1 of 1

**A Model of the Capital Cost of a
Natural Gas-Fired Fuel Cell-Based Utilities Plant**

Topical Report

June 1993

Work Performed Under Contract No.: DE-FC21-92MC29227

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

**By
The Southern California Gas Company
Research Department
Los Angeles, California**

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MASTER

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ABSTRACT

The "Capital Cost Model" is the fifth 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 defines the methods used in the Economic Analysis to estimate the cost associated with acquisition and installation of the capital equipment of the fuel cell systems defined by the central utility plant model.

The capital cost model estimates the cost of acquiring and installing the fuel cell unit, and all auxiliary equipment such as a boiler, air conditioning, hot water storage, and pumps. The model provides a means to adjust the initial cost estimates to consider learning associated with the projected level of production and installation of fuel cell systems. The capital cost estimate is an input to the cost of ownership analysis where it is combined with the operating cost and revenue model estimates.

Keywords: Capital Cost, Installation, Fuel Cell, Economic Analysis, Thermal Energy Distribution, Distributed Power Generation, Feasibility Analysis, Central Plant Configuration

FOREWORD

his 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, A Model for Estimating the Capital Cost of a Natural Gas-Fired Fuel Cell, is the fifth 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

This report presents methods for estimating the capital cost of the several types of central utility plant systems configurations described in the Central Utility Plant Model Report.

The capital cost model :

- estimates capital cost associated with the design capacity of the fuel cell defined by the central utility plant model,
- estimates the installation and start-up costs associated with the design capacity of the fuel cell defined by the central utility plant model,
- adjusts the estimated cost to allow for industry improvement in production and installation costs as the number of fuel cell applications increase, and
- provides a total capital cost value for each equipment scenario specified in the cost of ownership model.

ECONOMIC FEASIBILITY ANALYSIS OVERVIEW

This report describes the **Capital Cost Model** of the fuel cell and ancillary elements of the central utility plant. The cost of ancillary equipment is forecast by scaling cost data from the R. S. Means Co.'s "Means Mechanical Cost Data, 1992" with a series of 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 an important parameters of the feasibility analysis.

The "*Economic Feasibility Analysis of Distributed Electric Power Generation Based upon the Natural Gas-Fired Fuel Cell*" is comprised of a survey of energy users, the development of numeric models of an energy distribution system and a central plant utilities system that includes a fuel cell. A model of the capital cost of the hardware elements is combined with a series of ownership scenarios and an operations model that provide the necessary input for a model of the cost of ownership of a fuel cell-based power generation system. The relationship among these elements of the project is represented by Figure No. 1.

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

Combined Use Energy Survey

A survey of the extensive literature on energy consumption among a variety of user classes was conducted. It established 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 demand on the fuel cell-based utility plant.

Central Plant Utility Model

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.

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.

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.

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 stream is 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 RECLAIM¹ permit sales. In some cases the enabling legislation to support these incentives does not yet exist. Provisions have been included in the operations model to enable the prospective owner to account for this important source of revenue and public good-will.

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. The variety of output forms has been chosen to accommodate the expected interests of the variety of industries that will evaluate the Economic Feasibility of Distributed Electric Power Generation Based on the Natural Gas-Fired Fuel Cell.

¹RECLAIM 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 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.

INTRODUCTION

Fuel cell capital costs are a function of the fuel cell size and systems capacity. The fuel cell size and capacity are selected when the Central Utility Plant configuration is selected. The Capital Cost Model estimates the acquisition and installation costs associated with the size and configuration of the selected Central Utility Plant configuration.

CENTRAL 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 capital costs.

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. 6.) plant cooling Tower. The principle of plant operation and the basis for the model of capital costs 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. 3., Utility Plant Capital Cost Model Elements

Item 1. Fuel Cell

There are several different fuel cell technologies² 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.

The fuel cell streams that are represented in the operations model are fueled by natural gas and produce electricity and thermal energy in the form of hot water. Cooling water is also supplied to the fuel cell 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.

²There 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.

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 loop is comprised of a heat exchanger and a number of circulating pumps. 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 suitable boiler over the life of the plant.

Item 5. Auxillary 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.

CAPITAL COST MODEL STRUCTURE

The capital cost model uses the systems capacity parameters defined in the Central Utility Plant model to estimate the cost of acquiring and installing the fuel cell system. The procurement cost for the hardware are estimated based upon the size of the system and the number of systems in use. for the balance of plant equipment, the per unit cost is estimated by multiplying the capacity of the unit by a cost factor. The cost factor is a linear regression of the capacity of each hardware element and the published cost of the unit in 1992 dollars. The detail data and the results of the multiple linear regression computation are included in Appendix 1.

Model Input

The model is directly linked to the Central Utility Plant Model for input. The user is also given the option of direct input to the model. Table No. 1 is a reproduction of the model input sheet.

Table No. 1, Capital Cost Model Input Sheet

Central Utility Plant Capital Cost Model User Input Parameters		Parameter Name	Parameter Value
Fuel Cell			
Electric power generation capacity, kW		320	320
Fuel Cell market growth rate, kW per year		Growth_Rate	133,333
Manufacturing learning rate, %		Learning	96
Initial price, \$ per kW		First_Price	2500
Total capacity in operation when purchased, kW		Population	2000
Installation cost, % of purchase price		Installation	10%
Boiler			
Boiler Capacity, Btu per hour		750000	750000
Boiler cost capacity coefficient, \$ per 1000 Btu		Boiler_Coefficient	73.88
Boiler cost capacity exponent, DMLS		Boiler_exponent	0.72
Air Conditioning			
Air conditioning chiller capacity, tons		Air_Conditioning	200
Chiller cost capacity coefficient, \$ per ton		Chiller_Coefficient	2526
Chiller cost capacity exponent, DMLS		Chiller_Exponent	0.7083
Hot Water Storage Tank			
Thermal accumulator tank capacity, gal.		Volume	1878
Accumulator cost capacity coefficient, \$ per ton		Accumulator_Coefficient	252.8
Accumulator cost capacity exponent, DMLS		Accumulator_Exponent	0.6694
Cooling Tower			
Cooling Tower Capacity, refrigeration tons		Cooling_Tower_Capacity	400
Cooling tower cost capacity coefficient, \$ per refrigerant ton		Tower_Coefficient	72
System Pumps, miscellaneous hardware			
Space Cooling pump capacity, hp		Cooling_Pump_Capacity	3.23
Space Heating pump capacity, hp		Heating_Pump_Capacity	0.60
Domestic hot water pump capacity, hp		Hot_Water_Pump_Capacity	0.16
Chiller_Pump_Capacity		Chiller_Pump_Capacity, hp	5.59
Tower pump capacity, hp.		Tower_Pump_Capacity	4.19
Pump cost capacity coefficient, \$ per hp		Pump_Cost_Coefficient	3097
Pump cost capacity exponent		Pump_cost_Exponent	0.1503

Cost Model Equations

The capital cost model uses the results of the Central Utility Plant Model that defines the elements of the plant and their capacity. In addition, the model requires an estimate of size of the fuel cell market. This is used to predict the appropriate position on the manufacturing learning curve for both the fuel cell unit and the installation cost.

Capital Equipment

The cost of the central utility plant configuration of the fuel cell system is comprised of fixed capital equipment, installation and start-up.³ The capital equipment of the fuel cell central utility plant include

³ All costs associated with replacing capital equipment, such as the fuel cell stack, are a function of the predicted operating profile of the fuel cell. Therefore, the costs associated with replacing the fuel cell stack are included in maintenance portion of the Operations Model.

(1) the fuel cell plant, including the cell stack ⁴,

and

(2) the balance of plant equipment associated with the plant system.

Acquisition Cost

Acquisition Cost for the primary capital equipment is estimated by summing the estimated cost of the capital equipment defined by the Central Utility Plant Model along with use taxes and the cost of transportation to the fuel cell site. The installation costs are also included with each item of capital equipment as described on Page 8, following.

$$C_{\text{Plant}} = C_{\text{FC}} + C_{\text{B}} + C_{\text{AC}} + C_{\text{TA}} + C_{\text{CT}} + C_{\text{ME}} + T + T_x$$

Where:

C_{Plant} = Central Plant Acquisition Capital Equipment Cost

C_{FC} = Fuel Cell Cost+ Fuel Cell Installation Cost

C_{B} = Boiler Cost + Boiler Installation Costs

C_{AC} = Air Conditioning Unit (s) Cost + Air Conditioning Installation Cost

C_{TA} = Thermal Accumulator Equipment Cost +Thermal Accumulator Installation Cost

C_{CT} = Cooling Tower Cost + Cooling Tower Installation Cost

C_{ME} = Miscellaneous Equipment Cost +Miscellaneous Equipment Installation Cost

T = Transportation Costs

T_x = Use Taxes

The model estimates the equipment cost as a function of the capacity, output or size of each type of equipment. The general expression for each cost estimating relations is:

$$C_x = \text{Capacity} \times \text{Cost Factor}$$

Where:

C_x = the capital cost of equipment X

⁴ Currently the phosphoric Acid fuel cell capital cost is approximately \$2,500 per kilowatt.

Capacity = The performance capacity of the equipment, i.e cooling capacity of an air conditioning unit is expressed in tons.

Cost Factor = The estimating relationship factor developed for the equipment item from historical and industry data sources. The factor is a least squares regression fit of per unit cost to the capacity unit term related to the equipment item.

The expression and coefficients for each type of equipment are derived by correlating the per unit cost to the equipment capacities or output. The per unit costs includes acquisition costs, use taxes, transportation, site engineering, ancillary equipment, installation labor, and the necessary building and operation permits and fees. This approach should not affect the conclusions drawn from the model results since each of the elements of equipment cost are proportional to capacity or fuel cell acquisition cost and the fuel cell cost is treated as a parameter rather than a dependant variable.

Site and Installation Cost

The elements of the site and installation costs that were included in developing the equations for each item of capital equipment are engineering, permitting, construction and startup costs. The model equations for learning were developed from data from 10 recent installations Southern California. The elements of cost were combined into a single value for acquisition that included all of the costs that are proportional to acquisition cost.

$$C_I = C_E + C_P + C_{Con} + C_{S/T}$$

Where:

- C_I = Installation Cost for the Fuel Cell System
- C_E = Cost of Engineering
- C_P = Cost of Permits and Licenses
- C_{Con} = Cost of Construction
- $C_{S/T}$ = Cost of start-up and initial systems tests

Engineering Cost (C_E).- The model estimates the cost of engineering to be approximately 5 percent of the original equipment cost. This is consistent with the experience on the first ten units installed in southern California during 1992 and 1993.

Permits and Licenses (C_P).- The submission of applications to the permitting authority, support during the permitting process and payment of the appropriate fees are estimated to be approximately 1 percent of the fuel cell cost.

Construction (C_{Con}).- Construction of the fuel cell site including all utilities, foundations and electrical power connections are estimated to be 25 percent of the fuel cell cost.

The results of a sample calculation of the capital costs of a fuel cell based central utility plant are presented in Table No. 2.

Fuel Cell Unit Cost (C_{FC}).-

$$C_{fc} = (E_{fc} \times C_{kW}) / (N)^{(2-\text{LOG}(L))/\text{LOG}(M)}$$

Where

C_{FC} = Cost of the fuel cell

E_{FC} = Fuel Cell electrical capacity in kW

C_{kW} = Cost of the fuel cell per kW of electric capacity in \$ / kW

U_{FC} = Unit price of the fuel cell unit after having produced M units

N = Number of fuel cell units produced at the time of the installation

M = Number of fuel cell units produced at the time the cost C_{kW} was evaluated

L = the assumed learning curve slope

Auxiliary Equipment Cost (Balance of Plant)

Virtually all of the balance of plant equipment may vary in size depending upon the energy consumption characteristics of the given user. The equipment with the greatest variability in size (and cost) will be the boilers, chillers, storage tanks, and cooling towers. Piping, pumps, controls, and heat exchangers there will be much less variability in size and cost, depending on the individual user.

Boiler (C_B):-

$$C_b = 73.87 \times (O / 1000)^{.7153}$$

Where:

C_B = Cost of the boiler in the central utility plant configuration

O = Boiler capacity in Btu / hr

Air Conditioning (C_{AC})

$$C_{ac} = 2526 \times (AC_t)^{.7083}$$

Where:

AC_T = Air Conditioning Chiller Capacity in tons

Thermal Accumulator Tank (C_{TA})

$$C_{C_{ta}} = 109.84 \times (T_{hw})^{.6894}$$

Where:

T_{HW} = Thermal Accumulator Tank Capacity in gallons

Cooling Tower (C_{CT})

$$C_{ct} = 72.00 \times CT_t$$

Where:

CT_T = Cooling tower cooling capacity in tons of refrigeration

Miscellaneous Hardware (C_{ME})

Air Conditioning Loop Pump

$$C_{pac} = 3108 \times (P_{pac})^{.1431}$$

Space Conditioning Loop Pump

$$C_{sc} = 3108 \times (P_{sc})^{.1431}$$

Domestic Hot Water Loop Pump

$$C_{ahw} = 3108 \times (P_{shw})^{.1431}$$

Cooling Tower Water Loop Pump

$$C_{atw} = 3108 \times (P_{stw})^{.1431}$$

Table No. 2, Capital Cost Model Output Sheet

CENTRAL UTILITY PLANT SYSTEM CAPITAL COST MODEL		Parameter Name	Parameter Value
Fuel Cell			
Fuel Cell Electrical Capacity, kW		320	320
Fuel Cell Cost, \$ per kW		Cell_Cost_Rate	\$2,111
Fuel Cell Capital Cost		Cell_Cost	\$675,390
Boiler			
Boiler Capital Cost, \$		Boiler_Cost	\$8,415
Air Conditioning			
Space Cooling Absorption Chiller Cost		Chiller_Cost	\$107,726
Hot Water Storage Tank			
Thermal Accumulator Tank Cost, \$		Accumulator_Cost	\$39,275
Cooling Tower			
Cooling Tower Cost, \$		Tower_Cost	\$28,800
Miscellaneous Equipment			
Air Conditioning Loop Pump Cost, \$		Cooling_Pump_Cost	\$3,694
Space Conditioning Loop Pump Cost, \$		Heating_Pump_Cost	\$2,865
Domestic Hot Water Loop Pump Cost, \$		Water_Pump_Cost	\$2,352
Concentrator Loop Pump Cost, \$		Concentrator_Pump_Cost	\$4,012
Cooling Tower Water Loop Pump Cost, \$		Tower_Pump_Cost	\$3,842
Total Miscellaneous Equipment Costs, \$		Miscellaneous_Equipment	\$16,765
CENTRAL UTILITY PLANT CAPITAL COST SUMMARY			
Fuel Cell Capital Cost		Cell_Cost	\$675,390
Boiler Capital Cost, \$		Boiler_Cost	\$8,415
Space Cooling Absorption Chiller Cost		Chiller_Cost	\$107,726
Thermal Accumulator Tank Cost, \$		Accumulator_Cost	\$39,275
Cooling Tower Cost, \$		Tower_Cost	\$28,800
Total Miscellaneous Equipment Costs, \$		Miscellaneous_Equipment	\$16,765
Central Utility Plant Capital Cost, \$		Plant_Capital_Cost	\$876,371
Trial Capital Cost Component of \$/kW*hr			0.0227
Fuel Cell Refurbishment			0.0241

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APPENDIX 1, EQUIPMENT COST TABLES

The following is a list of the equipment discussed previously along with their associated costs broken down by the size or type of the equipment: ⁵

Material costs is the actual bare material cost as gathered from manufacturers, dealers, and distributors. It does not include sales tax.

Labor costs are based on the type of crew necessary, the average productivity, and the hours necessary.

Equipment costs are the rental and operating & maintenance costs for equipment necessary for installation of the item of interest.

Total costs including overhead and profit represents the initial costs plus 10% of the material and equipment costs, and 10-18% of the labor costs (depending on the type of crew necessary).

⁵ The primary source for this information is from construction/ engineering cost estimating guides such as Means Mechanical Cost Data 1992, and Means Facilities Cost Data 1987.

Absorption Chiller Cost

Capacity Tons	Material Cost, \$	Installation hours	Installation Cost @\$25/hr	Installed Cost, \$	Mtl Hand'g Profit, \$	Total Cost, \$
101	50344	221	5519	55863	10553	66417
200	81545	361	9028	90573	17183	107756
230	90000	399	9985	99985	18985	118969
288	105484	470	11740	117224	22289	139513
336	117610	525	13119	130729	24880	155609
432	140439	629	15723	156162	29767	185930
480	151282	679	16963	168245	32091	200337
768	210803	952	23799	234602	44879	279481
960	246766	1118	27949	274715	52626	327341
1056	263939	1197	29936	293875	56330	350205

Absorption Chiller Costs

X Capacity, tons	Y Costs, \$	Log X Log(Capacity)	Log Y Log (Cost)	Y Calc Cost, \$
101	66,417	2.0043	4.8223	66,415
200	107,756	2.3010	5.0324	107,756
230	118,969	2.3617	5.0754	118,970
288	139,513	2.4594	5.1446	139,514
336	155,609	2.5263	5.1920	155,611
432	185,930	2.6355	5.2693	185,931
480	200,337	2.6812	5.3018	200,338
768	279,481	2.8854	5.4464	279,480
960	327,341	2.9823	5.5150	327,339
1056	350,205	3.0237	5.5443	350,201
		0.7083	3.4025	2526
		3.9398E-06	1.026E-05	
		1	3.81809E-06	
		3.2325E+10	8	
		0.47122958	1.16623E-10	

Gas Fired Boiler Costs

Capacity Btu X 1000	Material Cost \$	Installation hours	Installation Cost @\$25	Installed Cost,\$	Mtl Hand'g Profit	Total Cost,\$
100	1,125	24	600	1,725	713	2,438
203	1,760	32	810	2,570	986	3,556
320	2,540	40	1,000	3,540	1,254	4,794
440	3,310	49	1,250	4,560	1,581	6,141
544	4,460	53	1,350	5,810	1,796	7,606
765	5,770	58	1,475	7,245	2,052	9,297
1088	7,610	64	1,625	9,235	2,386	11,621
2000	13,200	84	2,125	15,325	3,445	18,770
5520	37,750	228	5,775	43,525	9,550	53,075

Last Data point not used for regression

Boiler Costs less last data point

X Capacity, 1000 Btu	Y Cost, \$	Log X Log Capacity	Log Y Log Cost	Y Calc Calculated Cost
100	2,150	2.0000	3.3324	1,991
203	3,150	2.3075	3.4983	3,304
320	4,325	2.5051	3.6360	4,575
440	5,525	2.6435	3.7423	5,745
544	6,925	2.7356	3.8404	6,686
765	8,575	2.8837	3.9332	8,533
1088	10,800	3.0366	4.0334	10,978
2000	17,700	3.3010	4.2480	16,968
		0.7153	1.8685	73.87
		0.0207	0.0559	
		0.9950	0.0225	
		1199.1799	6.0000	
		0.6091	0.0030	

Pressure Pump Costs

Capacity hp	Material Cost, \$	Installation hours	Installation Cost @\$25/hr	Installed Cost, \$	Mtl Hand'g Profit, \$	Total Cost, \$
1.00	2335	12.30	307.50	2642.50	574.63	3217.13
1.50	2365	12.80	320.00	2685.00	585.00	3270.00
2.00	2440	13.30	332.50	2772.50	604.38	3376.88
3.00	2550	14.50	362.50	2912.50	636.88	3549.38
5.00	2752	16.00	400.00	3152.00	690.40	3842.40
7.50	3025	16.90	422.50	3447.50	752.88	4200.38

Pressure Pump Costs

X	Y	Log X	Log Y	Y Calc
1.00	3217.13	0.0000	3.5075	3108.48
1.50	3270.00	0.1761	3.5145	3294.21
2.00	3376.88	0.3010	3.5285	3432.68
3.00	3549.38	0.4771	3.5502	3637.78
5.00	3842.40	0.6990	3.5846	3913.72
7.50	4200.38	0.8751	3.6233	4147.56
10.00	4408.13	1.0000	3.6443	4321.90
	0.1431	3.4925	3108.4798	
	0.0117	0.0071		
	0.9676	0.0106		
	149.5140	5.0000		

Hot Water Storage Tank

Capacity Gal	Material t Cost, \$	Installation hours	Installation Cost @\$25/hr	Installed Cost, \$	Mtl Hand'g Profit, \$	Total Cost, \$
225	3,540	4	100	3,640	372	4,012
460	6,190	4	100	6,290	637	6,927
740	8,400	4	100	8,500	858	9,358
940	9,730	4	100	9,830	991	10,821
1,505	12,550	4	100	12,650	1,273	13,923
3,815	25,200	4	100	25,300	2,538	27,838

Water Storage Tank Costs

X Capacity, Gallons	Y Cost, \$	Log X Log Capacity	Log Y Log Cost	Y Calc Calculated Cost, \$
225	4,012	2.3522	3.6034	4,125
460	6,927	2.6628	3.8405	6,658
740	9,358	2.8692	3.9712	9,153
940	10,821	2.9731	4.0343	10,743
1505	13,923	3.1775	4.1437	14,721
3815	27,838	3.5815	4.4446	27,440
		0.6694	2.0407	109.84
		0.0181	0.0535	
		0.9971	0.0171	
		1373.4011	4.0000	
		0.4017	0.0012	

Cooling Tower Costs

Cooling Tower costs are liner (directly proportional) with capacity

Capacity Ton	Material Cost, \$	Installation hours	Installation Cost @\$25/hr	Installed Cost,\$	Mtl Hand'g Profit, \$	Total Cost, \$
1	59	0.25	6.25	65.25	7.025	72

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	Gas_Price_Growth

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
Plant_Capital_Cost	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

**DATE
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