Evaluating cogeneration for your facility:

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

> **White Paper**

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Cummins Power Generation

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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)

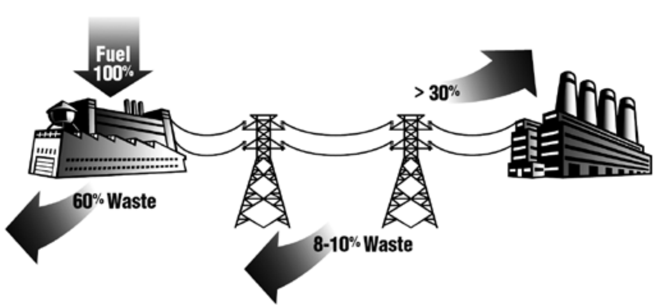


Figure 1 - Today's "grid" system of central power plants and transmission lines wastes much of the energy in the original fuel.

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.

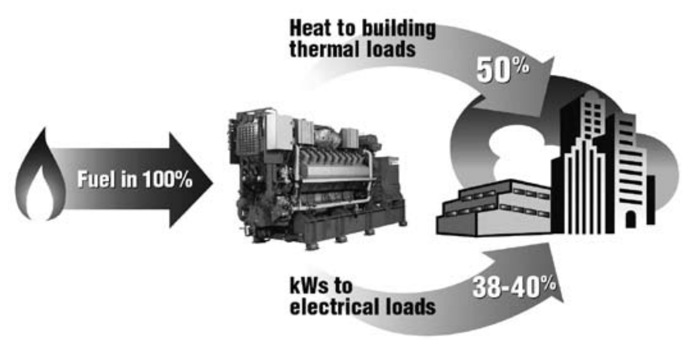


Figure 2 - CHP plants operate at twice the average efficiency of the U.S. power system.

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. 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 box 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 doubling installed cogeneration capacity by 2010. The European Union has established a similar target. Switzerland, where cogeneration accounts for 77 percent of the country's electricity, and Denmark (40 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. Below 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 of less than 0.5 grams of NOx per brake horsepower-hour. Without exhaust aftertreatment, these generators are suitable for high-hour use in most geographic areas of the United States. With exhaust aftertreatment, these systems are suitable for even the most environmentally sensitive areas of the country — such as California's southern coast. 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.

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. *Is the base electrical load at your facility greater than 1,000 kW?* 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.

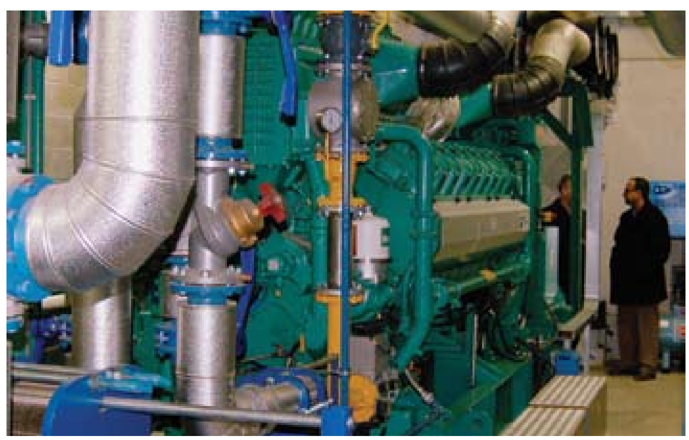
3. *Is the thermal load at your facility consistent and equivalent to 1 million Btu/hr or more?* This could take the form of hot water, an absorption chiller load, low-pressure steam — or a combination of all three. Excess electrical power is a salable commodity that can sometimes be fed back into the 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 "spark-spread," 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 of the country, 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.



A 1.5 MW lean-burn gas generator set provides heat and power as well as CO_2 to accelerate the growth of tomatoes at a large greenhouse in Belgium.

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 per million Btu; 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 commercial facility in Southern California illustrates the energy cost savings that can be realized with a cogeneration system.

Before the system was installed, the facility:

- Consumed 12.4 million kWh of energy per year with a peak electrical demand of 2,656 kW.
- Had an average cooling load of 500 tons with a peak of 1,000 tons.
- Paid an average of $0.1419 per kWh for electricity and $0.55 per therm for natural gas.

To combat the high electricity charges from the utility, the facility owners chose to install an on-site cogeneration system to generate 80 percent of their electrical and thermal needs on an annual basis. Following are the system's characteristics:

- Prime mover was Cummins QSV91G lean-burn natural gas engine generator (with selective catalytic reduction aftertreatment) that produced 1,250 kW of electricity.
- "Waste" heat from the generator engine was sufficient to power a 250 ton absorption chiller.
- Generator set typically operates at a 38.1 percent electrical efficiency and a 48.0 percent thermal efficiency — resulting in a net running cost of $0.0648 per kWh and a net thermal output of 4,191,118 Btu/hr.

Cost calculations

Total installed system cost *(after state rebate)*	$2,581,982
Projected annual electric savings	($1,280,123)
Generator operating costs *(including fuel and maintenance)*	$ 631,792
Net annual cash flow from savings	$ 648,331
Payback period	3.98 years

Environmental savings

By displacing power generated by coal-burning utilities, this cogeneration system delivers significant reductions in greenhouse gas emissions in addition to energy savings.

Nitrogen oxide (NO_X) reduction	6.14 tons/year
Sulfur dioxide (SO_2) reduction	14.60 tons/year
Carbon dioxide (CO_2) reduction	3,056 tons/year

You can see from the figures that an on-site generator that produces both electricity and thermal energy can cut total energy expenditures and greenhouse gas emissions by a significant amount. In this example, the cogeneration system will pay for itself in less than four years and thereafter provide annual positive cash flow for the facility.

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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 the 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.

If your facility is considering Leadership in Energy and Environmental Design (LEED) certification, you may be aware that the LEED-NC (New Construction) standards now include a requirement for two energy optimization credits; facilities can earn one of these credits by installing a cogeneration system. LEED is a green building rating system developed by the U.S. Green Building Council that provides a number of standards for environmentally sustainable construction. In addition to addressing water usage, indoor environmental quality and innovative building design, LEED addresses both energy usage and the atmosphere. An emerging LEED standard includes 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.

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/documents/chp_emissions_calc_103006.xls*

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

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*
- Midwest Cogeneration Association, *www.cogeneration.org*
- U.S. Clean Heat & Power Association, *www.uschpa.org*
- U.S. Department of Energy (DOE), *www.eere.energy.gov*
- LEED Rating System, U.S. Green Building Council, *www.usgbc.org*
- EPA, *www.epa.gov/chp/basic/calculator.html*

This cogeneration unit produces 1,250 kW of electricity, 2,200 pounds of steam and 30 gal/min of hot water, while besting local air-quality standards at a California animal feed processor.

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About the author

Joel Puncochar is a product manager with the Energy Solutions Business of Cummins Power Generation. He manages lean-burn and low Btu generator set product lines often used in cogeneration and alternative fuel applications. Joel has been with the company for 35 years, with his most recent accomplishment being the development of Cummins Power Generation's first commercial generator sets to come out of the U.S. Department of Energy's ARES (Advanced Reciprocating Engine Systems) program. ARES is a multifaceted research program involving engine manufacturers, research laboratories, universities and the government. Cummins is one of three U.S. engine manufacturers to participate in the program that seeks to design engines with improved fuel efficiency and reduced emissions.

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 LEED certification are becoming reasons on their own to investigate the potential benefits of cogeneration for your facility. For more information, contact your consulting engineering firm or power system manufacturer.

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