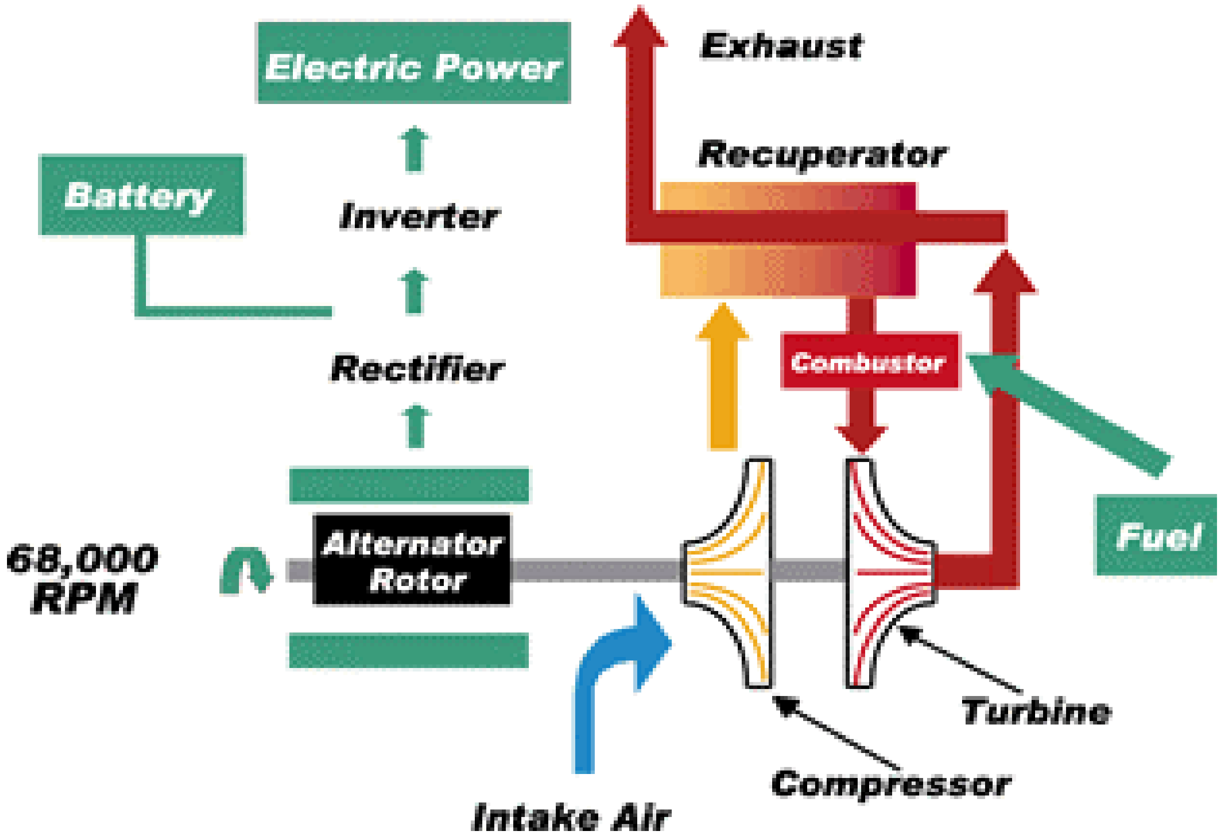
MICROTURBINES for Power Generation -Technology Scan

1.0 INTRODUCTION

Microturbines are small, high speed (30000 to 80000 rpm) gas turbines in the capacity range of 25-300 kW fueled by natural gas, propane, diesel, kerosene or methane from landfills etc. The hot exhaust gas (at 700^{o}F) of the microturbine which is a by-product can be then used to provide heat or cooling (the latter if a chiller is attached). If used only for electricity generation, the efficiency of the system is 25-30%, but if it is used as with heat recuperation such as a Combined Heat & Power (CHP) plant, then the efficiency can be increased upto >80%. Air pollution emissions of microturbines are much lower than any reciprocating diesel generator because the continuous combustion inside a turbine permits complete combustion of fuel. NO_X emissions are less than 9 ppm and carbon monoxide (CO) emissions are nearly zero.

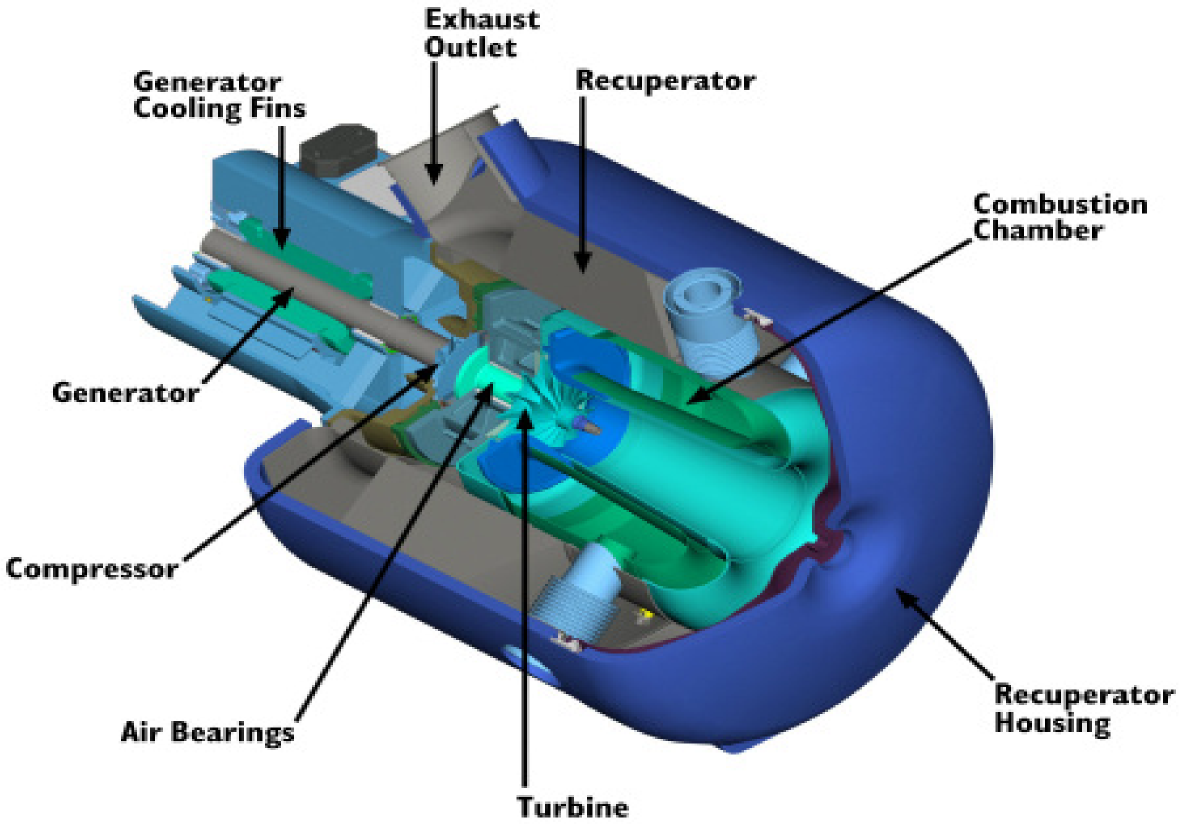


BLOCK DIAGRAM OF A MICROTURBINE UNIT

2.0 TECHNOLOGY

The basic technology used in microturbines is derived from aircraft auxiliary power systems, diesel engine turbochargers, and automotive designs. A number of companies are currently field-testing demonstration units, and several commercial units are available for purchase.

Microturbines consist of a compressor, combustor, turbine, and generator. The compressors and turbines are typically radial-flow designs, and resemble automotive engine turbochargers. Most designs are single-shaft and use a high-speed permanent magnet generator producing variable voltage, variable frequency alternating current (AC) power. Most microturbine units are designed for continuous-duty operation and are recuperated to obtain higher electric efficiencies.



Microturbines are generally characterized by the following design features:

- Radial flow compressors
- Low pressure ratios defined by single-or possibly two-stage compression
- Minimal use of vane or rotor cooling
- Recuperation of exhaust heat for air preheating
- Use of materials that are amenable to low cost production
- Very high rotational speeds on the primary output shaft (25,000 RPM, or more)

3.0 ADVANTAGES:

- High reliability
  - One moving part, no gearbox, pumps or subsystems.
  - Low pressure and low temperature design.

- Low maintenance (annually)
  - No liquid coolants
  - No liquid lubricants

- Versatility
  - Affordable
  - Multi-fuel
  - Grid parallel or stand alone
  - Indoor or outdoor
  - Low noise and no vibration
  - Compact and light weight

• Clean, dry exhaust
  – Ultra low NOx <9 ppm
  – Heating and cooling opportunity

4.0 APPLICATIONS:

- Peak shaving and load management - Business customers connected to the electric grid can use microturbines to reduce electric costs during periods of peak power usage. Because of the microturbine's compact size, reliability, as well as its low levels of emissions and noise, it can be installed at a number of locations that would be inaccessible to traditional generating applications.

- Cogeneration - Microturbines produce heat that can be reclaimed for secondary uses (e.g., air or water heating or drying applications). Recycling the waste heat for productive uses significantly enhances the cost savings to small and medium-sized businesses.

- Standby or backup power generation - Backup power generation is important to most businesses. Short-term power interruptions can result in lost sales, lower productivity and damage to inventory. The microturbine provides a reliable source of backup power for your business.

- Hybrid-electric busses, which are now operating with Capstone microturbines in Chattanooga, Tampa, Los Angeles, and New Zealand (Tempe, Arizona has ordered 31 MicroTurbine-powered buses with options for another 169). Capstones are also going into U.S. Department of Transportation- funded projects for parcel vans, class 8 (16-wheel) vehicles, garbage trucks, and light rail applications.

5.0 TECHNOLOGY STATUS:

Microturbines are a very recent development, with the first microturbine introduced in the market in December 1998. There are currently very few manufacturers of microturbines in the world. Most of the research & development is funded jointly with government agencies and the technology is still being demonstrated on commercial scale. Capstone had installed more than 2500 microturbines (Prior to introducing the product commercially in 1998, the company installed about 130 prototype units worldwide for testing.) Elliott Energy System Inc (EESI) has been designing and developing microturbines since 1995. EESI is in the final stages of commercializing an 80kW natural gas powered microturbine generator set. Honeywell's Power Systems has successfully demonstrated its Parallon 75 microturbine parallel to the Eskom utility grid during a demonstration in Johannesburg, South Africa. Honeywell's had a short-lived microturbine business shipping some 326 microturbine units in 2000 and another 160 in 2001 before the company closed down its microturbine business. Other companies are still field testing their models.

<u>LIST OF MANUFACTURERS OF MICROTURBINES</u>

S. No	Manufacturer	Models	Remarks
1.	Capstone Turbine Corporation, USA	M330 (30kW) / 60kW	First model introduced in December, 1998; 2500 microturbines already installed; Estimated capital cost < $1000/kW; COG 9 cents/kWh; 90% market share.

2.	Elliott Energy Systems, USA	TA-80 (80kW)	Under commercialisation; Subsidiary company of Ebara Corporation, Japan;
3.	Honeywell Power Systems, Inc. USA	Parallon 75kW	Under demonstration; Installed units COG: 7.6 cents/kWh; Shutdown business after supplying 486 units during 2000-2001.
4.	Ingersoll-Rand Energy Systems, USA	PowerWorks 70kW	NOx emissions less than 9 ppm. Overall efficiency with cogeneration systems can reach 70%. designed specifically for stationary industrial and commercial applications.
5.	Bowman Power Systems Limited, England	TG80 (80 kW)	Natural gas, propane and kerosene systems are currently available and a biogas version is due for release in the near future. 70 microturbine systems installed in Europe, the USA and Japan.
6.	Turbec AB, Sweden	T100 (100 kW)	ABB-Volvo joint venture; 82 units commissioned as of October, 2002; COG~8.5 euro cents/kWh
7.	DTE Energy Technologies, Inc.	400 kW ENT400	Mini-turbine; Under testing.
8.	ABB	MT 100 (100kW)	Under demonstration; Estimated COG: 8 to 9 cents/kWh.
9.	ALM Turbine, USA	300 kW	Production expected in 2004-2005

6.0 COSTS

Microturbines are already available commercially, and their current capital cost is around US$ 1000/kW. Here it faces competition with the diesel generator which is available at US$ 250-500 per kW. The industry aim is to bring the capital cost down to US$ 500 per kW, which can be achieved at annual industry volumes of 100,000 units, at which price the diesel generator will be seriously threatened. Electricity generating costs are comparable to grid prices at US$ 0.07 kWh but maintenance costs are very low at US$ 0.0135/kWh compared to the diesel generator cost of US$ 0.0225/kWh. Further, life-cycle costs are much lower, requiring only 3-5 hours of annual maintenance and a major overhaul every 30,000 hours.

California Power Authority, USA in December, 2001 issued Request for Bids (RFB) for Combined Heat and Power Systems (CHP) for distributed generation applications. The economics of various technology options based on the bids submitted by 22 bidders are summarised below:

Type of System	**Size kW**	**Effective Price per kWh 2002/03 (90% availability)**	**Effective Price per kWh 2002/03 (60% availability)**
CHP Internal Combustion Engine	750	4 cents	7 cents
Non-CHP Internal Combustion Engine	750	8 cents	13 cents
CHP Microturbine	60	7 cents	11 cents
Non-CHP Microturbine	30	8 cents	13 cents

Assumptions:

(i) Energy Output - assumed to remain at 100% of rated capacity for entire life (20 years).

(ii) Gas price remains constant at $.50/therm.

(iii) Turnkey pricing based on generic site specifications included:

- Production capacity and installation commitments.
- Prices for all components of the system inclusive of design, engineering, permitting, skid-mounted equipment assembled and delivered, construction, installation, electrical interconnection, at least a 5 year comprehensive warranty, and
- Annual service and maintenance agreements following the warranty period guaranteeing 95% availability (on an average annual basis).

Source: http:// www.capowerauthority.ca.gov

COMPARISON OF DG SETS WITH MICROTURBINES:

	Conventional DG Set	**Capstone Microturbine**
Life Resource	10, 000 to 15,000 hrs	40,000 hrs
Oil Change	Yes	No
Water Cooling	Yes	No
Ultra Low Emissions	No	Yes
Heat Recovery Capability	Limited	Yes
Maintenance Frequency	Monthly	Annually
Grid-Quality Power	No	Yes
Noise Level	Loud	As low as 55dBA*
Vibration	Present	None
Capital Cost	US $ 500/kW	US $ 1000/kW
Technology	Well established & proven	Under demonstration

** With optional silencer kit*

7.0 FUTURE PROSPECTS IN INDIA

Interactions with the leading manufacturers of microturbines have revealed that they do not have immediate plans to market their products in Asian countries. There are three key barriers to market penetration for both microturbines and fuel cells in India: capital costs, regulation, and availability of natural gas. In India, the initial markets (the innovative customers) for microturbines and fuel cells are likely to be for cogeneration and for premium power (UPS systems). When these technologies mature and their economics make them strong competitors to the diesel genset, they will penetrate the mass market for back-up power for small industries, commercial establishments, office buildings, housing communities, and individual homes. In conclusion, the time frame for this focused market segment penetration is likely to be within 2-3 years as the technology matures, as the capital costs come down to US$ 500/kW, and as there is widespread availability of natural gas in India.

DETAILS OF MICROTURBINE MANUFACTURERS:

(a) CAPSTONE:

The first commercial product--Capstone's model 330 was introduced in the market in December 1998. Microturbines use the same basic technology as jet engines, only instead of producing thrust, the combustion-air stream generates torque. As with other gas turbines, fuel is injected into a combustion chamber along with air. The fuel-air mixture is ignited, generating gas pressure that spins a turbine extremely fast (96,000 rpm in the Capstone products). The basic design involves a turbine wheel, a compressor wheel, and a permanent-magnet generator, all connected to, or part of, a central shaft. While the Capstone MicroTurbine involves over 30 patents, one of its most unique features is the complete lack of any liquid lubrication or coolants--the entire system is air-cooled, and the shaft (the only moving part) is supported by *air bearings*. This means that, despite the extremely rapid spinning, there is very little required maintenance (just periodic air and fuel filters, igniter, and temperature sensor replacement) and no disposal problems or potential leakage of lubricants and other fluids. Microturbine efficiency is typically in the 25-30% range, with most Capstone products rated at 27%.

Air pollution emissions of gas turbines are much lower than any reciprocating engine because the continuous combustion of a turbine permits more complete combustion; according to Cambridge Energy Associates (quoted by Capstone), a 4.5 MW conventional gas turbine generator typically has nitrous oxide (NO_X) emissions of 25 ppm; a 500 MW coal-fired steam power plant has NO_X emissions of 200 ppm; and a 500 kW reciprocating gas engine has NO_X emissions of 2,100 ppm. The Capstone MicroTurbine has particularly low emissions--using propane or natural gas, NO_X emissions are less than 9 ppm and carbon monoxide (CO) emissions are nearly zero. These levels are achieved because of patented processes that control combustion temperatures and fuel-air mixtures.

By the end of 1999, Capstone had shipped more than 200 microturbine systems. Another 338 were shipped as of June this year, according to Keith Field, communications director of the company. (Prior to introducing the product commercially in 1998, the company installed about 130 prototype units worldwide for testing.)

Installed cost of the Capstone 330 today is typically less than $1,000 per kW of capacity. adding cogeneration to a microturbine reduces the payback from 5 years to 2.4 years with an electricity cost of 9¢/kWh and natural gas cost of 44¢/therm ($15/MWh). When used in off-grid applications or for peak shaving, the payback can be much more rapid because the value of the electricity saved is higher.

(b) Elliott Energy Systems Inc (EESI)

EESI is a fully owned subsidiary company of Ebara Corporation of Tokyo, Japan. Formerly known as Universal Turbine Energy Systems, the company was founded in 1993 to develop and manufacture 35kW microturbine generators. Product lines have now been extended to 35kW, 60kW and 80kW units. EESI has been designing and developing microturbines since 1995. The EESI microturbine was developed in Stuart, Florida, an area with a large concentration of aerospace industry professionals and highly skilled metal workers. Home to many well-known international aerospace organizations including NASA, Florida has been the center for the aerospace industry since the late 1950’s. This is the reason EESI located in Florida, and is why the company has been able to build the highly skilled team that is one of the true assets in this growing company. EESI continues to develop new technologies with a vision to become a leader in an evolving market for micro power generation. To market its microturbines, Elliot has teamed up with GE Power Systems, a unit of the General Electric Company.

EESI is in the final stages of commercializing an 80kW natural gas powered microturbine generator set. It produces 80kW of high-quality electrical power and significant thermal energy that can be used for cogeneration; (e.g hot water packages, absorption chillers and drying systems.) It is a viable alternative both functionally and economically to traditional reciprocating equipment and as a supplement to the utility grid.

TA-80 Microturbine has the following features:

80 kW of Electrical Power at ISO conditions (15°C day, Sea Level).

- 28% Efficiency, Heat Rate = 11,350 BTU/ kWhr
- Low Emissions
- Low Noise - less than 65 dBA at 10 m
- Weight - 1,000 kg
- A single piece rotor provides high reliability
- One moving part provides lower maintenance costs
- An oil-cooled alternator provides higher efficiency
- Ceramic ball bearing forward & hydrodynamic sleeve bearing aft.
- Advanced inverter technology to supply reliable power with low electrical noise

The TA-80 starts with two 12-volt batteries (in series) that provide the 24 volts used by the system. A 24 volt DC signal is supplied to a rectifier circuit which converts the voltage to AC ~ 500 volts. The AC signal is used to excite the stator and cause the permanent magnet alternator, located inside the stator, to rotate. The alternator rotor is mounted on a common engine rotor shaft therefore, when the alternator rotates so does the engine rotor. The engine rotor increases in speed up to 20,000 RPM (electrical acceleration). The gas turbine draws air into the, single stage compressor section. The air is compressed and directed through a diffuser into the combustion section where fuel is added and ignited. The exhaust is directed through a nozzle and directed to the turbine. As more fuel is added the turbine rotor spins faster (mechanical acceleration). The fuel flow is stabilized when the engine reaches operating speed. The alternator rotor spins inside the stator. The stator generates an AC output signal. The signal is ~600 volts with a frequency of 2267 Hz. The signal is converted from AC to DC then back to AC, 480 volts 60 Hz. As electrical load is applied more fuel is added to the combustor to maintain a constant speed.

(c) Honeywell Power Systems (Formerly AlliedSignal Power Systems Inc.)

AlliedSignal Power Systems gave Honeywell exclusive rights to install and maintain its "Parallon 75" microturbine. AlliedSignal hopes to begin commercial production of its 75-kW Parallon 75 at their Albuquerque, New Mexico facility in the fourth quarter of 1999.

Honeywell's Power Systems has successfully demonstrated its Parallon 75 microturbine parallel to the Eskom utility grid during a demonstration in Johannesburg, South Africa making it the first microturbine to connect to the grid in South Africa. The Parallon 75, remotely operated from a distance of 50 kilometers, was installed and successfully connected to the grid within three hours of its delivery to the site demonstrating the "plug and play" design philosophy.

University of Maryland, College Park has installed a Honeywell Parallon 75 microturbine and a 25 ton Lithium Bromide/Water absorption chiller for electric power and cooling requirements. The Parallon 75 will produce electricity; recoverable heat from the unit will run the absorption chiller, avoiding the need for grid-connected electricity. The combination will be self sufficient, running on natural gas. Annual savings for the system are forecasted to be $25,000 with a 40% reduction in CO_2.

(d) ABB MT 100

The MT100 microturbine is a small yet highly efficient turbine that runs on gas or liquid fuels – usually natural gas, but also waste gas, ethanol, methanol or even diesel. In an integrated, combined heat and power, process, the MT100 is capable of producing all the heat and electricity needed for an apartment building or small hospital.

ABB's Model MT100 microturbine, developed in 1998 with Volvo Aero Corp., is a single-shaft unit that generates 100 kW of electricity and 167 kW of thermal energy. According to ABB, it is designed for remote-controlled, unsupervised operation. Emissions of unburned hydro-carbons are less than 10 parts per million; NOx and CO are less than 15 ppm. The cost of the energy it generates is between 6 and 8 cents per kilowatt-hour.

(e) Ingersoll-Rand Power Systems

Ingersoll-Rand Power Systems (formerly Northern Research Engineering Company) of Woburn, Massachusetts: An advanced technology product design and development company, NREC's manufacturers its PowerWorks™ line of turbines-which in contrast to other firms' offerings feature two shafts-in sizes from 30 to 250 kW.

(f) DTE Energy Technologies

The ENT 400 is the first natural gas mini-turbine available for distributed generation products with a unit rating up to 400 kW. This highly efficient, innovative system uses turbine power to deliver high quality, reliable electricity to medium and large commercial and light industrial operations, new residential developments and premium power parks.

The Energy-now mini-turbine systems combines a Turbo Genset high-speed electric generator driven by a specially designed, high-efficiency aero-derivative, gas turbine engine. DTE Energy Technologies has designed the controls that operate the turbine and generator and allow for the integration of the energy-now mini-turbine system into microgrids, and/or interface with utility grids.

The ENT 400 is part of the T Series mini-turbine product family from energy-now - the comprehensive portfolio of best-of-breed distributed generation products and services from DTE Energy Technologies.

- proprietary lean-burn fuel system, axial flux generator and power electronics.
- emissions of less than 10 ppm NOx.
- an output range of 270 kW to 400 kW depending on ambient air temperature with capacity enhancements expected in the near future.
- power quality comparable to a UPS (Uninterrupted Power Supply)
- approximately 32,000 hours of operation between engine overhauls.
- high efficiency
- better motor starting capability.
- capability to handle unbalanced loads of up to 50 percent.
- lower costs for interconnection.