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Evaluating cogeneration for your facility:

A look at the potential energy-efficiency, economic and environmental benefits

White Paper

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Cogeneration, also known as Combined Heat and Power (CHP), is the on-site production of multiple types of energy — usually electricity, heat and/or cooling — from a single source of fuel. Cogeneration often replaces the traditional methods of acquiring energy, such as purchasing electricity from the power grid and separately burning natural gas or oil in a furnace to produce heat or steam. While the traditional method of purchasing electric energy from a utility is convenient, it is very inefficient and wastes almost 75 percent of the energy in the original fuel due to production and transportation losses. (See Figure 1)

Figure 1 - Today's "grid" system of central power plants and transmission lines wastes much of the energy in the original fuel.

On-site cogeneration systems convert 70 percent to 90 percent of the energy in the fuel that is burned into useful electricity or heat. Depending on the application, the integration of power and heating/cooling production into one on-site cogeneration system can often produce savings of up to 35 percent on total energy expenditures. If your facility is a big energy user, those kinds of savings can pay for installing a cogeneration system in as little as two to three years for some applications.

A technology for today – again

The principles of cogeneration have long been known and put to use in a wide variety of applications — from Thomas Edison's first electric generating plant in 1882 to modern chemical processing facilities, to municipal utilities supplying power and district heating. In the past, economies of scale favored large, complex projects or special situations.

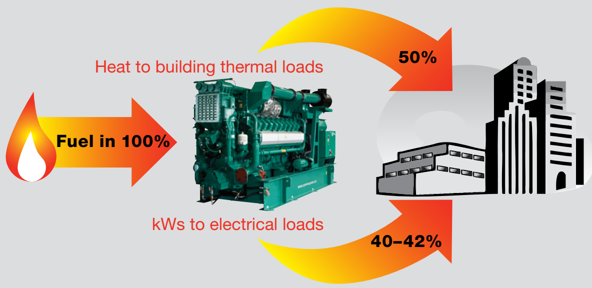

Figure 2 - CHP plants operate at twice the average efficiency of the U.S. power system.

Today, however, advances in lean-burn gas reciprocating engine technology, heat exchangers and digital system controls make cogeneration both practical and economical for applications as small as 300 kW. This is causing many more types of facilities — large and small — to take a fresh look at cogeneration as a way to improve energy efficiency, cut greenhouse gas emissions and reduce costs.

A cogeneration system normally consists of a prime mover turning an alternator to produce electricity, and a waste heat recovery system to capture heat from the exhaust and engine-cooling water jacket. The prime mover can be a lean-burn natural gas reciprocating engine, diesel reciprocating engine, gas turbine, microturbine or fuel cell. While the ratio of heat to electricity production differs between reciprocating engine systems and gas turbine systems, as much as 90 percent of the energy in the original fuel is put to productive use in a cogeneration system. (See prime mover options below.)

Less than 10 percent of the electricity used in the United States today is produced by cogeneration systems, but the Department of Energy (DOE) has established a goal of having cogeneration comprise 20 percent of generation capacity by 2030. The European Union generates 11 percent of its electricity using cogeneration. Denmark (43 percent) followed by Latvia (41 percent) are already well ahead of the curve.

Cogeneration system prime mover options

The heart of a cogeneration system is the prime mover, and each technology option — reciprocating natural gas engine, gas turbine or fuel cell — has characteristics that may make one or another better suited to your particular application. In general, systems based on reciprocating engines offer the greatest electrical output per Btu of input energy and the highest overall efficiency.

Reciprocating engine systems represent the largest share, by far, of all installed cogeneration systems. Both the reliability and availability of most systems are in the range of 90 percent to 95 percent.

The following are some characteristics of typical cogeneration systems:

Lean-burn gas engine generator cogeneration systems

Recent advances in natural gas engine combustion technology have created a reciprocating engine generator system with excellent performance and very low emissions. Lean-burn engine generators from Cummins Power Generation feature emissions down to 0.5 grams of NO_x per brake horsepowerhour. Without exhaust aftertreatment, these generators are suitable for high-hour use in most geographic areas of the world.

With exhaust aftertreatment, these systems are suitable for even the most environmentally sensitive areas such as California's southern coast in the USA. These systems also feature fast availability and installed costs that are about one-half that of cogeneration systems based on gas turbines. Practical systems range in size from 300 kW to 10 MW or more electrical output, and 1.5 MBtu to 45.2 MBtu thermal output.

Gas turbine generator cogeneration systems

Systems based on microturbines or larger gas turbines have the advantage of greater thermal output per Btu of input. Although costing considerably more per kW of capacity, and having somewhat lower overall efficiency than reciprocating engine-based cogeneration systems, turbine-based systems have slightly higher availability and lower maintenance. Gas turbines have been favored for very large cogeneration systems where high-quality heat or high-pressure steam is a required output for industrial processing. The size of gas turbine systems ranges from 30 kW to hundreds of megawatts. Emissions are similar to that of a lean-burn gas engine generator cogeneration system.

Fuel cell cogeneration systems

Fuel cells convert a fuel (usually natural gas) directly into electricity and heat without going through a typical combustion process. The main byproduct is water. While fuel cells are very clean and reliable, they are the most expensive to purchase of all available cogeneration technologies. Most installations to date have been demonstration projects.

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Is your facility a candidate for cogeneration?

The first step in deciding whether a cogeneration system is right for your facility is to perform a quick analysis of your energy use. This analysis can be reduced to a few simple questions. If you answer “yes” to all the questions, then you may be a good candidate for a more comprehensive analysis.

1. Have you taken all reasonable steps to reduce both electric and heat energy consumption at your facility? Obviously, if you can make improvements in the way you use energy in your facility, these changes will translate into lower operating costs and perhaps reduce the size of the cogeneration system needed, as well as your investment.

2. Are your operating needs 24/7? While cogeneration systems incorporating smaller generating systems are available, facilities with larger energy needs can generate proportionately larger savings and a shorter payback period. The most cost-effective cogeneration systems operate at full output 24/7. To make sure your cogeneration system is running at full capacity most of the time, only plan on generating a portion of your total electric and thermal needs – about 50 percent to 80 percent. You’ll still need a utility connection to supply the remainder of your load and an on-site boiler to handle peaks in your thermal demand.

3. Is the thermal load at your facility consistent? This could take the form of hot water, an absorption chiller load, low-pressure steam — or a combination of all three. Excess electrical power is a salable commodity that can sometimes be fed back into the grid for additional savings if allowed by your utility. Heat production is necessarily restricted to on-site or district heating use. Excess heat is usually released as waste heat, lowering overall efficiency.

4. Is the duration of your simultaneous need for heating/ cooling and electric power greater than 4,000 hours per year? While some applications are feasible when simultaneous electric and thermal demand is around 2,000 hours per year, economics favor systems that operate at least half the year. Thermal processing loads at industrial facilities tend to be rather constant, whereas space-heating or space-cooling loads are seasonal. Facilities with substantial space-heating needs in the winter and space-cooling needs in the summer are generally good candidates for cogeneration systems.

5. Are local electric rates high in relation to the local cost and availability of natural gas? Known as the “sparkspread,” the greater the differential between the price of electricity and the price of natural gas (on an equivalent Btu basis), the greater the likelihood that a cogeneration system will provide substantial savings.

6. Is your physical site suitable for the installation of a cogeneration system? You’ll need sufficient space to house the generators, heat-exchangers, switchgear and control systems. Small systems can be located outdoors in special packaged enclosures; however, larger systems may need their own room or a freestanding building. There also needs to be a supply of natural gas to the facility. Environmental factors should also be considered, such as state and local air-quality standards and noise ordinances.

7. Is reliability of electric service a major economic concern? For many commercial and industrial facilities, a power outage can be very costly due to lost productivity or revenue. In many areas, utilities are incapable of delivering the kind of reliability that is necessary. In contrast, on-site cogeneration systems — when designed with sufficient redundancy, standby generators and uninterruptible power supply (UPS) systems — offer significantly better reliability than local utilities. On-site power systems are less vulnerable to storm damage and transformer or transmission line failures, and, with proper maintenance, will offer decades of reliable operation.

This 2 MW lean-burn gas engine generator set supplies heat, steam and power for a Danish poultry farm, and heat for a nearby village.

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Analyzing costs and payback

If your answers to many of the above questions are a "yes," then your facility is a likely candidate for a cogeneration system. The next step in determining the viability of a cogeneration system for your facility is to do a simple cost analysis and calculate the number of years it will take for such a system to pay for itself.

A cost analysis is best done with the help of a representative from a system manufacturer such as Cummins Power Generation or a consulting engineer familiar with cogeneration systems. However, the factors that go into the calculation are: 1) electricity costs per kWh; 2) electricity demand charges; 3) cost of natural gas; 4) number of anticipated hours of operation per year; 5) utilization of recovered heat; and 6) installed cost of the cogeneration system. This information is used to estimate the annual savings and payback for your facility.
For a sample payback analysis, read below:

Sample Payback Analysis

A recent economic analysis for a university in Scotland illustrates the energy cost savings that can be realized with a cogeneration system. The university chose a cogeneration solution. Cummins provided a 995 kWe QSK60 Hi-Efficiency Natural gas generating set including additional ancillary items, acoustic enclosure, installation and commissioning.

Cost calculations

Energy Costs:	
Electricity	8 p/kwhr
Gas	2.3 p/kwhr
Cogeneration maintenance charge	£ 10.90 p/hr run
Project Costs:	
Customer infrastructure cost	£ 100,000.00
Cogeneration CAPEX cost	£ 615,000.00
Total project cost	£ 715,000.00
Cogeneration Costs:	
Fuel Cost	£ 452,272.00
Maintenance cost	£ 87,200.00
Total cogeneration costs	£ 539,472.00
Energy Savings:	
Electricity	£ 636,800.00
Heat	£ 222,525.00
Total energy savings	£ 859,325.00
Net benefit to client	£ 319,853.00
Payback period	2.2 years

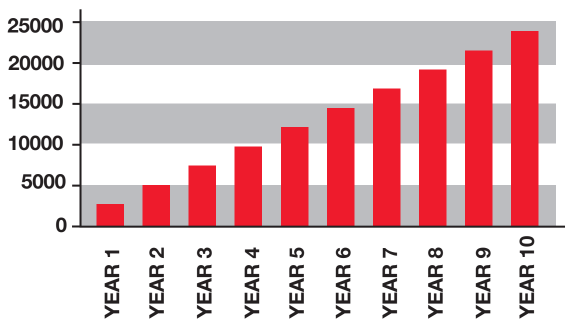
Environmental savings

The cogeneration installation has helped the university meet its objectives of reducing carbon emissions in line with the university's carbon management plan, as well as providing a flexible and sustainable future energy supply for its growing campus.

Carbon Dioxide Savings:

Cogeneration displaced electricity	4391 tonnes CO_2
Cogeneration delivered heat	1587 tonnes CO_2
Less fuel CO2 produced	3629 tonnes CO_2
Net carbon dioxide saving	2349 tonnes CO_2

You can see from the figures that an on-site generator that produces both electricity and thermal energy can cut total energy expenditures and carbon dioxide emissions by a significant amount. In this example, the cogeneration system will pay for itself in little more than two years.



CO² Savings

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These two 2MW lean-burn gas fueled generator sets are in operation at a cogeneration plant that provides base load power and hot water for an Australian hospital.

The environmental factors

Cogeneration is a technology that offers a win-win for businesses and the environment. Greater use of natural gas-based cogeneration systems would have the effect of displacing electricity produced by a nation's power grid. Since the lion's share of this power is produced by older coal-fired power plants, a reduction in electric demand would reduce carbon dioxide, nitrogen oxides, sulfur dioxide, particulates and other noxious emissions.

In terms of CO_2 emissions alone, burning natural gas in an on-site reciprocating engine generator produces less than half of the CO_2 produced by an equivalent amount of coal burned in a central power plant. In this way, cogeneration is a technology that reduces pollution overall and helps in the fight against global warming. In addition, since CO_2 production is directly related to the amount of fuel burned, cogeneration's significantly greater fuel efficiency reduces CO_2 emissions overall, while lowering costs and conserving natural resources. Cogeneration systems can also make users eligible for carbon credits for their CO_2 reduction.

Green building rating systems have been developed in many countries around the world to provide standards for environmentally sustainable construction. In addition to addressing water usage, indoor environmental quality and innovative building design, these standards typically address both energy usage and the atmosphere. Such a standard may include a requirement for reducing a facility's "carbon footprint," primarily emissions of carbon dioxide (CO_2). By displacing the energy that would normally be produced by central power plants that burn fossil fuels, cogeneration systems significantly reduce the amount of carbon and other pollutants that are released into the atmosphere. For example, the Leadership in Energy and Environmental Design (LEED) standards developed by the U.S. Green Building Council include an LEED-NC (New Construction) certification with a requirement for two energy optimization credits; facilities can earn one of these credits by installing a cogeneration system.

To help facility managers calculate the amount of reduction in greenhouse gases and fuel that can be achieved with a cogeneration system, the U.S. Environmental Protection Agency (EPA) has created an online tool. This interactive tool can help facility managers or consulting engineers evaluate the environmental and energy-saving benefits of cogeneration. This calculator can be found at www.epa.gov/chp/basic/calculator.html

Applications that are candidates for cogeneration

Advancing technology has made cogeneration systems suitable for a much wider range of applications than in the past, although the simultaneous need for electric power and heat or cooling is common to all cogeneration applications. Facility types that are good candidates for cogeneration today include:

- Hospitals
- Greenhouses
- Hotels
- Industrial/chemical plants
- Manufacturing
- Commercial facilities
- Government facilities
- Colleges and universities
- Food processing plants
- Health clubs
- Swimming pools
- Nursing homes

Conclusion

Cogeneration systems that produce both electricity and heat/cooling from the same fuel can offer energy savings of up to 35 percent for a wide range of facilities, while at the same time contributing to building sustainability and protecting the environment. The potential for cost savings in energy expenditures is usually the motivating reason to consider cogeneration, but building sustainability and regional certifications are becoming reasons on their own to investigate the potential benefits of cogeneration for your facility.

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Information resources

For additional environmental and cogeneration information, visit the web sites listed here:

- The Association of Energy Engineers, www.aeecenter.org
- Buildings Cooling, Heating, and Power (BCHP) Initiative, www.chpcentermw.org
- Electric Power Research Institute (EPRI), www.epri.com
- EPA, www.epa.gov/chp/basic/calculator.html
- TA Luft, http://www.bmu.de/en/topics/air-mobility-noise/air-pollution-control/ta-luft/

About the author

Keith Packham started out as a marine engineer working in the UK Merchant Navy. He is now ESB Applications Manager for Cummins Power Generation, and provides expert technical advice and support to the global Energy Solutions Business team on the design, installation and operation of energy efficient plants. He has been involved with the design, installation, maintenance, and operational aspects of combined heat and power (CHP) plants, boiler plants for steam or hot water, power generation and distribution, refrigeration, water and effluent treatment plants and their optimum performance. He holds a Bachelor's degree in Energy Engineering from Southbank University in England.

For more information on cogeneration, contact your consulting engineering firm, power system manufacturer or email energysolutions@cummins.com

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