

Benefits and Applications of Small-scale and Micro-CHP Systems

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ABSTRACT

Why pay for the inefficiencies of the utility companies? Combined heat and power (CHP) is a proven technology that provides clean, reliable, and affordable energy to a variety of institutions. CHP systems allow a facility to produce on-site electrical power and obtain overall efficiencies of over 85%. Standard power production provided by the utility companies is generally only 40% efficient. This is possible because CHP systems are designed to recover thermal energy from the prime mover (electrical generating equipment). In the past, many CHP systems have only been considered for large industrial and large commercial institutions because of the high capital costs and the increased need to reduce energy costs. These institutions primarily use large reciprocating engines, combustion turbines, and steam turbines to produce electricity, as well as steam or pressurized hot water.

With advancements in manufacturing and design, many CHP technologies have become more affordable for smaller institutions to yield both economic and other advantages. These technologies include microturbines, small reciprocating engines and fuel cells that will produce electricity in addition to low pressure steam or low temperature hot water. The lower grade of heat recovery available from these small-scale and micro-CHP technologies is ideal for smaller institutions.

This article details the benefits and applications of small-scale and micro-CHP systems. It also discusses proven examples of how these CHP systems are being utilized in a variety of institutions. Many of these small scale and micro-CHP technologies have been on the market for years; however, with the rising cost of energy, the savings using these technologies are now justified for smaller systems. Some of the examples will include new techniques for application, emerging technologies and renewable energy sources.

INTRODUCTION

What is Combined Heat and Power?

Combined heat and power (CHP) is the installation of an on-site integrated energy system that generates both electrical and thermal energy for use for an institution. Combining both electrical and thermal energy allows for higher system efficiencies and reduced operating costs.

To better understand the principle of combined heat and power, it is necessary to understand the process of typical power generation. In a standard power plant utilizing coal, oil, or natural gas, as shown in Figure 1, only 40% of the fuel entering the plant is converted to electrical energy. The majority of the energy entering the plant is converted to and rejected as waste heat to the environment. This waste heat is typically in the form of exhausted gases, which contribute to greenhouse gas emissions and global warming. In addition, a portion of the electrical energy produced is lost in transmission. The electrical energy is lost because of the resistive nature of copper in high voltage power lines, as well as the inherent inefficiencies of utility substations. By the time the electricity reaches the end user, overall efficiency is approximately 33%-40% of the input energy that enters the power plant.

In a CHP plant, as shown in Figure 2, 40% of the fuel entering the plant is translated into useful electrical energy, just as in a standard power plant. As in the standard plant, 60% of the input energy is converted to heat. Unlike the standard power plant, however, only 20% of the total input energy is rejected as heat. The majority of this heat, 40% of the input energy into the plant, is recovered and used to provide hot water, steam or even chilled water. Because the electricity created by the CHP system is used on site, the transmission losses are negligible. CHP plants can attain energy efficiencies of over 75%.

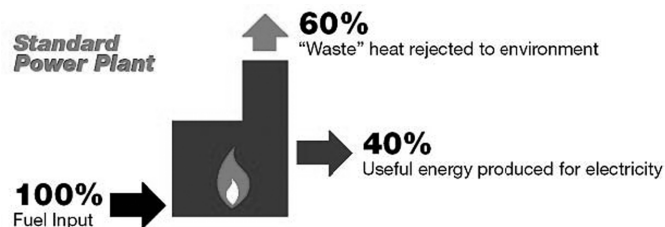


Figure 1. Standard Power Plant Power Generation

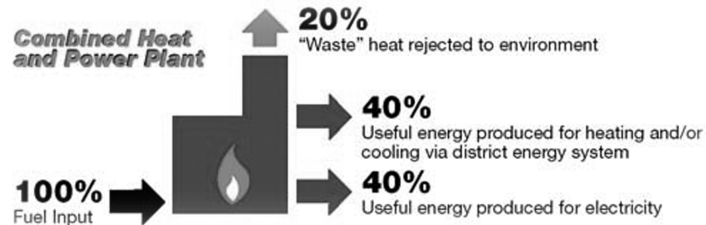


Figure 2. CHP Plant Power Generation

CHP is a clean and effective way to generate electricity that can increase the overall energy efficiency of a facility, while making it more resistant to high or volatile energy rates, as well as less susceptible to power outages or interruptions.

CHP Terminology

CHP has gone by many names in the past. Other terms for on-site power generation that utilizes waste heat are:

- Cogeneration (Cogen)
- Tri-generation (Trigen)
- Total Energy Systems (TES)
- Integrated Energy Systems (IES)
- Building Cooling, Heating and Power (BCHP)
- Combined Cooling Heating and Power (CCHP)

What is Small-scale and Micro-CHP?

Many definitions exist for the small-scale and micro-CHP systems. For the purposes of this report, a small-scale CHP system has an electric generation capacity under 300 kW. A micro-CHP system provides electrical generation with coincident thermal energy for a single residence (typically in the 1 to 25 kW range).

BENEFITS OF SMALL-SCALE AND MICRO-CHP SYSTEMS

There are many benefits from operating a CHP system of any size and capacity. These include:

1. *Reduced Energy Costs:* CHP offers the ability for a building owner/operator to change the way that energy is supplied to the facility to yield best economic results.
2. *Improved Electric Reliability:* The advantage to the on-site generation provided by a CHP system is that the facility then can have two sources of electricity, the generator sets as well as the electric utility.
3. *Improved Power Quality:* Buildings that are located far from the utility substations sometimes have voltage sags that affect the quality of the electricity available to the facility. This is generally more of a problem in the summer months when overall electric demand is increased as a result of cooling loads. Installing a CHP system allows the owner/operator to maintain proper voltage requirements for the facility no matter what the condition of the utility power supply.
4. *Improved Economics for Enhancing Indoor Air Quality:* In some cases, building owners desire or are required to increase indoor air quality (IAQ) for the building occupants. Generally, this comes at a significant cost increase in energy use. Adding air quality equipment to the project costs of a CHP system allows the IAQ improvements to share in the reduced operating costs associated with a CHP system. This yields shorter paybacks and improved returns on investment for these projects.
5. *Improved Emissions and Improved Environmental Friendliness:* The increased efficiency from installing a CHP system lowers greenhouse gas emissions. A CHP system avoids 40% of the heat that is lost in standard power production. The less fuel burned, the lower the overall emissions.

Installing small-scale or micro-CHP systems offer additional benefits than other CHP systems. These benefits include:

1. *Reduced Capital Costs:* Smaller CHP systems require less initial capital investment. Small-scale and micro-CHP systems allow for facilities to install smaller systems that fit into limited budgets.

2. *Increased Ability to Match Building Loads:* CHP systems are most cost effective when matching the thermal output of the system to a building thermal load and generating as much electricity as can be created at that thermal load capacity. Many small commercial and large residential buildings have lower heat requirements. Sizing smaller units allows for better matching of heat capacities for increased economics.
3. *Availability of Waste Fuel Sources:* Many renewable fuel sources are not available in large enough quantities to justify the use of a large CHP system. Installing smaller generating units can match the renewable fuel availability to the electrical and thermal generation.

CHP TECHNOLOGIES

What is a Prime Mover?

A prime mover is a device that converts a fuel source to mechanical energy. When evaluating a CHP system, the prime mover is the device from which the electrical power is produced and the thermal energy is extracted. There are three major categories of prime movers that are used in small-scale and micro-CHP systems. These prime movers are as follows:

- Microturbines
- Reciprocating engines
- Fuel cells.

Microturbines

A microturbine is a very small version of a combustion turbine. Combustion turbines use technologies very similar to a jet engine or a turbo-charger in an automobile. In power generation, combustion turbines reach generation capacities of 50,000 kW. Microturbines have electrical generation capacities of 25 kW to 400 kW. These units reach electrical generation efficiencies 25% to 30%. There are two types of microturbines: recuperative and non-recuperative. The recuperative microturbine has a feature that routes the exhaust gases over the combustion chamber to preheat the charge before combustion. This creates better electrical generation efficiencies. After some heat is removed from the exhaust by

the recuperation process, the exhaust stack temperature is maintained at approximately 232°C [450°F], which offers a lot of potential to recover heat. The useful thermal energy extracted from the exhaust gases that is available from a microturbine includes hot water (82°C [180°F]) or low pressure steam (103 kPa [15 psig]). An internal schematic of a microturbine can be seen in Figure 3.

Microturbines are generally less expensive than reciprocating engines of similar electrical capacities. The installation of a microturbine is generally \$1,000/kW to \$2,000/kW, with smaller units having the higher cost per kilowatt. An internal view of a microturbine can be seen in Figure 4.

Reciprocating Engines

The reciprocating engine is similar to the internal combustion (IC) engine that is found in automobiles. Reciprocating engines have electrical generating capacities of 100 kW to 2,000 kW. Smaller reciprocating engines, between 100 kW to 500 kW, have generating efficiencies of 24% to 28%. Heat recovery from a reciprocating engine comes from two sources, the engine jacket and the exhaust. The heat recovery from the engine jacket is available in the form of low grade hot water (82°C to 99°C [180°F to 210°F]). The exhaust gases are capable of producing a

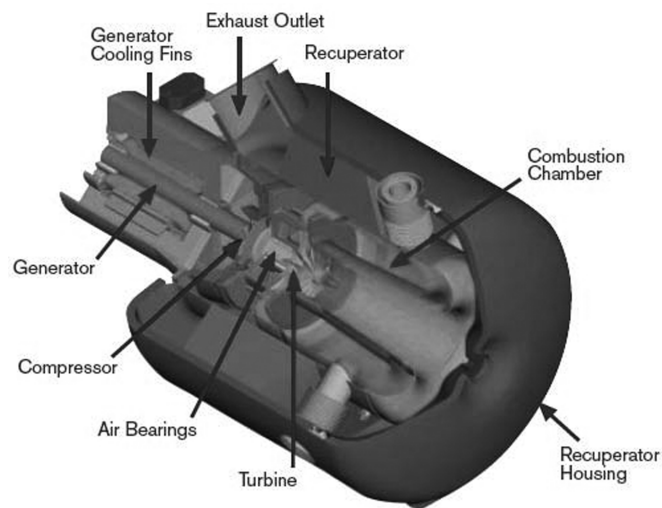


Figure 3. Internal Schematic of a Microturbine



Figure 4. Internal View of a Microturbine

higher grade of heat including low pressure steam (up to 103 kPa [15 psig]). Typical small-scale systems utilize hot water heat recovery to maintain building loads. It is possible to recover 30% of the fuel input from the engine jacket and 20% from the exhaust. Small-scale reciprocating engines can reach overall system efficiencies of 75% or higher. A schematic of CHP cycle using a reciprocating engine is depicted in Figure 5.

The installation of a reciprocating engine, between 100 kW to 500 kW, is generally \$1,400/kW to \$1,800/kW, with smaller units having the higher cost per kilowatt. A 200-kW reciprocating engine can be seen in Figure 6.

Fuel Cells

Fuel cells are considered a prime mover even though they do not fit the traditional definition for a prime mover. They do not produce mechanical work from a fuel source, they produce electricity directly. Fuel cells in essence, act like a battery that is continuously being replenished with fuel. Fuel cells use a chemical reaction to produce electricity. The chemical reaction is the combining of hydrogen and oxygen to produce water. There are four types of fuel cells, which are defined by the type of electrolyte used in the electrical production process: phosphoric acid

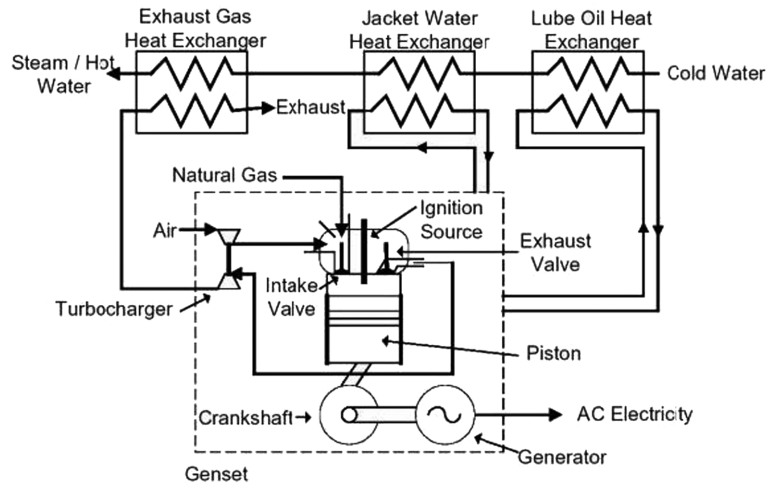


Figure 5. The Reciprocating Engine Cycle

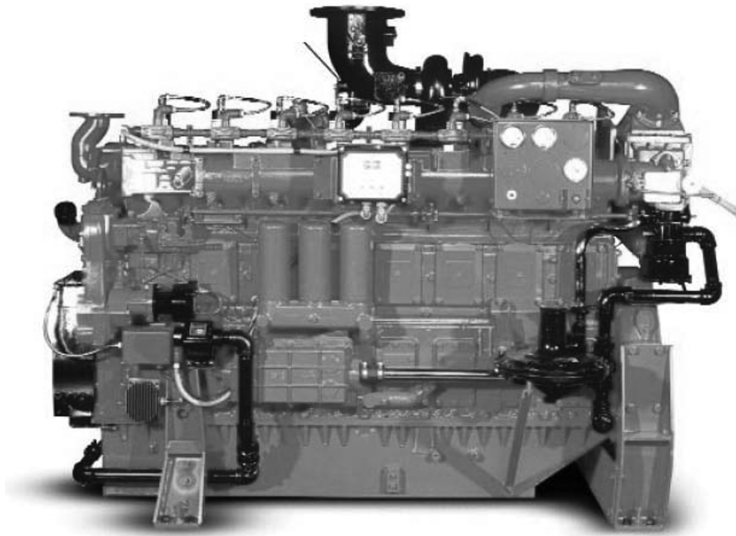


Figure 6. A 200-kW Reciprocating Engine

fuel cell (PACF), solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC) and proton exchange membrane fuel cell (PEMFC).

A fuel cell has three sections: the reformer, the power section and the power conditioner.

The Reformer

Sources of pure hydrogen are not readily available for use in a fuel cell. Instead, more traditional fuels such as natural gas are chemically broken down to produce hydrogen. Most fuels contain hydrocarbons and are composed of both hydrogen and carbon atoms. To extract the hydrogen from the carbon atoms, the fuel is burned in a low oxygen environment, which produces carbon dioxide and useful hydrogen gas. The only major source of pollution, which is emitted from a fuel cell is located in the reformer that only partially burns fuel. This is why fuel cells are considered the cleanest of the prime movers.

The Power Section

The power section of a fuel cell receives the hydrogen from the reformer and combines it with oxygen from the air through an intermediate electrolyte. This chemical reaction produces direct current (DC) electricity and water. The reaction is an endothermic reaction, which is a reaction that produces heat. The water that is ejected from the power section is in the form of hot water or steam, which can be recovered for use in a CHP system.

The Power Conditioner

The power emitted from the power section is direct current (DC) power. Most equipment used in buildings today operates with alternating current (AC) power. The power conditioner is also known as a power inverter, which is a device that produces AC power from DC power.

A schematic of the basic fuel cell concept is depicted in Figure 7.

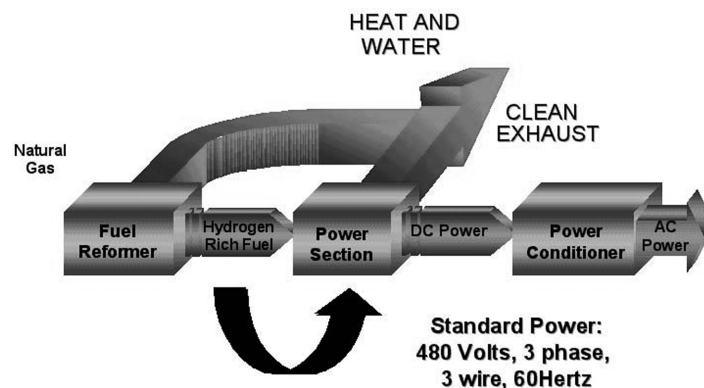


Figure 7. Basic Fuel Cell Concept

The basic efficiency ranges and heat recovery availability for fuel cells are shown in Table 1.

Table 1. Fuel Cell Characteristics

Proton Exchange Membrane Fuel Cell (PEMFC)	Electrical Generation Efficiency	33-45%
	Operating Temperature	79°C [175°F]
	Heat Recovery Available	Hot Water
Phosphoric Acid Fuel Cell (PAFC)	Electrical Generation Efficiency	38-45%
	Operating Temperature	249°C [480°F]
	Heat Recovery Available	Hot Water
Molten Carbonate Fuel Cell (MCFC)	Electrical Generation Efficiency	50-60%
	Operating Temperature	649°C [1,200°F]
	Heat Recovery Available	Medium to High Pressure Steam
Solid Oxide Fuel Cell (SOFC)	Electrical Generation Efficiency	40-45%
	Operating Temperature	982°C [1,800°F]
	Heat Recovery Available	High Pressure Steam

A view of a PAFC is located in Figure 8.

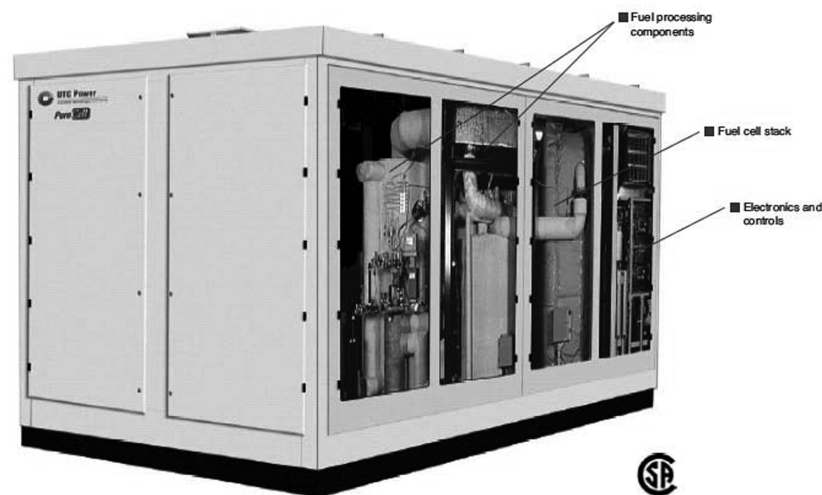


Figure 8. A Phosphoric Acid Fuel Cell

The only commercially available fuel cell on the market today is the PAFC. The other fuel cell types are available as demonstration units. The PAFC installed cost is generally upwards of \$3,500/kW. Because fuel cells are an emerging technology some energy efficiency and new technology incentives and rebates are available to lower the installed cost to become comparable to the other prime movers.

WHAT ARE THE AVAILABLE FUEL TYPES?

There are several fuel types available for the aforementioned prime movers for small-scale systems. These are as follows:

- Natural Gas
- Propane
- Diesel Fuel
- Digester Gas
- Landfill Gas
- Gasified Fuels

Natural Gas

Natural gas (methane) is the most common fuel used in small-scale CHP systems. Natural gas requires no storage, and the fuel source is usually readily available without major infrastructure changes. Natural gas also has one of the higher heating contents, which is the amount of energy available from a fuel source compared to the unit volume. The heat content of natural gas is 54 MJ/kg [1,050 Btu/scf]. The drawback to utilizing natural gas is that in the more recent years, the cost of natural gas has been rising and has created longer payback periods, particularly on smaller-scale systems. Natural gas also burns cleaner than many of the other CHP fuel sources.

Propane

Propane, a derivative of petroleum, is an alternative to natural gas. Propane is commonly referred to as liquefied petroleum gas (LPG). The major benefit to using propane is fuel availability. In remote areas, where natural gas infrastructure is not readily available, liquid propane can be transported relatively easily. The heating content of propane is 50 MJ/kg [92,000 Btu/gal]. Propane is also a clean burning fuel.

Diesel Fuel

Diesel fuel, also a derivative of petroleum is an alternative to natural gas. It is also known as #2 distillate fuel oil. Similar to propane, the major advantage to using diesel fuel is the ability to transport it to remote areas that do not have a natural gas infrastructure. In addition, diesel fuel is commonly used as a backup fuel to natural gas, because it is able to be stored on site easily. One of the drawbacks to using diesel fuel is that it is not a very clean burning fuel and produces very high particulate (or soot) and sulfur dioxide emissions. The heat content of diesel fuel is 45 MJ/kg [138,300 Btu/gal].

Digester Gas

Particularly useful on livestock farms and wastewater treatment plants, digester gas is an alternative CHP fuel source. An anaerobic digester is a device that produces methane from animal and human waste. A digester works very similar to a stomach in which an enzyme/bacteria culture breaks down organic material, in this case into methane. Many livestock farms and wastewater treatment plants use digesters as a method of odor and waste mitigation. Using the digester gas is a good way to produce a renewable energy source that may otherwise be wasted. The heating content of digester gas is 19 MJ/kg [380 Btu/scf].

Landfill Gas

Landfill gas is another renewable energy source similar to digester gas. As waste in a landfill decomposes, methane gas is produced. This methane gas is generally released and is flared (or burned off). Flaring this useful methane gas is wasteful. Using this energy in a CHP system eliminates wasting this fuel source and can also be a form of odor mitigation at a landfill. This generates a potential revenue stream for a landfill. The heating content of landfill gas is 19 MJ/kg [380 Btu/scf].

Gasified Fuels

Solid fuel sources (such as coal or wood) are not practical for small-scale generation. With recent improvements in gasification technologies, solid fuels have more potential to be used in a CHP system. A gasifier is a device very similar to the reformer in a fuel cell. The difference is that the reformer converts a gaseous hydrocarbon to hydrogen and carbon dioxide, where a solid hydrocarbon is used as the initial fuel source in a gasifier. The major benefits to using gasified

fuels are that these fuels burn cleaner in a gaseous form and there is a potential to use a wide range of solid waste fuel sources. The heating content of gasified fuels ranges from 5 MJ/kg [100 Btu/scf] to 13 MJ/kg [250 Btu/scf].

Fuel Pricing

To provide an idea of the standard fuel costs, Table 2 provides the average annual fuel costs in the United States for the year 2004. These fuel costs are listed by state, as provided by the Energy Information Administration (EIA).

HEAT RECOVERY OPTIONS

Direct Use of the Hot Gases

By far the easiest form of heat recovery available from a CHP system is using the hot exhaust gases directly. This is the best way to recover nearly all of the energy in the exhaust stream of a prime mover. This technique is not very effective for producing heat for space heating. Using the exhaust gases is generally used for drying applications. A schematic of how the exhaust gases could be used in a CHP system is shown in Figure 9.

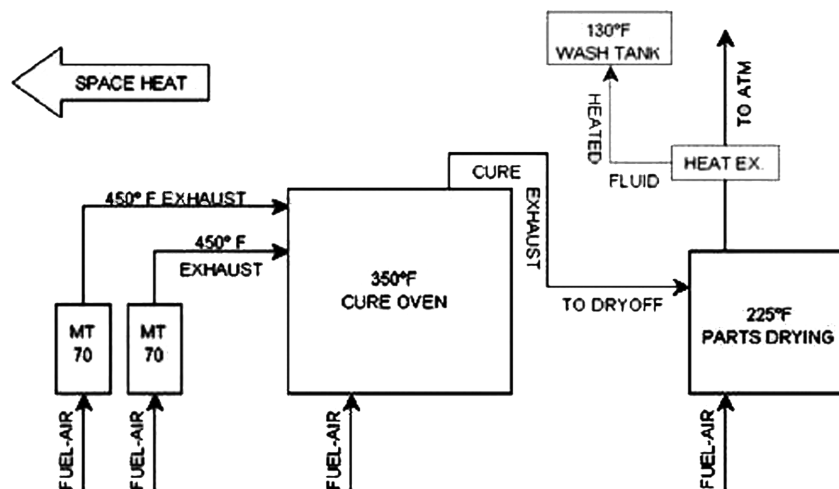


Figure 9. Direct Use of Microturbine Exhaust

Table 2. Average Fuel Prices in Dollars per Million Btu for 2004 [2]

State	Natural Gas	Propane	Diesel Fuel	Wood and Waste (Biomass)	Coal	Retail Electric
Alabama	7.72	15.78	11.91	1.81	1.57	18.01
Alaska	3.59	19.64	12.43	6.68	1.91	32.29
Arizona	6.84	18.4	13.59	5.90	1.31	21.83
Arkansas	8.09	14.8	12.01	1.79	1.25	16.76
California	7.63	19.09	13.58	3.60	1.82	33.61
Colorado	7.15	15.59	12.44	5.10	0.99	20.44
Connecticut	10.11	19.02	11.82	1.33	2.38	30.07
Delaware	8.62	18.43	11.51	4.93	2.18	22.11
District of Columbia	13.53	19.11	11.57	5.18	2.27	21.89
Florida	7.08	20.8	12.36	1.24	1.93	23.91
Georgia	9.65	17.21	11.55	1.89	1.82	19.30
Hawaii	20.34	15.9	13.12	1.18	1.87	46.16
Idaho	7.29	16.84	12.95	1.92	1.75	14.58
Illinois	8.89	13.79	12.60	1.97	1.18	19.98
Indiana	8.34	15.37	12.00	2.34	1.41	16.40
Iowa	8.40	13.23	11.86	2.56	1.00	18.76
Kansas	8.07	13.44	11.95	4.31	1.03	18.71
Kentucky	8.61	14.63	12.02	2.24	1.41	13.61
Louisiana	6.57	10.08	11.99	1.80	1.38	21.00
Maine	6.95	20.18	11.50	1.40	2.62	28.39
Maryland	10.37	20	12.12	1.64	1.77	20.97
Massachusetts	10.14	21.12	11.86	1.51	1.98	31.56
Michigan	7.39	15.55	12.19	1.61	1.46	20.40
Minnesota	8.22	14.19	12.04	1.79	1.11	18.32
Mississippi	6.75	15.91	11.98	1.91	1.70	20.70
Missouri	9.63	13.95	11.89	3.60	0.95	17.79
Montana	8.15	14.34	12.00	2.17	0.66	18.88
Nebraska	7.78	13.35	11.80	2.99	0.68	16.71
Nevada	6.83	18.73	13.18	6.36	1.37	25.18
New Hampshire	8.64	18.29	11.17	1.34	2.02	33.33
New Jersey	9.67	20.5	12.02	1.61	2.05	30.18
New Mexico	7.51	16.94	12.51	6.74	1.48	20.95
New York	9.81	19.46	12.02	2.42	1.78	36.78
North Carolina	9.09	17.39	12.15	1.94	2.01	20.42
North Dakota	7.39	13.38	11.74	2.96	1.12	16.72
Ohio	9.29	15.94	12.58	2.92	1.39	20.26
Oklahoma	7.54	14.02	11.30	2.07	1.05	19.10
Oregon	6.79	16.82	13.06	3.37	1.21	18.19
Pennsylvania	9.91	18.48	12.16	1.58	1.52	23.53
Rhode Island	9.39	22.17	11.97	2.64	2.68	32.13
South Carolina	8.71	18.27	12.02	1.82	1.94	18.23
South Dakota	7.78	13.37	11.68	4.64	1.42	18.88
Tennessee	8.61	16.92	11.87	2.03	1.40	18.03
Texas	6.29	10.29	12.04	2.18	1.32	23.46
Utah	6.76	16.38	12.69	3.45	1.17	16.76
Vermont	8.64	18.43	11.79	2.30	2.74	32.31
Virginia	9.61	19.15	11.30	2.02	1.97	18.89
Washington	7.69	17.9	14.53	2.87	1.46	17.06
West Virginia	7.95	18.84	12.16	3.70	1.40	15.09
Wisconsin	8.78	14.49	12.21	1.79	1.25	20.23
Wyoming	6.90	15.47	12.03	5.72	0.89	14.69
United States	7.95	12.32	12.22	2.03	1.41	22.40

In this case the exhaust gases from two microturbines are used to supplement a curing oven. The heat from the curing oven is then cascaded into a parts drying oven to recover even more energy. This is a very efficient application. In this case, if additional heat is needed, the standard operating equipment (burners) on the oven is used to supplement additional heat. Another way to add additional heat is to use a duct burner. A duct burner is a burner that is placed in an exhaust stream. Additional fuel and air is added and burned off in the duct to raise the temperature of the exhaust. This allows the equipment to reach temperature requirements without adding a large amount of additional energy. A duct burner schematic is shown in Figure 10.

Heat Recovery Steam/Hot Water Generator

Many buildings that would be applicable for a small-scale CHP system use hot water for space heating as well as for domestic hot water. Hot water usually represents an effective form of heat recovery available from CHP equipment. A device known as a heat recovery steam/hot water generator (HRSG) is used to recover waste heat from hot exhaust gases to make either hot water or steam. A HRSG is a shell-and-tube heat exchanger that works very similar to a boiler. A HRSG, however, operates off of hot air or exhaust streams and does not require a burner. For additional heating capacity, duct burners can be installed before the HRSG to produce additional hot water or steam. A HRSG used in small-scale generation is depicted in Figure 11.

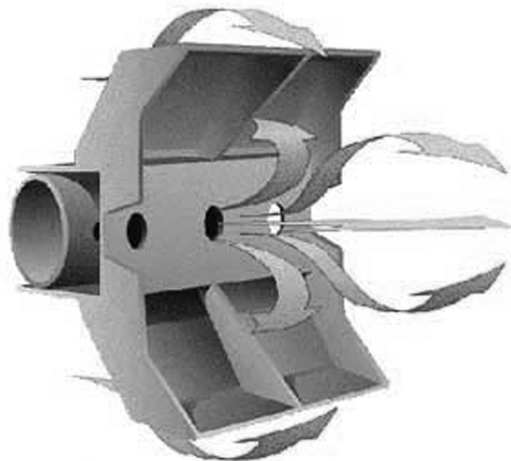


Figure 10. A Duct Burner

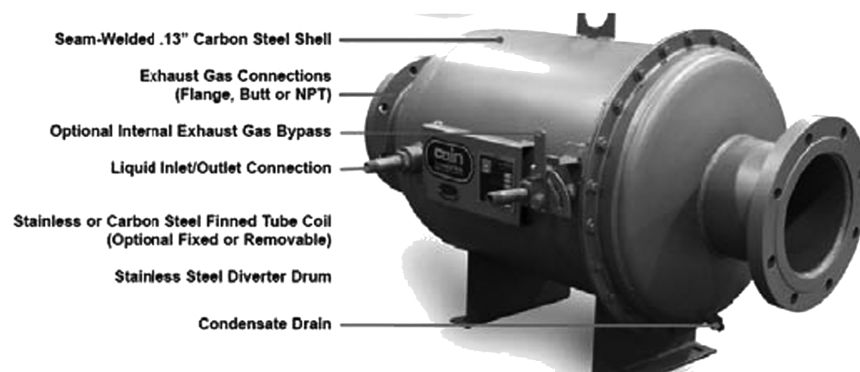


Figure 11. A Heat Recovery Steam Generator

Absorption Chiller

Another application for heat recovery off of a prime mover is to produce chilled water through an absorption chiller. An absorption chiller is a device that uses steam or hot water to create chilled water. Absorption chilling allows a facility to take advantage of heat recovery in the summer to supply cooling loads. In the past, the high cost of absorption chillers has limited their use to large commercial or industrial use. In recent years, smaller more efficient absorption chillers have been developed to offer attractive paybacks for small-scale and micro-CHP systems. In addition, some newer units utilize direct-fired heat sources to produce chilled water. Some absorption chiller units have been developed that double as a heat pump in the winter, driving the installation cost down by purchasing one piece of heat recovery equipment. A schematic of an absorption chiller is shown in Figure 12.

APPLICATIONS

Henry Doorly Zoo

General Facts

- Installation Date: 2001
- Generating Capacity: 200 kW
- Prime Mover: Fuel Cell
- Location: Omaha, Nebraska
- Type of Facility: Museum and Zoo
- Heat Recovery: Domestic Hot Water and Space Heating

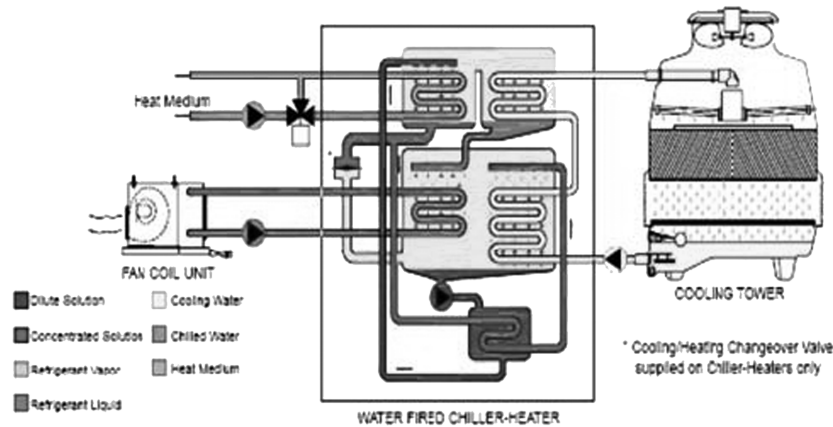


Figure 12. Absorption Chiller Schematic

Project Economics

- Project Cost: \$1.2 million
- Funding/Grant Opportunity: \$200,000 from DOE

Reasons for Small Scale CHP

- Application of New Technology
- Formation of Partnership between Municipality and Dependable Customer
- Ability to Add PAFC as Addition to Existing CHP Infrastructure
- Use of "Green" (Clean) Power Source
- Good Publicity for Zoo and Municipality

Project Overview

The Omaha Public Power District (OPPD) installed a fuel cell in the Henry Doorly Zoo to research small-scale on-site generation. The OPPD installed a fuel cell to supply electricity to the Lied Jungle Habitat. The fuel cell is displayed in Figure 13. A schematic of the CHP system is depicted in Figure 14.

The fuel cell produces 200 kW of energy at a generation efficiency of 38%. The electricity from the fuel cell was required at all hours of the day, which is ideal for a CHP system. The maximum load is 172 kW and the minimum load is 80 kW.

The stack temperature of the unit is 177°C [350°F]. The heat recovered from the stack is used to maintain 82°F [180°F] hot water for



Figure 13. 200 kW Fuel Cell

heating and cleaning the habitat. The unit produces 700,000 Btu/hr of recycled energy.

The Jungle previously was served by two 60-kilowatt co-generation units, which the zoo removed because of high maintenance costs of the aging system. The piping for the natural gas supply and heat recovery left over from these removed units will be placed back into service for the fuel cell.

The fuel cell offers a very clean source of energy. The unit produces 1 ppm of NO_x and 5 ppm of SO_x . All other emissions are considered negligible.

The installation of the fuel cell cost \$1.2 million, including equipment, installation, engineering and transfer switch to connect to the utility. The fuel cell received a grant for \$200,000 from the USDOE to supplement the cost of the installation. [5] [8]

Forrest Service Research Laboratories

General Facts

- Installation Date: 2005
- Generating Capacity: 15 kW
- Prime Mover: Reciprocating Engine
- Location: Madison, Wisconsin

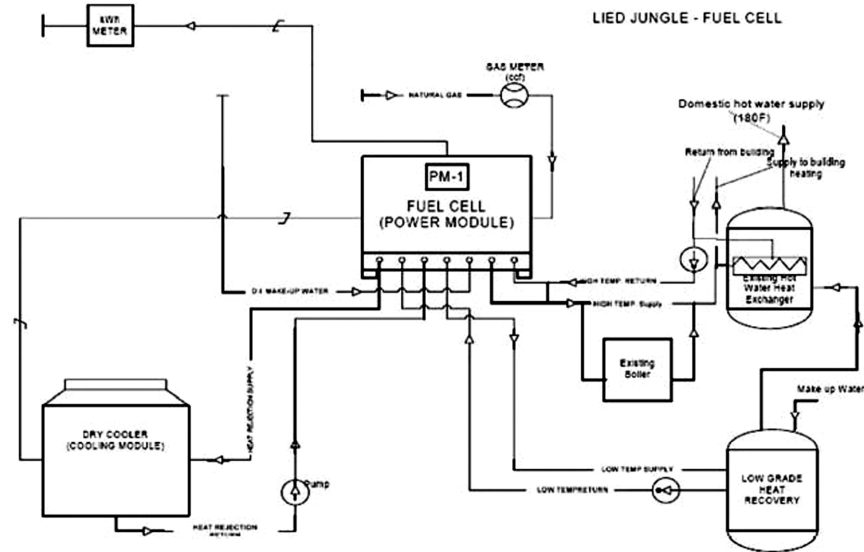


Figure 14. The Lied Jungle Fuel Cell System

- Type of Facility: Research Institution
- Heat Recovery: Domestic Hot Water and Dehumidification

Project Economics

- Electric Production Cost: \$0.04/kWh
- Installation Cost: \$1,500/kW to \$2,000/kW

Reasons for Small Scale CHP

- Application of New Technology
- Ability to Use Solid Fuel Source
- Small Capacity Available for Micro-CHP
- Cleaner than Using Solid Fuel in a Boiler

Project Overview

In 2003, in a partnership with the National Renewable Energy Laboratory (NREL) the Forest Service Research Laboratories formed the Community Power Corporation (CPC) to design and build four wood gasification power systems around the US. The entire program cost \$2 million dollars to start up and was sponsored, half by the U.S. DOE and half by the Forreest Service Research Laboratories.

One of the first demonstration units installed was in the Big Bear Discovery Center, a Forrest Service Research Laboratory, located in Madison, Wisconsin. The CHP system at the Big Bear Discovery Center consists of two pieces of equipment, the wood gasification unit and a 15-kW reciprocating engine, as seen in Figure 15.

The location was a good fit for the installation because the location was a research institution that had the ability to monitor the system easily. The exhaust from the engine is used to generate domestic hot water and supply heat to a desiccant dehumidification system. A dehumidifier is a device that removes heat from a wet warm air stream and creates a drier cooler air stream. The device requires hot air stream to remove water from the system. The hot side of a desiccant dehumidification system can easily be supplied from a CHP system.

The gasification unit and generator system is available in various sizes ranging from 5 kW to 50 kW. This makes the unit ideal for small-scale and micro-CHP systems. The demonstration unit in Madison, WI, utilizes wood pellets to generate gasified gases. The heating content of the wood chips is 17 MJ/kg [8,000 Btu/lb]. The gaseous fuel that results is cleaner but has a lower heating content at 150 Btu/scf. The unit produces electricity at a cost of \$0.04/kWh. The estimated installation



Figure 15. A 15-kW Generator and Gasifier

cost of the units, once they become available in the market, will range between \$1,500/kW to \$2,000/kW, which is comparable to a microturbine installation.

The gasification unit and generator have already been installed in a demonstration residence in Madison, Wisconsin showing the potential applications for the home. The demonstration home is shown in Figure 16. [1]



Figure 16. Wood Gasifier Demonstration Home in Madison, Wisconsin

Wooster Manor

General Facts

- Installation Date: 1998
- Generating Capacity: 60 kW
- Prime Mover: Reciprocating Engine
- Location: Danbury, Connecticut
- Type of Facility: Multi-unit Housing Residence
- Heat Recovery: Domestic Hot Water and Space Heating

Project Economics

- Electric Production Cost: \$0.04/kWh
- Project Cost: \$275,000

Reasons for Small Scale CHP

- Application of New Technology
- Offers Cost Savings to Necessary Heating System Upgrades

Project Overview

Wooster Manor is a seven-story, 100-unit, multifamily residential building in Danbury, Connecticut, operated by the Danbury Public Housing Authority (DHA). Before installing the CHP system, the facility used electricity for all of the building's energy needs. The building had baseboard heating and central electric water heaters for hot water supply. DHA converted units on four floors to hydronic baseboard heating, removed the electric water heaters, and installed a reciprocating engine driven CHP system to provide electricity and hot water to the building. The system upgrades reduced the energy costs by almost 50%. Wooster Manor is shown in Figure 17.



Figure 17. Wooster Manor, Connecticut

The packaged unit serving Wooster Manor features a 454-cubic-inch displacement natural-gas-fired engine that turns a generator supplying 60 kW of electricity. The CHP system generates electricity to meet approximately 60% to 70% of the total building load. Electricity from the grid serves the remaining load.

The heat recovery from the engine jacket and engine exhaust is captured to produce hot water (102°C [215°F]). The hot water is distributed to dwelling unit baseboards for space heating through the hydronic piping in the building. The CHP system meets 50% of the building's total space heating needs and 100% of domestic hot water needs.

In summer, when space heating is not needed and the domestic hot water load is lower, excess heat from the engine is dispersed through a radiator to the outside. A large fan coil unit keeps the engine at optimum operating temperature.

Overall, Wooster Manor reduced its annual energy expense by \$40,000, nearly half of their standard operating costs. In addition to benefiting from energy cost reductions, the DHA qualified for a HUD energy consumption reduction incentive. The incentive program allows the housing authority to keep 100% of the difference between its new, lower utility costs and the HUD subsidy that covered utility costs at the pre-conservation level of consumption.

The project was funded through a Yankee Energy Financial Services, a financing affiliate of Yankee Gas, with a 10-year \$275,000 loan. [10]

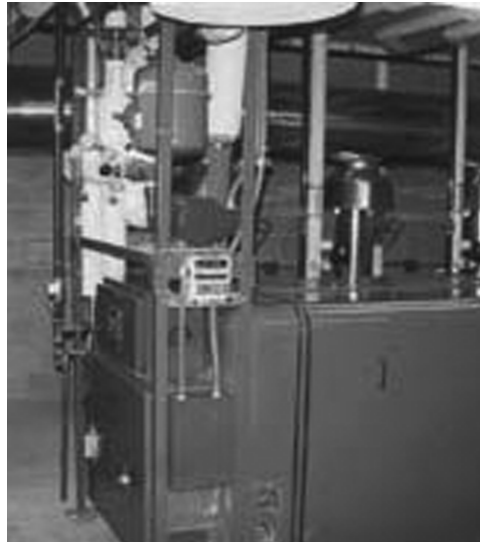


Figure 18.
The 60-kW Packaged
CHP Unit

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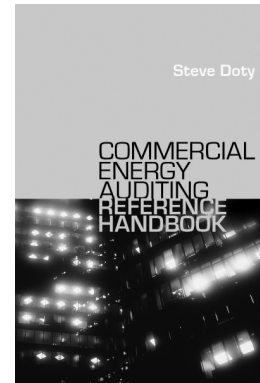


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Massachusetts Homes

General Facts

- Generating Capacity: 1.2 kW
- Location: Braintree, Massachusetts
- Heat Recovery: Space Heating

Project Economics

- Annual Savings: \$800/yr to \$1,000/yr
- Project Cost: \$13,500
- Funding/Grant Opportunity: \$2,000 Rebate
- Simple Payback: 11.5 years

Reasons for Small Scale CHP

- Application of Micro-CHP Systems
- Offer Residential Potential to Reduce Greenhouse Gas Emissions
- Offers Cost Savings to Necessary Heating system Upgrades

Project Overview

Many homeowners are interested in using CHP in their homes. Many residential customers in Massachusetts have been putting micro-CHP systems to the test. In Braintree, Massachusetts, one home is using a 1.2-kW reciprocating engine as a prime mover in a CHP system. The engine produces electricity and heat in the winter. If the residence produces more power than is necessary, the excess electricity is fed into the grid. The micro-CHP system is designed to supply thermal energy through the existing forced air heating systems that are found in most homes. One of the Massachusetts micro-CHP systems can be found in Figure 19.

The micro-CHP system is estimated to reduce household greenhouse gas emissions by 25% in addition to reducing energy costs.

One of the CHP system owners had this to say about his installation: "These gas systems burn really clean, so virtually nothing breaks. So you can really justify it with a little bit of savings on the electric bill. Just having a little bit more (energy) independence away from everybody else is really nice." [3]

The estimated life of the system is 20 years. The benefits of installing a micro-CHP system is that the system costs the same as purchasing a high-end furnace, however with the increased benefits of electrical production, the system can yield savings and offer homeowners flexible



Figure 19. The Micro-CHP System

and reliable energy alternatives. At \$800/yr to \$1,000/yr and system efficiencies of over 90%, this technology is proven viable for the home.

For additional savings in the summer, the system can be configured to supplement domestic hot water needs or cooling loads with an absorption chiller.

The system costs \$13,500 to install. The local utility, Keyspan Energy Delivery, offered a \$2,000 rebate for installing energy efficient systems in the home, including the micro-CHP system. With the rebate, the system yields a payback of 11.5 years. In the future as micro-CHP technologies become more standard, the initial costs will be lower and have more attractive paybacks. The configuration of a micro-CHP system in the home is shown in Figure 20. [9]

CONCLUSION

In summary, combined heat and power (CHP) is a proven technology that provides clean, reliable, and affordable energy to a variety

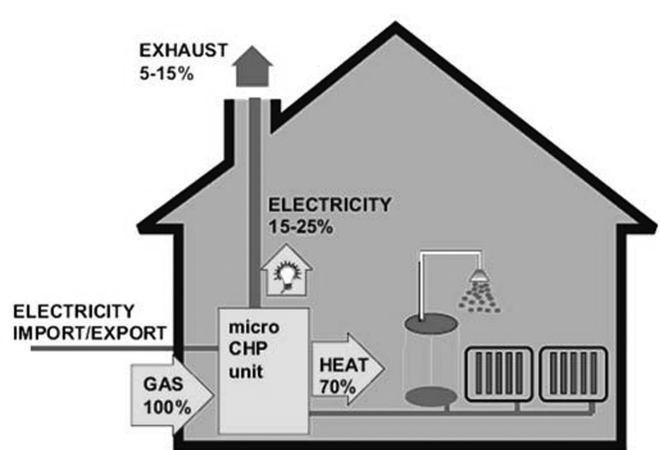


Figure 20. A Typical Micro-CHP System Configuration

of institutions. CHP systems allow a facility to produce on-site electrical power and obtain overall efficiencies of over 85%. Standard power production provided by the utility companies is generally only 40% efficient.

With advancements in manufacturing and design, many CHP technologies have become more affordable for smaller institutions to yield both the economic and other advantages. These technologies include microturbines, small reciprocating engines as well as fuel cells, which will produce electricity in addition to low pressure steam or low temperature hot water. The lower grade of heat recovery available from these small-scale and micro-CHP technologies are ideal for smaller institutions. Some of the benefits of small-scale and micro-CHP systems include:

- Reduced Energy Costs
- Improved Electric Reliability
- Improved Power Quality
- Improved Economics for Enhancing Indoor Air Quality
- Improved Emissions and Improved Environmental Friendliness
- Reduced Capital Costs
- Increased Ability to Match Building Loads
- Availability of Waste Fuel Sources

This article has detailed a number of examples of CHP systems that are applicable in a variety of ways. Various institutions have seen the benefits of small-scale and micro-CHP systems, including a zoo habitat, a research institute, a multi-family housing complex, and a residence. This only represents a fraction of potential applications of CHP systems. As the availability of CHP technologies becomes more affordable, many smaller institutions will be able to reap the benefits of this technology.

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