times price per ton for the criteria pollutant times the annual fuel cell electrical production.

Under another scenario a fuel cell owner might retire an older piece of equipment and replace it with a fuel cell. The owner will be entitled to an **Emission Reduction Credit (ERC)** in the amount of the emissions permitted for the retired unit. The credit can be applied to other equipment in the facility, or it may be traded or transferred. In Addition, the credit for the thermal energy produced may be traded or sold at a price that may approach the CPUC abatement expense estimates for the category pollutants. The model computes the value of the ERC from the amount of the previously permitted emission times the price of the criteria pollutant.

⁸The SCAQMD is the local government agency that is responsible the formation and enforcement of air quality regulations in Southern California.

⁹ROG is the acronym used for reactive organic compounds. These compounds react with sunlight to produce a family of ozone-like compounds, a major source of air pollution.

A recent California Administrative Law Judge's finding¹⁰ will require a utility to pay an additional allowance for the purchase of electricity from "clean sources". The commission directs the utilities to compensate the independent power producers for the installation of pollution abatement equipment by an extra allowance in their payment for power under long-term (FSO4) contracts. The allowance is calculated from the utilities permitted emission level less the emission level of the proposed source (fuel cell) times the value of the criteria pollutant noted in Table No. 5.

Table No. 5, CPUC Criteria Pollutant Values

Criteria Pollutant	1987 \$ / ton
NOx	24,500
SOx	18,300
ROG	17,500
PM10	5,300

At this writing 17 Of the 50 states¹¹ have similar proposals under various stages of development. Additional information on the environmental cost of electricity is becoming available rapidly. We expect that the final report on the cost of ownership of the natural gas-fired fuel cell based central utilities plant will include significant additional benefits to the owner(s).

¹⁰CPUC D.89-07-004.

¹¹ The Environmental Cost of Electricity, Pace University

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GLOSSARY OF TERMS

Absorption chiller

The absorption chiller is a refrigeration system that uses the evaporation and condensation of a lithium bromide salt and water solution to produce refrigeration. The evaporation is driven by thermal energy as steam or hot water. The temperature of the refrigerant (gas) is reduced by transfer to a wet cooling tower. The cool gas is returned to the point of refrigeration where the condensation absorbs the heat. The hat liquid is returned to the evaporator and the process is repeated. The system has been in commercial use for a number of years. It is marketed by Trane and Rheem.

Centrifugal chiller

The centrifugal chiller is a freon vapor-cycle refrigeration system that uses a mechanically driven centrifugal compressor. These systems are common in large industrial applications where the required system capacity is from 10 to 200 tons.

Fan-coil heat exchanger

The fan-coil heat exchanger is used on hydronic space conditioning systems. They are installed at the point-of-use provide heated or chilled air. Hot and cold fluid are supplied to a temperature controlled valve that admits the correct temperature fluid to the heat exchanger coil. The heat exchanger fan circulates room air across the heat exchanger coil.

Hydronic

A hydronic space conditioning system provides heating or cooling by circulating a heat transfer fluid (usually treated water) from a central heating or chilling source to the point of use.

Potable

A potable water source delivers water that is suitable for drinking.

Turn-down performance

Turn-down performance is the performance of a machine that is operating at less than rated capacity. It is generally stated as the ratio of the performance at reduced load to the performance at full or design load. The term is commonly used to express the performance or efficiency of turbines or electrical generators.

Emission Replacement Credit (ERC)

The ERC is a credit issued by air quality regulation authorities that allows the owner of a permitted piece of equipment to install improved (lower emission) equipment and retain the permission to operate the facility at the previous, higher emission levels.

Utility Displacement Credit (UDC)

The UDC is a credit issued by air quality regulation authorities that allows the owner of a permitted electric generation facility to emit the same level of criteria pollutants that the electric utility in the service area is allowed for the same electric power produced.

APPENDIX 1, OPERATIONS MODEL EQUATIONS

The fuel cell operations model is principally an extension of the capacities and flow rates computed by the Central Utility Plant Model by the unit costs of the streams. Default unit costs are included with the model or the user may choose from among several options. Provisions are also made for user input data. The model will display a data input screen to facilitate manual input if the user chooses that option. The following equations and descriptions follow the order of the Input Parameters, Figure No. 4, Fuel Cell Operations Benefits Output, Figure No. 5 and Figure No. 6, Fuel Cell Operations Cost Output.

1. Select Electricity Rates for Avoided Cost Computations. The rates are in the form of paired arrays for each rate category as a function of the time of day. There is a winter rate and a summer rate for each category of use. The rates are expressed in \$ per kilowatt hour for each hour of the day.

$$Electricity_Rate = Rate(i) \begin{pmatrix} i = 1 \\ i = 3 \end{pmatrix}$$

where:

$Rate(1) \equiv Industrial_Electricity_Rates$

$Rate(2) \equiv Residential_Electricity_Rates$

$Rate(3) \equiv Input_Electrical_Rate$

2. Select Electricity Rate Growth Forecast or choose constant rates over the model horizon. The forecasts are in the form of arrays of the ratio of the rate in the nth year to the present rate selected by equation 1. The values in the arrays are dimensionless.

$$Electricity_Rate_Growth = Forecast(i) \begin{pmatrix} i = 1 \\ i = 4 \end{pmatrix}$$

where:

$Forecast(1) \equiv DOE_Electric_Forecast$

$Forecast(2) \equiv GRI_Electric_Forecast$

$Forecast(3) \equiv Input_Electric_Forecast$

$Forecast(4) \equiv Constant_Electric_Rates$

3. Input or select the Natural Gas Prices and transportation charges. The model default prices are the current, non-core gas and transportation prices in the Southern California Market. The model computes a winter rate from the summer input by adding a 12% differential to the summer price. The differential is the average seasonal difference in the CBOE¹² closing contract prices, as reported in the Wall Street Journal. The gas prices and transportation charges are expressed in \$ per thousand cubic feet (MCF) at standard conditions. The model also adjusts the prices to a heating value of 1000 Btu / SCF.

$$\text{Summer_Gas_Price} = \text{Gas_Price} + \text{Gas_Xport}$$

$$\text{Winter_Gas_Price} = 1.12 \times [\text{Gas_Price} + \text{Gas_Xport}]$$

4. Select Natural Gas Price Forecast or choose constant rates over the model horizon. The forecasts are in the form of arrays of the ratio of the price in the nth year to the present price selected by equation 3. The values in the arrays are dimensionless. As with the electricity forecasts, the model presents an input screen to facilitate data entry if the user forecast is chosen.

$$\text{Gas_Price_Growth} = \text{Forecast}(i) \begin{bmatrix} i = 1 \\ i = 4 \end{bmatrix}$$

where:

$$\text{Forecast}(1) \equiv \text{DOE_Gas_Forecast}$$

$$\text{Forecast}(2) \equiv \text{GRI_Gas_Forecast}$$

$$\text{Forecast}(3) \equiv \text{Input_Electric_Forecast}$$

$$\text{Forecast}(4) \equiv \text{Constant_Gas_Price}$$

5. Input Operations Incentives Prices or choose the model default. The values for the Operations Incentives used in the model are based upon the values adopted by the CPUC¹³. The values are used to judge the suitability of rate cases that include costs associated with mitigating category¹⁴ emissions. The NOx, SOx, ROG and PM10 prices are expressed in \$ / ton of category pollutant avoided per year.

$$\text{NOx_Price} = 24500$$

$$\text{SOx_Price} = 18300$$

$$\text{ROG_Price} = 17500$$

$$\text{PM}_{10}\text{-Price} = 5300$$

¹²Chicago Board of Commodities Exchange

¹³CPUC, the California Public Utilities Commission

¹⁴Category Emissions are emissions that air quality regulators have restricted by statute or regulation. They generally include oxides of nitrogen (NOx), oxides of sulfur (SOx), reactive organic gases (ROG), sometimes referred to as "ozone", and PM10. PM10 is particulate matter smaller than 10 microns in diameter.

5. (cont'd) The computation of incentive benefits is based upon emission levels of the alternate source of electrical or thermal energy. The difference between the permissible boiler emissions of NOx and the emissions of the fuel cell is used to compute the emission reduction credit (ERC). The difference between emissions from a utility electric generator's facility and the fuel cell may be used to compute the utility displacement credit (UDC). Enabling legislation at the federal or local level will be necessary to recognize the fuel cell as a source qualified to receive those credits. The boiler allowable emissions are expressed in lb / mmBTU of input fuel. The UEG emissions allowable are expressed in lb / MeWhr of electric power output.

$$Boiler_NOx = .05$$

$$UEG_NOx = .76$$

$$UEG_SOx = .00$$

6. Input Operating and Maintenance Cost parameters. The fuel cell stack requires periodic refurbishment. The wear out rate of this element of the cell is directly proportional to the power generated by the cell. The mean time between overhaul (MTBO) is expressed as the product of hr at maximum design capacity times design capacity. The cost of the overhaul, Overhaul, can be expressed as a dimensionless fraction of the original purchase price. The annual cost of other routine maintenance is also modeled as a fraction of the purchase price.

$$MTBO = 43800$$

$$Overhaul = .5$$

$$O_and_M = .05$$

7. Fuel cell Operations Benefits, Annual Electricity Production. The Quantity of electricity produce in the summer and Winter is computed by the Central plant model and passed to the Operations model. The value of the power as an avoided cost is the sum of the product of rate at time t times the power produced at time t. The value is expressed in year earned dollars to account for rate growth over time.

$$Summer_Power_Value = \sum_{n=0}^{Summer} Electricity_Rates_{Summer} \times Summer_Power$$

$$Winter_Power_Value = \sum_{n=0}^{Winter} Electricity_Rates_{Winter} \times Winter_Power$$

$$Annual_Power_Value = Summer_Power_Value + Winter_Power_Value$$

where Summer is the number of days in the summer peak rates period and Winter is the number off days in the winter off-peak rate period. The equations for calculation of the value of power produced for sale are the same as the equations for the value of the avoided cost of Annual_Power_Value using the sales power rate schedule.

8. **Fuel Cell Operations Benefits, value of thermal energy produced.** The quantity of thermal energy produced is computed by the Central Plant model and passes to the operations model. The value of the thermal energy produced as an avoided cost is the product of the gas price for the season times the sum of the number of days in the season plus the payment for a boiler of appropriate capacity. The boiler capacity is computed by the Central Plant Model and the boiler price is computed by the capital cost model. The Thermal_Value is expressed in dollars.

$$\text{Summer_Thermal_Value} = \text{PMT}(\text{Boiler_Output}) + \text{Gas_Price}_{\text{Summer}} \times \sum_{n=0}^{\text{Summer}} \text{Summer_Thermal}$$

$$\text{Winter_Thermal_Value} = +\text{PMT}(\text{Boiler_Output}) + \text{Gas_Price}_{\text{Winter}} \times \sum_{n=0}^{\text{Winter}} \text{Winter_Thermal}$$

$$\text{Annual_Thermal_Value} = \text{Summer_Thermal_Value} + \text{Winter_Thermal_Value}$$

Note that the Gas_Price is a single value where the Electricity rates are an array of prices for each hour of the day.

9. **Fuel Cell Operations Benefits, Boiler Thermal Energy Produced.** The thermal energy produced by the boiler is included in the fuel cell costs and benefits calculation for the sake of simplicity. The allocation of gas costs between the fuel cell and the boiler is mathematically complex and serves no necessary purpose in the cost-of-ownership calculation. The value of the boiler thermal energy is expressed in dollars.

$$\text{Summer_Boiler_Thermal_Value} = +\text{PMT}(\text{Boiler_Coefficient} \times (\text{Boiler_Output})^{\text{Boiler_Exponent}}) +$$

$$\text{Gas_Price}_{\text{Summer}} \times \sum_{n=0}^{\text{Summer}} \text{Summer_Boiler_Thermal}$$

$$\text{Winter_Boiler_Thermal_Value} = \text{PMT}(\text{Boiler_Coefficient} \times (\text{Boiler_Output})^{\text{Boiler_Exponent}}) +$$

$$\text{Gas_Price}_{\text{Winter}} \times \sum_{n=0}^{\text{Winter}} \text{Winter_Boiler_Thermal}$$

$$\text{Annual_Boiler_Thermal_Value} =$$

$$\text{Summer_Boiler_Thermal_Value} + \text{Winter_Boiler_Thermal_Value}$$

Where:

The spreadsheet function PMT computes the annual payment required to amortize the purchase of a boiler with thermal capacity of Boiler_Output over the Life of the central utility plant.

The Boiler_Coefficient and Boiler_Exponent are terms developed for the Capital Cost model from a multiple linear regression on boiler cost as a function of heating capacity.

10. Operations Incentives Benefits. The operations incentive benefits are comprised of ERC and UDC benefits as described in equation(s) 5.

$$NOx_UDC = UDC_Power \times NOx_Price \times (UEG_NOx - Fuel_Cell_Emission)$$

$$Annual_Emission = (Fuel_Cell_Emission \times Annual_Cell_Gas \times (Hrate / (Hrate + Hrate \times Electrical_Capacity))) / 1000$$

$$NOx_ERC = NOx_Price \times (Annual_1146_Emission - Annual_Emission)$$

Where:

Hrate is the thermal energy produced per kW of electrical Energy, Btu / kWhr

Electrical_Capacity is the fuel cell design output, kW

NOx_UDC is the NOx Utility Displacement Credit, \$ and

NOx_ERC is the NOx Emission Reduction Credit, \$

11. Fuel Cell Operations Costs, Natural Gas Purchase. The gas consumption of the fuel cell, absorption chiller and the auxiliary boiler is computed by the Central Utilities Plant model and passed to the Operations model. The Operations model computes the gas cost from the appropriate seasonal rate. The quantity of Backup_Gas is computed from the annual heating requirement in Btu and the Availability of the fuel cell. Gas costs are expressed in \$, and Cell_Gas, Backup_Gas and Boiler_Fuel are expressed in MCF. Gas_Price is input as \$ / MCF.

$$Summer_Gas_Cost = Summer_Gas_Price \times (Summer_Cell_Gas + Summer_Boiler_Fuel)$$

$$Backup_Gas = Heating \times (1 - Availability) / 10^6$$

$$Winter_Gas_Cost = Winter_Gas_Price \times (Winter_Cell_Gas + Winter_Boiler_Fuel + Backup_Gas)$$

$$Annual_Gas_Cost = Summer_Gas_Cost + Winter_Gas_Cost$$

Note: The model assumes that backup boiler fuel for space heating during fuel cell service interruption is required during the winter season.

12. Operations Costs, Electricity Purchases of Load Leveling and Back-up power. Load-leveling power may be required if peak application(s) demand exceeds the electrical capacity of the fuel cell. The Load_Leveling_Power is computed from the number of days in the season times sum of the product of the generating shortfall times the appropriate seasonal rate. Demand is expressed in kWhr, Peak_Industrial and off_Peak Industrial electrical rates are expressed in \$ / kWhr

$$\text{if } (Electric_Demand(t) > Electric_Capacity, Summer_Load_leveling_Value =$$

$$Summer \times \sum_{t=0}^{t=24} ((Demand(t) - Electric_Capacity) \times Industrial_Peak), Load_Leveling = 0)$$

$$\text{if } (Electric_Demand(t) > Electric_Capacity, Winter_Load_leveling_Value =$$

$$Winter \times \sum_{t=0}^{t=24} ((Demand(t) - Electric_Capacity) \times Industrial_OffPeak), Load_Leveling = 0)$$

$$Backup_Power = (1 - Availability) \times (Summer_Power_Value + Winter_Power_Value)$$

$$Power_Purchase = Summer_Load_Leveling_Value + Winter_Load_Leveling_Value + Backup_Power$$

13. Operating and Maintenance Cost, Routine repairs and the replacement of fuel cell consumables. The cost of routine maintenance is assumed to be from 3 to 10%. If an overhauled Cell stack lasts 5 years and the cost of the overhaul is 25% of the purchase price the annualized overhaul cost is 5% of the purchase price. This added to routine maintenance of about 5% per year brings the maintenance costs to

10% per year, well within industry norms for sophisticated electro-mechanical equipment. The original fuel cell purchase price is fed to the operations model by the capital cost model. The MTBO, ratio of overhaul cost to purchase price and the fraction of purchase price attributable to routine maintenance are input constants to the operations model. Routine, Cell_Stack and Maintenance are all expressed in dollars

$$O_and_M = .05$$

$$Routine = Cell_Cost \times O_and_M$$

$$Cell_Stack = Overhaul \times Cell_Cost \times Annual_Power / (MTBO \times Electrical_Capacity)$$

$$Maintenance = Routine + Cell_Stack$$

APPENDIX 2, LIST OF MODEL VARIABLE NAMES

Absorption_DelP	class
AC_Thermal_Booster	Class_I_Electric
Accumulator_Coefficient	Class_I_Thermal
Accumulator_Cost	Class_II_Electric
Accumulator_Exponent	Class_II_Thermal
Air_Conditioning	Class_III_Electric
Air_conditioning_chiller_capacity_tons	Class_III_Thermal
Annual_1146_Emission	Class_IV_Electric
Annual_Emission	Class_IV_Thermal
Annual_Gas_Cost	ClassI_Electric
Annual_Incentives	Concentrator_Pump_Capacity
Annual_Operating_Costs	Concentrator_Pump_Cost
Annual_Power	Constant_Electric_Rates
Annual_Power_Costs	Constant_Gas_Rates
Annual_Power_Value	Convert
Annual_Thermal	Cooling
Annual_Thermal_Demand	Cooling_Pump_Capacity
Annual_Thermal_Value	Cooling_Pump_Cost
Application_Electrical_Demand	Cooling_Pump_Power
Application_Thermal_Demand	Cooling_Tower_Capacity
Availability	Daily_Boiler_Value
Backup_Gas	Daily_Gas_Consumed
Backup_Power	Daily_Power
Boiler_Coefficient	Daily_Thermal
Boiler_Cost	Day
Boiler_Efficiency	DOE_Electric_Forecast
Boiler_exponent	Domestic_DelT
Boiler_Fuel	Elec_Demand_to_Peak_Ratio
Boiler_NOx	Electric_Demand
Boiler_Output	Electrical_Capacity
Btu_perTon_Hr	Electricity_Rate
CEC_Gas_Forecast	Electricity_Rate_Growth
Cell_Cost	Excess_Thermal_Produced
Cell_Cost_Rate	First_Price
Cell_Stack	Fraction_Fuel
Chiller_Coefficient	Fraction_Thermal
Chiller_Cost	Fuel_Cell_Emission
Chiller_Exponent	Fuel_Cell_NOx
Chiller_Pump_Capacity_hp	Gas_Price
Chiller_Pump_Power	

APPENDIX 2., CONT'D

Gas_Price_Growth	Plant_Capital_Cost
Gas_Xport	PM10_Price
Gasrate	Population
GRI_Electric_Forecast	Print_Area
GRI_Gas_Forecast	Pump_Cost_Coefficient
Grid_Connection	Pump_cost_Exponent
Grid_Standby_Connection	Purchased_Power
Growth_Rate	Purchased_Power_Cost
Heating	Residential_Electricity_Rates
Heating_Pump_Capacity	Residential_Off_Peak
Heating_Pump_Cost	Residential_Peak
Heating_Pump_Power	ROG_Price
Heating_Value	Routine
Hot_Water_Pump__Power	SOx_Price
Hot_Water_Pump_Capacity	Space_Cooling_DelT
Hrate	Space_cooling_pump_capacity_gal_per_min.
Industrial_Electricity_Rates	Space_Heat_Capacity
Industrial_Off_Peak	Space_Heat_DelT
Industrial_Peak	Summer
Input_Electricity_Rates	Summer
Input_Off_Peak	Summer_Boiler_Fuel
Input_Peak	Summer_Boiler_Thermal
Installation	Summer_Boiler_Thermal_Value
Interest	Summer_Cell_Gas
kWhr_per_hp	Summer_Chiller_Fuel
Lb_per_Gallon	Summer_Demand
Learning	Summer_Gas_Cost
Life	Summer_Gas_Price
Load_Level	Summer_Gas_Purchase
Loop_DelP	Summer_Power
Maintenance	Summer_Power_Sales
Makeup_Boiler_Capacity	Summer_Power_Value
Miscellaneous_Equipmant	Summer_Sale_Power
Miscellaneous_Equipment_Costs	Summer_Thermal
MTBO	Summer_Thermal_Demand
NOx_Emission	Summer_Thermal_Value
NOx_ERC	Thermal_accumulator_tank_capacity_gal.
NOx_Price	Thermal_Capacity
NOx_UDC	Thermal_Demand
O_and_M	Thermal_Demand_to_Peak_Ratio
Other_Thermal	Thermal_Output_Ratio
Overhaul	Tower_Coefficient
Peak_Electrical	Tower_Cost
Peak_Thermal	Tower_DelT

APPENDIX 2., CONT'D

Tower_Pump_Capacity
Tower_Pump_Cost
Tower_Pump_Power
UDC_NOx
UDC_Power
UEG_NOx
UEG_SOx
User_Class
User_Input_Electric_Forecast
User_Input_Forecast
User_Input_Gas_Forecast
Volume
Water_Pump_Capacity
Water_Pump_Cost
Winter
Winter_Boiler_Fuel
Winter_Boiler_Thermal_Value
Winter_Cell_Gas
Winter_Demand
Winter_Gas_Cost
Winter_Gas_Price
Winter_Gas_Purchase
Winter_Natural_Gas_Purchase
Winter_Power
Winter_Power_Sales
Winter_Power_Value
Winter_Sale_Power
Winter_Thermal
Winter_Thermal_Demand
Winter_Thermal_Value
Year

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