A SIMPLIFIED SELF-HELP APPROACH TO SIZING OF SMALL-SCALE COGENERATION SYSTEMS

A Report Submitted to

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by

S. Somasundaram, Ph.D., P.E.
W. D. Turner, Ph.D., P.E.

Energy Systems Laboratory
Mechanical Engineering Department
Texas A&M University
College Station, Texas 77843

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Summary

The following report is a description of a simplified and a self-help approach to determining the economic feasibility of a small-scale cogeneration system. It has been compiled for use by the energy managers/physical plant directors of various Texas state agencies, so that an initial screening of the potential candidates for cogeneration can be made.

The technique used in this study is extremely simple, and certain optimistic assumptions have been made to facilitate the approach. An approximate feasibility of a cogeneration system will be determined simply from the available billing data for electricity and natural gas use at the state agency. If the decision for a system is deemed to be "GO" or "POSSIBLE" on the basis of this initial screening, then the state agency/building complex will be considered a prime candidate for a more detailed feasibility analysis.

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Glossary of Terms

Electrical energy	Consumption measured in kilowatt-hours (KWH). 1 KWH = 1,000 watt-hours.
Electrical demand	Electrical power consumed measured in kilowatts (KW). 1 KW = 1,000 watts.
Natural gas consumption	Measured in thousands of cubic feet or in MCF. 1 MCF = 1,000 ft^3 of volume 1 CCF = 100 ft^3 of volume
Simple payback	Period of time (years) over which a capital investment loan is paid back.
Thermal energy	Energy obtained by burning a thousand cubic feet of natural gas is measured in terms of Btu (British Thermal Unit). 1 MCF = 1,000,000 Btu.
Thermal load	Thermal energy consumed per hour measured in Btu/hour.
Capital investment cost	The total cost for design, engineering and installation of the cogeneration system.
Thermal energy utilization (TU)	Measured in percentage, is the fraction of the total thermal energy output of the cogeneration system that a plant can use.
Efficiency	(η) of the boiler is given by

$$\eta = \frac{\text{Thermal energy output}}{\text{Thermal energy equivalent input of fuel}}$$

AN ANALYSIS OF SMALL-SCALE COGENERATION SYSTEMS

Introduction

Cogeneration is the sequential production of electrical energy and useful thermal energy from a single fuel source. In comparison to conventional systems that produce electrical and thermal energy separately, cogeneration is 10 to 30 percent more efficient.

Many cogeneration applications for buildings are best served by small-scale systems such as a combustion turbine or engine coupled with a generator and a waste heat boiler. Natural gas and light fuel oils are the fuels best suited to these systems. Gas-fired cogeneration systems are of the most interest to state agencies because of their high efficiencies and the current availability of cheap natural gas to the state.

The term "small-scale cogeneration systems" used in this report refers to mass- or semi-mass-produced, packaged cogeneration systems, which use a wide range of conventional fuels (natural gas, diesel fuel, gasoline or propane) and well-developed engines and generator sets. The packaged units are skid-mounted with appropriate controls and electrical switchgear included for ease of installation. Heat recovery systems can either be packaged or added at the site. The packaged units can be enclosed for outdoor installation, and installation time can be as short as one day. The analysis of small-scale cogeneration systems included in this report is for system capacities ranging from 20 KW up to about 1100 KW.

This report describes a "do-it-yourself" method of economic analysis to determine the feasibility of a cogeneration system for a particular building/complex. It is intended for use by individual power plant managers/directors to allow them to do an initial screening. If, after the screening, a cogeneration system is found to be feasible, then a more detailed engineering study can be considered.

The screening procedure is based solely on the price of electricity and natural gas and the percentage of thermal energy utilized. In certain utility areas, the electrical power rates may be too low or the natural gas prices too high which will preclude any chance of an economic cogeneration system. The present approach is to make certain, fairly optimistic assumptions as to the efficiency and performance of the system. If the building/complex does not indicate cost effectiveness for a cogeneration system, it can then be eliminated from further consideration.

Method of Analysis

The analysis is based on a simple payback period (in years) for the capital cost of the cogeneration system. The simple payback is the length of time over which the capital investment loan can be paid back by the potential cogeneration plant owner. A payback period of under five (5) years is considered to be good, while if it is under two (2) years, it is very attractive. The simple payback is defined by the following relationship:

$$\textbf{Simple payback} = \frac{\text{Capital Cost of the System}}{\text{(Total electrical and thermal energy cost savings) - (Fuel costs)}}$$

The capital cost of the system will simply be the cost per KW of installed capacity times the total capacity of the system. The electrical cost savings are calculated based on the amount of electricity that is generated by the engine multiplied by the unit cost of electricity that would have been charged by the utility company. The thermal energy cost savings are based on the amount of thermal energy that is produced by the waste heat boiler, multiplied by the fuel costs which would have been required if the thermal energy had been produced by conventional means.

Therefore, for this analysis, one needs to determine the following three quantities:

(a) average cost of electricity purchased (¢/KWH)

(b) average cost of natural gas purchased ($/MCF) and

(c) the amount of thermal energy used or required by the agency (Btu/hr)

(a) Determination of Average Electricity Costs

The average cost of the electricity being purchased by the agency (¢/KWH) is determined simply by adding up the total electrical bills (dollars) for the past year and then dividing by the total electrical energy (KWH) purchased. Demand charges and fuel adjustment charges will ultimately be considered for a more detailed cogeneration analysis, but this simple model will use only the annual average cost for electricity. The average cost of electricity purchased (¢/KWH) is given by

$$(¢/\text{KWH}) = \frac{\text{Total Annual Electric Cost } (\$) \times 100\ (¢/\$)}{\text{Total Annual Electric Consumption (KWH)}}$$

(b) Determination of Average Natural Gas Price

The natural gas prices may vary monthly and the bills may contain certain service charges. For this analysis, we will use only the average cost ($/MCF) by adding up the total natural gas bills for the past year, and dividing the total cost by the total amount of gas purchased (in MCF or thousands of cubic feet). Some utilities may use CCF (hundred cubic feet) rather than MCF; therefore the annual CCF consumed should be divided by 10 to give the amount in MCF. Hence, the average cost of natural gas purchased ($/MCF) is given by

$$\$/MCF = \frac{\text{Total Annual Gas Cost (\$)}}{\text{Total Annual Gas Consumption (MCF)}}$$

or if the gas billing is in terms of CCF,

$$\$/MCF = \frac{\text{Total Annual Gas Cost (\$)}}{\text{Total Annual Gas Consumption (CCF)} \times \text{(1 MCF/10 CCF)}}$$

(c) Average Thermal Load

The utilization of the thermal energy output from a cogeneration system is very important. A potential cogenerator generally cannot produce power as cheaply as a utility company can; therefore it is the thermal energy utilization (TU) that makes the process of cogeneration more economical. The building/ complex manager must determine its average thermal energy needs before the potential for a cogeneration system can be determined. For steam or hot water production only, a rough estimate of the thermal energy requirements can be obtained as shown below.

From the gas bills, determine the total gas consumed for the year in MCF. Multiply the MCF of natural gas by 1,000,000 Btu/MCF in order to convert to Btu, and the boiler efficiency (η). The boiler efficiency, η, if it is not known, can be assumed to be 0.80 or 80%. Then, divide the quantity obtained above by the total number of operating hours of the system in a year, to get the average hourly thermal load of the agency, i.e.,

Average hourly thermal load, in Btu/hour

$$= \frac{\text{(Annual MCF)} \times \text{(1,000,000 Btu/MCF)} \times \eta}{\text{Total operating hours in a year}}$$

(d) Selection of Engine Size

Table 1 is a representative list of small cogeneration systems. It is not intended to be an all inclusive list, and vendor's names have been omitted. The approximate engine size selection for a particular application is made from the average electrical demand (KW). From the bills, add up the monthly demand for the past twelve month period and divide it by 12.

$$\text{Average demand (KW)} = \frac{\text{Sum of 12 months of demand from the electrical bills}}{12}$$

From Table 1 select an engine which has an output closest to your average monthly electrical demand. In general, there may not be an engine which matches your needs exactly.

Table 1: A Representative List of Small Cogeneration Systems

Application	Electrical Output (KW)	Thermal Output (Btu/hr)
Compact packaged systems	20	130,060
	40	260,120
	75	486,750
Medium size systems for cogeneration and combined cycle applications	100	650,000
	200	1,300,600
	300	1,950,900
	400	2,600,000
Various commercial and industrial applications	664	11,040,328
	1130	18,510,530

(e) The Percent Thermal Energy Utilization (%TU)

After selecting the engine size, it is now necessary to calculate the percent of thermal energy produced by the engine which can be utilized by the building/complex. One hundred percent or more of the thermal energy utilization is desirable. Divide the average thermal energy requirements calculated previously, in (c), by the rated thermal energy output of the engine selected in (d) above.

$$(\%TU) = \frac{\text{Average hourly thermal load (Btu/hr)}}{\text{Average thermal output of engine (Btu/hr)}} \times 100$$

If the % TU works out to be greater than 100%, assume a value of 100% for the rest of the calculations.

(f) Use of Nomographs to Determine Economic Feasibility of a Cogeneration System

Knowing the average costs of purchased electricity and natural gas, and the percent thermal energy utilization, (%TU), one can then determine the economic feasibility of a cogeneration system.

1. Select the appropriate nomograph to use from Figures 1, 2, or 3. The selection depends on the size of the engine determined in (d) above. The larger the engine size, the smaller are the capital costs per installed KW. Figure 1 is for the larger engines (greater than 400 KW) which assumes a cheaper capital cost ($700) per installed KW. Figure 2 is to be used for medium-sized engines (101-400 KW) with an assumed cost of $1000/KW. Figure 3 is for the very small-scale installations (20-100KW), and which assumes a cost of $1300/KW.

2. Having selected the appropriate figure, use the price of natural gas ($/MCF) and the percent thermal energy utilization (% TU) determined earlier to

locate the proper point on the bottom half of the nomograph. Draw a vertical line from this point until it intersects a horizontal line corresponding to the cost of electricity (¢/KWH) in the top half of the nomograph.

3. Note the region in which the intersection lies, whether it is in the "GO", "POSSIBLE", or in the "NO GO" region. An intersection in the "GO" region indicates a potential simple payback of 2 years or less. An intersection in the "POSSIBLE" region indicates a potential payback of 2-5 years, while an intersection in the "NO GO" region indicates a simple payback of greater than 5 years.

A selected cogeneration engine with a simple payback of less than five years is generally considered economically feasible, and the agency will be a prime candidate for a more detailed feasibility analysis.

Table 2 may be used to fill out the utility bills. The step-by-step procedure is outlined in Table 2 as well.

FIGURE 1

Nomograph to determine Economic Feasibility
Systems Ranging from **400KW on up ($700/KW)**

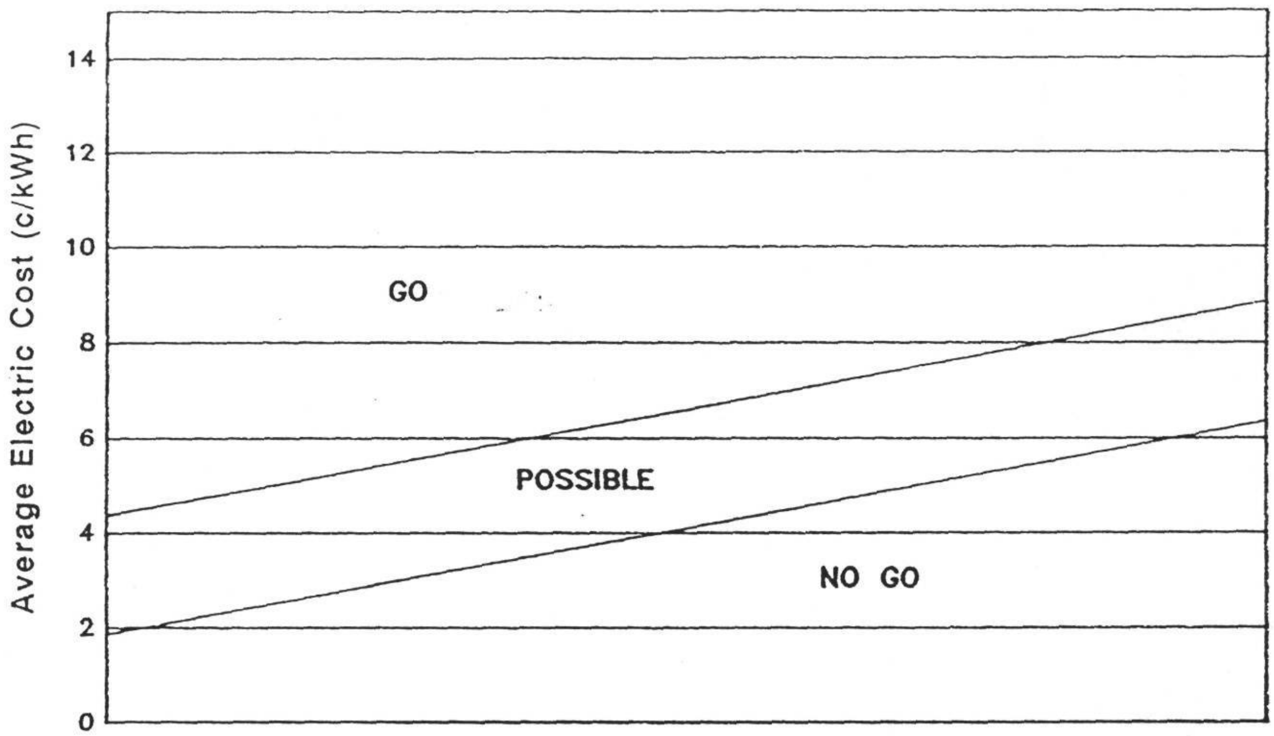

Figure 1a.

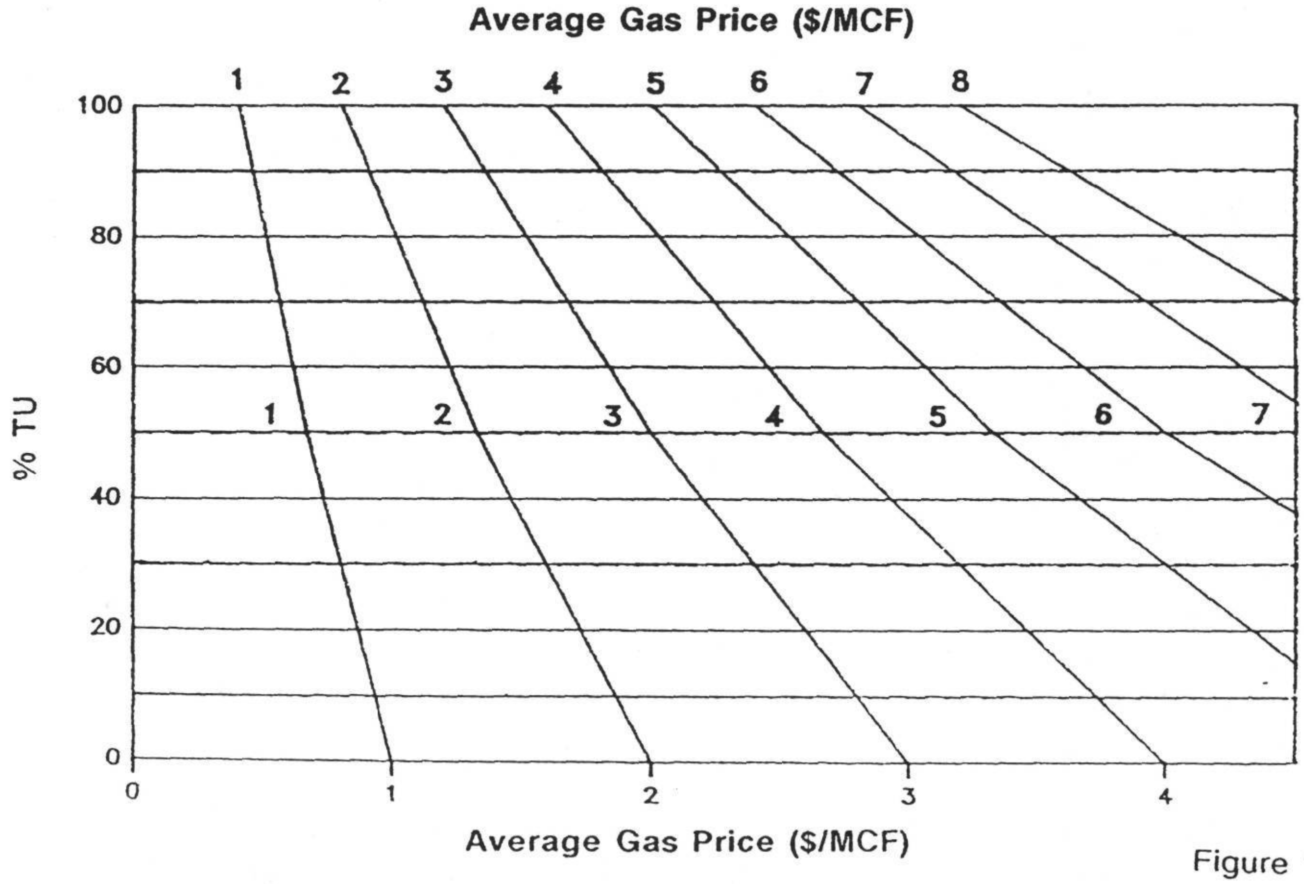

Figure 1b.

FIGURE 2 Nomograph to determine Economic Feasibility Systems Ranging from **101KW-400KW ($1000/KW)**

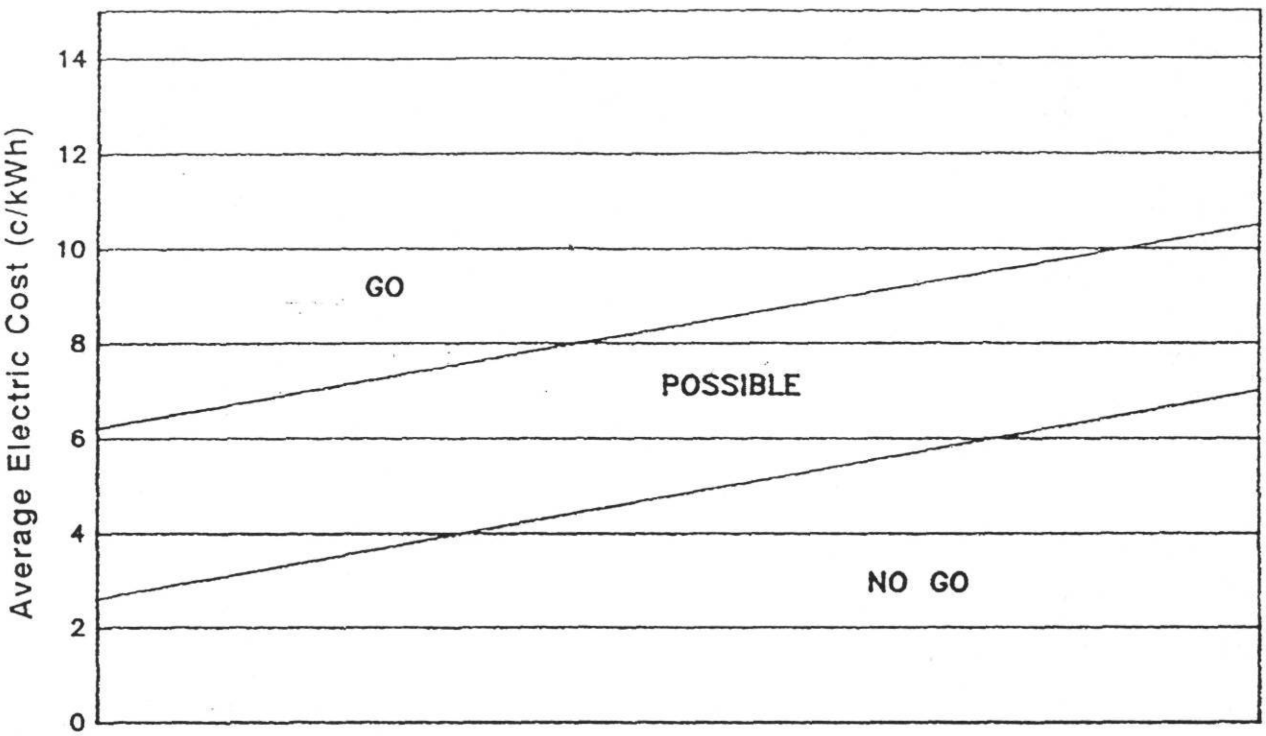

Figure 2a.

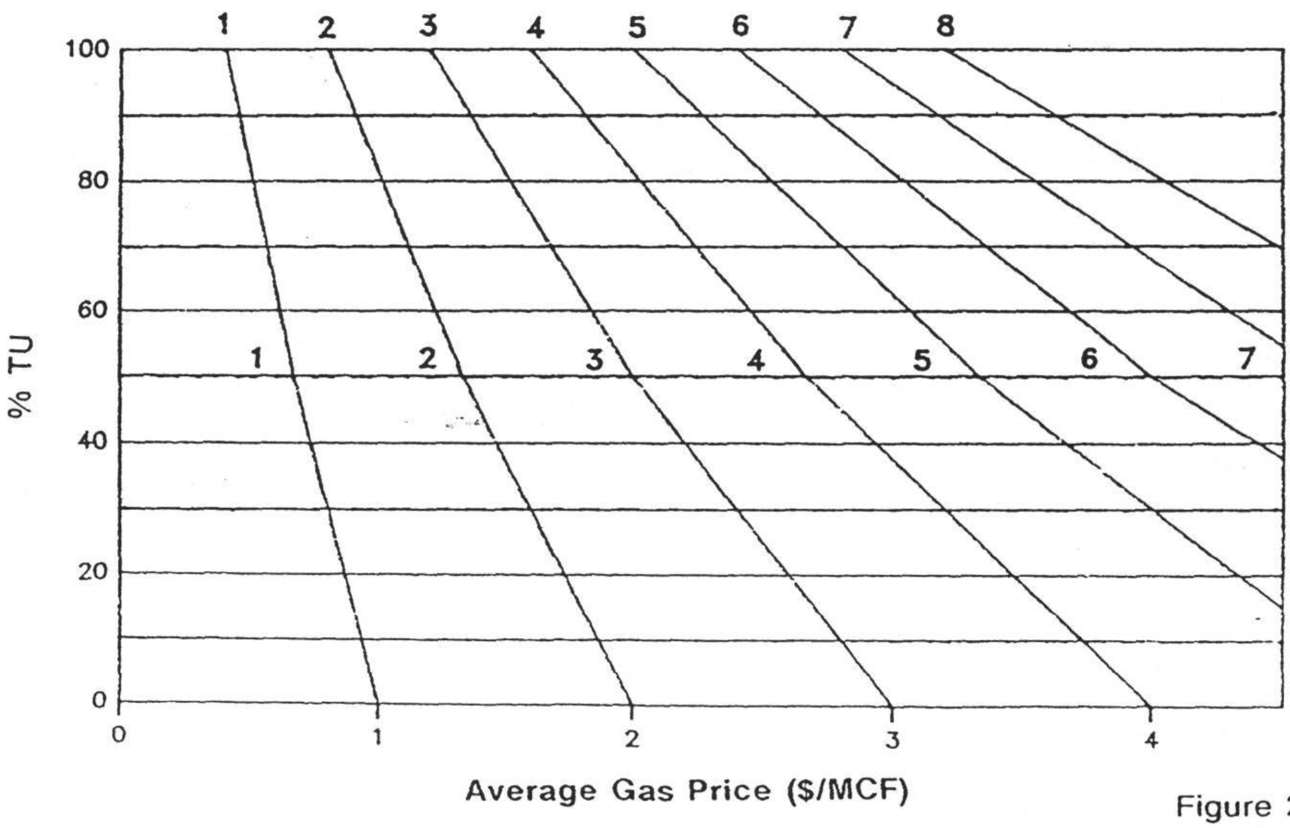

Figure 2b.

FIGURE 3 Nomograph to determine Economic Feasibility Systems Ranging from 20KW-100KW ($1300/KW)

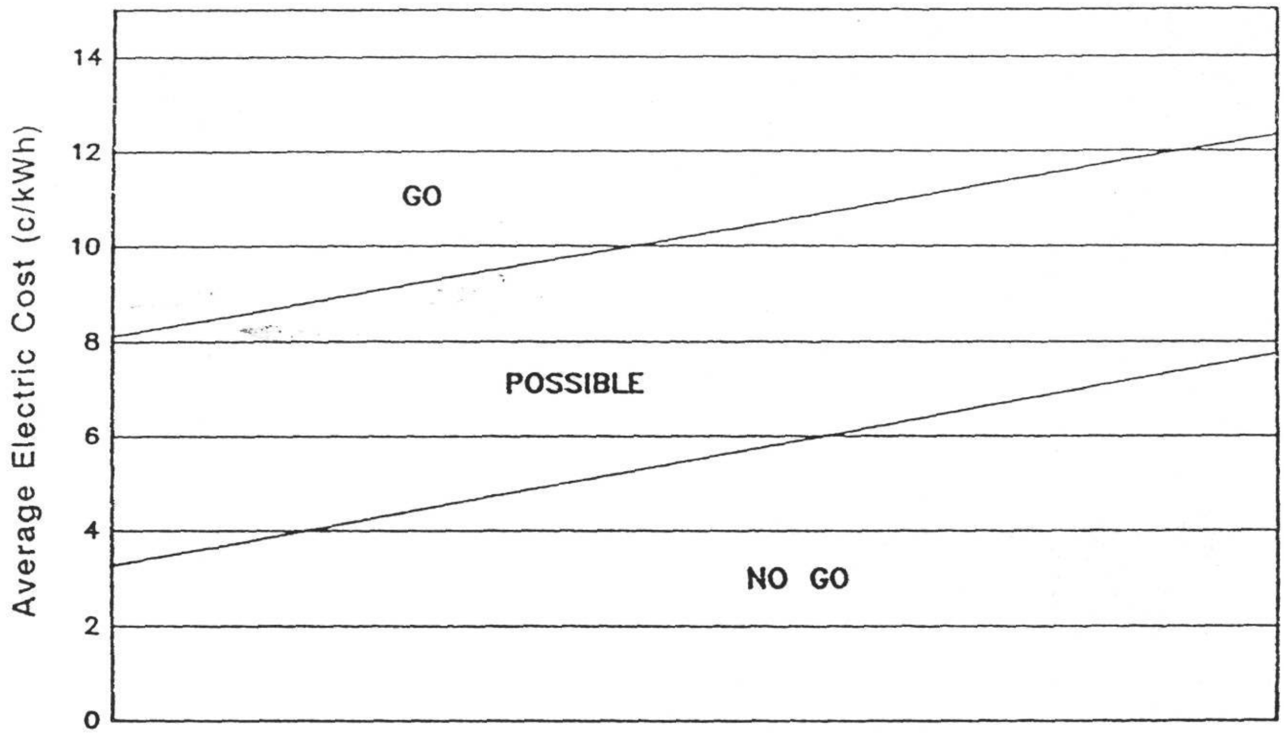

Figure 3a.

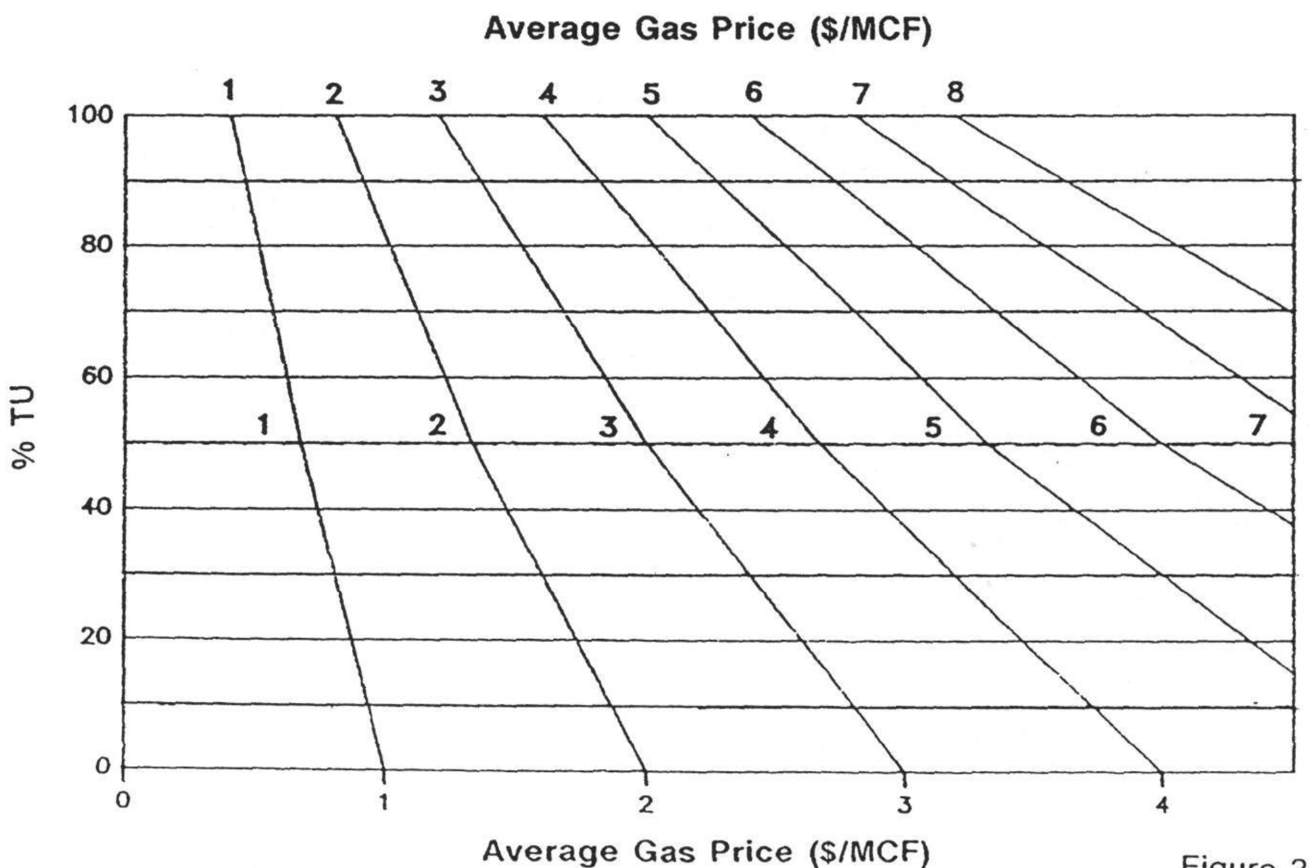

Figure 3b.

Table 2

SIZING OF A SMALL-SCALE COGENERATION SYSTEM

Electricity and Natural Gas Billing Details for
the Past Calendar Year

Month	ELECTRICITY			NATURAL GAS	
	Energy, KWH (1)	Demand,* KW (2)	Total Cost, $ (3)	Consumption, MCF** (4)	Cost, $ (5)
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					
TOTALS					

(a) **Average Cost of Electricity**

$$= \frac{\text{Column (3) Total}}{\text{Column (1) Total}} \times 100\ ¢/\$ = \underline{\hspace{3cm}} \times 100 = \underline{\hspace{3cm}}\ ¢/\text{KWH}$$

Notes: *If the building does not have a demand meter, an approximation of average demand can be found by dividing column (1) total by the number of system operating hours in a year, 8760 if operated on a year-round basis.

**If gas is metered by CCF, divide the CCF monthly totals by 10 to get MCF.

(b) **Average Electrical Demand**

$$= \frac{\text{Column (2) Total}}{12} = \frac{\_\_\_\_\_\_}{12} = \_\_\_\_\_\_ \text{ KW}$$

Hence, size of the cogeneration system selected from Table 1 is ________.

(c) **Average Cost of Gas**

$$= \frac{\text{Column (5) Total}}{\text{Column (4) Total}} = \_\_\_\_\_\_ = \$\_\_\_\_\_\_/\text{MCF}$$

(d) **Average Thermal Energy Required** =

(Total MCF of Gas Used Annually for Heating Steam and Hot Water) x 1,000,000 Btu/MCF x 0.8/(operating hours in a year)

$$= \frac{(\qquad\qquad) \times 1{,}000{,}000 \times 0.8}{(365 \text{ days/year} \times 24 \text{ hours/day})} = \_\_\_\_\_\_ \text{ Btu/hr}$$

(assuming a year-round operation)

(e) **% Thermal Energy Utilized (% TU)** =

$$\frac{\text{Average Thermal Energy Required (from (d) above)}}{\text{Thermal Energy Produced by the Engine (from Table 1)}}$$

$$= \_\_\_\_\_\_ \times 100 = \_\_\_\_\_\_ \text{ \% TU}$$

(f) Choose one of Figures 1, 2 or 3 (depending on the size of the chosen cogeneration system) and do the nomograph illustration to find if the decision is a GO, POSSIBLE or NO GO at this stage and indicate here ———> ________

Discussion of Examples

The appendix to this report contains a discussion of three examples illustrating the use of the step-by-step procedure outlined earlier. These three examples indicate the interdependence of cogeneration on the three main variables--cost of electricity, cost of natural gas, and the percent thermal energy utilized. In the first example of a hospital, gas prices are high, electricity prices are moderately high, but all of the thermal energy from the engine is being utilized. A cogeneration system appears feasible, largely because of the high thermal energy utilization, the "free" energy gained.

In Example 2 of a state school, there is only a 28% utilization of thermal energy. Electricity and gas are both cheaper, but the low utilization of the "free" thermal energy makes a cogeneration system look unattractive.

In Example 3 of an office building, the thermal energy utilized is less than 50%, the electricity rate is high, but the gas price is moderate. A cogeneration system looks very attractive for this application, largely because of the high electrical rates.

Limitations of this Simplified Self-Help Approach

All of the discussion herein assumes that the candidate building/complex is metered such that both natural gas and electrical utility bills are available. If the buildings are not metered, the analysis becomes much more complicated. If the building/complex has been audited recently, either as part of the Institutional Conservation Program (ICP), or the Texas Energy Cost Containment Program (TECCP), then engineering estimates of building energy consumption are available. Although these are not exact, they could be used as an input to this self-help approach in lieu of the metered data.

If none of the above are available for an individual building or complex which could be a possible cogeneration site, the state agency energy manager should contact the authors of this report at Texas A&M University.

Conclusions

This document can be used to make a preliminary assessment of the feasibility of a small-scale cogeneration system. The authors recognize that the assumptions made have greatly simplified this analysis. We have combined both energy and demand charges in computing an "average" electric rate. This can have a dramatic effect on the cogeneration economics, particularly if the demand charges are high. A fixed cost per installed KW was assumed for many different cogeneration system sizes. These costs are site dependent, and also depend on availability of a physical space to locate a system, nearness to an electrical substation, etc. There is also no consideration of the agency's ability to operate a system. These factors and others would have to be taken into consideration in a more detailed engineering study. The assumptions made herein will lead to an optimistic result. Any potential system which falls in the "GO" area will probably be a successful candidate. Any potential system which falls in the "NO GO" area should definitely be eliminated unless there are known reasons, such as an expected sharp increase in future electrical rates or much cheaper gas rates if a cogenerating system were installed. The primary area where a very thorough study will be necessary is for those systems which fall into the "POSSIBLE" range. A small change in the percent thermal energy utilization, including the installation of absorption chillers for the bigger systems, could effect a large change in the economics.

Any questions concerning the details of this document or the procedures used should be addressed to the authors at Texas A&M University, Department of Mechanical Engineering.

Appendix

Three examples illustrating the use of the step-by-step procedure outlined in this document.

Example 1 - Hospital

Example 2 - State School

Example 3 - Office Building

EXAMPLE 1

A hospital produces steam for heating, cooking and sterilization. The total annual electricity bill including demand and service charges is \$157,680 and the total electrical energy consumed is 2,628,000 KWH. The average cost of electricity is given by

$$\frac{\$157,680}{2,628,000 \text{ KWH}} \times 100\ (\text{¢}/\$) = \underline{\underline{6\text{¢}/\text{KWH}}} \qquad \text{(a)}$$

From the electricity bills, the maximum demand is determined to be 400KW, and the average demand is 300KW. Select a 300 KW engine from Table 1.

The annual natural gas consumption is 31,900 MCF and the total cost is \$146,000. Therefore, the average cost of natural gas purchased is given by

$$\frac{\$146,000}{31,900 \text{ MCF}} = \underline{\underline{\$4.57/\text{MCF}}} \qquad \text{(b)}$$

From the gas bills, the average thermal load, using a boiler efficiency, η, of 0.8, is calculated to be:

$$\frac{31,900 \text{ MCF/year} \times 1,000,000 \text{ Btu/MCF} \times 0.80}{365 \text{ days/year} \times 24 \text{ hours/day}} \simeq \underline{\underline{2,913,000}} \text{ Btu/hr} \qquad \text{(c)}$$

It has been assumed that the hospital operates on a year-round basis.

From Table 1, a 300KW engine would provide about 1,950,900 Btu/hr of thermal energy. Since the average thermal load is greater than the rated output of the engine selected, we can assume 100% thermal energy utilization (100% TU).

Since the engine size selected is 300 KW, the appropriate figure to use is Figure 2. Start with the bottom part of Figure 2, i.e., Figure 2b, and move horizontally over on the 100% TU line, intersecting with a gas price of \$4.57/MCF. From this point, run a line vertically up to the top part of the nomograph and intersect with a horizontal line corresponding to the electricity rate of 6¢/KWH. Note that the point of intersection of the two lines lies in between the two-year and the five-year payback lines in the "POSSIBLE" region. This implies that a cogeneration system is economically feasible and the hospital (in this example) is a prime candidate for a more detailed feasibility analysis. Since the point of intersection lies approximately half-way between the two-year payback line and the five-year payback line, the simple payback should be about three and a half years.

All the steps involved in the example are also illustrated in Table 3.

FIGURE 2 Nomograph to determine Economic Feasibility Systems Ranging from **101KW-400KW ($1000/KW)**

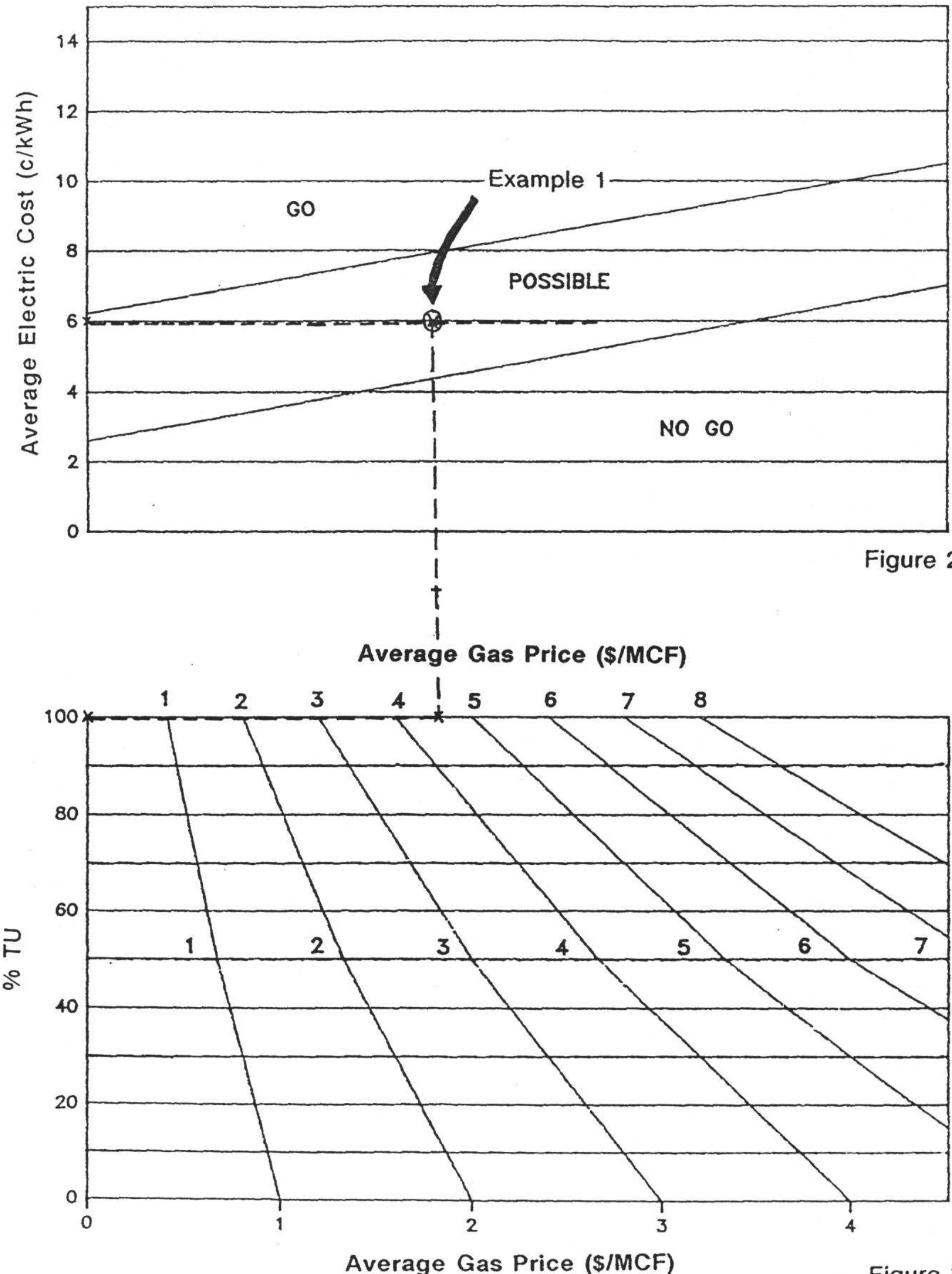

Figure 2a.

Figure 2b.

Table 3

SIZING OF A SMALL-SCALE COGENERATION SYSTEM

Electricity and Natural Gas Billing Details for the Past Calendar Year

Month	ELECTRICITY			NATURAL GAS	
	Energy, KWH (1)	Demand,* KW (2)	Total Cost, $ (3)	Consumption, MCF** (4)	Cost, $ (5)
January	225,000	400	13,600	2,800	14,000
February	230,000	300	13,700	2,750	13,500
March	200,000	250	12,800	2,600	12,000
April	210,000	350	13,000	2,300	8,000
May	220,000	300	13,150	2,400	9,800
June	200,000	300	12,800	2,600	12,000
July	195,000	350	12,700	2,700	13,000
August	180,000	300	12,500	2,900	14,000
September	200,000	250	12,800	2,800	14,000
October	293,000	250	14,500	2,750	13,500
November	235,000	250	13,800	2,700	13,000
December	240,000	300	12,330	2,600	9,200
TOTALS	2,628,000	3,600	157,680	31,900	146,000

(a) Average Cost of Electricity

$$= \frac{\text{Column (3) Total}}{\text{Column (1) Total}} \times 100\ ¢/\$ = \frac{157{,}680}{2{,}628{,}000} \times 100 = \underline{\quad 6 \quad} ¢/\text{KWH}$$

Notes: *If the building does not have a demand meter, an approximation of average demand can be found by dividing column (1) total by the number of system operating hours in a year, 8760 if operated on a year-round basis.

**If gas is metered by CCF, divide the CCF monthly totals by 10 to get MCF.

(b) **Average Electrical Demand**

$$= \frac{\text{Column (2) Total}}{12} = \frac{3600}{12} = \qquad \underline{\quad 300 \quad} \text{ KW}$$

Hence, size of the cogeneration system selected from Table 1 is <u>300 KW</u> .

(c) **Average Cost of Gas**

$$= \frac{\text{Column (5) Total}}{\text{Column (4) Total}} = \frac{146,000}{31,900} = \qquad \$ \underline{\quad 4.57 \quad} \text{/MCF}$$

(d) **Average Thermal Energy Required =**

(Total MCF of Gas Used Annually for Heating Steam

and Hot Water) x 1,000,000 Btu/MCF x 0.8/(operating hours in a year)

$$= \frac{(31,900) \times 1,000,000 \times 0.8}{(365 \text{ days/year} \times 24 \text{ hours/day})} = \qquad \underline{2,913,000} \text{ Btu/hr}$$

(assuming a year-round operation)

(e) **% Thermal Energy Utilized (% TU) =**

$$\frac{\text{Average Thermal Energy Required (from (d) above)}}{\text{Thermal Energy Produced by the Engine (from Table 1)}}$$

$$= \frac{2,913,000}{1,950,900} \times 100 = 150\% > 100\% \qquad \underline{100\%} \text{ \% TU}$$

(f) **Choose one of Figures 1, 2 or 3 (depending on the size of the chosen cogeneration system) and do the nomograph illustration to find if the decision is a <u>GO</u>, <u>POSSIBLE</u> or <u>NO GO</u> at this stage and indicate here** ——————> <u>POSSIBLE</u>

EXAMPLE 2

A second example is one of a state school which uses natural gas for heating and hot water only, and has a considerably smaller thermal load than a hospital.

The total electricity bill is \$178,870 and the energy consumed is 3,134,160 KWH.

Average cost of electricity is

$$\frac{\$178,870}{3,134,160\ \text{KWH}} \times 100\ ¢/\$ = \underline{\underline{5.7¢/\text{KWH}}} \qquad \text{(a)}$$

The average demand is approximately 300KW. Select a 300 KW engine.

The annual gas consumption is 6,050 MCF at a total cost of \$34,300 and the average gas cost is

$$\frac{\$34,300}{6,050\ \text{MCF}} = \underline{\underline{\$5.67/\text{MCF}}} \qquad \text{(b)}$$

Assuming a boiler efficiency of 0.8 and a year-round operation of the school, the average thermal load is given by

$$\frac{6,050\ \text{MCF} \times 1,000,000\ \text{Btu/MCF} \times 0.80}{365\ \text{days/year} \times 24\ \text{hours/day}} \simeq \underline{\underline{552,511}}\ \text{Btu/hr} \qquad \text{(c)}$$

From Table 1, a 300KW cogeneration system would provide about <u>1,950,900</u> <u>Btu/hr</u>. Calculate the (% TU) by dividing the average load by the ouput of the engine.

$$(\%\ \text{TU}) = \frac{552,511\ \text{Btu/hr}}{1,950,900\ \text{Btu/hr}} \times 100 \simeq 28\%$$

Using the bottom nomograph of Figure 2, locate the point of intersection between the % TU of 28% and the natural gas price of $5.67/MCF. Note that this intersection is nearly off the graph.

Draw a vertical line up to the top nomograph and intersect with a horizontal line corresponding to the electric cost of 5.7¢/KWH. Note that the intersection lies below the "POSSIBLE" region and in the "NO GO" region. The simple payback, under the assumed conditions, would exceed five years, and a cogeneration system is, therefore, not recommended for further study.

The details of this example are illustrated in Table 4.

FIGURE 2 Nomograph to determine Economic Feasibility
Systems Ranging from **101KW-400KW ($1000/KW)**

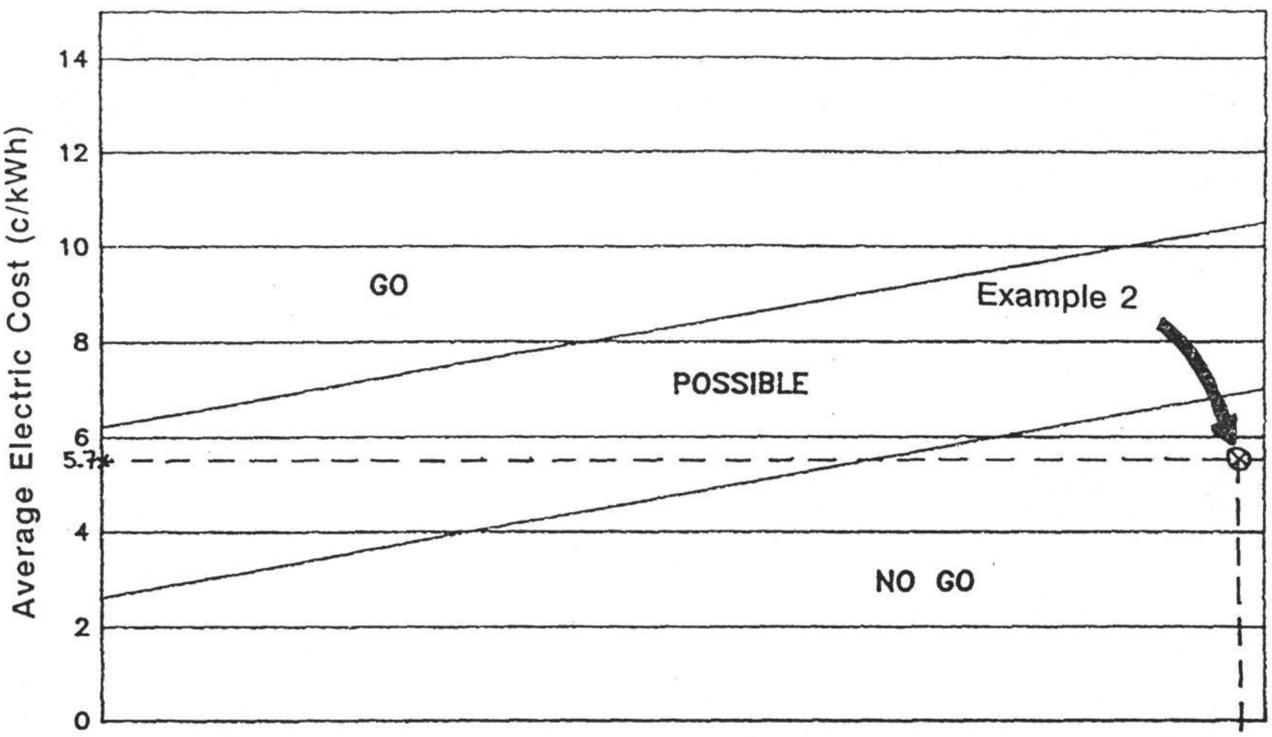

Figure 2a.

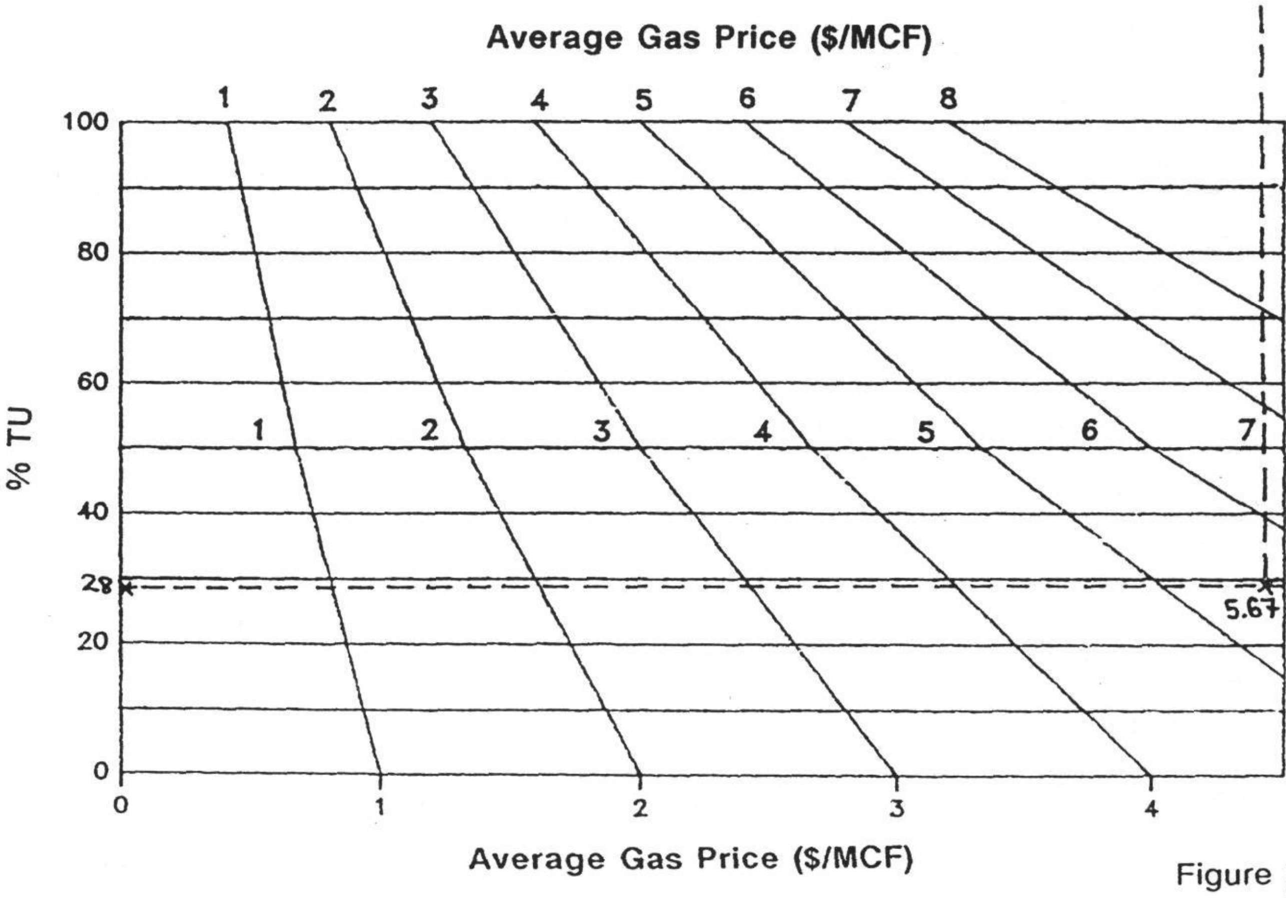

Figure 2b.

Table 4

SIZING OF A SMALL-SCALE COGENERATION SYSTEM

Electricity and Natural Gas Billing Details for the Past Calendar Year

Month	ELECTRICITY			NATURAL GAS	
	Energy, KWH (1)	Demand,* KW (2)	Total Cost, $ (3)	Consumption, MCF** (4)	Cost, $ (5)
January	275,000	350	16,000	1,000	6,000
February	390,000	425	23,000	850	5,000
March	260,000	400	10,000	650	4,000
April	300,000	350	13,500	450	2,000
May	270,000	250	15,000	450	2,000
June	70,000	100	4,000	50	600
July	100,000	100	5,000	50	600
August	80,000	100	4,500	50	600
September	440,000	450	28,000	400	2,000
October	350,000	375	21,000	500	2,500
November	350,000	375	21,000	800	4,500
December	249,160	375	17,870	800	4,500
TOTALS	3,134,160	3,650	178,870	6,050	34,300

(a) **Average Cost of Electricity**

$$= \frac{\text{Column (3) Total}}{\text{Column (1) Total}} \times 100 \text{ ¢/\$} = \frac{178,870}{3,134,160} \times 100 = \underline{5.7} \text{ ¢/KWH}$$

Notes: *If the building does not have a demand meter, an approximation of average demand can be found by dividing column (1) total by the number of system operating hours in a year, 8760 if operated on a year-round basis.

**If gas is metered by CCF, divide the CCF monthly totals by 10 to get MCF.

(b) **Average Electrical Demand**

$$= \frac{\text{Column (2) Total}}{12} = \frac{3650}{12} = \qquad \underline{304}\ \text{KW}$$

Hence, size of the cogeneration system selected from Table 1 is 300 KW .

(c) **Average Cost of Gas**

$$= \frac{\text{Column (5) Total}}{\text{Column (4) Total}} = \frac{34,300}{6,050} = \qquad \$\ \underline{5.67}\ /\text{MCF}$$

(d) **Average Thermal Energy Required =**

(Total MCF of Gas Used Annually for Heating Steam

and Hot Water) x 1,000,000 Btu/MCF x 0.8/(operating hours in a year)

$$= \frac{(\ 6,050) \times 1,000,000 \times 0.8}{(365 \text{ days/year} \times 24 \text{ hours/day})} = \qquad \underline{552,511}\ \text{Btu/hr}$$

(assuming a year-round operation)

(e) **% Thermal Energy Utilized (% TU) =**

$$\frac{\text{Average Thermal Energy Required (from (d) above)}}{\text{Thermal Energy Produced by the Engine (from Table 1)}}$$

$$= \frac{552,511}{1,950,900} \times 100 \qquad \underline{28\%}\ \%\ \text{TU}$$

(f) **Choose one of Figures 1, 2 or 3 (depending on the size of the chosen cogeneration system) and do the nomograph illustration to find if the decision is a GO, POSSIBLE or NO GO at this stage and indicate here** ——————> NO GO

EXAMPLE 3

An office building consumes 255,000 KWH of electricity annually and has a utility bill of $21,675. Natural gas is used for heating hot water, for building heating using a hot water system, and for producing steam used in a small cafeteria. The natural gas consumed is 640 MCF, and the cost is $1984.

Average cost of electricity is

$$\frac{\$21,675}{255,000 \text{ KWH}} \times 100\ ¢/\$ = 8.5¢/\text{KWH}$$

The average demand (from the electric bills) is 25 KW. From Table 1, select a 20 KW system, which has a rated thermal output of 130,060 Btu/hr.

Average cost of natural gas is

$$\frac{\$1984}{640 \text{ MCF}} = \$3.10/\text{MCF}$$

The average hourly thermal load, using a boiler efficiency of 0.8, is

$$\frac{(640 \text{ MCF}) \times 1,000,000 \text{ Btu/MCF} \times 0.8}{(365 \text{ days/year}) \times 24 \text{ hours/day}} = 58,447 \text{ Btu/hr}$$

Compute the % TU by dividing the thermal load by the rated output of 130,060 Btu/hr,

$$(\% \text{ TU}) = \frac{58,447 \text{ Btu/hr}}{130,060 \text{ Btu/hr}} \times 100 = 45\%$$

Since the size of the engine is 20 KW, use Figure 3 for this example.

Using the bottom half of the nomograph, extend a horizontal line from the 45% TU value to the intersection of the gas price at $3.10/MCF. From that point, draw a vertical line up to the top nomograph. The intersection of this vertical line and a horizontal line corresponding to an average cost of electricity of 8.5¢/KWH intersects in the "POSSIBLE" region.

This example illustrates an economically feasible cogeneration system and the office building is a prime candidate for a more detailed feasibility analysis. The details of the billing and calculated data for this example are given in Table 5.

FIGURE 3

Nomograph to determine Economic Feasibility
Systems Ranging from **20KW-100KW ($1300/KW)**

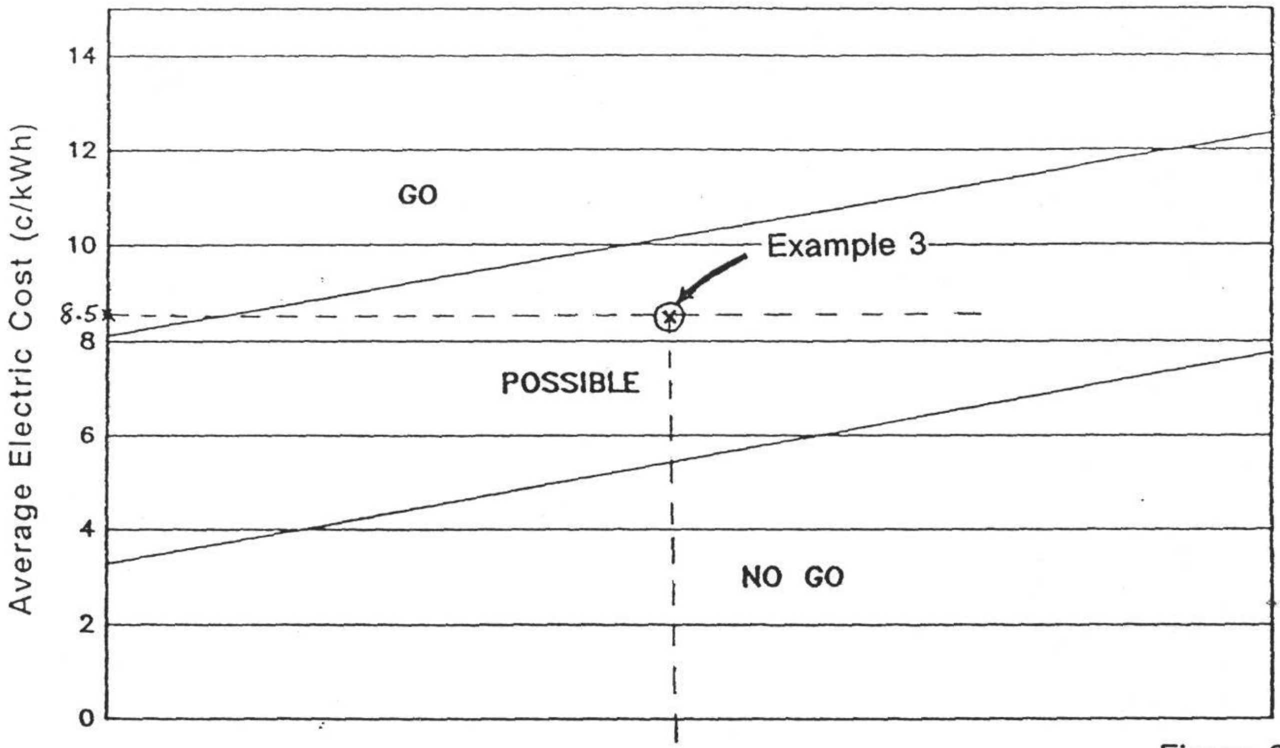

Figure 3a.

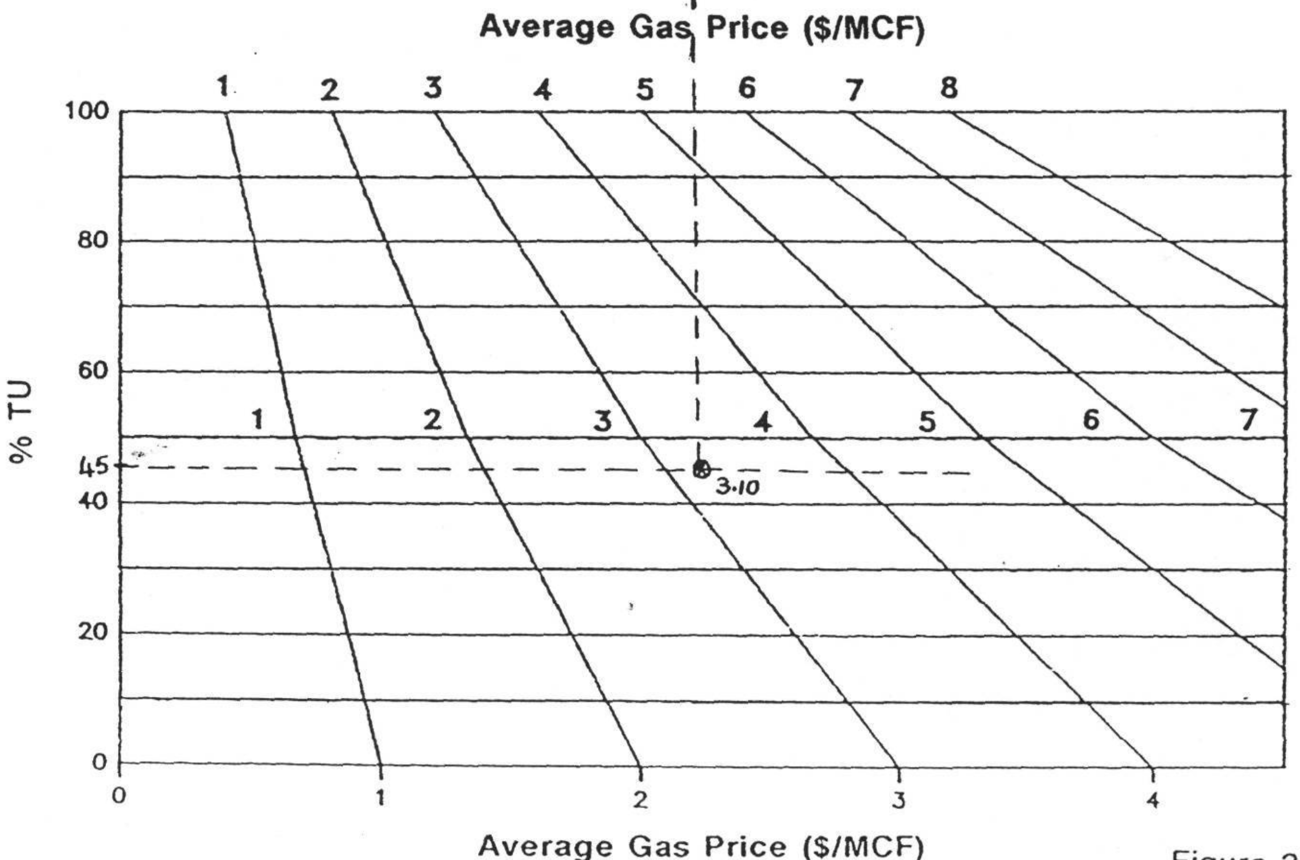

Figure 3b.

Table 5

SIZING OF A SMALL-SCALE COGENERATION SYSTEM

Electricity and Natural Gas Billing Details for the Past Calendar Year

Month	ELECTRICITY			NATURAL GAS	
	Energy, KWH (1)	Demand,* KW (2)	Total Cost, $ (3)	Consumption, MCF** (4)	Cost, $ (5)
January	10,000	20	1,200	45	140
February	20,000	25	1,800	50	155
March	20,000	25	1,800	55	170
April	25,000	25	2,000	60	185
May	25,000	25	2,000	60	185
June	30,000	25	2,300	55	170
July	30,000	30	2,300	55	170
August	30,000	30	2,300	50	155
September	25,000	25	2,000	60	185
October	15,000	25	1,400	50	155
November	15,000	25	1,400	50	155
December	10,000	20	1,175	50	159
TOTALS	255,000	300	21,675	640	1,984

(a) **Average Cost of Electricity**

$$= \frac{\text{Column (3) Total}}{\text{Column (1) Total}} \times 100\ ¢/\$ = \frac{21{,}675}{255{,}000} \times 100 = \underline{\ 8.5\ }\ ¢/\text{KWH}$$

Notes: *If the building does not have a demand meter, an approximation of average demand can be found by dividing column (1) total by the number of system operating hours in a year, 8760 if operated on a year-round basis.

**If gas is metered by CCF, divide the CCF monthly totals by 10 to get MCF.

(b) **Average Electrical Demand**

$$= \frac{\text{Column (2) Total}}{12} = \frac{300}{12} = \underline{\quad 25 \quad} \text{ KW}$$

Hence, size of the cogeneration system selected from Table 1 is <u>25 KW</u>.

(c) **Average Cost of Gas**

$$= \frac{\text{Column (5) Total}}{\text{Column (4) Total}} = \frac{1{,}984}{640} = \$\underline{\quad 3.10 \quad}\text{/MCF}$$

(d) **Average Thermal Energy Required** =

(Total MCF of Gas Used Annually for Heating Steam and Hot Water) x 1,000,000 Btu/MCF x 0.8/(operating hours in a year)

$$= \frac{(\ 640\ ) \times 1{,}000{,}000 \times 0.8}{(365 \text{ days/year} \times 24 \text{ hours/day})} = \underline{\quad 58{,}447 \quad} \text{ Btu/hr}$$

(assuming a year-round operation)

(e) **% Thermal Energy Utilized (% TU)** =

$$\frac{\text{Average Thermal Energy Required (from (d) above)}}{\text{Thermal Energy Produced by the Engine (from Table 1)}}$$

$$= \frac{58{,}447}{130{,}060} \times 100 \qquad \underline{\quad 45\% \quad} \text{ \% TU}$$

(f) **Choose one of Figures 1, 2 or 3 (depending on the size of the chosen cogeneration system) and do the nomograph illustration to find if the decision is a <u>GO</u>, <u>POSSIBLE</u> or <u>NO GO</u> at this stage and indicate here** ————> <u>POSSIBLE</u>