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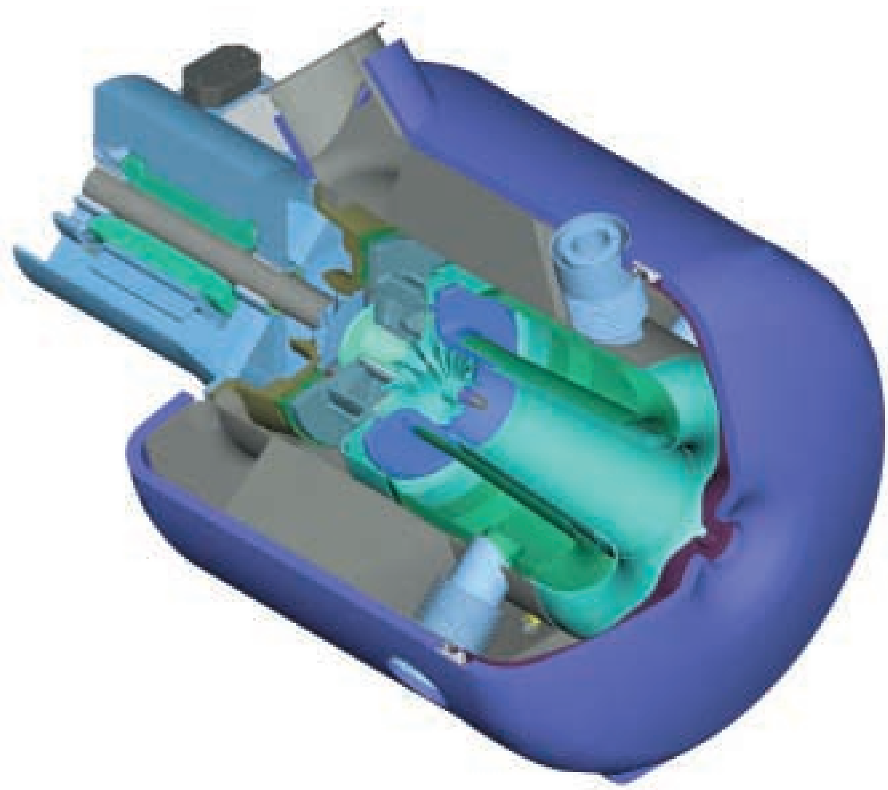
LP Gas Use in Microturbine Applications



WORLD LP GAS ASSOCIATION

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LP Gas Use in Microturbine Applications

Executive Summary

Among the new technologies for generating heat and power, microturbines are at the top of the list. “Microturbine” is the term typically applied to turbines rated at 0.2 mW (megawatts) to 2 mW, and are essentially small jet engines that produce power and heat. Microturbine technology has emerged from four different technologies: small gas turbines, auxiliary power units, automotive gas turbines, and turbochargers. Typically microturbines consist of several subsystems including a compressor, a combustor, a turbine, an alternator, a recuperator and a generator.

Microturbines have the potential to offer advantages over conventional reciprocating engines. These advantages include very low emissions, small number of moving parts, long term reliability, lower vibrations, lower maintenance costs, compactness, light weight and greater energy efficiencies when using waste heat from the exhaust.

Our initial report issued in 2001 described microturbine technology, the advantages and limitations of such, and discussed the state of the rapidly evolving microturbine industry. This Final Report includes that initial discussion along with some actual “case studies” where LP Gas microturbines are in use today. These case studies provide an interesting variety of end uses in three distinct countries.

As with any new technology, reality sometimes differs from “potential”. In the case of microturbines, many of the technical issues have been overcome. One technical challenge remains and is being actively pursued: how to provide ample pressure to the turbine particularly in colder climates. When using a microturbine in the automotive market (hybrid electric vehicle) another challenge has been identified: how to educate those integrating the power unit into a vehicle configuration so as to provide a safe, efficient and reliable source of power. Finally, the euphoria of any new technology must be tempered with marketing reality. Here the challenge is to find those unique applications where the benefits of microturbines match the customer’s needs.

Microturbines are no longer a technological dream that must leap from the laboratory into commercialised reality with an unknown time frame. As shown in the case studies microturbines have made that leap. Yet, reality dictates that a microturbine is not a power unit than can simply be dropped off a truck and “plugged in”. A keen understanding of the technology, integration with the fuel system and matching customer expectations is essential. The LP Gas industry and the customer will be best served if these requirements are well understood and practiced before promises are made.

Acknowledgements

The primary work for this project was performed by the ADEPT Group, Inc. of Los Angeles, California, USA. ADEPT has extensive experience in microturbine applications using LP Gas, and has been instrumental in identifying unique issues, and resolving many of those issues, associated with using LP Gas in microturbines. Their work has been supported in part by the US Propane Education and Research Council (PERC). The contributions of both ADEPT and PERC are greatly appreciated in making this report possible.

I. Introduction and Background

In 2001 WLGA published a “snapshot” of the microturbine industry that provided an overview of the status of the microturbine industry, the opportunities for LP Gas and described some “what is good” and “what is not so good” about microturbines at that stage of their development. The second phase of the project was to provide some case studies, i.e., a brief overview of some actual in-use LP Gas microturbine applications. Those case studies begin on page 14 of this report along with the original “snapshot” so as to provide a single-source microturbine document.

The five case studies are by no means a complete list of current or planned LP Gas microturbine applications. Rather, they are a cross-section of different type uses in three different countries: US, New Zealand and Japan. All of these applications use the Capstone unit since it is the only manufacturer with actual commercialisation to date. However, more manufacturers are either planning to introduce LP Gas versions of their units or have shown interest in doing so. A review of these manufacturers and their plans will be found at the end of this report.

The purpose of this report is to provide WLPGA members

- A primer on just what is a microturbine
- A status report on the fast moving microturbine industry
- A candid assessment of the benefits and barriers of the microturbine industry
- Some examples where microturbine technology is actually delivering benefits to users, and
- A listing of manufacturers and contacts

Generally, we can conclude from this assessment that microturbines have overcome nearly all the technical hurdles common to developing any new product. The one remaining issue seems to relate to delivering adequate fuel vapour pressure to the power unit. Several approaches are discussed and options are being actively pursued.

Microturbines often share the spotlight with fuel cells when discussing new technologies for power generation and heat. Both do essentially the same thing: they produce electricity, and the waste heat from combustion can be used for a variety of heating, cooling and drying needs. Fuel cells are quieter, have extremely low emissions and have the potential for great reliability. Microturbines, on the other hand, are available to the market today, have demonstrated very high efficiency, low NOx, and reliability seems to be meeting customer expectations.

Like fuel cells, capital costs for microturbines are still higher than originally expected and must be brought down if they are to compete with conventional internal combustion engines. Unlike fuel cells, however, lowering the cost of microturbines is mainly a function of production volumes—the more units produced, the lower per unit cost. In the case of fuel cells substantial technical barriers are still to be overcome centred mainly on reducing the costs of the components, not to mention actual production costs.

Both technologies offer substantial benefits to the LP Gas industry as they move from the laboratory to demonstration to commercialisation. WLPGA will keep you advised on their progress through periodic reports posted to our website **www.worldlpgas.com**

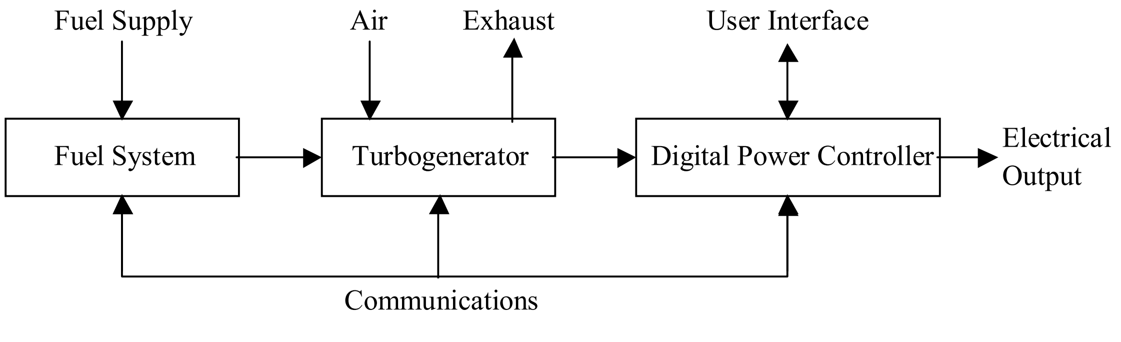
II. What is a Microturbine?

Microturbines are essentially small jet engines that produce electrical power and heat. They can be designed to be more efficient and less polluting than reciprocating engines (diesel, natural gas, LP Gas, or gasoline piston-driven engines). The term "microturbine" is typically applied to turbines rated at 0.2 mW (megawatts) or less, but may be used for units as large as 2 mW. Microturbines that are now sold or that are in advanced prototype stage of development range in size from 30 kW (kilowatts) to 500 kW. Most microturbine manufacturers make or plan to make units that are rated at or below 200 kW.

Microturbine technology has emerged from four different technologies: small gas turbines, auxiliary power units, automotive development gas turbines, and turbochargers. Microturbines typically include several subsystems: compressor, combustor, turbine, alternator, recuperator and generator.

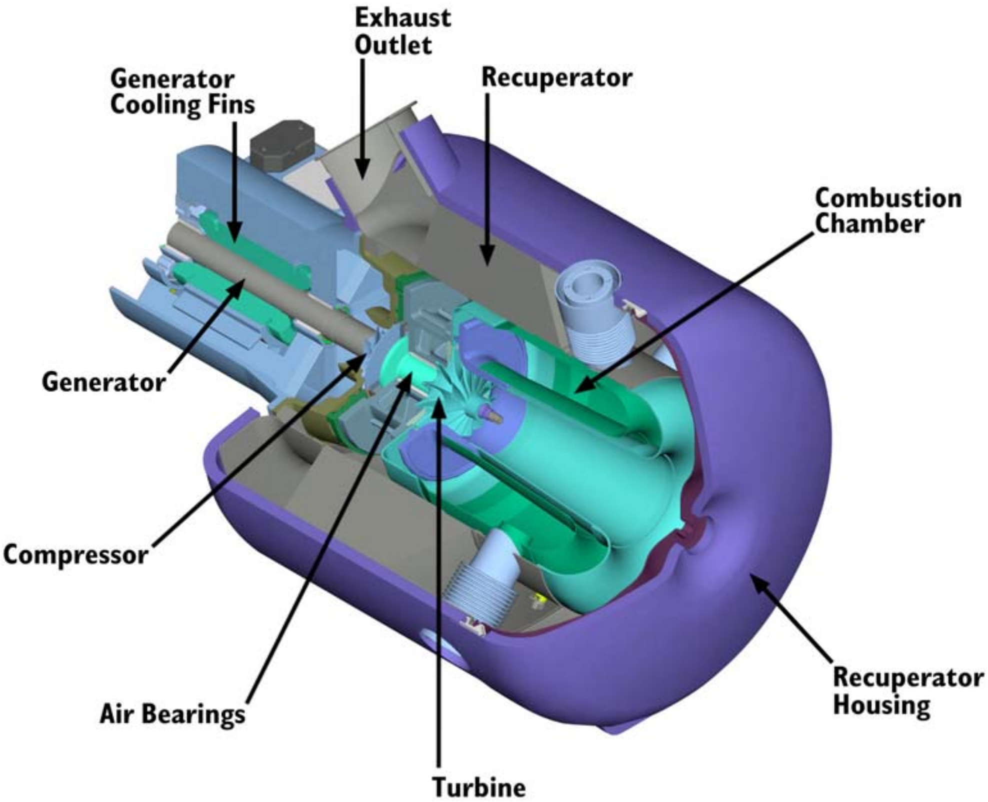
To illustrate one microturbine design approach, and how it operates, below is shown an overall system diagram for the Capstone microturbine as well as a Capstone turbine cutout diagram.

Capstone Microturbine System Diagram



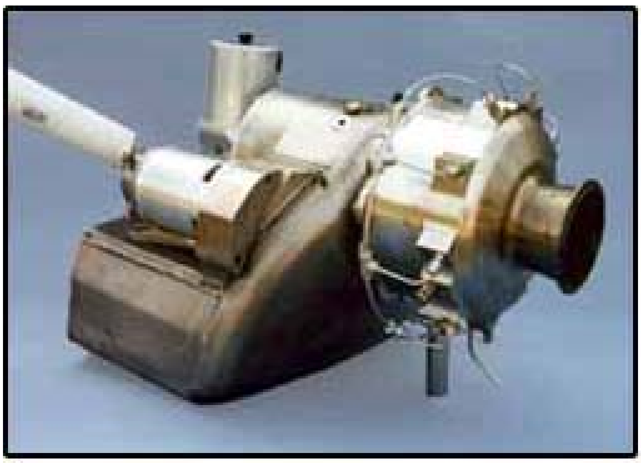
Courtesy of Capstone Turbine Corp.

Capstone Microturbine Cut-out Diagram



Courtesy of Capstone Turbine Corp.

Elliott Microturbine



Courtesy of Elliott Turbomachinery Co., Inc.

Microturbines are well suited to produce power on sites that have space limitations. The typical unit fits well within a 5’ x 5’ x 10’ (~1.52m x 1.52m x 3.05m) box. When waste heat recovery is added to these systems, efficiencies as high as 80% are claimed to be achievable. (See case study IV where greater than 70% efficiency is claimed). An example of a high efficiency waste heat recovery situation is a microturbine installed to meet a good part of the needs of a commercial laundry where the waste heat can be used to preheat water as well as to provide hot air for both the turbine and for drying clothes. Other co-generation applications include partial recovery of waste heat for heating water for swimming pools, restaurants, hospitals and car washes, providing heat for absorption chiller/refrigeration systems, for dehumidification applications, or to provide part of the combustion air for large drying kilns or ovens.

Microturbines offer several advantages versus other small-scale power generation technologies (e.g. reciprocating engines). These advantages include: small number of moving parts, lower vibrations, lower maintenance needs and costs, more compact, light weight, opportunities for greater efficiency, lower possible emissions, lower possible electricity costs, and the use of waste fuels. Microturbines face several hurdles: robustness (long term on-line uninterrupted availability), interconnection with the grid, and costs. In California, due to the electricity capacity crisis, the historical obstacle of interconnection with the grid (used by utilities to discourage competition) has made significant progress toward simplification and standardization, particularly via UL’s (Underwriters Laboratories) 2200 and 1741 standards. A national IEEE (Institute of Electrical and Electronic Engineers) standard is in the works, but with nearly 2,000 electric utilities in the United States, grid interconnection is still a process mired in greater than necessary red tape. However, as shown in the case studies two of the applications are in fact “grid connected” and actually sell surplus power back to the grid. Microturbine technology is still relatively young and efficiency testing is now at a point where precise emissions are beginning to be documented.

Without a heat recovery module, the estimated efficiency of the technology is currently at about 24%. This does not yet compare well with the average efficiency of the nation’s existing fossil fuels “at plant” electrical generation facilities (very large coal or natural gas burning plants), which has levelled at 32% to 33% since the mid 1960’s (even when subtracting for transmission and distribution losses of 1% to 7%).

One way turbines are classified is by the physical arrangements of the component parts: single shaft or two shaft, simple cycle or recuperated, inter-cooled, and reheat. A single shaft is the more common design as it is simpler and less expensive to build. Conversely, the split shaft is necessary for machine drive applications that do not require an inverter to change the frequency of the AC (alternating current) power.

These machines generally rotate over 40,000 rpm (revolutions per minute) and may go as high as 120,000 rpm. That can lead to very high stress areas. The bearing selection, whether the manufacturer uses oil or air, is dependent on usage. Oil bearings are believed by their proponents to last longer and to be less prone to catastrophic failure, especially when the power is frequently ramped up and down. Engineers who favour air bearings believe oil bearings may occasionally present limited emission problems (if oil escapes from the bearings), and may not be able to perform with the rapidity needed for near instantaneous rpm changes at speeds near 100,000 rpm. The same engineers further claim that air bearings require less maintenance (no need for an oil system and pump), but air bearings may require air filters (which must be cleaned and/or replaced).

III. Microturbine Manufacturing, Forces at Play, Trends, and Participants

Commercial microturbines are here to stay. More LP Gas is being sold (and will be) because of this technology. Of all the "new" technologies, microturbines are one of the few that is sure to generate new healthy sales of LP Gas within the next several years. Currently, commercially available microturbines run on natural gas (pipeline and LNG), diesel, kerosene, LP Gas, methanol, ethanol, and jet fuel.

In 1999, there were about 300 microturbines sold worldwide and in 2000 sales ramped up to about 1,200 units. However, that growth curved flattened out dramatically in 2001 when approximately 1,400 units were sold. The reasons are believed to be due to (1) higher natural gas prices making the technology less competitive that grid power, (2) a lessening in the US economy and (3) in some markets a sudden disappearance of the immediate energy crisis.

The bulk of the product development and commercialisation work in this field is taking place in North America and in Europe. Major industrial concerns in North America, Europe and Japan have committed to, and have made major investments in, various firms who are advancing this technology. Converging economic and political forces are encouraging the development of this industry although the pace of expected growth is now uncertain. Among these are: (1) U.S. federal stimuli for power generation and combined heat systems; (2) the growth of e-commerce and associated telecommunication power demand; (3) power crisis similar to that experienced in California; and (4) decades of transmission and distribution system under-investment and deferred maintenance. The general and established trend toward distributed power generation has helped accelerate the microturbine market penetration. It is estimated that within 10 years distributed generation could account for up to 20% of all new installed power capacity if the assumptions used in early 2000 projections are again restored.

In 1999, the average capacity of each unit shipped was 36KW, while in 2000 the per unit sold capacity was 45KW. For 2002, the average capacity of each unit is anticipated to be about 50KW. In 2000, shipment destinations were equally split between US and international markets. About 30% of all the microturbine installations in 2000 were for upstream oil and gas applications, including supplying power to oil and gas fields as well as gas processing. It is estimated that in 1999 about 5% to 6% of the shipments were for LP Gas applications (either fully or partially using LP Gas), whereas for 2001 it is estimated that 3 to 4% are were shipped for LP Gas applications (full and/or partial use).

Microturbines can help the impending capacity impasse that is being felt worldwide. In the US alone, the Department of Energy (DoE) estimates that 13% to 15% of the total power output is consumed by the Internet and telecommunication business, a figure expected to grow to 50% by 2021. While electric utilities may be able to supply this power, generally they cannot provide the required availability and reliability of "nine nines."[1] To supplement the obtainable 99.9% reliability of the grid, e-business consumers are turning to a combination of distributed generation and energy storage. Some energy storage devices that are already in such use are battery banks, flywheels and zinc oxide fuel cells. These electricity storage devices are to maintain seamless power continuity during micro-outages, voltage sags and frequency fluctuations. Electrical power is increasingly not just kiloWatt-hours; it is more and more becoming a matter of reliability and quality.

California has become "ground zero" for microturbine applications made possible by partial deregulation of the energy market. With electricity demand at times nearing full capacity, insurance against outages and disruptions as well as production losses is no small matter. Even a momentary outage can damage sensitive computers, servers, production processes, expensive chemical or pharmaceutical batches, etc., costing companies millions of dollars in lost product and lost productivity. Further, charges for peak demand have more than doubled to most Californian commercial and industrial users. And any new capacity (other than on emergency basis) must be clean emitting and quiet.

The microturbine manufacturers who have a presence or who are likely to soon have a sizeable presence are:

(1) Capstone Turbine Corp.,
(2) Bowman Power Systems
(3) Elliott Turbomachinery Co., Inc.,
(4) Ingersoll - Rand Energy Systems, and
(5) Turbec AB.

Brief descriptions of these firms are included in Appendix A. Other firms for now appear to have peripheral roles. These include: Canadian Microturbine Systems, DTE Energy Technologies, and Solo Energy Corp.

The current drawbacks to microturbines are:

(1) Technology is relatively expensive;
(2) Like all technological advances undergoing commercialisation, the sustained progress of microturbine technology requires the collective and integrated climbing of learning curves by the end-user, installer/integrator, and equipment distributor communities; and
(3) The main thrust of this budding industry is <u>not</u> LP Gas applications. The main thrusts are natural gas and "waste" (landfill, wastewater, livestock/agricultural and upstream oil) gases, diesel and (primarily in Asian markets) kerosene applications.

[1] 99.9999999% of the time

From an LP Gas point of view, Table 1 summarizes what's good and what's not so good about microturbines.

Table 1

What's Good About Microturbines	*What's Not So Good About Microturbines*
• Low to extremely low air pollution (provide power in areas where air pollution is a highly sensitive issue). • Improved efficiency possible with recuperation of exhaust heat (to preheat the intake air); very high efficiency using copious exhaust volume for heating, chilling, drying applications. • Constitute an excellent back-up system; enable extensive peak shaving since there may be no runtime limitations. • Provide electricity and heat in places where such energy commodities are already at a premium (e.g. remote areas or islands). • Low maintenance requirements. • Small "footprint." • Relatively quiet. • High quality electrical output. • Allows for protracted client retention in those areas/sites where LP Gas is already a dominant fuel commodity. • More forgiving of LP Gas fuel quality (once introduced as vapour in the combustion chamber) than reciprocating engines. • Lifetime own-and-operate costs lower than traditional generator sets. • Easy multi-unit arraying with no need for switchgear or other hardware.	• Higher initial cost than conventional generator sets. • Low efficiency on simple cycle (simple-cycle systems are used only at sites where "waste" gases are to be disposed of [e.g. landfill gas]). • Distribution networks for parts and service are not yet mature. • Fuel pressure booster is required in colder climates. • In the event of a supply shortage emergency, the end user may be at the mercy of a fuel company that may have its resources stretched for refuelling. • Currently, when burning LP Gas, the microturbine is designed for gaseous LP Gas only. It does not like liquid droplets in the engine intake (LP Gas must be fully vaporized). • LP Gas vaporizer is required. • Fuel quality and/or fuel quality control may be issues.

A potentially great advantage for LP Gas burning microturbines is that once the fuel enters the combustion chamber, the typical fuel quality considerations (i.e. maximum propane content, maximum butane content, methanol content, etc.) may not matter as much. But getting the fuel through the injector into the combustion chamber may still be an issue since there appears in several applications to be some deposits on the injectors. Thus, the composition of refinery produced LP Gas may be lesser of an issue as long as the “heavies” are controlled to some degree and a good vaporiser system is appropriately placed in line after an appropriately sized regulator. In the course of this study, several LP Gas microturbine installations were found where the overall system has failed, or was in the process of failing, because of the absence of vaporizers or improperly sized regulators. As mentioned earlier, adequate pressure is still a problem particularly in colder climates.

Given the state of advancement of the subject technology, LP Gas microturbines can make sense in the situations listed below:

- Power reliability installation (where disruption of grid generated electrical power or pipeline gas supply is not an option).
- Where electrical line losses are high.
- In hot climates, at remote locations.
- Where LP Gas is already the common and dominant energy/fuel source.
- For back-up systems at health care facilities in air quality sensitive areas (in urban areas for stand-by power).
- Where LP Gas is a low-cost and/or an ample supply.
- Peaking power plants in air pollution sensitive regions (to replace diesel power generators). Microturbines typically have no air quality runtime restrictions (most air quality sensitive areas limit conventional generator set operation to 2%-5% of the hours in a year).
- For small auxiliary power generation at LP Gas dealership locations in air quality sensitive areas where there are high electricity peak charges and/or in areas susceptible to blackouts.
- Where LP Gas can be used as a fuel quality booster for low cost, low quality, low volume combustion gases (i.e. landfill gas, digester gas, coaled methane well development).

IV. Economic Considerations

On initial cost-based economics alone, microturbines will not replace reciprocating piston technology. On an initial “installed” cost-basis, LP Gas dedicated reciprocating piston technology is at about $105/kW (~$500/kW when grid connected) whereas LP Gas dedicated microturbines are at about $1,050/kW (grid connected). Over the next few years, increased production and competitive forces will lower the cost to buy and install microturbines. By 2005, the goals for microturbines are: 40% electrical efficiency, single digit emissions, and system costs below $500/kW. Whereas for power generation $500/kW is quite competitive, in the automotive industry a passenger car engine operating on traditional fuels must be below $50/kW to be competitive. Some microturbine engineers predict that when annual production exceeds 100,000 units, microturbines will cost the same or less than reciprocating engines. Without those volumes of sales, manufacturers may lose interest in the market, or be financially unable to participate.

Using industry preliminary figures, it is estimated that for each delivered kW microturbines consume between 0.14 and 0.18 gallons (0.62 and 0.80 litres) of LP Gas (at 84,000 Btu/gallon lower heating value). With estimated microturbine efficiency at 24% to 27%

(without heat recovery), peak electricity prices at \$0.24/kW hour, the cost of LP Gas per gallon to the dealer/distributor of \$0.75 or less, and the LP Gas retailer's electrical load estimated to be at least 5W, it could in some cases, make good economic sense to set up a microturbine in the vicinity of the bulk tank farm and run it during peak demand periods.

In the short term, the LP Gas industry can best benefit from the imminent growth of this technology by cooperating as much as possible with the microturbine designers and integrators/installers to insure the highest possible success rate of LP Gas powered "pioneer" applications. Well-trained and capable integrators are crucial to the development of microturbine applications on LP Gas. Like in most fast growth industries, manufacturers are primarily focused on seizing market share and increasing production and sales. Often, in such conditions, product support is relegated to lower priority consideration, and more so when relatively small niche applications are concerned. From early experience integrators/installers are frequently not familiar with LP Gas, installation procedures or applicable codes and standards. Since they are a crucial component in the entire equation of successful performance, close cooperation with LP Gas industry technical support is essential.

Elliott Microturbine-Driven Mobile Generator

Courtesy of Elliott Turbomachinery Co., Inc.

V. Industry Associations

Several related industries associations exist whose objectives appear to be aligned with the promotion of microturbine technologies. These associations include: the American Gas Association (AGA), Gas Technology Institute (GTI), Electric Power Research Institute (EPRI), International Combined Heat and Power (CHP) Association, U.S. Combined Heat and Power Association (USCHPA), the International Cogeneration Alliance, Distributed Power Coalition of America (DPCA), Electric Vehicle Association of the Americas (EVAA), and the International District Energy Association. There are also public entities (at federal, state, and local levels) whose mission is aligned with distributed power and/or efficient energy production. (i.e. Natural Resources Canada, US DoE Energy Efficiency and Renewable Energy Division, Environmental Protection Agency, California Energy Commission, California Air Resources Board, etc.).

Five Diverse Case Studies of Operating LP Gas Fuelled Microturbines

The following five (5) case studies represent diverse applications of microturbines operating on LP Gas. Capstone and Bowman are the only microturbine manufacturers with installations currently utilizing LP Gas. Other manufacturers have experimented with LP Gas and have expressed interest in the LP Gas market. The case studies below all use Capstone microturbines. Information on other microturbine manufacturers can be found at the end of this report.

I. Interstate Detroit Diesel (IDD), Gillette, Wyoming, USA

Primary Contact: Mr. Kevin Schram, IDD (307) 682-8596

IDD rents and sells Capstone microturbines for powering pumps to lift water from coal methane beds. Water is removed to expose buried natural gas (NG) resources. The mining locations are often remote sites not served by power lines. At such remote sites, microturbines on LP Gas are an attractive power source.

The microturbines are fuelled with LP Gas stored in 1,000-gallon on-site storage tanks. The initial dewatering process can take from a few weeks to a few months. Once the NG reserves can be extracted and utilized, the microturbines' fuel system is switched to NG directly supplied by the well.

Natural Gas Wellhead – tall enclosure houses microturbine

IDD put its first microturbine in service in December 1999. On average, there are about 20 units operating in the field. IDD has had up to 85 units operating at one time. All units are rated at 30 kW. Some sites have multiple microturbines operating in parallel. Currently, all the microturbines on LP Gas are operating on a rental basis. The three main propane suppliers to the wellhead locations are: Blakeman Propane, Big Horn Propane, and the local farmers' cooperative.

IDD personnel report that the LP Gas powered microturbines run exceptionally well as long as the system receives the required amount of gaseous LP Gas.

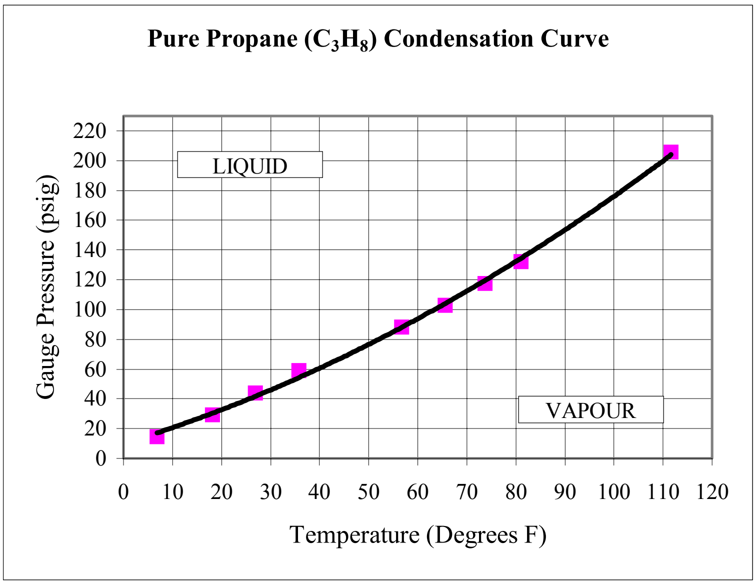
Photos courtesy of IDD

Microturbine installation at IDD site

Capstone user connection bay for electrical and communications connections

Problems encountered to date:

The microturbines require 52 psig (pounds per square inch-gauge) of gas at the inlet of the fuel system. In cold weather conditions, it is difficult to meet this pressure requirement without supplemented heat[2].



[2] Pure propane's vapour pressure at approximately 33º F is 52 psig. At temperatures less than 33º F, pure propane requires pretreatment to reach Capstone's required inlet pressure.

The following solutions were utilized to increase inlet pressure to the microturbine:

(A) Capstone-developed rotary flow compressor.

The compressor increased flow to the Capstone system inlet but could not be used on a production basis due to the short life of critical bearings. Capstone now offers a compressor model with air bearings. The new model is designed for NG and cannot be used in its current configuration for LP Gas due to LP Gas's higher energy density.

(B) Superior Gas Plants gas-fired vaporiser.

This system is a water-glycol vaporiser utilizing a 24-volt liquid fuel pump. The vaporiser does not require additional electrical power and has very low pump power requirements (85 watts). The vaporiser works well to increase the LP Gas flow to the microturbine. The vaporiser cost of $5,000+ is prohibitive to some end users. However, it is the only known solution to reliably increase LP Gas pressure on a production basis in cold weather.

NG wellhead pressure is only 1-2 psig, far below the Capstone requirement of 52 psig. This requires the use of a NG compressor prior to the Capstone system. For most of the year the LP Gas delivered to the turbine injectors does not require a boost in pressure. Such boost is needed only in the coldest months.

Whenever the fuel source of the microturbine is changed from LP Gas to NG (or vice versa) a hardware change is required. This hardware change requires physically removing the Capstone Smart Proportioning Valve and installing the NG compressor. This fuel system modification is reported to be relatively complex and takes approximately three hours. The switch from LP Gas to NG is even more difficult in cold weather because the vaporiser must also be removed before installing the compressor.

II. Brownway Residence, Nursing Home, Vermont, USA

Primary Contacts: Mr. Dennis Moraski, Superior Gas Plants (425) 603-1075 and Mr. John Pifer, Capstone (802) 879-7724

One 30 kW Capstone microturbine has been installed in a large nursing home for combined heat and power generation. The microturbine supplies some of the power for the facility and the hot exhaust heats water for domestic uses and building heating. Boilers provide supplemental heat when needed. This site was commissioned in November 2001. The microturbine replaced an older Mohawk system powered by a General Motors engine (also operating on LP Gas).

LP Gas is supplied by Ultramar and stored in three (3) 1,000-gallon underground tanks. The microturbine operates well when there is sufficient gas pressure at the Capstone fuel system inlet (52 psig).

Problems encountered to date:

In very cold weather the site experienced LP Gas pressures as low as 40 psig. The microturbine fails under such conditions.

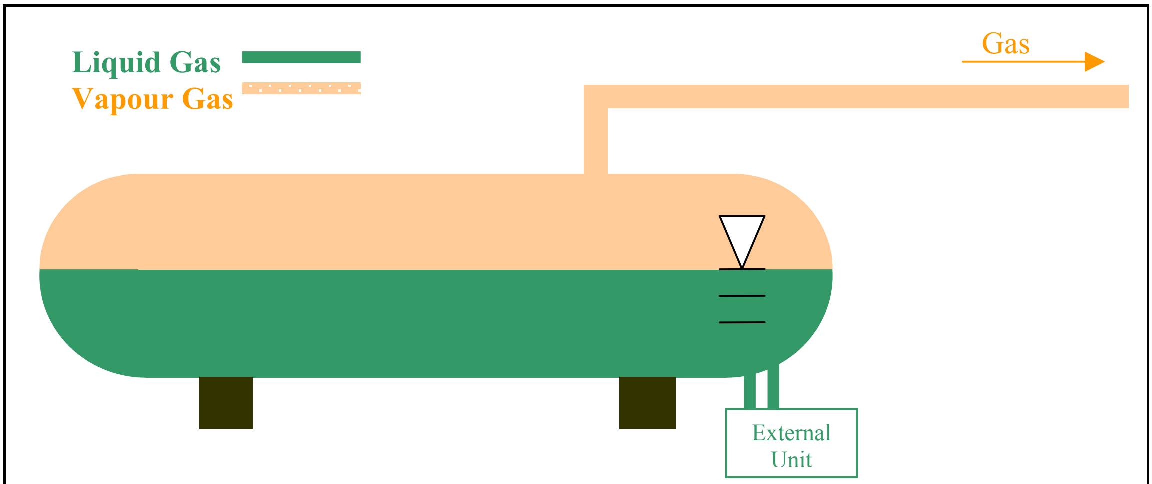
Capstone and Superior Gas Plants engineers are investigating various methods to raise gas pressure. An effective heating system must be installed by winter 2002 or the site is in jeopardy. Traditional vaporiser/pump systems are not possible because the gas tanks are underground. Most liquid pumps require positive head above the liquid inlet[3]. Thus, there would be no easy way to pump liquid LP Gas from the tank to an above ground vaporiser. To remedy the situation, Capstone has proposed the Flow Stabilizer system manufactured by Exclusive Thermodynamic Applications Ltd. (ExTA).[4] This system is designed to raise the liquid fuel temperature a few degrees to provide enough gas pressure to properly operate the microturbine. There are several such installations in Israel and Turkey. If and when the unit is installed at the Brownway Residence, it will be the first installation in the United States and the first installation for a microturbine application.

[3] Water pressure above the pump inlet that pushes down.
[4] In the United States, the Flow Stabilizer system is distributed by Superior Gas Plants. The Flow Stabilizer was developed in Israel.

Internal Unit

ExTA's Flow Stabilizer system includes an indoor unit containing a pump and the controller (internal unit). Hot water from the building is pumped through plastic pipes to an outdoor unit mounted near the LP Gas tank (external unit). The hot water turns an impeller in this unit, which draws liquid LP Gas in for heating. The LP Gas passes through a heat exchanger and circulates back to the storage tank. The smallest Flow Stabilizer unit provides 25 gal/hr of available vapour, far above the microturbine's requirements of 4.2 gal/hr. The unit will be operated at the 25 gal/hr capacity. The site plans to install Flow Stabilizer units on two of the LP Gas storage tanks. The cost of one 25 gal/hr ExTA unit is approximately $3,800. With installation, the total cost is around $5,000.

External Unit



Schematic of gas tank with ExTA External Unit

Photos & schematic courtesy of Superior Gas Plants and ExTA

III. Christchurch Shuttle, Christchurch, New Zealand

Primary Contact: Mr. Mike Parker, Designline (643) 3084811

Four 34-foot hybrid electric vehicle (HEV) buses are operating on one 30 kW Capstone microturbine each. Three HEVs have been in service in Christchurch, NZ since March 2000. A fourth bus was added in April 2001. These HEVs operate on LP Gas supplied by Rock Gas LTD (reportedly ~90% propane and ~10% butane). These buses follow a scenic route around downtown Christchurch. They were assembled by Designline (a New Zealand based bus manufacturer). They are operated by Redbus. The passengers travel free of charge, complements of the Christchurch City Council.

All four buses are achieving an average availability of ~95%. This is superior to Designline's average diesel bus availability of ~90%.

Problems encountered to date:

Initial problems were due to low gas pressure delivery to the Capstone fuel system inlet. Vaporisers were investigated, but were found to be inadequate. Designline has since developed a proprietary system to control the temperature of the tank[5]. This system has been shown to work in temperatures as low as 0˚C.

The site also experienced problems due to butane enrichment, also known as "weathering." This was caused by drawing fuel from the gas phase at low temperatures allowing a disproportionate accumulation of butanes in the liquid phase. Although fuel is still drawn from the vapour phase, the tank temperature is now controlled so that weathering of the fuel is not a concern.

The site has not experienced any other fuel quality related problems.

Photo courtesy of Capstone Turbine Corporation

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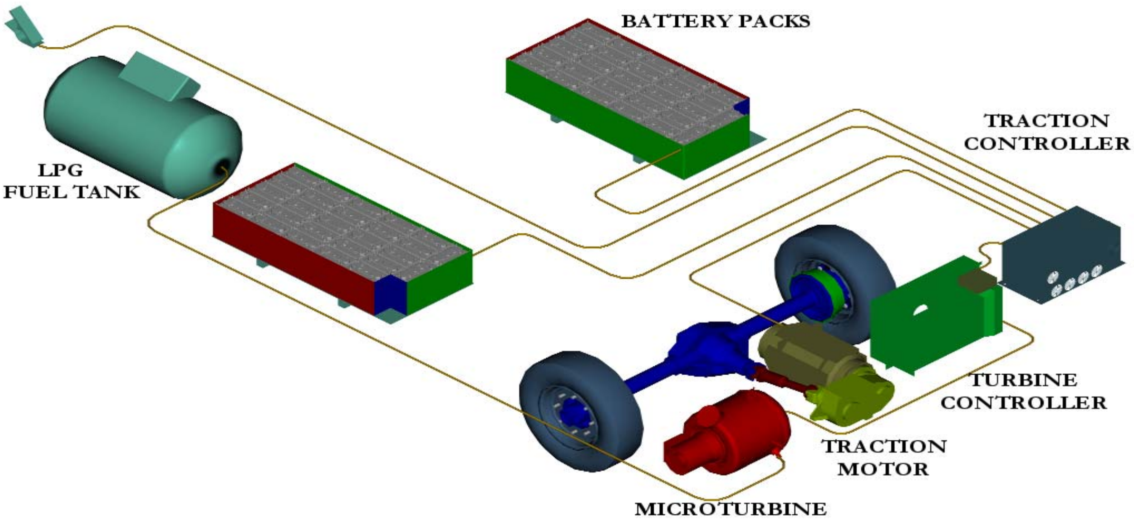
[5] In the United States, current NFPA regulations specify a maximum working pressure for on-board tanks. Mobile applications will need to monitor the tank temperature to ensure that this maximum pressure is not exceeded.

Example of Microturbine Configuration in a Hybrid Shuttle



Courtesy of Ebus, Inc.

The use of microturbines for powering buses is one of the more innovative applications of this HEV technology. In addition to the Christchurch fleet described, several transit operations in the US are also putting HEVs into revenue service. In an HEV the microturbine supplies electricity to the battery pack that in turn powers the vehicle. This results in very low noise, increased fuel economy and very low emissions. Expectations are that vehicle maintenance will be reduced since there is no engine cooling system and no engine oil sump.

IV. Sinanen Taxi Maintenance Shop, Tokyo, Japan

Primary Contact: Mr. Jason Karpf, Capstone (818) 734-5495

A Capstone microturbine is installed for combined heat and power in a taxi maintenance shop. This shop operates 24 hours a day, seven days a week. Sinanen sells CNG, LP Gas, kerosene, and butane. They also provide maintenance services and car washes. In a 24-hour period, Sinanen fills the tanks of ~1,000 taxi cabs. Each night, between midnight and 8 am, the Simanen car wash cleans between 70 and 100 taxis.

This site uses an LP Gas powered TCP-30 system known as a "MicroCHP" (microturbine derived combined heat and power) generator. The TCP-30 is produced by Takuma, a Japanese distributor and integrator of power systems and equipment. The TCP-30 combines Capstone's 30 kW microturbine, fuel system and digital power controller with a Vacotin boiler to produce both heat and power. According to Capstone, the total fuel efficiency of the TCP-30 system exceeds 70 percent.

The LP Gas storage tank is housed in a shed adjacent to the building. Water is heated to 80° C by the microturbine exhaust and is moved to a 5 m^3 (1,300 gal) reserve tank. From there, the water is divided between the car wash and the fuel storage shed. The water keeps the temperature of fuel storage to above 35° C, thus allowing adequate and constant LP Gas vapour pressure for the microturbine. Hot water is thermostatically blended with city water to maintain a 60° C temperature water for the car wash stream.

The electricity generated by the microturbine is three-phase 220V AC. This electricity is used to cover internal electrical needs to power water and fuel pumps. Excess power is sold to the local electrical grid.

Photos courtesy of Capstone Turbine Corporation

V. Superior Gas Plants, Columbia Station, Ohio, USA

Primary Contact: Mr. Dennis Moraski, Superior Gas Plants (425) 603-1075

Superior Gas Plants (Superior) develops products for the LP Gas industry. As part of a Propane Education and Research Council (PERC) funded project, Superior is demonstrating the viability of LP Gas to fuel a 30 kW Capstone microturbine for power generation. Partial funding is carried over from a previously PERC-funded project to develop LP Gas processing equipment for microturbines. As of late May 2002, the demonstration microturbine has run for over 430 hours of service. Superior plans to operate the microturbine over a 14-month period covering two winter seasons.

Microturbine and Vaporiser

The microturbine is installed in parallel to the local electrical grid. For eight hours per day, the microturbine supplies power to the building with excess power transferring to the grid. The site uses the grid protect relays built into the Capstone generator control system. Superior has a net metering contract with Ohio Edison. The contract gives Superior 10 cents per kW-hr credit for electricity. This compares to the 2 cents per hour that Ohio Edison would pay to directly buy electricity.

Microturbine and Vaporiser

This arrangement took around four (4) months to coordinate and to properly connect to the electric utility grid. Superior was the first Ohio Edison customer to be connected to their grid with distributed power.

Vaporiser with pipe insulation

LP Gas is stored in a 1,000-gallon tank on site. Superior is testing the system using it's own design of water-glycol vaporiser[6] which draws liquid fuel from the tank with a small pump. The system is reported to have performed reliably over its first four months of operation.

Superior plans to demonstrate two other alternatives that may provide adequate gas pressure to the Capstone fuel system inlet. The devices include:

(1) ExTA Flow Stabilizer unit; and
(2) a heating blanket designed by Superior.

[6] Same vaporiser as in IDD Case Study.

Both devices have potential drawbacks. Both technologies are tank heating devices that require tank insulation to reduce heat loss to the atmosphere. If a tank is refilled with cold LP Gas, the microturbine will be temporarily offline until the tank heats up to the required temperature.

Problems encountered to date:

1. The Capstone electronic control system had a component failure two days after starting the system. Capstone replaced the entire system with a newer production model.
2. The filter on the vaporiser plugged after 200 hours of operation and had to be replaced.

Photos courtesy of Superior Gas Plants

All the turbine manufacturers contacted in the course of this study were interested in more information on the LP Gas market. Several mentioned that if such information were available, they would accelerate LP Gas product development.

Problems encountered at the sites were often related to inadequate gas pressure at the inlet to the Capstone side of the fuel system. As larger microturbines (60-80 kW) come into the market, this problem is likely to worsen because larger units require additional gas pressure. The development of a relatively inexpensive and reliable method of LP Gas vaporization across a broad range of ambient conditions will be key to the long-term success of microturbines operating on LP Gas. Furthermore, the development of an affordable compressor than can switch relatively seamlessly between NG and LP Gas is likely to be well received by microturbine manufacturers as well as by other dual fuel equipment manufacturers.

Appendix A

Microburtine Manufacturers

Capstone Turbine Co.
21211 Nordhoff Street
Chatsworth, CA 91311 USA
Phone: 1-818-734-5300, Fax: 1-818-734-5320
www.capstoneturbine.com

President and CEO: Dr. Ake Almgren
Ownership: publicly traded

Incorporated in California in 1988, Capstone was the first company to produce commercially available distributed power generation systems using microturbine technology. During its first 10 years of operations, Capstone focused primarily on research and development. The first commercial launch of the Model 330 unit took place in December 1998. Capstone reincorporated in Delaware subsequent to its initial public offering in June 2000.

Although there are five other microturbine manufacturers with established credentials, Capstone is the only one with on-going installations on LP Gas outside of Japan. The present position of the other microturbine manufacturers regarding commercialisation of an LP Gas model is detailed below:

Bowman Power Limited
Ocean Quay, Belvedere Road
Southhampton, SO14 5QY
UK

Phone: 44-(0)23-8023-6700, Fax 44 (0)23-8021-2110
www.bowmanpower.com

CEO: Mr. Tony Davies

Bowman Power Systems is developing the Turbogen family of small-scale compact power systems ranging from 25 kW to 80 kW for distributed power generation and for mobile power applications. Bowman buys the basic turbo machinery from the engine industry and integrates this technology into specific end use applications.

Bowman is focused on supplying combined heat and power (CHP) systems where the exhaust heat is recovered to provide hot water or air conditioning when coupled with an absorption chiller. Effective use of exhaust heat can reach an efficiency up to 80% thus providing a quick payback in addition to providing improved power quality, availability and reduced emissions.

Bowman offers two gas-fired units, an 80 kW, and a 50 kW[7]. Bowman is reportedly developing larger units in the 200 kW range. Bowman Systems are integrated with either Bowman developed microturbines or other manufacturer's microturbines. Units include a heat exchanger as part of the package to be optimised for cogeneration. Bowman microturbines are not suitable for mobile applications (80 kW unit dimensions are 3' x 6' x 10'). They currently have LP Gas installations in Japan for cogeneration applications in hotels and bath houses.

Elliott Turbomachinery Co., Inc.
901 North Fourth Street
Jeannette, PA 15644-1473 USA
Phone: 1-724-527-2811, Fax: 1-724-600-8442
www.elliott-turbo.com

President and CEO: Mr. David G. Assard;
Ownership: wholly-owned subsidiary of Ebara Corporation, Japan

Elliott started in 1895 as the Chicago Boiler Company, a small manufacturer of boiler cleaning equipment based on the patents of William Swan Elliott. In 1924, Elliott purchased the Kerr Turbine Company, and two years later it purchased Ridgway Dynamo & Engine Co., adding turbines and compressors to its portfolio, thus entering the rotating machinery market as a manufacturer.

Elliott has been in business for over a century. The firm has focused on the vision of remaining at the technological forefront in designing, manufacturing and servicing air and gas compressors, steam turbines, power recovery turbines, turbochargers and power generation equipment.

Elliott offers one microturbine that operates on LP Gas. Elliott has consolidated its line of microturbines to one model, the 80 kW. The 80 kW model is large (approximately 9.2' Length x 4.3' Height x 2.7' Width). As such, it is only suitable for stationary applications.

Ingersoll - Rand Energy Systems
32 Exeter Street
Portsmouth, NH 03901 USA
Phone: Inside the US 1-877-IR-POWER
Outside the US 1-603-430-7013
www.powerworks@irco.com

Chairman, President and CEO (Ingersoll-Rand Co.) Herbert L. Henkel
Ownership: publicly traded

The IR PowerWorks™ microturbine line is designed to provide a cost-effective independent power source to supermarkets, small-industrial factories, hotels, schools, utilities, hospitals, office buildings and multifamily homes. Featuring a versatile design, the

[7] The 50 kW unit is not available in the United States.

new line of microturbines generates electricity for base consumption or peak shaving and also provides heat for other applications, such as hot water. In addition, the PowerWorks microturbines can be integrated into mechanical-drive applications, such as compressed air, refrigeration and air conditioning equipment. IR is currently conducting a field test program evaluating the performance of its 70-Kw microturbine and is planning to deliver commercial PowerWorks units in Fall 2001.

Currently, only NG units are available commercially. An LP Gas model is in development. It is expected to be offered for sale in the third quarter of 2002.

Turbec AB

Regnvattengatan 1
200 21 Malmö SWEDEN
Phone: 46-40-680-0000, Fax: 46-40-680-0001
www.turbec.com

Ownership: Jointly owned by Volvo Aero and ABB.

Volvo Aero and ABB founded Turbec in 1998. Turbec has focused on the development of the microturbine technology for small-scale power generation. Prototypes were designed and tested leading to the first commercial product, the T100 microturbine. The T100 fulfills the automotive industry requirements of a long life and high efficiency needed in power generation applications with low cost and easy maintenance.

Turbec is currently developing an LP Gas model. The model is likely to be available in the spring of 2003.

Honeywell Power Systems – No longer manufactures microturbines. General Electric has reportedly purchased a number of Honeywell's microturbine related technologies.