



CHP Technologies: Microturbines

Microturbines emerged in the 1990s, driven in part by a need for clean distributed generation technologies that complied with stringent emission regulations. Microturbines, like larger capacity gas turbines, have inherently low NO_x and CO emissions with no aftertreatment. Microturbines can be operated on a wide range of fuels, including natural gas and hydrogen, and can be packaged with an integrated heat exchanger to capture thermal energy for combined heat and power (CHP) operation. Attractive features for microturbines include high reliability, small footprint, quiet operation, streamlined permitting and interconnection, flexible thermal outputs for a variety of applications, and low maintenance costs.

Microturbines for CHP

Microturbines and gas turbines—discussed in a separate fact sheet¹—operate on similar thermodynamic principles. The two technologies are divided into separate categories, however, based on several operating characteristics, including those shown in [Table 1](#).² As the name implies, microturbines have smaller electric power capacities compared to gas turbines, typically below 400 kW for a single unit, although multiple units can be combined into modular systems with higher capacities. All available heat from a microturbine is contained within the exhaust stream, whose energy can be recovered and utilized in various CHP applications. [Table 2](#) provides a summary of microturbine attributes.



Microturbine CHP Installation at a Commercial Facility.
Photo courtesy of Capstone Green Energy

Table 1. Comparison of Microturbine and Gas Turbine Characteristics

Characteristic	Gas Turbine	Microturbine
Size	2–400 MW	<400 kW per unit
Rotational Speed	3,000–20,000 rpm	40,000–100,000+ rpm
Pressure Ratio	Up to 25 (multiple stages)	2–5 (single stage)
Exhaust Temperature	>800°F	500°–650°F

Table 2. Summary of Microturbine Attributes for CHP Applications

Attribute	Description
Size Range	Individual microturbines are available in sizes under 400 kW. Two or more microturbines can be combined into modules to achieve capacities of 1,000 kW or higher.
Thermal Output	Microturbines have exhaust temperatures of 500° to 650°F, and this exhaust can be used to produce hot water, steam (with a heat recovery steam generator), or chilled water (with an absorption chiller). It can also be used directly for industrial process heating or drying.
Start-Up	Microturbines start quickly, typically reaching full capacity in under 2 minutes.
Part-Load Operation	The electrical generation efficiency of a microturbine slowly declines as load decreases. Multiple microturbines can be combined into a modular system. In a modular design, one or more units can be shut down to meet part-load demand, which allows the remaining microturbines to operate efficiently near full load.
Fuel	Microturbines can be operated with a wide range of gas and liquid fuels. For CHP, natural gas is the most common fuel, followed by biogas. Manufacturers are now introducing products compatible with hydrogen fuels.
Reliability	Microturbines share design principles with larger capacity gas turbines, and like gas turbines, microturbines routinely operate with 95% or higher availability. ^a
Other	Microturbines have low NO _x and CO emissions and require no cooling or radiators. Individual units are compact with a small footprint and can be sited in space constrained locations.

Notes: a) Availability based on information provided by solution providers listed in DOE Combined Heat & Power eCatalog, [Link](#).

1 Department of Energy (DOE), Combined Heat and Power Technology Fact Sheet Series, CHP Technologies: Gas Turbines, 2024, [Link](#).

2 Comparison based on multiple sources including European Turbine Network (ETN), Micro Gas Turbine Technology, Section 3.4, [Link](#).

Applications

Microturbines are used in distributed generation applications due to their flexibility in connection methods, their ability to be stacked in parallel to serve larger loads, their ability to provide stable and reliable power, and their low emissions compared to other technologies. Microturbines are well-suited to be used in CHP applications because the exhaust heat can either be recovered in a heat recovery boiler or the hot exhaust gases can be used directly. There are over 450 sites in the United States that currently use microturbines for CHP. These microturbine

sites represent over 11% of the total number of CHP sites in the United States, accounting for 153 MW of aggregate capacity.³ Microturbines are used for CHP in multifamily buildings; wastewater treatment facilities; schools, colleges, and universities; hotels; commercial buildings; hospitals and healthcare facilities; recreational and athletic buildings; food and beverage plants; and a variety of other applications, such as greenhouses and data centers (Figure 1).

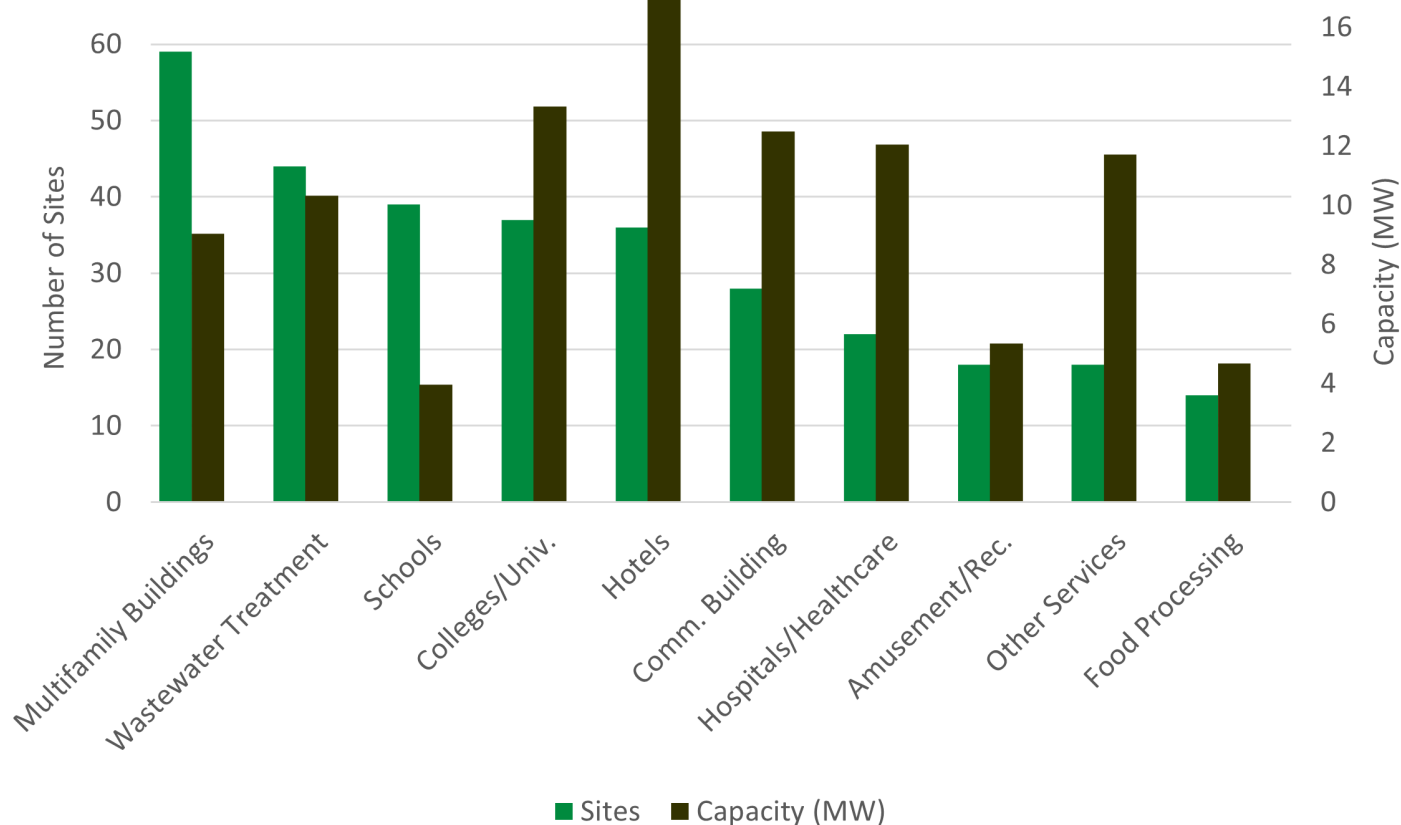


Figure 1. Number of CHP Microturbine System Installations and Total Capacity by Application

Thermal energy from microturbine exhaust can be recovered to produce hot water, steam, or chilled water (when integrated with an absorption chiller). Microturbines have a high ratio of thermal to electric energy, making them well-suited for applications with high thermal needs, including sites with variable thermal loads.

Microturbines can use a variety of fuels including natural gas, propane, landfill gas, digester gas, and process waste gas. These fuels vary across applications, with certain industries such as wastewater treatment using overwhelmingly renewable fuels, most commonly digester gas. Other applications such as livestock and food processing also heavily utilize digester gas, which is the second most abundant fuel type for microturbines after natural gas.

Hydrogen fuel, especially hydrogen produced using renewable electricity, offers a pathway to reduce or eliminate carbon emissions. Microturbines currently have the ability to operate on up to 30% hydrogen blended with natural gas. Research efforts are underway to develop microturbines that operate on higher hydrogen concentrations, with the ultimate goal of commercializing microturbines that can be fueled with 100% hydrogen. Manufacturers are also developing field retrofit solutions to convert in-service microturbines to operate on up to 100% hydrogen fuel.

3 DOE Combined Heat and Power Installation Database, February 2024, [Link](#).

Technology Description

Microturbines are compact machines with all major components factory assembled into a single unit (Figure 2). The heart of a microturbine is the compressor-turbine package (or turbocompressor), which is commonly mounted on a single shaft along with an electric generator. The shaft, rotating at high speed, is supported by either air bearings or conventional lubricated bearings. Microturbines produce electrical power either with a high-speed generator turning on a single turbo-compressor shaft or through a speed reduction gearbox driving a conventional 3,600 rpm generator. High-speed single-shaft designs employ a permanent magnet and an air-cooled generator that produce variable voltage and high-frequency AC power. A power conditioning unit (inverter) is then used to convert high-frequency AC power to constant 60 Hz power. These inverters have built-in protective relay functionality, are self-synchronizing, and in most cases, comply with grid interconnection requirements IEEE1547 and UL1741SA.

Microturbines and larger capacity gas turbines both operate on the Brayton thermodynamic cycle. In the Brayton cycle, inlet air is compressed and then mixed with fuel in a combustion chamber. Hot combustion gas then flows through a turbine, which rotates a mechanical shaft. Shaft power drives an electrical generator and the inlet air compressor. Exhaust from the turbine flows through a recuperator, which preheats combustion air (preheated air increases electric generation efficiency). Exhaust from the recuperator then flows through a heat recovery unit, typically designed to supply hot water for onsite thermal requirements.

Microturbines are typically offered as a complete package, including power conditioning and heat recovery designed to produce hot water. The DOE Packaged CHP eCatalog includes microturbine systems from 65 to 1,000 kW.⁴

Performance Characteristics

Microturbines tend to have lower electric efficiencies than reciprocating engines⁵, but they have other benefits like lower noise/vibration, compact sizing, and increased thermal output flexibility. All of the heat recovered from microturbines is located in the high-temperature exhaust stream, which can be used to produce hot water, steam at varying pressures and temperatures, or chilled water for cooling with high-efficiency, direct-fired absorption chillers. Like larger gas turbines,

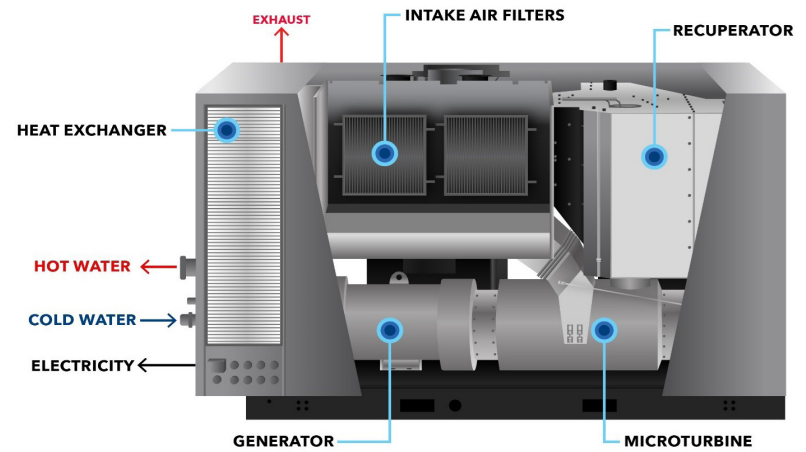


Figure 2. Microturbine Illustration

microturbines operate at high excess air levels, enabling the high temperature exhaust to be used as preheated combustion air for supplemental firing, increasing the level of steam output at greater efficiency than a conventional boiler. Exhaust from microturbines can also be applied directly to industrial process heating applications. Further, microturbine heat recovery systems can incorporate control systems and valves to produce varying amounts of hot water, steam, chilled water, and/or direct exhaust for each end-use as demand fluctuates.

Table 3 summarizes technical performance characteristics for packaged microturbine CHP systems ranging in size from 65 to 1,000 kW, all operating on natural gas and producing 180°F hot water. The efficiency values in the table are based on systems connected to low pressure (<5 psig) natural gas. Microturbines typically require an inlet fuel pressure near 75 psig, and approximately 2 out of 3 microturbine packages include an onboard compressor option to provide the required fuel pressure when needed. The net power shown in Table 3 represents the maximum power available after parasitic power, including the fuel compressor, has been subtracted. The overall CHP efficiency is between 66% and 72% for representative microturbines shown in Table 3, and the power to heat ratio ranges from 0.50 to 0.75. CHP systems with low (<1) power to heat ratios are a good fit for sites that have high thermal loads compared to electric loads. Microturbines are also a good fit for CHP applications that require cooling. When paired with microturbines, direct exhaust absorption chillers can achieve 0.5–0.6 tons per kW of cooling and boost total system efficiencies into the range of 85%–90%.

⁴ DOE Combined Heat & Power eCatalog, Accessed October 2023, [Link](#).

⁵ Department of Energy (DOE), Combined Heat and Power Technology Fact Sheet Series, CHP Technologies: Reciprocating Engines, 2023, [Link](#).

Table 3. Microturbine Performance Characteristics (Natural Gas Fuel)

Description	Gross Electric Power (kW)			
	65	200	600 ^a	1,000 ^a
Parasitic Load (kW, with fuel gas compressor)	4	10	30	50
Net Electric Power (kW) ^b	61	190	570	950
Fuel Input (MMBtu/hr, HHV) ^c	0.87	2.28	6.84	11.40
Hot Water Output (MMBtu/hr, based on 180 °F)	0.42	0.90	2.60	4.30
Power to Heat Ratio	0.50	0.72	0.75	0.75
Net Electric Efficiency (net power basis, HHV)	23.9%	28.4%	28.4%	28.4%
Thermal Efficiency (HHV)	48.2%	39.5%	38.0%	37.7%
CHP Efficiency (net power basis, HHV) ^d	72.1%	67.9%	66.4%	66.2%

Notes:

- a) Modular system that includes more than one microturbine.
- b) Net power equals gross power minus parasitic load.
- c) All calculations are based on higher heating value (HHV) of fuel.
- d) Overall efficiency is sum of electric and thermal efficiency. Total may differ due to rounding.

Capital and O&M Costs

Table 4 provides cost estimates for microturbine CHP systems with a breakout of costs in two categories:

- **Microturbine Package.** The microturbine package includes a microturbine designed for natural gas operation, controls, and power electronics for basic interconnection and paralleling functionality. The package includes a fuel gas compressor, generator, power conditioning electronics, on-board recuperator, and hot water heat exchanger.
- **Construction and Installation.** Construction and installation costs are based on a simple installation with no unique or complicated site-specific requirements. Construction and installation costs include balance of plant (BOP) hardware, installation labor and materials (including site work), and soft costs (e.g., engineering, project management, licensing, insurance, and commissioning/startup support).

As indicated in Table 4, installed capital costs on a per kW basis decline as capacity increases, ranging from \$4,900 to \$3,400 per kW. Operation and maintenance (O&M) costs are estimated to range from 1.9 to 1.6 cents/kWh (variable and fixed maintenance combined).

Costs in Table 4 are representative estimates for typical, or baseline, microturbine installations. Project costs can vary significantly based on site-specific requirements and hardware configurations as discussed below and shown in Figure 3:

Table 4. Microturbine Costs (Typical)

Description	Gross Electric Power (kW)			
	65	200	600	1,000
Microturbine Package (\$/kW)	\$3,200	\$2,900	\$2,400	\$2,200
Construction and Installation (\$/kW)	\$1,700	\$1,500	\$1,300	\$1,200
Total (\$/kW)	\$4,900	\$4,400	\$3,700	\$3,400
Non-Fuel O&M (cents/kWh)	1.9	1.7	1.6	1.6

- **Typical, or baseline, costs** (green circle in Figure 3) – Typical costs, which are shown in Table 4, are based on a natural gas microturbine with a fuel compressor, no emission reduction systems, a clean site ready for construction (i.e., no removal of existing structures or hardware), and installation on an outdoor concrete pad or within an existing building with a concrete floor.

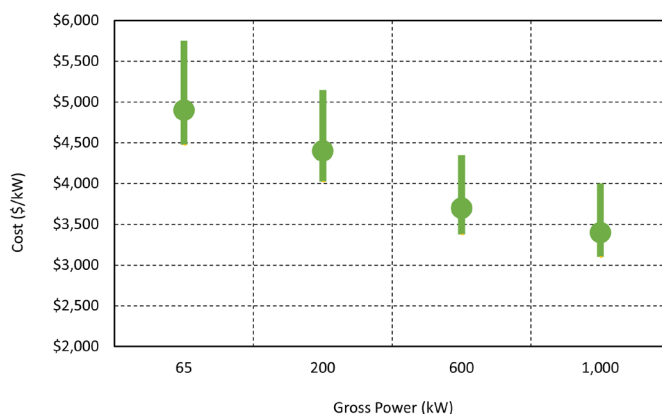


Figure 3. Installed Cost Range for Microturbine CHP Systems

- **Factors that increase costs** – Costs are higher if one or more of the following conditions apply: need for emission reduction catalyst, complex heat recovery equipment, complex electrical interconnection, complicated thermal interconnection, or need to remove existing structures or equipment before construction.
- **Factors that reduce costs** – Costs can be lower with one or more of the following conditions: simplified interconnection process (local utility requirements), simplified thermal interconnections (e.g., pre-existing thermal piping), high pressure (e.g., 75 psig) fuel connection (no fuel compressor), or geographic area with competitive local labor market and experienced CHP contractors.

Emissions

Microturbines have inherently low emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs), requiring less aftertreatment than other CHP options. Microturbine criteria pollutant emissions are typically below 9 ppm NO_x, 40 ppm CO, and 7 ppm VOC (all measured at 15% oxygen) without aftertreatment. If needed, CO emissions can be further reduced to less than 10 ppm at 15% oxygen by using an oxidation catalyst placed in the exhaust stream. Some commercially available microturbine packages are pre-certified for compliance with stringent emission standards required by the California Air Resources Board (CARB).

Attainment and Non-Attainment Areas

The Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards for six criteria pollutants. Regions that follow standards set for these pollutants are referred to as attainment areas, and regions that are out of compliance for one or more of the pollutants are designated non-attainment areas. All attainment areas, and most non-attainment areas, present no air emission challenges for siting microturbines.

CO₂ Emissions

Table 5 shows CO₂ emissions for microturbine CHP systems fueled with natural gas. The CO₂ emissions are calculated based on the assumption that thermal energy supplied by the CHP system offsets thermal energy that would otherwise be produced with an 80% efficient natural gas boiler.⁶ As indicated in Table 5, effective CO₂ emissions for CHP microturbines are in the range of 663–741 lbs/MWh for hot water applications. For comparison, effective CO₂ emissions from CHP systems are about 50% lower than marginal grid emissions, which are estimated at over 1,400 lbs/MWh on average in the United States.⁷

For microturbines, direct use of the high-temperature exhaust gas—either for heating or with a direct fired absorption chiller for cooling—can result in higher total CHP efficiencies and lower effective CO₂ emissions compared to those shown in Table 5. CO₂ emissions for CHP installations can be further reduced, or eliminated, by using low or zero-carbon fuels such as biogas, renewable natural gas, and hydrogen. ■

Table 5. Microturbine CO₂ Emissions Characteristics (Natural Gas)

Description	Gross Electric Power (kW)			
	65	200	600	1,000
Total CO ₂ Emissions (lbs/MWh) ^a	1,669	1,403	1,403	1,403
CHP Effective Electric CO ₂ Emissions (lbs/MWh) ^b	663	711	736	741

Notes:

- a) CO₂ emissions based on net power, natural gas fuel, and CO₂ emissions factor of 116.9 lbs/MMBtu.
 b) Effective emissions include credit based on avoided thermal emissions from 80% efficient natural gas boiler.



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For more information, visit: energy.gov/eere/iedo/onsite-energy-program

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6 Effective Electric CHP CO₂ Emissions is equal to CO₂ emissions from fuel chargeable to power divided by net MWh generated; fuel chargeable to power is equal to total CHP fuel input minus displaced thermal energy fuel from an 80% efficient boiler; emissions factor for natural gas is 116.9 lbs CO₂/MMBtu. For more information on CHP emission reduction calculations, see the recommended methodology from the EPA CHP Partnership, [Link](#).

7 2023 AVERT Uniform EE marginal emissions factor, [Link](#).