WINTER 2005

TECHNOLOGY Spotlight

Keeping You Informed about Today's Distributed Energy Applications

In This Issue:

Now on the Market see page 4

Take a look at several companies offering commercialized microturbines

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Technology Spotlight is an occasional publication of the Gas Technology Institute. Each issue is devoted to analyzing the viability and value of a particular type of Distributed Generation applications available to consumers. Technology Spotlight is meant to foster better understanding of the technologies and uses, so that consumers can make more informed choices for their businesses.

Technology Spotlight
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The Benefits and Challenges of Microturbines

At most central station power plants, waste heat from electricity production is cast off into the environment. Unlike these plants, microturbine and other DG systems are located entirely on customers' sites. There, the systems can harness the waste heat in a combined heat and power (CHP) unit that can be connected to, or be completely independent of the electric grid.

Major advantages of a microturbine system:

- *Decreased grid electricity costs.*
- *Lower installation costs.*
- *Electric chillers supplanted by thermally activated chillers.*
- *Immunity to grid power outages.*
- *Quiet operation.*
- *Low vibration.*
- *Simple design relative to other DG technologies.*
- *Fuel flexibility.*
- *Simple grid interconnection.*

The major advantage of these systems is better long-term economics. Not only are customers avoiding grid electricity purchases, but by recovering waste heat, they're also avoiding fuel costs associated with the operation of separate heating equipment. Microturbine customers also realize savings when waste heat is used in thermally activated cooling equipment, which can eliminate the need for electric chillers and electric refrigeration compressors. Another advantage is energy security: Microturbines with black start options (the capability to start without being connected to the grid) provide a measure of immunity to grid outages that can interrupt operations and cut into revenues. Finally, customers in grid locations where voltage sags are common, can benefit from the VAR support offered by local power production.

What about the disadvantages? For starters, microturbines' relatively low electrical efficiency, which increases operating costs and highlights the need to maximize the use of waste heat to make the overall system more economical than power from a central generating station. Microturbine efficiency also drops off faster with rising temperature (see Figure 1). The units typically need high-pressure gas (60psig) to operate, which requires a separate booster compressor. Compared to reciprocating engines, microturbines have higher engine/generator costs. However, overall system and installation costs are comparable to reciprocating engines because microturbines come as a fully integrated system with air cooling, power electronics and controls. Also, microturbine costs may be offset by lower installation and maintenance costs compared with reciprocating engines.

Continued on page 3…

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Questions about Reliability

Microturbines are fairly new products with limited operating history. Capstone has the longest history with over 10 million hours on their microturbine fleet. The results so far are promising: several generators have operated for 40,000 hours with no maintenance. The earlier commercial units have yet to complete a full life cycle, in terms of a manufacturer's expected service life, and some manufactures are still commercializing new products. Because relatively few operating hours have been logged for any single unit in the field, the available field data is not sufficient to definitively project realistic reliability and maintenance costs.

However, most manufacturers offer service contracts priced at about $0.01/kWh, which equates to $2,628/yr. for a 30 kW microturbine operating 24/7 for an entire year. The combustor and associated parts are inspected annually. Air and oil filters are replaced annually, and oil bearings (certain models only) are inspected annually as well. Microturbines operating in environments with dusty air require more frequent air-filter changes.

Analyzing the Value

So how can you determine if you will realize a significant ROI for your investment in a microturbine unit? The first step in analyzing the economics of a microturbine project is to compare the cost of grid power with generating costs. The difference between the cost of grid electricity and natural gas prices is typically referred to as the "spark spread." Knowing the microturbine's electric efficiency and the cost of fuel, it is possible to calculate the electric production cost. Figure 2 shows microturbine electricity production cost (¢/kWh) as a function of gas price and electric efficiency.

The next step is to determine the value of any recovered waste heat, which will translate into avoided fuel purchases. Figure 3 converts recovered heat to ¢/kWh at various gas prices as a function of varying percentages of waste heat recovery.

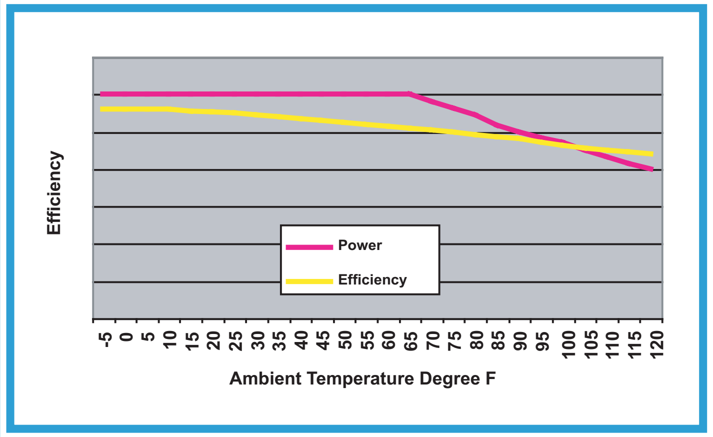

Figure 1: Typical performance with Respect to Ambient Temperature

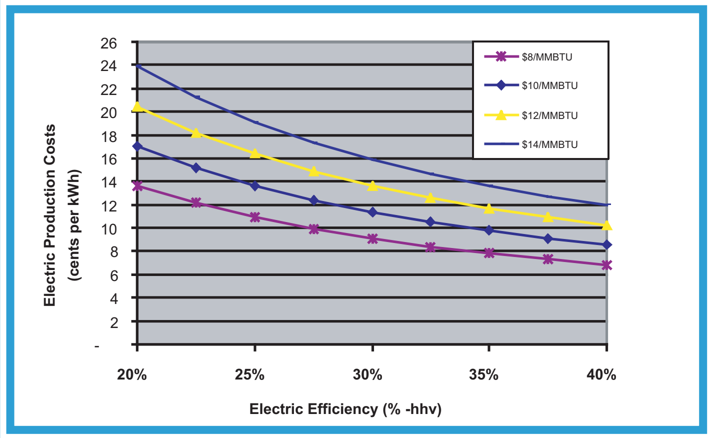

Figure 2: Microturbine Electricity Production Cost (¢/kWh) vs. Gas Price and Electric Efficiency

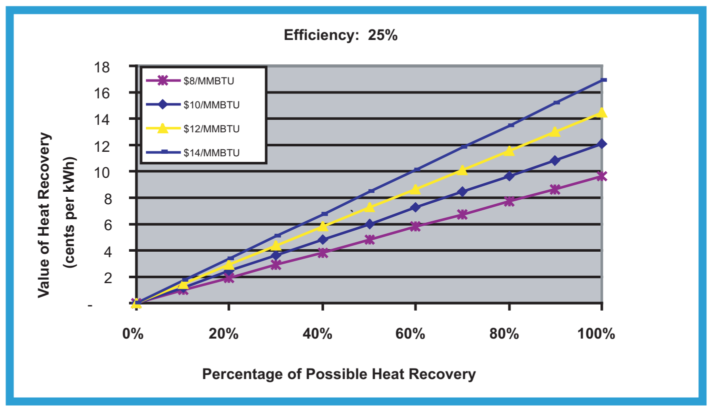

Figure 3: Recovered Heat to ¢/kWh as a Function of Varying Percentages of Waste Heat Recovery.

Now on the Market

Several companies have commercialized microturbines. Some of them are offering multiple products or are in the process of commercializing new products. Here's a look at what's currently available.

Capstone

Capstone has offered microturbines in two sizes—60 kW and 30 kW. They have recently introduced a 65kW unit that will replace the older 60 kW unit. Capstone also offers a 30 kW unit with an industrial enclosure where all panels can be removed for service. The standard 30 kW Capstone unit operates at an electrical efficiency of 26 percent (LHV) with a natural gas inlet pressure of 55 psig (booster not included). The 65 kW Capstone unit at an electrical efficiency of 29 percent (LHV) with a natural gas inlet pressure of 75 psig (booster not included). The turbine and compressor are mounted on a single shaft that rotates at 96,000 rpm. The shaft is suspended on patented air bearings that require no lube oil system. Capstone began offering the C65 as a CHP package with an integrated exhaust 220ºF hot water heat exchanger. This CHP package doesn't require additional floor space and the top-mounted heat exchanger increases height by less than 18". Capstone also offers an optional Dual Mode Controller that allows the microturbine to automatically switch from grid-parallel to grid-isolated operation. Capstone is working on a 200kW unit with a target efficiency above 30% but a release date is not yet available.

Ingersoll-Rand

Ingersoll-Rand PowerWorks™ offers a 70 kW two-shaft microturbine with oil-lubricated bearings. The turbine shaft is connected to a gearbox which drives a low-speed 70 kW induction generator and has an advertised electrical efficiency of 29% LHV. The 70kW unit includes an option for a built-in gas compressor that allows the system to operate on 1/4 psig gas supply.

Ingersoll-Rand introduced a 250 kW microturbine in 2003 with a rated efficiency of 30% without the optional gas booster. This uses a single shaft fixed speed turbine with a gearbox driven synchronous generator. Ingersoll Rand also offers fuel clean up systems for biogases, switchgear, and brake resistors to compliment their microturbine lines.

Elliott

Elliott Energy Systems Inc. manufacturers a 100 kW microturbine for use in distributed generation, CHP, biogas and offshore applications. Their TA100 CHP package is the result of more than ten years of research, development and testing. It is capable of producing 100kW of electrical energy and 172kW of thermal power that can be used for hot water, absorption chiller or drying system applications. Depending on the user application, overall CHP efficiency could be greater than 75 percent.

Bowman/Kohler

The Bowman TG80CG is an 80 kW fully-integrated cogeneration system that has an electric efficiency of about 26 percent and a CHP efficiency of 80 percent. The Bowman TG80CG is built around Elliott turbomachinery, but uses Bowman power electronics. An optional Dual Mode Switch allows the TG80 to automatically switch from grid-parallel to grid-isolated operation.

In December 2002, Kohler announced a partnership agreement with Bowman Power Systems Limited, a leading developer and supplier of microturbine power generation systems headquar-

Current Microturbine Availability and Specifications

Manufacturer Claimed Performance and Features

Manufacturer		Capstone		Elliott	Bowman	Turbec	Ingersoll-Rand PowerWorks	
Power Rating		30 kW	65 kW	80 kW	100 kW	100 kW	70 kW	250 kW
Electrical Efficiency (LHV) w/o Cogeneration		26%	29%	26%	29%	30%	29%	30%
Recuperator Effectiveness		85%	80%	90%	90%	80%	90%	90%
Exhaust Temperature		520 °F	588 °F	550 °F	535 °F	550 °F	400 °F	400 °F
Emissions	NO_x	< 9 ppm	<5 ppm	24 ppm	24 ppm	<15 ppm	< 9 ppm	<9 ppm
	CO	< 15 ppm	<? ppm	<30 ppm	<41 ppm	<15 ppm	25 ppm	<9 ppm
Number of Shafts		1	1	1	1	1	2	1
Shaft Speed (rpm)		96,000	96,000	68,000	68,000	70,000	43,000	43,000
Bearings Type		Air	Air	Oil	Oil	Oil	Oil	Oil
Electric Frequency (Hz)		50/60	50/60	50/60	50/60	50/60	50/60	50/60
Inlet Fuel Pressure (psig)		.2 -15 and 55	75 -80	75	.5 – 5	87/138	0.25-5	.25 - 200
Gas Booster Included		Yes	No	No	Yes	No	Yes	Optional
Dimensions	Length (in)	28	77	122	120	115	35	127
	115Height (in)	75	83	75	83	75	70	90
	Width (in)	53	30	35	33.5	34	40	85
Weight (lbs)		1,052	1,671	~2,000	4,500	4,470	3,000	11,700
Noise (dba @ 10 meters)		65	65	77@ 1 m	75 @ 1m	70 @ 1m	< 68	<78@ 1m
Cogeneration Included		No	No	Yes	Yes	Yes	Yes	Yes
Expected Service Life (hours)		40,000 (4.6 years)	40,000	54,000	40,000	60,000	80,000	80,000
Availability		In the market	In the market	In the Market	In the Market	Not Available In US	In the Market	In the Market

Note: The high inlet fuel pressure requirements of most microturbine products are a major concern. Because of the low gas pressure at the typical meter (0.25 to 1.5 psig), most microturbines listed above will require a gas compressor in most applications. The IR PowerWorks does have and integral gas booster and will operate with 0.29 to 5 psig. The Elliott also has an integral gas booster and will operate with 0.5 to 5 psig. Capstone offers an external compressor for both the C30 and C65. Most other microturbines require an external gas compressor to increase the fuel pressure above 60 psig.

Continued on page 5…

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tered in Southampton (U.K.). Kohler Power Systems will market and provide service warranties for Bowman products in the Americas under the Kohler brand name.

Turbec

Volvo Aero and ABB founded Turbec AB in 1998 to develop microturbine technology for small scale power generation. Turbec developed their first 100 kW microturbine product in 2001 which incorporated Bowman power electronics. Turbec started offering products in 2001 in Europe and introduced their T-100 product to the US in early 2002. However, in April 2003 Turbec decided to postpone sales activities in the US due to slow product sales and unclear DG regulation policy. In December 2003, Italian-based API Com srl acquired all of the share capital of Turbec AB. Currently, Turbec S.p.A. is only selling microturbines in Europe and Japan.

Technical Assessment

The technical viability of microturbine technology primarily hinges on turbomachinery, combustor and recuperator durability. The inverters and power electronics are simple proven reliable technology. For economic feasibility, these core components will have to last at least 40,000 hours (4-5 years), but this target could be adjusted depending on where the manufacturing costs settle out for the different microturbine concepts. Electrical efficiency will also play a role in technical viability. However, installed cost, maintenance costs and combined electrical and thermal efficiency will play a far greater role in determining life cycle economics. The value of microturbine systems will also depend on the price of natural gas and the corresponding price of electricity (or the spark spread) by region.

Gas compressor and fuel delivery technology will also have a major impact on technical viability. Capstone has developed an innovative fuel delivery system. The low-pressure version of their Model 330 incorporates what Capstone calls a ‘foil bearing rotary flow controller’. When outfitted with this device, the Model 330 can accept inlet gas pressures from .25 -15 psi. Capstone achieves their very low NOx emission levels by maintaining turbine exhaust temperature at about 1,100°F. To do this at various electrical loads, Capstone varies their turbine speed. To accomplish this they must maintain very fine control of fuel flow.

Ingersoll Rand uses an integrated reciprocating gas compressor. Ingersoll claims its PowerWorks microturbine can operate with inlet gas pressures down to 8 inches of water column. The reliability and durability of the compressor is another critical factor in the microturbine’s technical viability.

There are also technical issues involved with interconnecting these microturbines with the electric grid. Most microturbines simplify the interconnect process. Some of the inverter-based microturbines are type-tested and approved by New York and California (Rule 21).

The following table is an attempt to rank the leading microturbine products for overall technical viability, reliability and performance. Category scoring is based on a combination of data gleaned from manufacturer’s specs, laboratory and field testing and industry publications. Relative scores ranging from 1-10 were assigned to each element with the individual scores totaled to arrive at a final composite score. (1 representing high risk and 10 no risk at all)

Microturbine Generator Evaluation

Manufacturer	Electrical Efficiency	Combustor Life	Power Electronics	Fuel Delivery	Emissions	Packaging	Total Points
Capstone-30 kW	7	3	8	7	9	7	41
Capstone-65 kW	8	3	8	7	9	8	43
Bowman/Kohler	7	2	6	7	7	7	36
Elliott	8	2	6	8	7	8	39
Turbec	8	2	6	7	8	7	38
Ingersoll-70 kW	8	3	7	8	9	6	41
Ingersoll-250 kW	8	3	7	7	9	7	41

Comparing the Capital Costs

Equipment and installation costs are estimated for a microturbine CHP application where direct exhaust or hot water is utilized for on-site use. These are only estimates for budgetary purposes. It should be noted that installation cost can vary significantly, depending on the details of the plant equipment, geographical area, competitive market conditions, special site requirements, interconnection requirements and whether the installation is new or a retrofit application.

The equipment cost represents the selling price to the end customer, including any other major ancillary components. The actual customer cost for installing a microturbine-based CHP system includes a number of other factors that could increase the total costs by an estimated 70 percent to 90 percent over equipment costs. The total installed-cost estimates are based on a simple installation with minimal site preparation required. These cost estimates include provisions for grid interconnection and paralleling. Although a reciprocating engine/generator can be purchased for $350/kW, the support components (radiators/fans, pumps/piping enclosure, power electronics) raise the equipment costs to nearly $1,000/kW and increase the installation costs.

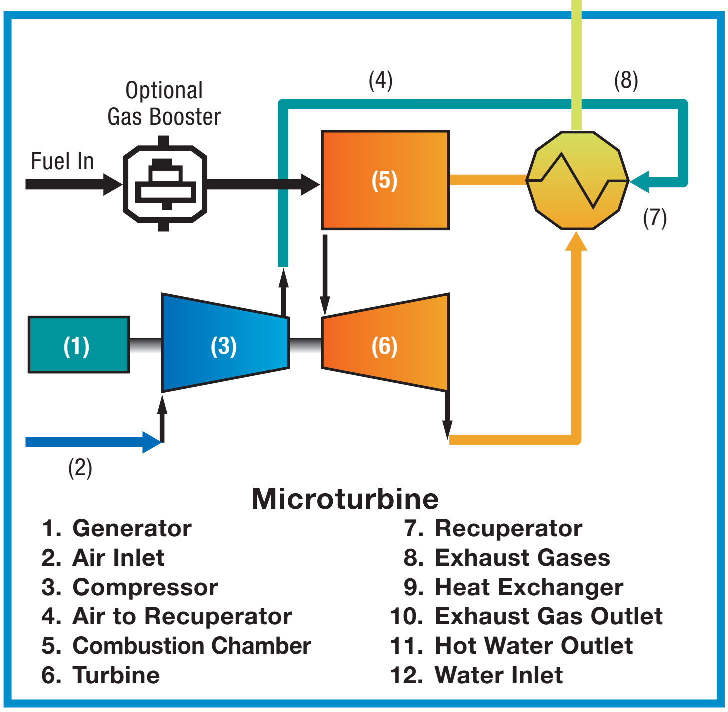
Manufacturer	Capstone		Bowman /Kohler	Elliott	Turbec	Ingersoll-Rand PowerWorks	
Power Rating	30 kW	65 kW	80 kW	100 kW	100 kW	70 kW	250 kW
Cost ($/kW)							
Equipment							
Microturbine	1,100		1,112		870		
Gas Compressor	100		52.5		Included		
Gas Safety Train			44				
Heat Recovery	175				Included		
Interconnect					155		
Protection/Relays							
Total Equipment	**1,375**				**1,025**		
Mechanical Contractor	500				450		
Electrical Contractor	400				350		
Permitting & Interconnect	100				30		
Total Installation	**1,000**				**830**		
Contingency	70				100		
Total CHP Cost	**2,445**				**1,955**		

Inside the Technology

Microturbines are offered today in units with capacities ranging from 30 kW to 250 kW. Several companies have products that are in the early market-entry stage. In the typical single-shaft configuration, the turbine spins at nearly 100,000 rpm and drives a high-speed alternator. The alternator's high-frequency output is converted to 60-cycle power using solid-state power electronics. Electrical efficiencies of 26-30 percent (LHV) are achieved by utilizing a recuperator to transfer exhaust heat back into the combustion air stream.

Operating Theory

In a typical microturbine, a radial compressor (#3 in diagram) forces combustion air (#2) into the combustor (#5), where it is mixed with the fuel that is burned to produce a high-pressure exhaust stream (#8). The hot gases expand through the power turbine (#6), which drives both the air compressor and the generator (#1). To improve efficiency, a recuperator (#7) is used to transfer waste heat in the exhaust stream over to the inlet air stream. Another heat exchanger (#9) can be used to capture remaining exhaust heat, which can be used to produce hot water.



Types of Microturbines

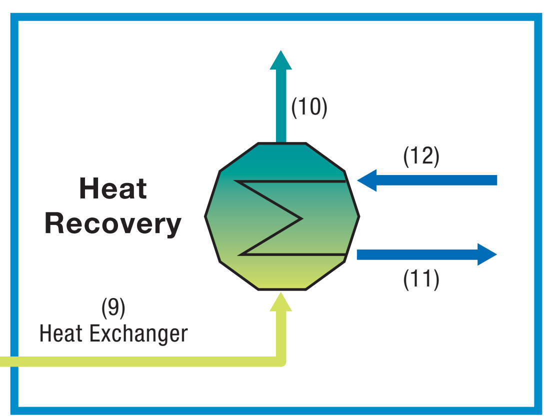
Most microturbines use a single-shaft design. This single turbine shaft turns both the inlet air compressor and the generator. Two-shaft designs use one turbine to drive the air compressor and a second turbine to drive the generator, with the exhaust stream from the compressor turbine powering the generator turbine. With the pressure ratio split between the two turbines, the lower speed of the second stage turbine is more conducive to directly driving a conventional generator.

Single-shaft models are designed to operate at higher speeds, some in excess of 100,000 RPM. These systems generate high-frequency alternating current (AC). This high frequency output is rectified to direct current (DC) and then inverted to 60 hertz (Hz) AC.

Comparing the Designs

The obvious advantage of single-shaft microturbines is fewer moving parts. They are also typically more compact and lighter. One manufacturer that uses this design also uses patented air bearings that eliminate the need for a lube oil system. That model also requires no coolant system; consequently, there are no liquids inside the package. The results: lower maintenance and higher reliability.

Some single shaft systems feature variable-speed designs, allowing the efficiency curve to remain flatter at part loads. These systems use variable-speed generators that require power electronics to convert the high-frequency generator output into useable 50 or 60 Hz power. Protective relay functions, normally required for grid connection, can be built into the power electronics—potentially reducing the size and cost of the system.



The one available two-shaft design doesn't require power electronics, and its lower output shaft speed can accommodate conventional induction or synchronous generators. The two shaft system will also improve part load efficiency, though it tends to be a more complex system. This model also is expected to be compatible with other products like air compressors or chillers.

Heat recovery options are another point of design distinctions. For instance, because Capstone Turbine Co.'s design incorporates no lube oil or coolant systems, the only option for recovering waste heat is via the exhaust stream with an exhaust gas heat exchanger. With this design, customers have the option of forgoing any heat recovery if, for some reason, they lose the entire thermal load. Systems that do have lube oil or coolant systems must always have some method of removing heat from the system. For those

Continued on page 7...

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installations where the thermal load could drop below some minimum requirement, it might be necessary to install a dump radiator or fluid cooler that can provide the lube oil or other system-cooling requirements.

People researching microturbine projects must also consider energy strategy in the decision. All microturbines are designed to run in parallel with the grid, but the various manufacturers use different approaches to run grid-isolated during grid outages. Many customers want this option so the microturbine can provide backup power, particularly to critical loads during a grid outage. When inverter-based machines are run grid-parallel, the power electronics are "line commutated" and act as a current source while matching whatever voltage the grid is supplying. To run these systems grid-isolated, it is necessary to "self-commutate" the inverter and incorporate some complement of batteries to provide "black start" capability when the grid is down. Non-inverter-based designs must use a synchronous generator and voltage regulator. When it comes to interconnect approval, the inverter-based machines have an advantage because they contribute less fault current and can be turned off faster than rotating synchronous machines.

Finally, the location of the unit is a critical factor. The market studies conducted by some manufacturers have indicated that most customers would prefer to install a microturbine indoors. Consequently, these manufacturers haven't designed weatherproof enclosures for their systems. Therefore, if a customer can't find a suitable indoor location, a new weatherproof enclosure might be required—adding $5,000 to $15,000 to the installed cost. However, some microturbines are available with integrated weatherproof enclosures.

Another disadvantage of microturbines is their need for a high-pressure gas supply – typically 60-70 psig. While three manufacturers have a gas booster incorporated into their package, most systems require the use of a separate gas compressor which must be purchased and integrated into the entire system. Another factor influencing the overall economics of a microturbine system is the typical, ambient temperature that the microturbine will operate at. This is important because the total power output is dependent on the ambient temperature, where high ambient temperatures adversely affect the overall efficiency and total power output.

Microturbines under the Microscope

Assessing Viability of one of the Newest DG Technologies

Distributed Generation (DG) is not a new concept. But over the last few years, electric capacity shortages, grid reliability concerns, environmental considerations, technological advancements and the changing needs of the marketplace have combined to re-energize interest in DG technology. DG will never replace central power plants, but it can supplement the output of these large generators, reduce peak electric demand, provide reliable backup and play a permanent part in the future of electric infrastructure.

For national chains and other large facilities, the potential benefits of microturbine DG systems are plentiful. But how reliable are microturbines? Are they worth the cost? Do they make sense for your business? In this issue, we take a close look at available microturbine products to find out.

DG technologies operate on the consumer's site, often in parallel with the utility grid. Current technologies include reciprocating engines, fuel cells, photovoltaic (solar) systems, wind turbines and microturbines. Among the newest DG technologies, microturbines are compact, lightweight Brayton cycle gas turbines (similar to jet engines) that burn gaseous or liquid fuels to create a high-energy exhaust stream. The exhaust turns a power turbine, which in turn drives an electrical generator.

Microturbines generally have marginally lower electrical efficiencies than similarly sized reciprocating engine generators. However, because of their simplicity, lighter weight, lower vibration, very low emissions and relatively small number of moving parts, microturbines have the potential for, easier siting, higher reliability and lower maintenance requirements. They can operate using a number of different fuels: natural gas, sour gases (high sulfur, low Btu content), landfill gas, digester gas and liquid fuels (gasoline, kerosene, and diesel fuel). They also produce significantly lower pollutant emissions (NO_x and CO) than do reciprocating engines.

	Large Systems		Small Systems			
Technology Type:	Gas Turbine	Gas Engine	Microturbine	Gas Engine	Stirling Engine	PEM Fuel Cell
Electrical Efficiency	Low	High	Low	Medium	Medium	High
O&M Costs	Low	Medium	Low	Medium	Low	High
Installed Cost	Low	Low	Medium	Low	Medium	High
Thermal Output Capacity	High	Medium	High	Medium	Low	Low
Thermal Output Quality	High	Medium	High	Medium	Low	Low
Commercial Maturity	High	High	Medium	High	Low	Low

The table above shows how microturbines stack up against other DG technologies, in general terms.

The Manufacturers

Capstone Turbine Co.

www.capstoneturbine.com

Location: 21211 Nordhoff Street
Chatsworth, CA 91311

Source: Field & Lab Test, Factory visit, Presentation, Conferences, Web Site, News, Technical specs.

Ingersoll-Rand

www.ingersollrand.com

Location: 800-A Beaty Street,
Davidson, North Carolina 28036

Source: Field & Lab test, Web Site, Presentation, Technical specs.

Elliott Energy Systems

www.tapower.com

Location: 2901 SE Monroe Street
Stuart, FL 34952

Source: Conferences, Technical specs.

Turbec S.p.A.

www.turbec.com

Location: Via Statale, 20/A
440 40 Corporeno (FE) Italy

Source: Field & Lab Test, Presentation, Web Site, Conferences, Technical specs.

Bowman/Kohler Power System

www.kohlerpowersystems.com

Location: Bowman Power Systems
Ocean Quay, Belvidere Road,
Southampton, SO14 5QY England

Kohler Power Systems
Kohler, Wisconsin 53044

Source: Conferences, Web site, Field & Lab Test, Technical specs