Microturbines

Microturbines are relatively small combustion turbines that can use gaseous or liquid fuels. While large gas turbines (described in a separate fact sheet[1]) have been used for CHP applications for several decades, microturbines emerged as a CHP option in the 1990s. Individual microturbines range in size from 30 to 330 kilowatts (kW) and can be integrated to provide modular packages with capacities exceeding 1,000 kW. **Table 1** provides a summary of microturbine attributes.

Microturbine CHP installation at a commercial facility.
Photo courtesy of Capstone Turbine Corporation

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 360 sites in the United States that currently use microturbines for CHP. These microturbine sites represent over 8% of the total number of CHP sites in the United States, accounting for 92 MW of aggregate capacity.[2] Sites that use microturbines for CHP include hotels, nursing homes, health clubs, commercial buildings, food processing plants, and small manufacturing operations. In CHP applications, thermal energy from micro-turbine exhaust is recovered to produce either hot water or low pressure steam. The temperature of microturbine exhaust also allows for its effective use with absorption cooling equipment that is driven either by low pressure steam or by the exhaust heat directly. Microturbine systems that provide both cooling and heating can be used in a variety of commercial and institutional applications. Microturbines can burn a variety of fuels, making them useful for resource recovery applications, including landfill gas, digester gas, oil and gas field pumping, and coal mine methane use.

Table 1. Summary of Microturbine Attributes

Size range	Available from 30 to 330 kW with integrated modular packages exceeding 1,000 kW.
Thermal output	Microturbines have exhaust temperatures in the range of 500 to 600 °F, and this exhaust can be used to produce steam, hot water, or chilled water (with an absorption chiller).
Part-load operation	The electrical generation efficiency of microturbines declines significantly as load decreases. Therefore, microturbines generally provide best economic performance in base load applications where the system operates at, or near, full load. An exception is modular packages where one or more individual microturbines can be shut down while the remaining microturbines operate at or 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.
Reliability	Microturbines are based on the design principles used in larger capacity combustion turbines and, like combustion turbines, microturbines have high reliability.
Other	Microturbines have low emissions and require no cooling. Individual units are compact and can be easily shipped and sited in confined spaces.

1 U.S. Department of Energy, Combined Heat and Power Technology Fact Sheet Series – Gas Turbines, 2016.

2 U.S. DOE *Combined Heat and Power Installation Database*, data compiled through December 31, 2015.

Technology Description

Microturbines operate on the same thermodynamic cycle (Brayton Cycle) as larger combustion turbines and share many of the same basic components. In the Brayton cycle, atmospheric air is compressed, heated by burning fuel (e.g., natural gas), and then used to drive an expansion turbine that in turn drives both the inlet compressor and a drive shaft connected to an electrical power generator. **Figure 1** shows a schematic of the basic microturbine components, which include the combined compressor/turbine unit, generator, recuperator, combustor, and CHP heat exchanger.

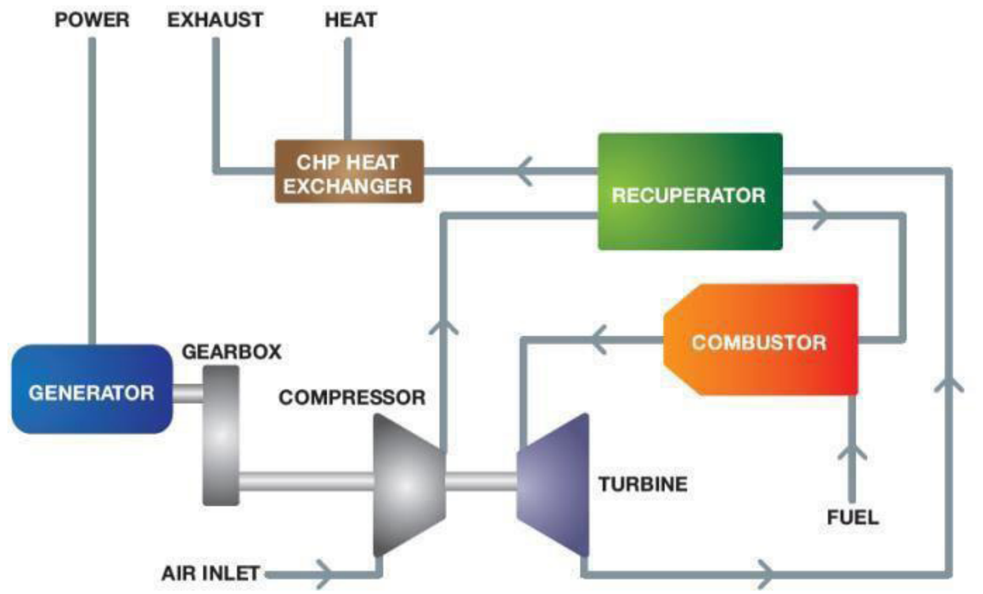

Figure 1. Microturbine configuration for CHP.
Graphic credit Flex Energy.

Figure 2 shows an illustration of a microturbine. The heart of the microturbine is the compressor-turbine package (or turbocompressor), which is commonly mounted on a single shaft along with the electric generator. The shaft, rotating at upwards of 60,000 rpm, is supported on either air bearings or conventional lubricated bearings. The single moving part of the one-shaft design has the potential for reducing maintenance needs and enhancing overall reliability.

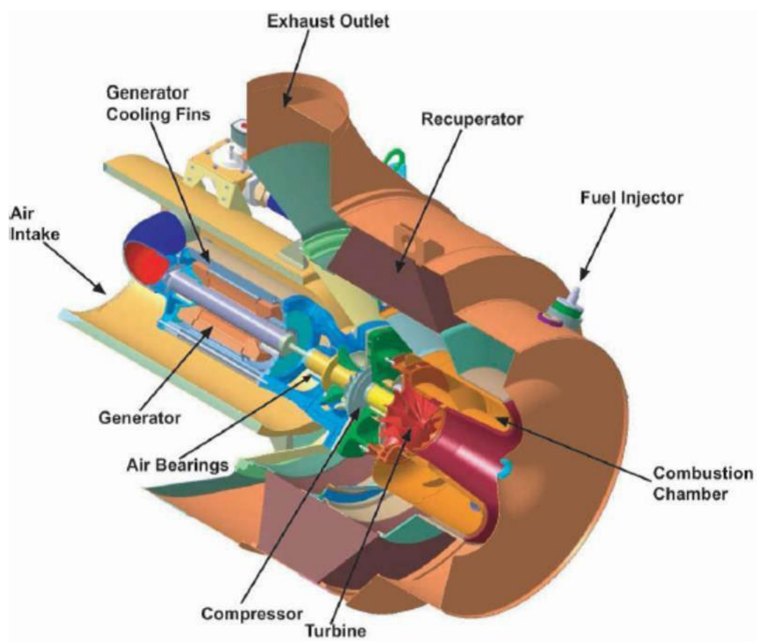

Figure 2. Microturbine illustration.
Graphic credit Capstone Turbine Corporation.

The microturbine produces electrical power either via a high-speed generator turning on the single turbo-compressorshaft or through a speed reduction gearbox driving a conventional 3,600 rpm generator. The high-speed generator single-shaft design employs a permanent magnet and an air-cooled generator producing variable voltage and high-frequency AC power. This high-frequency AC output (about 1,600 Hz for a 30 kW machine) is converted to constant 60 Hz power output in a power conditioning unit. The recuperator is a heat exchanger that uses the hot turbine exhaust gas (typically around 1,200°F) to preheat the compressed air (typically around 300°F) going into the combustor, thereby reducing the fuel needed to heat the compressed air to the required turbine inlet temperature. In CHP operation, microturbines offer an additional heat exchanger package, integrated with the basic system, that extracts much of the remaining energy in the turbine exhaust, which exits the recuperator at about 500-600°F. Other than the size difference, microturbines differ from larger combustion turbines in that they typically have lower compression ratios and operate at lower combustion temperatures. In order to increase efficiency, microturbines recover a portion of the exhaust heat in a heat exchanger called a recuperator. The recuperator increases the energy of the gases entering the expansion turbine thereby boosting efficiency. Microturbines operate at relatively high rotational speeds, often reaching 60,000 revolutions per minute.

Table 2. Microturbine Performance Characteristics

Description	System				
	1	2	3	4	5
Rated Power (kW)	65	200	250	333	1,000
Parasitic Load for Gas Compressor (kW)	4	10	8	10	50
Net Electric Power (kW)	61	190	242	323	950
Fuel Input (MMBtu/hr, HHV)[3]	0.84	2.29	3.16	3.85	11.43
Useful Thermal (MMBtu/hr) [4]	0.39	0.87	1.20	1.60	4.18
Power to Heat Ratio[5]	0.53	0.75	0.69	0.69	0.77
Electric Efficiency (%, HHV)	24.7%	28.4%	26.1%	28.7%	28.3%
Thermal Efficiency (%, HHV)	46.9%	38.0%	38.0%	41.6%	36.6%
Overall Efficiency (%, HHV)	71.6%	66.3%	64.0%	70.2%	64.9%

Note: *Performance characteristics are average values and are not intended to represent a specific product.*

Performance Characteristics

Table 2 summarizes technical performance characteristics for microturbine CHP systems ranging in size from 65 to 1,000 kW. The 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 most microturbines include an onboard gas compressor to provide the required gas pressure. The net power shown in **Table 2** represents the maximum power available after the parasitic compressor load has been subtracted. As indicated, the overall CHP efficiency for the five representative microturbines ranges from 64% (System #3) to slightly under 72% (System #1). The power to heat ratio ranges from 0.53 (System #1) to 0.77 (System #5).

Table 3. Microturbine Capital and O&M Costs[6]

Description	System				
	1	2	3	4	5
Net Electric Power (kW)	61	190	242	323	950
Complete Microturbine Package[7]	$2,120	$2,120	$1,830	$1,750	$1,710
Construction and Installation	$1,100	$1,030	$870	$800	$790
Installed Cost ($/kW)	$3,220	$3,150	$2,700	$2,560	$2,500
O&M, not including fuel (¢ /kWh)	1.3	1.6	1.2	0.8	1.2

Note: *Costs are average values and are not intended to represent a specific product.*

Capital and O&M Costs

Table 3 provides cost estimates for microturbine systems used in CHP applications that produce hot water at 140 °F. Thermal recovery in the form of cooling can be accomplished with the addition of an absorption chiller. The basic microturbine package consists of the microturbine and power electronics. All commercially available microturbines offer basic interconnection and paralleling functionality as part of the package cost. Most microturbine CHP systems offer an integrated heat exchanger with the basic package. As indicated, installed capital costs range from $3,220 to $2,500 per kW and decline with increasing capacity. The total plant

3 Fuel consumption and efficiency values are based on the higher heating value (HHV) of natural gas unless noted otherwise.

4 Useful thermal energy is based on producing hot water at a temperature of 140 °F.

5 Power to heat ratio is the electric power output divided by the useful thermal output. The ratio is unit-less.

6 Costs are based on vendor data, installation estimates, and information provided by project developers.

7 The complete package includes the microturbine engine, fuel gas compressor, and heat recovery hardware. The package does not include the cost of an absorption chiller for applications that produce chilled water.

cost consists of all equipment costs plus installation labor and materials (including site work), engineering, project management (including licensing, insurance, commissioning, and startup), and financial carrying costs during a typical three-month construction period. The costs shown are representative estimates and can vary significantly depending on the scope of the plant equipment, local emissions requirements, and other site specific requirements.

Non-fuel operation and maintenance (O&M) costs are also shown in **Table 3**. Maintenance costs vary with size, fuel type, and technology (air versus oil bearings). As indicated, maintenance costs for microturbines range from 0.8 to 1.6 ¢/kWh (includes fixed and variable maintenance based on 6,000 hrs/yr of operation).

Table 4. Microturbines Emission Characteristics

Description	System				
	1	2	3	4	5
Electric Capacity (kW)	61	190	242	323	950
Emissions (ppm at 15% oxygen)[9]					
NOx	9	9	5	5	9
CO	40	40	5	5	40
VOC	7	7	5	5	7
Emissions (lbs/MWh)[10]					
NOx[11]	0.46	0.40	0.24	0.22	0.40
CO[12]	1.24	1.08	0.15	0.13	1.08
VOC[13]	0.12	0.11	0.08	0.08	0.11
CO_2 Emissions (lbs/MWh)					
Electricity only	1,613	1,406	1,529	1,392	1,407
CHP w/ thermal credit[14]	667	739	804	668	764

Note: *Emissions are average values and are not intended to represent a specific product.*

Emissions

Microturbines are designed to meet state and federal emissions regulations, including more stringent state emissions requirements in California and some other states. **Table 4** shows maximum NOx, CO, and VOC emissions as reported by vendors. All systems have no emissions control hardware.[8] As indicated, maximum NOx, CO, and VOC emissions are 9, 40, and 7 ppm, respectively. These emission values are measured in the exhaust stack and corrected to 15% oxygen. Table 4 also shows NOx, CO, and VOC emissions in units of lbs/MWh. These values are based on the electric power production and do not include a credit for thermal recovery.

Table 4 shows CO_2 emissions for CHP systems based on the electric power output and on the complete CHP system. For the complete CHP system, CO_2 emissions are calculated with a thermal credit for natural gas fuel that would otherwise be used by an on-site boiler. With this credit, CO_2 emissions range from 667 to 804 lbs/MWh. For comparison, a typical natural gas combined cycle power plant will have emissions of 800-900 lbs/MWh, and a coal plant will have CO_2 emissions near 2,000 lbs/MWh. ■

8 The microturbines for Systems #3 and #4 use a lean premixed swirl-stabilized combustor to achieve low emissions with no after treatment.

9 NOx, CO, and VOC emissions are maximum exhaust emissions at full load ISO conditions.

10 NOx, CO, and VOC emissions expressed in units of lbs/MWh are based on electric output and do not include a thermal credit.

11 NOx conversion: NOx [lbs/MWh] = NOx [ppm @ 15% O2] / 271 / electrical efficiency [%, HHV] X 3.412.

12 CO conversion: CO [lbs/MWh] = CO [ppm @ 15% O2] / 446 / electrical efficiency [%, HHV] X 3.412.

13 VOC conversion: VOC [lbs/MWh] = VOC [ppm @ 15% O2] / 779 / electrical efficiency [%, HHV] X 3.412.

14 The CHP CO_2 emissions include a thermal credit for avoided fuel that would otherwise be used by an onsite boiler. The boiler is assumed to operate on natural gas with an efficiency of 80%.

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