A Cogeneration Case Study Using the Interactive Energy Balance Program

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ABSTRACT

Cogeneration is a highly effective means of increasing energy efficiency and reducing energy costs by utilizing the heat that would normally be wasted and use some or all of it for the thermal requirements of a facility. This effective utilization of heat generated during electricity production allows for an increase of fuel efficiency from 35% to almost 85%. Cogeneration not only reduces energy costs and increases energy efficiency, but is also beneficial to the environment by reducing the amount of pollutants that are emitted into the atmosphere.

In a previous work we presented and described the new Interactive Energy Balance (IEB) software. The package offers an easy way to account for energy bills, working equipment and their energy operating characteristics. Among the equipment considered are: lighting, air conditioning, refrigeration compressors, air compressors, motors, and others. The electric energy consumed by all pieces of equipment is balanced against the energy bills (last 12 months). The corresponding energy costs, graphs, pie-charts, and free format reports are automatically generated showing paths and trends on energy consumption. A "Recommendations" section allows for a quick, but beyond a back of the envelop type of calculation, initial analysis of potential energy improvement projects associated with current equipment, and/or for the installation of new ones.

As a result of the increasing interest, we have included in IEB's "recommendations" section a "cogeneration" option. Among its many features is a typical cogeneration environment window with fuel load,

power generated, thermal load output, and efficiency, allowing for a variety of uses for the exhaust heat. Furthermore, an information verification chart is displayed and a final "cogeneration savings" printable summary chart is shown. This chart includes (among others) the worth of thermal load, worth of cogeneration, fuel cost, operating cost, total savings, simple payback, and return on investment. In this work we briefly describe IEB and present a case study on a cogeneration recommendation. This provides insight on the versatility, faster data entry, balancing process, graphical display, recommendations and many other features of the software. In addition, we further demonstrate the value of the energy balance approach, and the many options for cogeneration and other energy savings projects.

INTRODUCTION

The Interactive Energy Balance (IEB) provides the user with a tool that incorporates the evaluation of energy bill data and energy use data to calculate cost savings for various energy efficiency projects. Currently the IEB is used by the University of Florida Industrial Assessment Center (UF-IAC) in the evaluations of their energy audits. With this database, audits can be evaluated in an efficient and timely manner. Similarly, productivity has improved by incorporating the Excel spreadsheet with the energy balance data for the customers into the IEB. However, one of the recommendations often explored by the UF-IAC, the installation of a combined heat and power system, is not included in this database. The increase in efficiency and the energy cost reduction provided by a cogeneration system is one that should not be overlooked. By adding this recommendation the user will be able to calculate a cost savings analysis on the installation of a cogeneration system. Furthermore, this addition will serve as a tool for gathering the data necessary to install a cogeneration system.

A brief description on the concept of cogeneration, its various uses, and an economic analysis are provided to highlight the benefits of installing a cogeneration system. The purpose of this article is to serve as a tutorial for the new section of cogeneration in the IEB. The article concludes with a case study that provides an overview into the new application of cogeneration.

GENERAL BACKGROUND

Cogeneration is a highly effective means of increasing energy efficiency and reducing energy costs. Also known as combined heat and power, cogeneration allows a facility to control and reduce energy costs by utilizing the heat that would normally be wasted and use some or all of it for the thermal requirements of a facility. This effective utilization of heat generated during electricity production results in an increase of fuel efficiency from 35% to almost 85%. Cogeneration not only reduces energy costs and increases energy efficiency, but is also beneficial to the environment by reducing the amount of pollutants that are emitted into the atmosphere.

In the late 1970s, increasing energy prices brought upon the idea of conserving energy and seeking alternative sources of energy. U.S. energy problems still exist and the efficiency of energy use and energy cost reduction are still major concerns. Cogeneration can be employed for energy efficiency in any process where steam, heat, or cooling is needed. It can be used in large-scale industrial plants, such as paper and pulp, textile, and food industries, where steam turbines, gas turbines, or diesel engines allow for the conservation of otherwise wasted energy. Similarly, cogeneration can also be used in small-scale businesses, such as hospitals, hotels, and schools. Regardless of where it is implemented, cogeneration can make a significant contribution to increasing energy efficiency and reducing energy costs.

Uses of Cogeneration

The conventional method of producing heat and electricity separately loses almost 50% of the energy content of fuel. Alternatively, the wasted energy can be used in its initial form or may be converted to useable energy for boiler systems, chillers, air conditioning, and many other applications, and will contribute significant savings to a facility using on-site generation. The most typical use of cogeneration is when a facility has a need for both electricity and hot water. This is seen in hotels, where a turbine provides electricity for the building and also provides heat for the pool, spa, or dish washing. Cogeneration can also be used for cooling in the form of air conditioning or refrigeration. Steam is also used in many facilities to provide space heating.

Cogeneration can be used anywhere a facility requires two or more energy uses. However, many factors must be considered when evaluating the viability of a cogeneration system. Cogeneration systems are usually installed if the system capacity can meet the average need for thermal load of the facility. Similarly, if an industry has a need for either cheaper sources of power, or new capacity additions to meet the demand for electricity, or if a reasonable return on investment is allowed on the power, then a cogeneration system may provide the facility with a beneficial solution.

Fuel Considerations

Cogeneration equipment can be fired by fuels other than natural gas. Other fuels used by cogeneration systems are biomass, coal, oil, wood chips, and waste heat. Even though biomass and waste heat are gaining favor as a fuel source for paper and food plants, conventional fuels such as natural gas and coal are still predominant as the primary fuel source. There are installations in operation that use wood, agricultural waste, peat moss, and a wide variety of other fuels, depending on local availability.

Economic Analysis

The most significant benefit of cogeneration is its high efficiency compared to the separate production of electricity and heat. By using otherwise wasted heat, cogeneration can produce electricity and steam at a much lower cost than making them separately. Another advantage of cogeneration is that the capital cost of cogeneration systems is usually lower than that of a new power plant. New technology is steadily improving cogeneration systems, presenting higher efficiencies and lower capital costs. Lastly, the high energy efficiency provides an economic advantage to environmental issues because less fuel is burned to produce the same energy output.

Implementation of a cogeneration system can become very costly. Along with planning costs and cost of equipment, there is also space, fuel, operation, and maintenance cost. The best way to determine the economical advantage of a cogeneration system is by calculating a return on investment, which is equal to the percentage of the total saving over the implementation costs. It would also be beneficial to conduct a sensitivity analysis for the most significant or the most unpredictable parameters in the economic evaluation.

THE IEB INTERACTIVE DATABASE APPLICATION

The IEB is a Microsoft Access application used to organize the energy data from different equipment groups such as lighting, motors, heating, ventilation and air conditioning, air compressors, and any other specific pieces of equipment that consume electrical energy. Once all the data is entered, the user is able to perform an energy balance for a particular facility. The energy consumption data is then displayed in graphs and charts, and recommendations are given for each piece of the equipment considered. Previously, the recommendations given were organized to estimate savings on specific types of equipment. However, the implementation of a cogeneration system in the facility is an option that needs to be considered as well. Cogeneration is added to the IEB data flow diagram to represent the addition of cogeneration as a recommendation with potential energy savings (Figure 1).

Recommendations

After entering the energy data and obtaining an energy balance spreadsheet, the user may choose to view any possible recommendations for their facility, as shown in Figure 2. These suggestions include recommendations on the uses of various equipment, and the possible installation of a cogeneration system. The option of cogeneration provides a solution that is not often explored, but may provide substantial savings. Not only is this option available for cost analysis, but is also available to answer questions on the implementation of cogeneration system, such as the appropriate size of a turbine for a certain thermal load demand. The different uses of this application will become apparent when the explanations on the individual windows are given.

Cogeneration

After selecting cogeneration, a window similar to Figure 3 enables. The window will display a typical cogeneration environment with fuel load, power generated, thermal load output, and efficiency. Default values for efficiency and exhaust are set at 35% and 65%, respectively. These values may be changed; however, exhaust will always be displayed as one minus the efficiency (1 – efficiency), and vice versa. The user will also need to indicate what equipment will receive the exhaust heat. Equipment options include boiler, absorption chiller, heater, and other. The coefficient of performance, or the efficiency of the equipment, is set

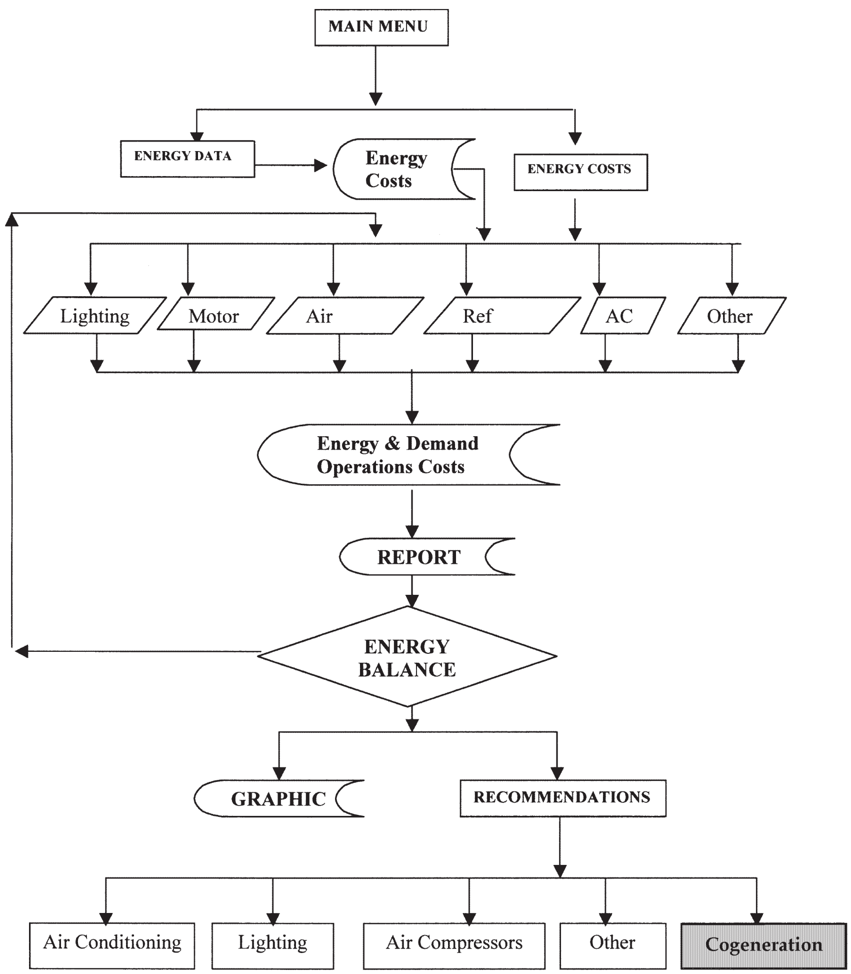

Figure 1. IEB Data Flow Diagram

at 0.8; however, this value may also be changed. The software is set to only accept numeric values between 0 and 1 for all efficiency and exhaust values. Efficiency values greater than 1 are halted by a pop-up warning message. A *Help* button is provided, offering a full explanation of this subroutine.

One of four inputs must be set to calculate all the values of the cogeneration system. These values are fuel, thermal load, power, and electricity. Once one of these is selected, all other inputs will become inactive to indicate that those values are not necessary to make calcula-

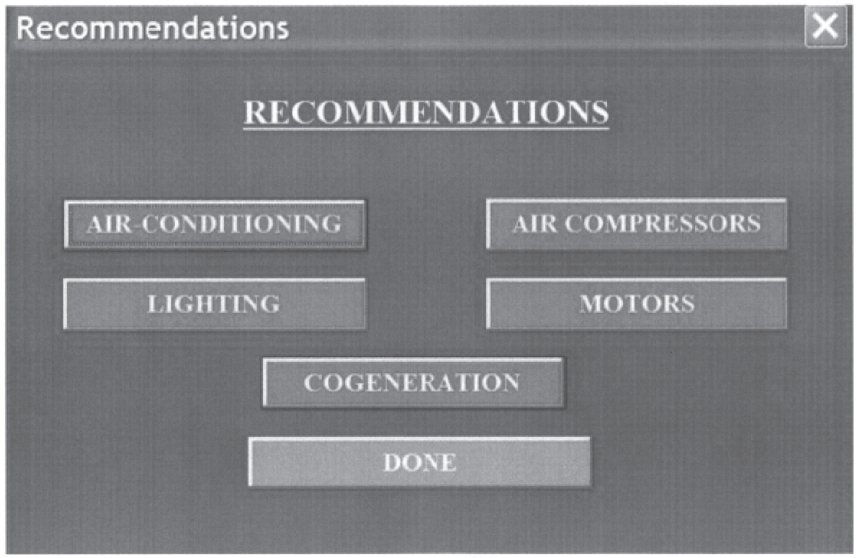

Figure 2: Recommendation Window

tions. The database is set to accept only numeric values. Once all the active windows contain a value, the *Calculate* button can be pressed to solve for all missing data. The formulas used are as follows:

- Electricity Generated From Fuel (kWh) = Fuel x Efficiency x Conversion Factor
- Power Generated Annually (MW) = Electricity/Operational Hours in a Year
- Thermal Load (MMBtu) = Fuel x Exhaust x Coefficient of Performance
- Thermal Energy (MMBtu/Hr) = Power x (Exhaust/Efficiency) x Conversion Factor
- Fuel (MMBtu) = Thermal Load/(Exhaust x Coefficient of Performance)
- Conversion Factor: 1kW = 0.003412 MMBtu

Once all values are displayed, the user may choose to reset the form and input new information. Default values will be set once again if the *Reset* button is pressed.

By adding this window into the database, the user can also acquire various answers to implementing a cogeneration system. For example,

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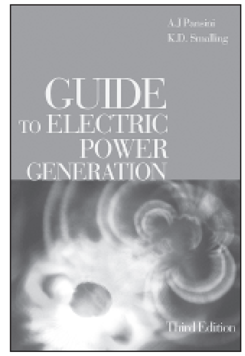

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performing these calculations, he or she will be able to know what size of turbine is needed, or how much thermal load can be acquired from the heat that is lost if a certain size turbine is available. Also, the user may find out how much fuel is needed for the gas turbine to satisfy a particular cooling or heating demand. If analysis of the aforementioned situations is desired, the user may press the *Done* button to return to the recommendations screen. Otherwise, if the user wishes to gather a cost analysis on implementing the cogeneration system given the various energy data previously entered, the user may press the *Cogen Project Evaluation* button. To proceed, every entry must have a value.

Cogeneration Information Verification

The *Cogeneration Information Verification* window is mainly designed to confirm the user's information, as seen in Figure 4. However, this window may also be used to make any changes to the previous data. The present gas charge, operating cost of cogeneration, facility load operating hours, gas turbine operating hours, and cogeneration implementation cost all have default values of \$7.41/MMBtu, \$15/kW-yr, 8,760 hours/yr, and \$1,600,000, respectively.

These values may be changed according to the user's needs; however, it is important to realize that for a cogeneration system to provide

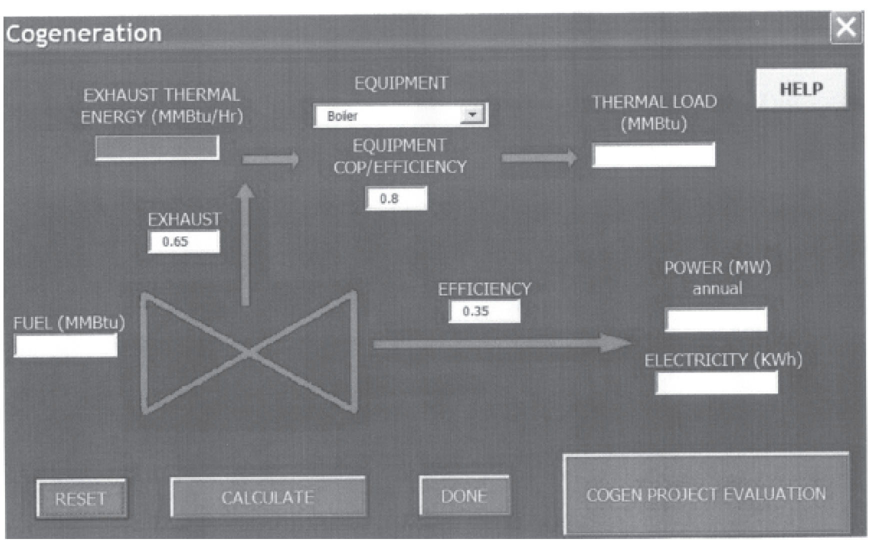

Figure 3: Cogeneration Window

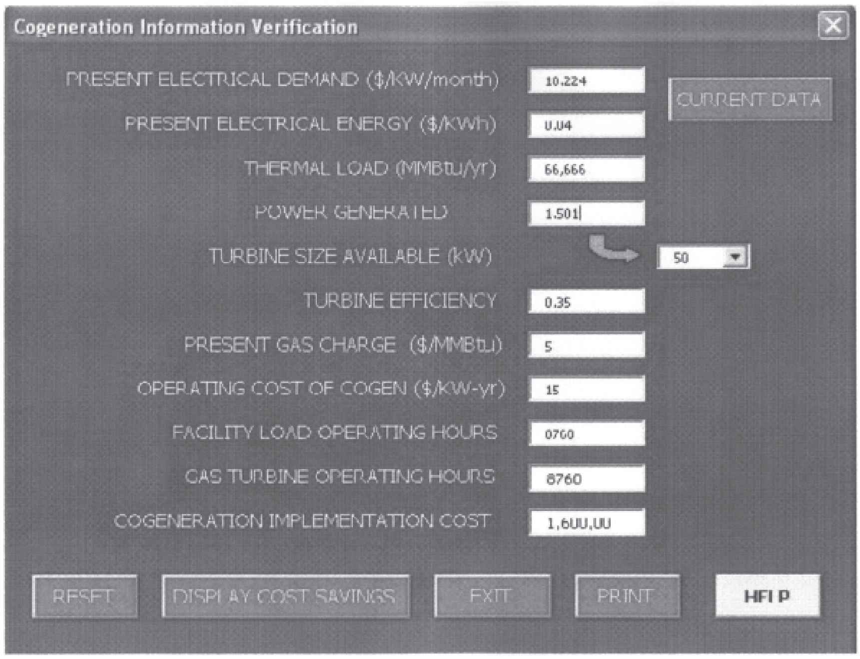

Figure 4: Cogeneration Information Verification

optimal cost savings, it must be utilized 8,760 hours a year, or 365 days a year.

To calculate a cost savings, current electrical demand and energy are needed. These values may be obtained by the data available on the energy balance sheets. To display these values, the *Current Data* button must be pressed. However, these values may also be entered by the user. The thermal load, power generated from turbine, and the turbine efficiency are transferred over from the previous screen. Once again these values may also be changed. If the user wishes to clear all the data and restart the window, the *Reset* button can be pressed. If the user does not desire to evaluate a cost savings or wishes to change data from the previous screen, the *Done* button will send the user to the previous screen. Otherwise, if the user wishes to proceed to the cost savings analysis, the *Display Cost Savings* button may be pressed.

Cogeneration Savings

After all the information has been verified, the user will prompt the cost savings window by pressing the *Display Cost Savings* button in the

Cogeneration Information Verification screen. Figure 5 shows an example of a cost savings analysis. These values will be visible as soon as the window opens. Cost analysis is performed by first calculating the worth of the thermal load from cogeneration.

- Worth of Thermal Load ($/year) = Thermal Load x Gas Charge

The demand and energy charge savings are calculated to calculate the worth of the cogeneration system.

- Demand Savings ($/year) = Power Generated x 12 months x Present Electrical Energy

- Energy Savings ($/year) = Power Generated x Turbine hours x Present Electrical Demand

- Worth of Cogeneration ($/year) = Demand Savings + Energy Savings

Gas cost is then displayed using the values calculated from the gas usage and net gas usage.

- Gas Usage (MMBtu/year) = (Power Generated/Turbine Efficiency) x Turbine hours
- Net Gas Usage (MMBtu/year) = Gas Usage – Thermal Load
- Gas Cost ($/year) = Gas Usage x Gas Charge

The operational cost is calculated as follows:

- Operational Cost ($/year) = Power Generated x Worth of Cogeneration

Total savings is computed from previous data. This is then used, along with the implementation cost, to calculate the return on investment (ROI) and the simple pay back period (SPP).

- Total Savings = Worth of Thermal Load + Worth of Cogeneration – Gas Cost – Operational Cost
- SPP = Implementation Cost/Total Savings
- ROI = (Total Savings/Implementation Cost) x 100

These values can be printed and used to further analyze whether implementation of cogeneration is beneficial for the facility and the current system.

CASE STUDY: INSTALLING A COMBINED HEAT AND POWER SYSTEM

In this example, a cogeneration system will be installed to produce high-efficiency electricity and heat for a facility. The exhaust heat from the gas turbine will be used to heat water for a high temperature hot water system. The following is a list of the relevant data:

- Present Electrical Energy Charge: $10.224/kW
- Present Electrical Demand Charge: $0.04/kWh
- System Thermal Load: 66,666 MMBtu/year

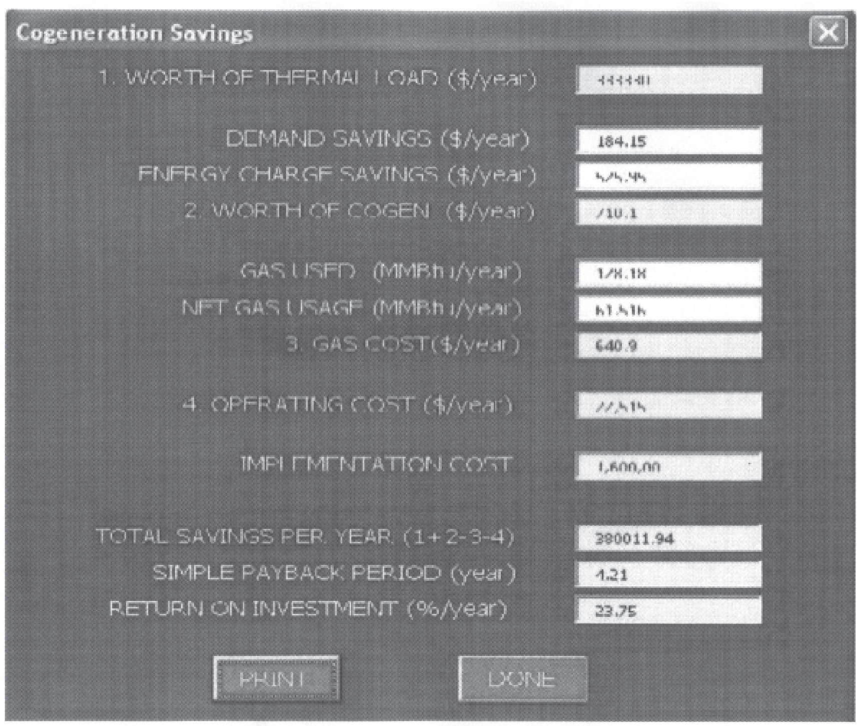

Figure 5: Cogeneration Savings

- Present Natural Gas Charge: $5.0/MMBtu
- Heat Load Operating Hours: 8760 hours/year
- Gas Turbine Operating Hours: 8760 hours/year

We also assume the gas turbine produces 30% electricity and 70% waste heat. Also the waste heat will be used for a heater whose coefficient of performance is 1.

After entering the given values in the *Cogeneration* window, the system shows that in order to produce 66,666 MMBtu of thermal load, a 1.501 MW size gas turbine is needed. The fuel needed will be 128,204 MMBtu, and the exhaust thermal energy produced will be 9.511 MMBtu. After achieving these values, the *Cogeneration Project Evaluation* button is pressed to gather values on the cost savings. First, all values must be verified. Because the values for power, efficiency, and load transfer from the previous window, and the default values for gas charge, operating cost of cogeneration, turbine hours, and load hours match those given in the problem, these values remain the same. However, the present energy and demand are needed. These values will not be available from the current data, so they will be input manually. These values are $0.04/kWh for energy and $10.224/kW for demand.

After calculating the cost savings, the *Cogeneration Savings* window showed that by implementing this system, the total savings from installing a $1,600,000 cogeneration system is $380,012 per year. The return on investment is 23.75% per year, and the simple pay back period is 4.21 years. These values are important when performing an economic analysis on implementing a cogeneration system. However, other factors (such as the ones previously mentioned in the background information) are also important when making the decision.

CONCLUSION

The addition of cogeneration as a recommendation for cost savings in the IEB software provides the user with a tool that not only aids in the decision-making process of whether or not to implement cogeneration, but also gives necessary data needed to install a cogeneration system. With a cost analysis on cogeneration implementation, customers will be able to evaluate whether it will be beneficial for the company to implement cogeneration. However, it is important to realize that there are other factors that must be considered when determining the feasibility of the project. It is highly recommended that additional engineering study and design be performed if cogeneration becomes a consideration.

In the future, this section can be enhanced by including different cost savings projects such as by considering sharing of cogeneration among facilities or utility providers.

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