Combined Heat and Power Technology Fact Sheet Series

Overview of CHP Technologies

Combined heat and power (CHP), also known as cogeneration, produces both electricity and thermal energy on-site, replacing or supplementing electricity provided from a local utility and fuel burned in an on-site boiler or furnace. CHP systems increase energy security by producing energy at the point of use, and significantly improve energy efficiency. Figure 1 illustrates the efficiency benefit that a typical CHP system achieves compared to the use of grid electricity and the production of steam or hot water with an on-site boiler. When electricity and thermal energy are provided separately, overall energy efficiency ranges from 45–55%. While efficiencies vary for CHP installations based on site-specific parameters, a properly designed CHP system will typically operate with an overall efficiency of 65–85%.

The deployment of CHP is driven by several factors, including:

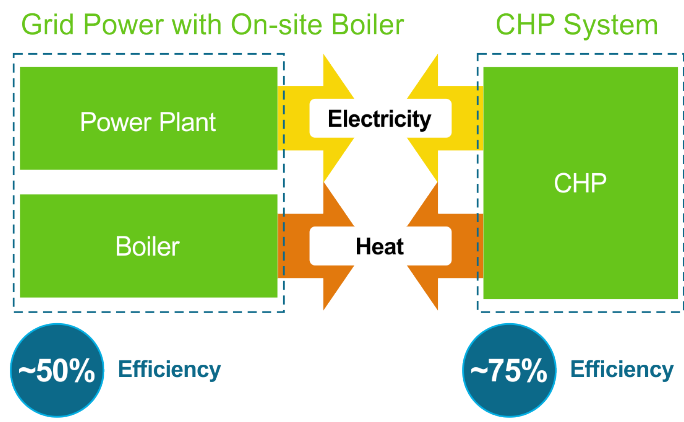

Figure 1. Efficiency benefit of CHP.

CHP User Benefits

- Decreased energy costs
- Enhanced energy resiliency
- Reduced risk from uncertain energy prices
- Increased economic competitiveness

National/Regional Benefits

- Typically utilizes abundant domestic natural gas or opportunity fuels, such as biogas or wood waste
- Increases energy resiliency of critical infrastructure and operations
- Enhances electric grid reliability
- Supports local economic growth and competitiveness

CHP Configurations

Every CHP application involves the recovery of thermal energy that would otherwise be wasted. Two common CHP configurations are shown in **Figure 2** and **Figure 3**.

In **Figure 2**, a gas or liquid fuel is combusted in a prime mover, such as a gas turbine or reciprocating engine. The prime mover is connected to a generator that produces electricity, and energy normally lost in the prime mover's hot exhaust and cooling system is recovered to provide useful thermal energy for the site.[1]

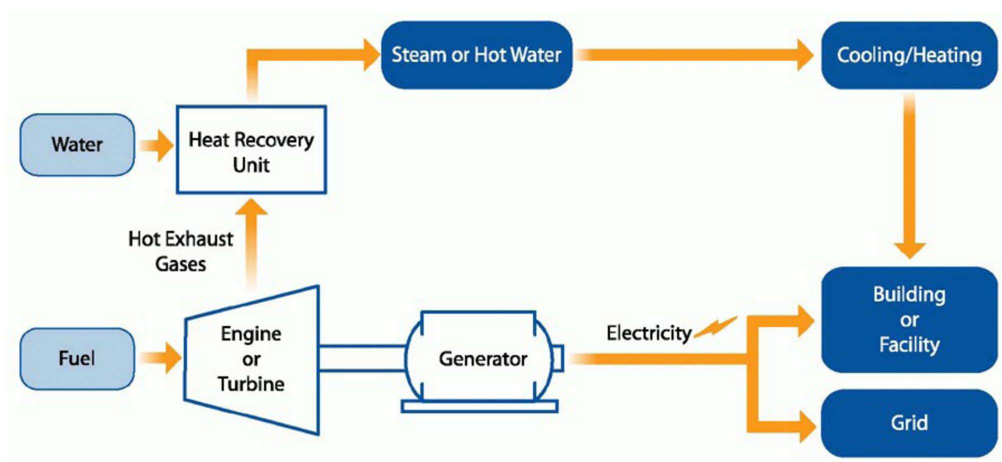

Figure 2. Reciprocating engine or gas turbine with heat recovery.

1 This fact sheet is focused on topping cycle CHP where fuel is first used to generate power. In a bottoming cycle CHP system, also referred to as "waste heat to power," fuel is first used to provide thermal input to a furnace or other industrial process and heat rejected from the furnace or process is then used for electricity production.

In **Figure 3**, fuel is burned in a boiler to produce high pressure steam that is sent to a backpressure or extraction steam turbine. The steam turbine, similar to the prime mover in **Figure 2**, is connected to an electric generator. The steam then exits the turbine at a lower pressure and is used for thermal needs at the site. Boiler/steam turbines are typically used when solid fuels (e.g., coal and biomass) or process waste streams are available for CHP applications.

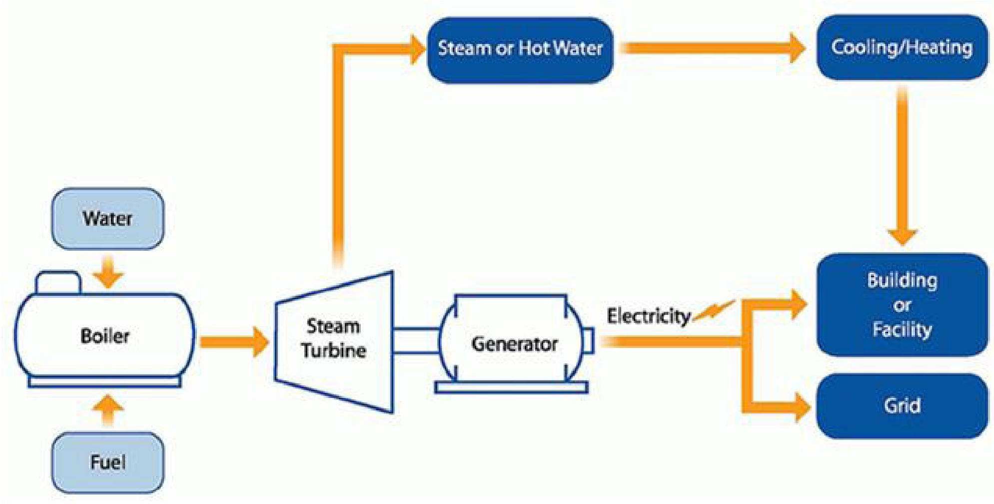

Figure 3. Boiler with steam turbine.

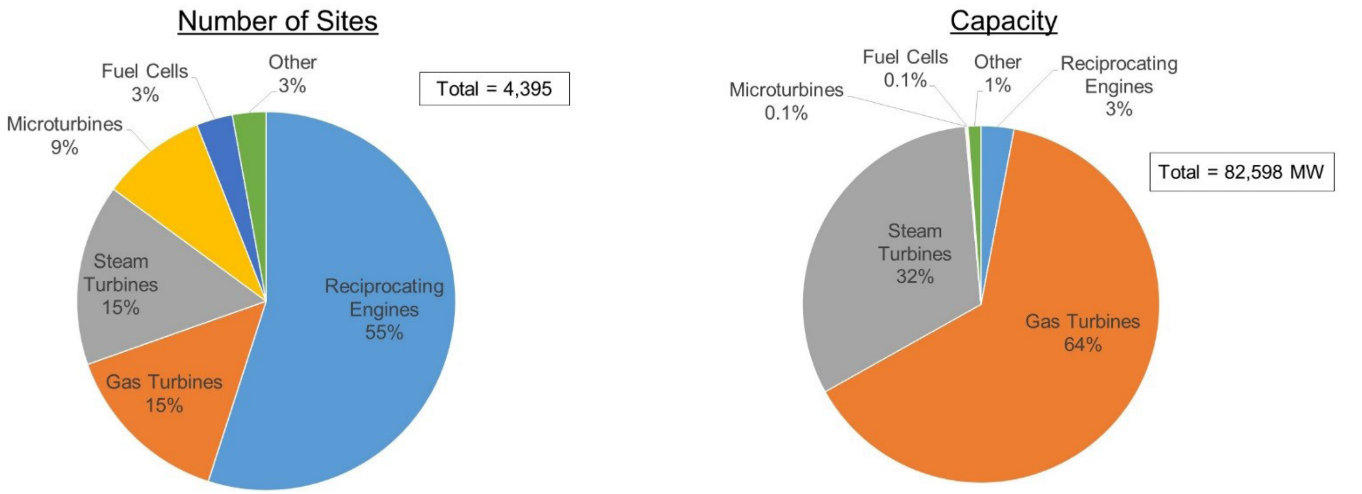

Figure 4. CHP installations in the United States.
Source: DOE CHP Installation Database, U.S. installations as of December 31, 2016

CHP Technologies

CHP systems are often categorized based on the type of prime mover that drives the system. There are five predominant prime mover technologies used for CHP systems: reciprocating engines, gas turbines, microturbines, fuel cells, and boiler/steam turbines.[2] Based on 2016 data from the DOE CHP Installation Database, these five technologies account for 97% of all CHP installations and 99% of total capacity in the United States (see **Figure 4**). Data for 2016 show that reciprocating engines represent 55% of all installations, and gas turbines account for 64% of all installed capacity.

CHP Performance and Cost Characteristics

Table 1 shows typical characteristics for each of the five CHP technologies. The following bullets provide additional information about the characteristics listed in the table:

- **Electric efficiency** varies by technology and by size with efficiency generally increasing as capacity increases. In general, the highest electric efficiencies are achieved by fuel cells and reciprocating engines, followed by gas turbines, microturbines, and steam turbines.[3] With the exception of steam turbines, the electric efficiencies in **Table 1** range from 24% to 42%. Steam turbine CHP systems are unique compared to other CHP technologies because steam turbine CHP installations are typically designed to produce large amounts of thermal energy with electricity generated as a byproduct. Steam turbine CHP systems typically have electric efficiencies below 10%.

2 Steam turbines are used for both topping and bottoming cycles. This fact sheet is focused on topping cycle CHP systems.

3 A gas turbine can also be operated in a combined cycle with a steam turbine that converts additional heat into electricity. Combined cycle systems can operate at electric efficiencies as high as 50%.

Table 1. Comparison of CHP Characteristics for Typical Systems [1, 2]

Characteristic	Technology				
	Reciprocating Engine	Gas Turbine	Microturbine	Fuel Cell	Steam Turbine
Size Range	10 kW–10 MW	1 MW–300 MW	30 kW–330 kW (larger modular units available)	5 kW–2.8 MW (larger modular units available)	100 kW–250 MW
Electric Efficiency (HHV)	30–42%	24–36%	25–29%	38–42%	5–7%
Overall CHP Efficiency (HHV)	77–83%	65–71%	64–72%	62–75%	80%
Total Installed Cost ($/kW) [3]	$1,400–$2,900	$1,300–$3,300	$2,500–$3,200	$4,600–$10,000	$670–$1,100 [4]
O&M Cost (¢/kWh)	0.9–2.4	0.9–1.3	0.8–1.6	3.6–4.5	0.6–1.0
Power to Heat Ratio	0.6–1.2	0.6–1.0	0.5–0.8	1.3–1.6	0.07–0.10
Thermal Output (Btu/kWh)	2,900–6,100	3,400–6,000	4,400–6,400	2,200–2,600	30,000–50,000
Fuel Pressure (psig) [5]	1–75	100–500 (may require fuel compressor)	50–140 (may require fuel compressor)	0.5–45	n/a
Part Load Efficiency	Good at both part-load and full-load	Better at full-load	Better at full-load	Better at full-load	Good at both part-load and full-load
Type of Thermal Output	LP steam, hot water, space heating, chilled water	LP-HP steam, hot water, process heating, chilled water	LP steam, hot water, chilled water	LP steam, hot water, chilled water	LP-HP steam, hot water, chilled water
Fuel	Can be operated with a wide range of gas and liquid fuels. For CHP, the most common fuel is natural gas.			Hydrogen, natural gas, propane, methanol	Steam turbines for CHP are used primarily where a solid fuel (e.g., coal or biomass) is used in a boiler.
Applications	• CHP is ideal for sites that have steady thermal and electric loads. Examples include: o Industrial – chemical plants, refineries, pulp and paper mills, wastewater treatment facilities, food processing sites o Commercial – hospitals, nursing homes, laundries, hotels, health clubs o Institutional & Residential – universities, prisons, multi-family buildings • As noted in this table, steam turbines used in CHP applications have relatively low power to heat ratios and are used primarily with solid fuel boilers. Rather than using a low power to heat ratio steam turbine, sites that have access to gas fuels (e.g., natural gas or biogas) generally install prime movers with higher power to heat ratios, such as reciprocating engines or gas turbines.				
Emissions	CHP technologies are capable of meeting or exceeding air quality regulations throughout the United States, including states such as California that have demanding limits for NOx, CO, and VOC emissions. To achieve compliance, a CHP technology may need to integrate an exhaust treatment technology such as an oxidation catalyst or a selective catalytic reduction system.				
Other	Reciprocating engines start quickly and operate on typical natural gas delivery pressures.	Gas turbines and microturbines have low engine-out emissions and require no cooling. A fuel gas compressor may be required to deliver the specified inlet gas pressure.		Fuel cells are quiet, have low emissions, and produce high quality power.	Steam turbines require a boiler or other steam source.

Notes:
1. Unless noted otherwise, information adapted from U.S. Department of Energy, *CHP Technology Fact Sheet Series*, 2016.
2. All performance and cost characteristics are typical values and are not intended to represent a specific product.
3. Costs will vary depending on site specific conditions and regional variations.
4. Costs shown are for a steam turbine only, and do not include costs for a boiler, fuel handling equipment, steam loop, and controls.
5. Adapted from Catalog of CHP Technologies, U.S. Environmental Protection Agency Combined Heat and Power Partnership, 2015.

- **Overall CHP efficiency** accounts for both electricity and useful thermal energy that is delivered from a CHP system. Properly designed and applied CHP systems have overall efficiencies exceeding 60% (HHV basis), with some systems exceeding 80%.

- **Installed capital costs** include all hardware and installation expenses required for an operational CHP system. For steam turbines, steam is assumed to be available on-site, and costs for a boiler, steam loop, and controls are not included. If the boiler uses a solid fuel such as coal or biomass, there are additional costs associated with fuel storage and processing. The cost ranges shown in **Table 1** are based on representative CHP sizes (see individual technology fact sheets for details[4]) using national average costs for typical sites with no unique installation requirements. Actual costs could be higher or lower based on site specific circumstances and regional variations. Reciprocating engines, gas turbines, and steam turbines are mature technologies, and these three technology classes have relatively low installed capital costs compared to similar capacity microturbines and fuel cells, which are products that have been more recently commercialized. With all CHP systems, there are economies of scale within a technology class, and capital costs decline with increasing capacity.

- **O&M costs** include routine inspections, scheduled overhauls, preventive maintenance, and operating labor (fuel cost not included in O&M costs shown in **Table 1**). Similar to installed capital costs, there are economies of scale and O&M costs decline as CHP capacities increase. Between technology classes, gas turbines and microturbines have lower O&M costs compared to comparably sized reciprocating engines. Fuel cell O&M costs can be high, depending on the frequency required for replacing the fuel cell stack, which is an expensive component.

- **Power to heat** is the ratio of electric energy generated divided by the amount of useful thermal energy delivered. A related metric is the thermal to electric ratio expressed in units of Btu/kWh. The power to heat ratio follows a trend similar to electric efficiency, with fuel cells generally having the highest value, followed by reciprocating engines, gas turbines, microturbines, and then steam turbines. As mentioned previously, steam turbine CHP installations are typically designed to produce large amounts of thermal energy with electricity generated as a byproduct. As a result, steam turbines have low power to heat ratios.

- **Thermal energy** can be recovered as steam, hot water, or hot process gas and used to meet on-site heating requirements. Available steam pressures vary depending on the type of CHP technology, but can range from low pressure (<15 psig), medium pressure (15-150 psig), to high pressure (>150 psig). In addition to heating loads, CHP systems can meet cooling or refrigeration loads by using a thermally activated technology, such as an absorption chiller.

- **Both fossil and renewable fuels** are used in CHP systems. While natural gas is the most common fuel, CHP systems are also capable of using renewable fuels such as biogas (e.g., landfill or digester gas) and wood waste. Fuel cells, which use an electrochemical process to convert hydrogen into electricity and water, are either supplied with hydrogen, or the hydrogen is created by reforming a fuel such as natural gas, propane, or methanol. Boiler/steam turbine CHP systems can utilize nearly any type of gas, liquid, or solid fuel, but the technology is typically used when low cost solid or liquid fuels are available (e.g., coal, biomass, or process waste).

- **Applications** with steady thermal and electric loads are ideal for CHP. In the industrial sector, CHP is well suited for chemical plants, refineries, pulp and paper mills, wastewater treatment plants, food processing sites, and many other locations with significant thermal and electric demands. In the commercial sector, attractive CHP sites include, but are not limited to, hospitals, nursing homes, laundries, hotels, health clubs, universities, and prisons. While most CHP systems have been installed in industrial, commercial, and institutional applications, residential applications, such as multi-family buildings, can also be a good match for CHP. As noted in Table 1, steam turbines used in CHP applications have relatively low power to heat ratios and are used primarily with solid fuel boilers. Rather than using a low power to heat ratio steam turbine, sites that have access to gas fuels (e.g., natural gas or biogas) generally install prime movers with higher power to heat ratios, such as reciprocating engines or gas turbines.

- **Emissions** from CHP systems, which are most often fueled with natural gas, are low. CHP technologies are capable of meeting or exceeding air quality regulations throughout the United States, including states such as California that have demanding limits for NOx, CO, and VOC emissions. To achieve compliance, a CHP technology may need to integrate an exhaust treatment technology such as an oxidation catalyst or a selective catalytic reduction system ■

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4 U.S. Department of Energy, *CHP Technology Fact Sheet Series*, 2016.

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