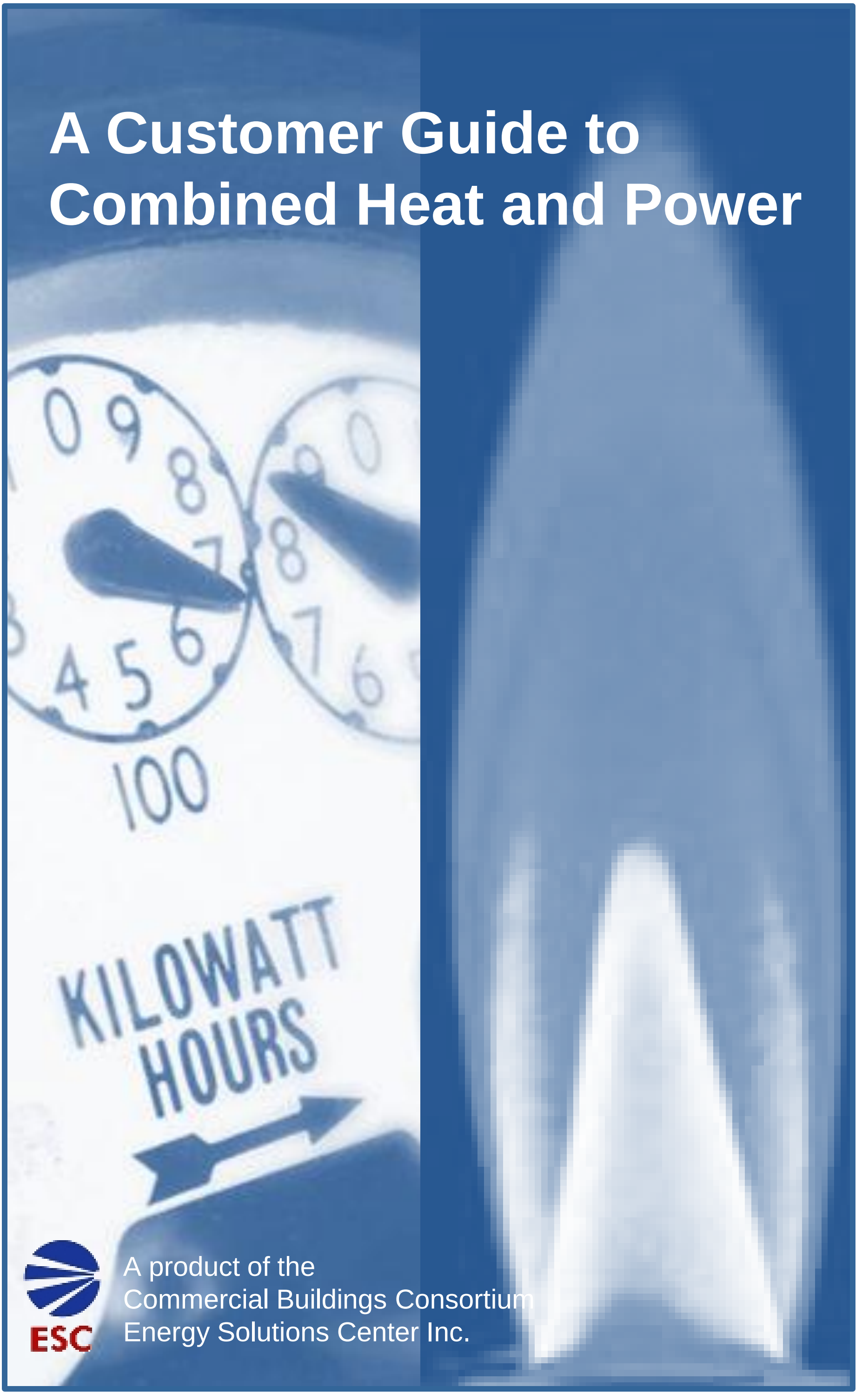
A Customer Guide to Combined Heat and Power



A product of the
Commercial Buildings Consortium
Energy Solutions Center Inc.

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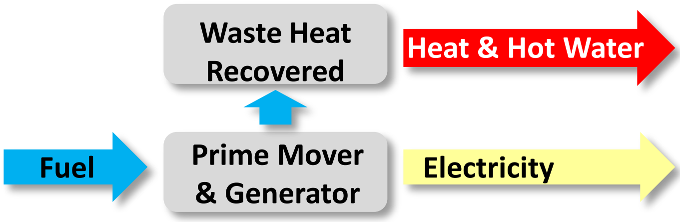
ESC

What is Combined Heat & Power

Combined Heat and Power (CHP) by definition is the generation of two forms of energy from one common source of fuel also known as Cogeneration.



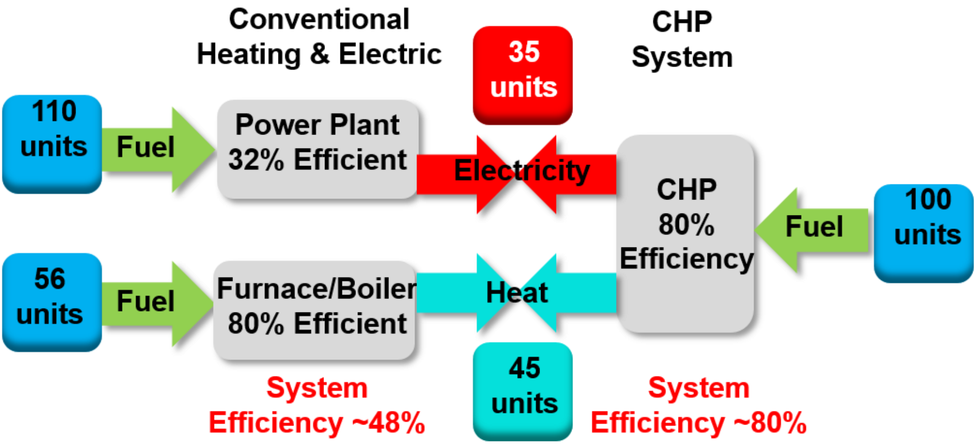
The CHP system is typically located at or near your building and generates electricity or mechanical power with the added benefit of recovering the waste heat in the form of hot water, steam, or warm air to meet thermal needs. This high quality and very reliable power system provides a secure energy source along with the ability to provide hot water, heating, cooling or de-humidification of your facility.

The real key to an efficient and economical CHP system is having the need for simultaneous use of both electricity and heat.

CHP is not a single technology, but an integrated energy system that can be modified depending upon the needs of the energy end user. These systems simply capture and utilize excess heat generated during the production of electric power. CHP systems offer economic, environmental and reliability-related advantages compared to power generation facilities that produce only electricity. Distributed power generation systems, which are frequently located near thermal loads, are particularly well suited for CHP applications.

The total CHP system efficiency is the combination of electrical efficiency and the efficiency of capturing the usable waste heat. By capturing & using the waste heat, CHP systems consume approximately 40% less energy than grid power and heating with a boiler.

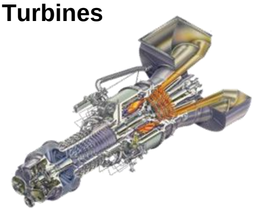
Because greenhouse gas emissions are related to energy consumption, CO_2 emissions are generally lower with CHP than using conventional grid power & a boiler.



Prime Movers

There are five types of prime movers for CHP systems:

- Reciprocating Engines
- Combustion Turbines
- Microturbines
- Steam Turbines
- Fuel Cells

Reciprocating Engine 	High fuel efficiency Lower Initial costs – vs. larger turbines Best for variable load applications More tolerant to high ambient conditions and high elevations) Lower fuel pressure requirement Accept low BTU fuels On line in less than 30 seconds Offer "black start" capability
Combustion Turbines 	Well suited for CHP w/ large heat to ekW ratio High exhaust temperatures :480 C / 900 F Low weight & minimal space requirement Very simple design Lower emissions capabilities Ideal for 24/7 operation Accept high or low BTU fuels Requires high pressure gas
Microturbines 	30 – 200 ekW sizes available Lightweight & small footprint Multi-fuel capability Air cooled Ultra low emissions High reliability Minimal scheduled maintenance Accepts various fuel sources
Fuel Cells 	Grid-independent operation Electric load following Multi-megawatt capacity Low pressure natural gas fuel Low noise and vibration Ultra-low emissions ~10 year cell stack life

Reciprocating Engines

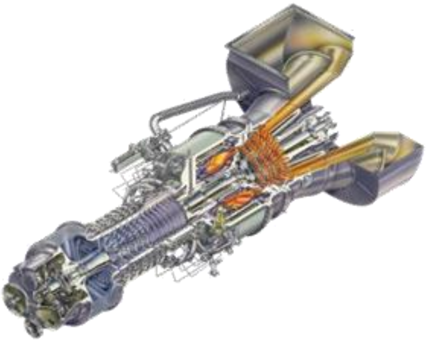
Reciprocating engines are the most common and most technically mature of all CHP technologies. They are available from small sizes (e.g., 1 kW for residential generation) to large generators (e.g., 7 MW). Typically, any power generation system smaller than 50 kW is considered micro CHP.

Currently available natural gas engines offer low first cost, fast start-up, proven reliability when properly maintained, excellent load-following characteristics, and significant heat recovery potential.

Electric efficiencies of natural gas engines range from 28% lower heating value (LHV) for small engines (<100 kW) to over 40% LHV for very large lean burn engines (> 3 MW). Waste heat can be recovered from an engine exhaust, jacket water and oil cooling systems to produce either hot water or low pressure steam for CHP applications. Overall CHP system efficiencies (electricity and useful thermal energy) of 70% to 80% are routinely achieved with natural gas engine systems.

Reciprocating engine technology has improved dramatically over the past three decades, driven by economic and environmental pressures for power density improvements (more output per unit of engine displacement), increased fuel efficiency and reduced emissions. Computer systems have greatly advanced reciprocating engine design and control, accelerating advanced engine designs and making possible more precise control and diagnostic monitoring of the engine process. Engine manufacturers and worldwide engine R&D firms continue to drive advanced engine technology, including accelerating the diffusion of technology and concepts from the automotive and marine markets to the stationary market.

Combustion Turbines



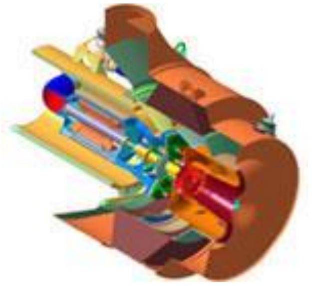
Conventional combustion turbine (CT) generators are a very mature technology. They typically range in size from about 500 kW to over 100 MW for central power generation. They are fueled by natural gas, oil or a combination of fuels (dual fuel). Modern single-cycle combustion turbine units typically have efficiencies in the range of 20 to 45% at full load. Efficiency is somewhat lower at less than full load.

Gas turbine CHP systems burn fuel to generate electricity and then use a heat recovery unit to capture heat from the combustion system's exhaust stream. This heat is converted into useful thermal energy, usually in the form of steam, hot water or heated air. Gas turbines are ideally suited for large commercial or industrial CHP applications requiring ample amounts of electricity and heat.

Gas turbines can be used in a simple cycle combined heat and power operation, or combined cycle operation in which high pressure steam is generated from recovered exhaust heat and used to create additional power using a steam turbine. Some combined cycles extract steam at an intermediate pressure for use in industrial processes as well.

Gas turbines produce high-quality exhaust heat that can be used in CHP configurations to reach overall system efficiencies of 70% to 80%. The efficiency and reliability of smaller gas turbines (1 to 40 MW) are an attractive choice for industrial and large commercial users for CHP applications.

Microturbines

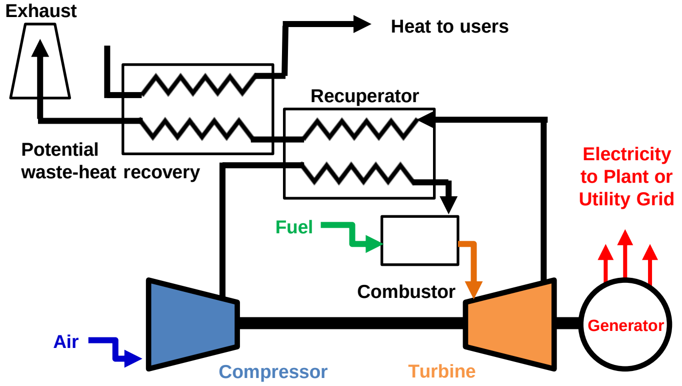


Microturbines are small combustion turbines that produce between 30 kW and 200 kW of power. Microturbines were derived from turbocharger technologies found in large trucks or the turbines in aircraft auxiliary power units (APUs). Most microturbines are single-stage, radial flow devices with high rotating speeds of 90,000 to 120,000 revolutions per minute.
A few manufacturers have developed alternative systems with multiple stages and/or lower rotation speeds.

Microturbine generators can be divided in two general classes:

- Recuperated microturbines, which recover the heat from the exhaust gas to boost the temperature of combustion and increase the efficiency
- Un-recuperated microturbines, which have lower efficiencies, but also lower capital costs.

While most early product introductions featured un-recuperated designs, todays products are focused on recuperated systems. The recuperator recovers heat from the exhaust gas and boosts the temperature of the air stream supplied to the combustor. Further, the exhaust heat recovery can be used in a CHP configuration. The figure below illustrates a recuperated microturbine system.



Steam Turbines

Steam turbines are one of the oldest prime mover technologies that are still used to drive a generator or mechanical machinery. Power generation using steam turbines has been in use for over 100 years, when they replaced steam engines due to their higher efficiencies and lower costs. Most of the electricity produced in the United States today is generated by conventional steam turbine power plants. The capacity of steam turbines can range from 50 kW to 1,500 MW for large utility power plants. Steam turbines are widely used for CHP applications in the U.S. and Europe.

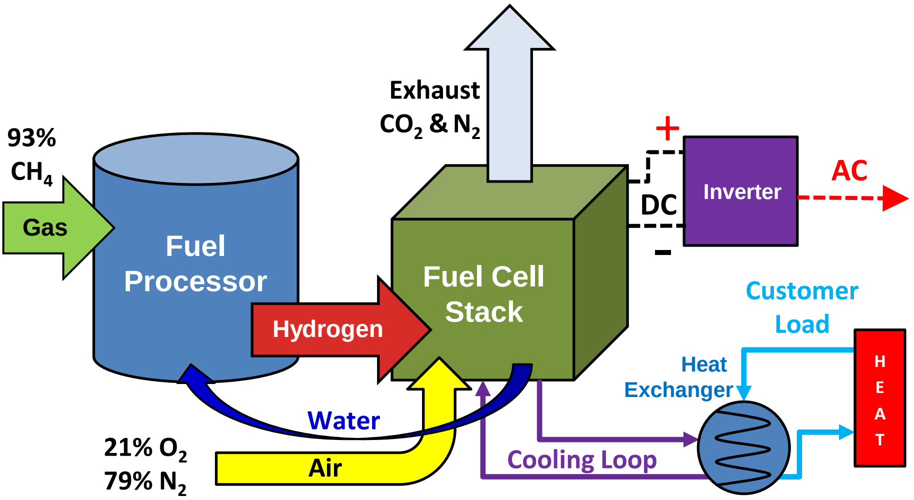
Unlike gas turbine and reciprocating engine CHP systems where heat is a byproduct of power generation, steam turbines normally generate electricity from heat (steam). A steam turbine is captive to a separate heat source and does not directly convert fuel to electric energy. The energy is transferred from the boiler to the turbine through high pressure steam that in turn powers the turbine and generator. This separation of functions enables steam turbines to operate with a wide variety of fuels. In CHP applications, steam at lower pressure is extracted from the steam turbine and used directly in a process or for district heating, or it can be converted to other forms of thermal energy including hot or chilled water.

Steam turbines offer a wide array of designs and complexity to match the desired application and/or performance specifications. Steam turbines for utility service may have several pressure casings and elaborate design features, all designed to maximize the efficiency of the power plant. For industrial applications, steam turbines are generally of simpler single casing design and less complicated for reliability and cost reasons. CHP can be adapted to both utility and industrial steam turbine designs.

Fuel Cells

Fuel cells are an entirely different approach to the production of electricity than traditional prime mover technologies. Fuel cell stacks available and under development are silent, produce no pollutants, have few moving parts, and have relatively high fuel efficiencies.

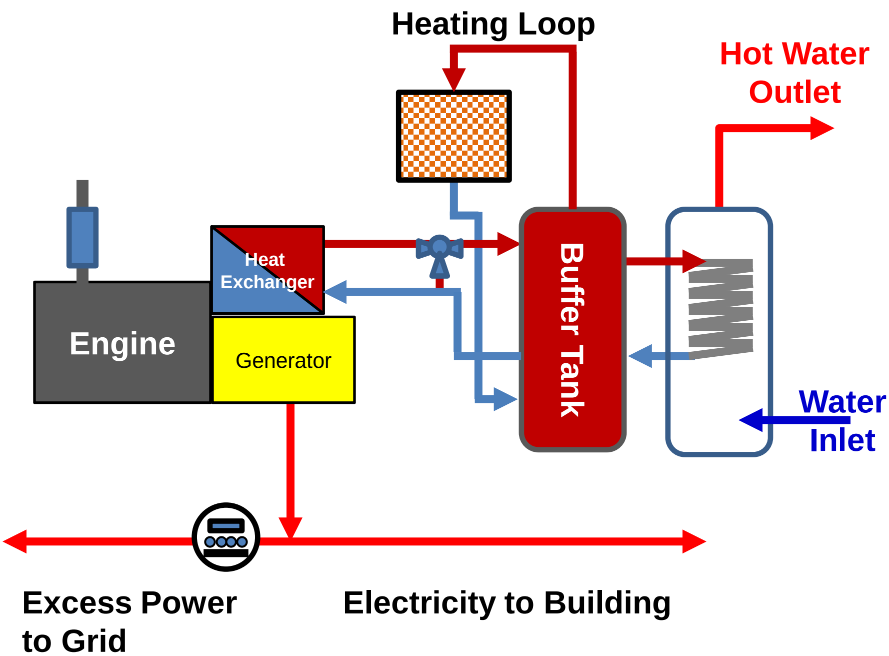
Fuel cell systems with their ancillary pumps, blowers, and reformers maintain most of these advantages. A schematic of a fuel-cell-based CHP system is shown below.



Fuel cells produce power electrochemically from hydrogen delivered to the negative pole (anode) of the cell and oxygen delivered to the positive pole (cathode). The hydrogen can come from a variety of sources, but the most economic method is by reforming of natural gas. There are several different liquid and solid media that support these electrochemical reactions - phosphoric acid (PAFC), molten carbonate (MCFC), solid oxide (SOFC), and proton exchange membrane (PEM) are the most common systems. Each of these media comprises a distinct fuel cell technology with its own performance. Fuel cell efficiencies range from 35-40 percent for the PAFC to upwards of 60 percent for the SOFC systems.

Micro CHP

Micro-CHP systems in small commercial buildings are generally designed to be controlled by heat-demand, delivering electricity as the by-product. Although similar to large CHP systems, these small systems generate heat that is pumped through a heat exchanger and used for water heating or heating loads. The generator provides power for on-site consumption and may exceed actual facility use. In this case, the power can be sold back to the local electric utility lowering the total operating cost.



There are several prime movers that can be used for micro CHP applications.

Waste Heat Recovery

A waste heat recovery unit is a heat exchanger that recovers heat from exhaust streams with potential high energy content, such as exhaust gases or from cooling water from a CHP system. Numerous options exist for the use of waste heat including:

- Steam-Low Pressure and High Pressure
- Hot Water
- Chilled Water

There are many commercially available heat recovery systems and technologies.

- Heat Recovery Steam Generator (HRSG)
- Shell and Tube, Plate & Frame Heat Exchangers
- Absorption Chillers

Typical system exhaust temperatures are:

- Combustion Turbine: 900 – 1000°F
- Recuperated Micro-Turbine: 500 – 600°F
- Reciprocating Engine: 900 – 1000°F + 200 - 200°F hot water
- Fuel Cell: 600 – 700°F

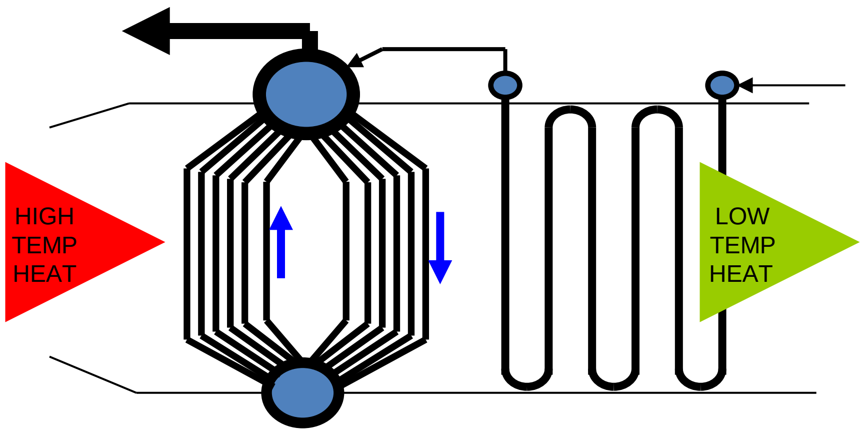
A HRSG is a steam boiler that uses hot exhaust gases from the gas turbines or reciprocating engine to heat up water and generate steam. The steam, in turn, drives a steam turbine or is used in commercial applications that require heat. Sometimes a duct burner may be incorporated into the exhaust stream to increase temperatures to provide higher quality steam from the HRSG.

Heat exchangers are available in several configurations that offer very economical heat recovery options.

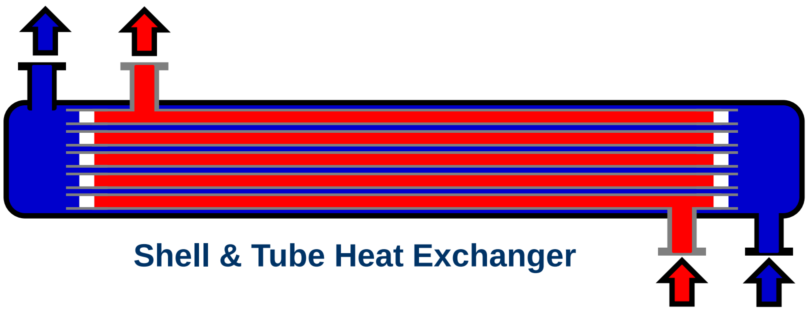
Plate and frame heat exchangers are composed of multiple, thin, slightly separated plates that have very large surface areas and fluid flow passages for heat transfer.

Shell and tube heat exchangers consist of a series of tubes. These tubes contains the fluid that will be either heated or cooled. The second fluid is in the shell and is pumped around the tubes to transfer the heat to the initial loop.

Waste heat recovery process systems have many benefits for CHP applications. The recovery process adds to the efficiency of the CHP system, decreasing the fuel and energy consumption needed for other applications at the facility (i.e. water or space conditioning). Other benefits can include the reduction in equipment sizes. As fuel consumption is reduced (due to the recovered heat), the size of the heating or water heating equipment normally used for that application can be downsized.



Generating Bank **Economizer**



Shell & Tube Heat Exchanger

Site vs. Source

Today, energy efficiency and environmental impacts are on everyone's mind. Understanding the real costs of the energy we consume in our buildings is also very important.

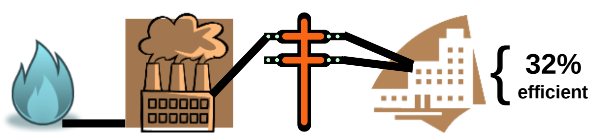
Statements about electricity being 100% efficient are misleading. That analysis simply focuses on the efficiency at the end use device — an energy-using piece of equipment — and doesn't take into account the entire energy delivery process from generation to end use. A significant amount of energy is wasted just to produce the electrical power that is ultimately delivered to your facility.

Natural gas comes directly from the well to your facility. More natural gas energy potential is delivered to your equipment on site, making natural gas a far more efficient energy choice overall.

Industry analysis shows that the production, transmission and delivery of electricity to the market has an overall efficiency of just 32%. This compares to natural gas at 92%.

These numbers reflect the total energy expended during the production-through-delivery process compared to the net energy delivered for use.

ELECTRIC



about 68% lost in generation and delivery

NATURAL GAS

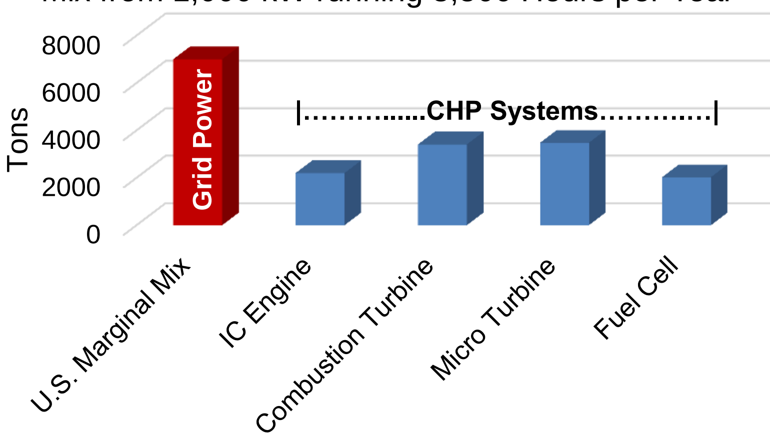
about 8% lost in extraction and delivery

Environmental Benefits

CHP plays an important role in meeting the North American energy needs as well as in reducing the environmental impact of power generation. Because less fuel is burned to produce each unit of energy output, CHP reduces air pollution and greenhouse gas emissions.

Natural gas CHP is the best choice for lowering carbon based emissions. Below is an example of a 1,000 kW CHP System compared to purchasing Grid power.

CO_2 Emissions for U.S. Average Marginal Power Mix from 1,000 kW running 8,500 Hours per Year



According to the U.S. Energy Information Administration, gas-fired CHP equipment offers the lowest carbon emissions versus alternate fueled technologies. Further, additional exhaust treatments including Selective Catalytic Reduction (SCRs) are available that can further improve the total exhaust emissions.

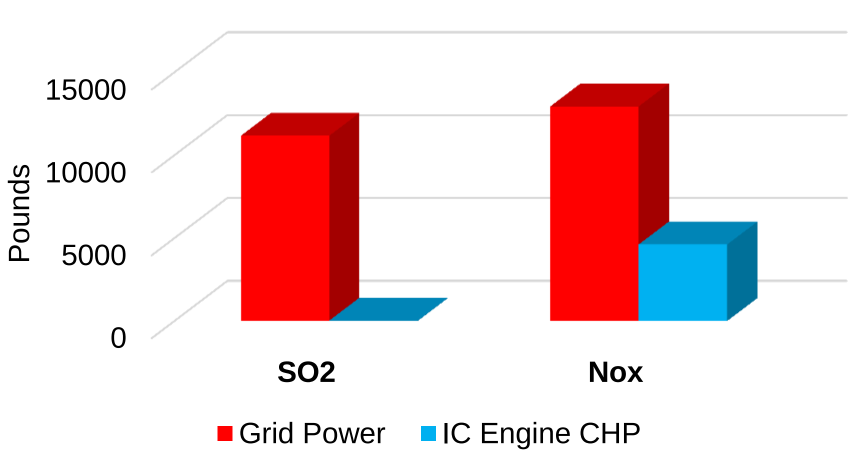
Fuel cell systems have inherently low emissions profiles because the primary power generation process does not involve combustion. The fuel processing subsystem does not require any emissions control devices to meet current or projected regulations.

While not considered a pollutant in the ordinary sense of directly affecting health, CO_2 emissions do result from the use the fossil fuel-based CHP technologies. The amount of CO_2 emitted in any of the CHP technologies discussed depends on the fuel carbon content and the system efficiency. Only 117 pounds of CO_2 are produced for every MMBTU of natural gas burned versus 161 #/MMBTU for fuel oil & 205 #/MMBTU for coal.

The use of natural gas is emerging as the preferred fuel choice for CHP. This is due to natural gas being widely available and competitively priced versus other fuel sources. Further, public policy and the local “green market” are causing businesses and institutions to re-think and consider gas fired CHP.

In addition to cost savings, CHP technologies offer significantly lower emissions rates compared to separate heat and power systems. The example below compares 1000 kW engine driven CHP system to emissions from grid power for the U.S. marginal power mix.

SO_2 & NOx Emissions from the Grid vs. 1,000 kW IC Engine running 8,500 Hours per Year



Economics

Cost is an important factor when considering the purchase of any product, including CHP. However, determining the cost of CHP technology is often more complex than simply purchasing a piece of hardware at a published price. In addition to equipment (or capital) cost, there are labor and other expenses related to installing the equipment. Once the system is installed and operational, there are energy costs and on-going maintenance costs for the CHP system.

There are also substantial energy savings to be expected from the CHP system. The system should generate power at a cost below purchasing electricity from the grid, and the use of the waste heat generated from the CHP system, reduces use of thermal energy.

Equipment costs for CHP technologies are often quoted in terms of their cost per kilowatt of electricity produced, or $/kW. Generally speaking, the larger the CHP system, the lower the installed cost per kW. Purchasing a system that matches your thermal need will offer the best economics with paybacks estimated to be 3-5 years.

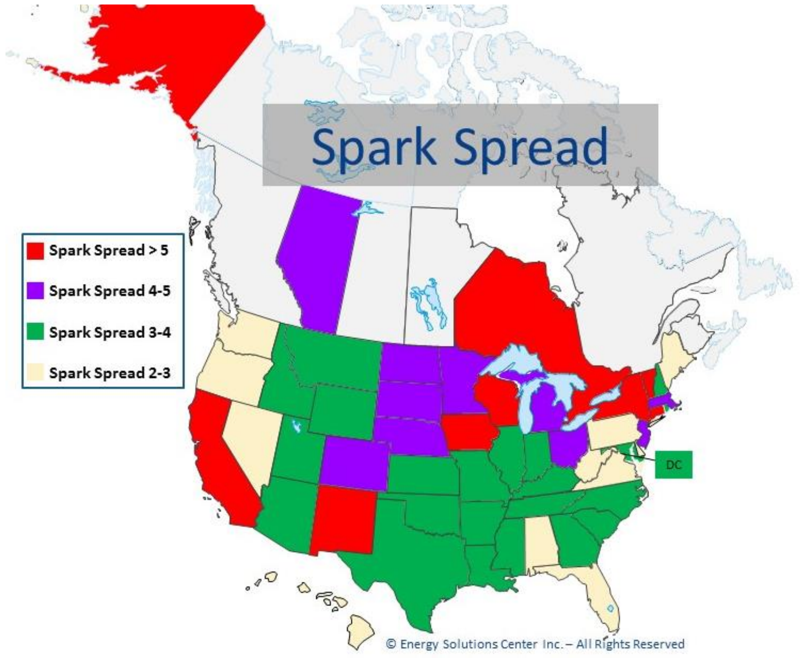
For any CHP economic analysis, Life Cycle Costing should be considered. A Life Cycle Cost analysis considers all costs of operating the system over the expected life of the equipment. This type of analysis is useful when comparing different system options to that of continuing with business as usual purchasing electric from the grid.

A typical CHP system life expectancy is 20 years. A CHP life cycle cost analysis will consider 3 things over the 20 year life as follows:

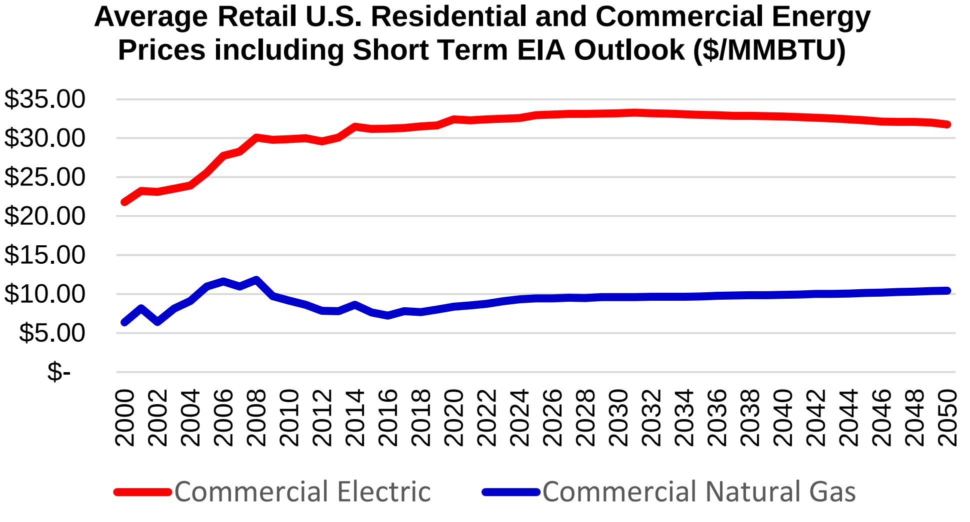
- All the capital costs amortized over the 20 years at your current loan interest rate.
- Expected energy costs for the 20 years. The cost in year one uses current energy rates and each subsequent year should increase slightly as we assume energy will cost more in 20 years than it does today. A typical energy escalation clause is 1%-2%.
- Maintenance costs for each of the 20 years needs to be factored in. The assumption is that the CHP system will require more maintenance in later years than in early years of operating. Some manufacturers offer maintenance plans that include costs for minor updates as well as major overhauls of the system.

A CHP analysis tool that calculates simple payback, IRR, Life Cycle Costs, and CO2 emissions is available at: https://understandingchp.com/resources/payback-tool/. This Excel tool compares 4 different prime movers to the ‘do-nothing’ scenario.

When considering the adoption of a CHP technology, many questions must be asked to determine which technology best fits the specific situation, especially in terms of meeting the energy requirements at a cost that is acceptable.



Spark spread is the relative difference between the price of fuel and the price of power. Spark spread is highly dependent on the efficiency of conversion. For a CHP system, spark spread is the difference between the cost of fuel for the CHP system to produce power and heat on site and the offset cost of purchased grid power.



Available Resources

ESC Energy Solutions Center

www.understandingCHP.com
www.GasAirConditioning.com

U.S. Department of Energy and FEMP

https://www.energy.gov/eere/amo/combined-heat-and-power-basics

https://www.energy.gov/eere/femp/federal-energy-management-program

CHP Installation database:
https://doe.icfwebservices.com/chpdb/

U.S. Environmental Protection Agency (EPA)

https://www.epa.gov/chp

Policies & Incentives Database:

https://www.epa.gov/chp/dchpp-chp-policies-and-incentives-database

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