

Propane-Fueled Microturbine: Case Study

Potential of Propane as a Microturbine Fuel

Microturbine generators are small turbine generators targeted for the distributed generation marketplace and located at or near sites where electrical power is consumed. The units presently under development range in size from 30 to 250 kWe. Capstone is a leader in the microturbine industry with the most units in the field; over 2,500 units have been sold (30 kW and 60 kW units). Other leading microturbine manufacturers with products available in the U.S. include Bowman Power Systems, Elliott Energy Systems, IR Energy Systems, and Turbec AB.



Distributed generation (DG) covers a variety of generating technologies; besides microturbines it includes fuel cells, wind turbines, photovoltaic cells, Stirling engines, small combustion turbines, and internal combustion (IC) engines. The main impetuses for distributed generation are savings in electrical transmission and distribution costs, higher reliability small power generation, and potentially higher fuel efficiency when waste heat is used for cogeneration.

While the potential market for microturbines is uncertain, there are significant advantages to the use of propane-fueled microturbines. There are a variety of circumstances where propane is the fuel of choice, including:

- Where natural gas is not available; those locations that are beyond the present natural gas pipeline distribution system.
- As a natural gas standby fuel; these applications will be based on the price difference between firm and non-firm natural gas.
- When propane is cheaper than natural gas.
- As a backup to natural gas or diesel when fuel redundancy is required for greater overall reliability.

The Challenges of Using Propane

A number of critical issues will have to be addressed prior to propane becoming a widely accepted fuel for microturbines. While the potential market for propane fuel in microturbines is large, no propane equipment development or testing has occurred to meet the unique requirements of microturbines. Most microturbine manufacturers have operated their systems on propane vapor in laboratory conditions without any problems; however, the following unique conditions require development of specialized equipment:

- **Relatively High Pressure Vapor is Required** - Microturbines require propane vapor at 55 to 80 psig, depending on the microturbine manufacturer. Propane vapor from the top of a liquid storage tank will have insufficient pressure to operate the microturbine in most of the U.S. (vapor pressure at 50°F is 77 psig). Thus, propane liquid pumping and vaporizing equipment of some type will be required.
- **The Required Propane System Sizes are Rather Small** - Very little of the conventional propane vaporizing equipment available is practical for the low flow rates of microturbines. For example, a 30-kW microturbine generator uses approximately 4 GPH of propane fuel while the lowest capacity gas-fired vaporizer is 40 GPH.
- **Electrical Energy is a Premium Product** – Since the primary reason for a microturbine generator is to produce electric power, any ancillary equipment, such as a propane vaporizer, should use a minimum of electricity.
- **Many Sites Will Not Have Electric Power Available** – In these cases the microturbine generator will be started with a battery system. The propane vaporization system must also be able to initially deliver propane vapor to the microturbine without line power; either by using a non-electrical gas fired burner or a battery system to operate the electrical system for the few minutes required during startup.
- **Safety is a Crucial Issue** - There is a unique safety issue when using propane with a microturbine because of the potential catastrophic failure that could occur if liquid propane were introduced to the combustor.
- **High Reliability is a Top Priority** – Microturbines will be installed at many sites specifically to provide ultra-reliable electrical power; that is, electrical power that has a much higher reliability than current line power.
- **Low First Cost is Extremely Important** – The single most important factor in determining the widespread acceptance of microturbines generators will be their installed cost.

For this demonstration, a Capstone system was chosen to test auxiliary equipment required by the propane microturbine system. Propane vapor fuel has been thoroughly tested by Capstone in the Model C30 microturbine power generator. Propane will operate in much the same way as natural

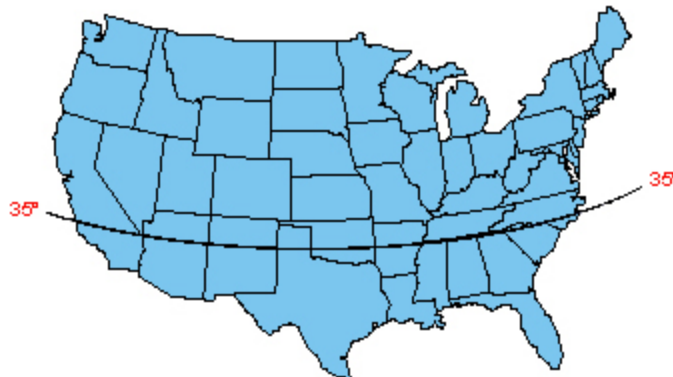
gas; it has the same manifold system as high-pressure natural gas, and the exhaust emissions are similar to those of natural gas. However, there are unique issues raised when using propane with a microturbine for power generation that are not standard for natural gas microturbines or propane-fueled appliances, such as space and water heating systems. Propane appliances typically use low-pressure vapor which is easily pulled from the top of the propane storage tank without additional equipment requirements.

Propane MUST be in vapor form at the microturbine fuel inlet. This issue is supported by the following considerations:

- If outside temperatures will be below 35°F propane vapor from the top of the tank will have insufficient pressure; a propane pump and vaporizer using liquid propane are required to be installed between the propane tank and the Capstone C30.
- When using a propane pump and vaporizer a liquid carryover safety valve must be included.

As a general rule of thumb, geographical areas north of the 35th parallel in the United States (see the figure below) require a pump and vaporizer when using propane as a fuel for the Capstone C30 generator. For geographical areas south of the 35th parallel in the United States tank vaporization is normally sufficient, and a pump and vaporizer may not be required. The following situations below the 35th parallel will require vaporizing and pumping capabilities:

- Minimum temperature is below 35 degrees Fahrenheit
- More than three C30's are being operated from a single 1,000 gallon tank
- A mixture of propane and butane is being used
- The equipment is located at high elevations



Vaporizer and Pump Required with a Propane Microturbine above 35th Parallel

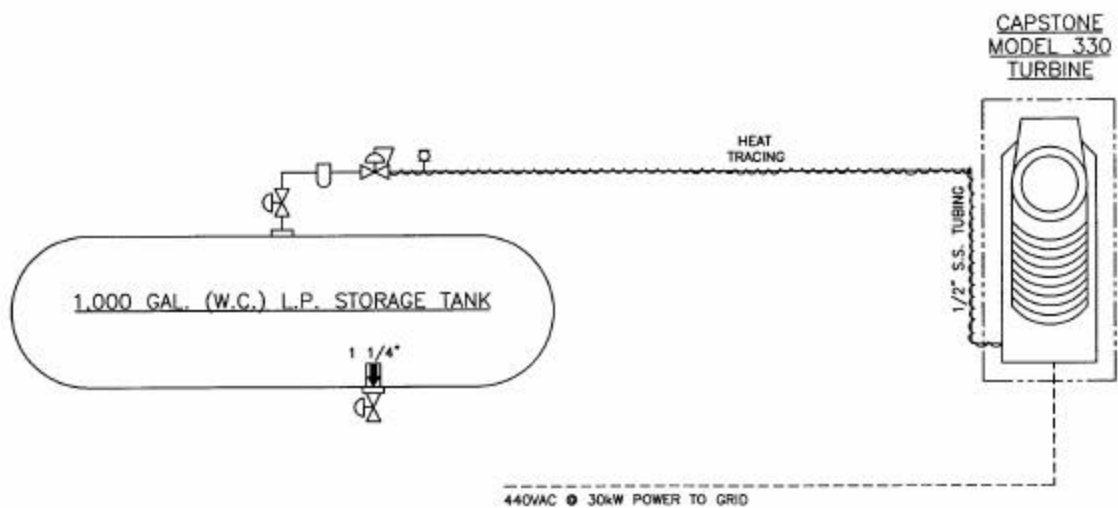
Equipment Solutions Reviewed

Three options for providing high pressure propane vapor to a microturbine system were reviewed. These fueling options include:

- Natural Tank Vaporization
- Liquid Pump and Gas Vaporizer
- Tank Heaters

NATURAL TANK VAPORIZATION

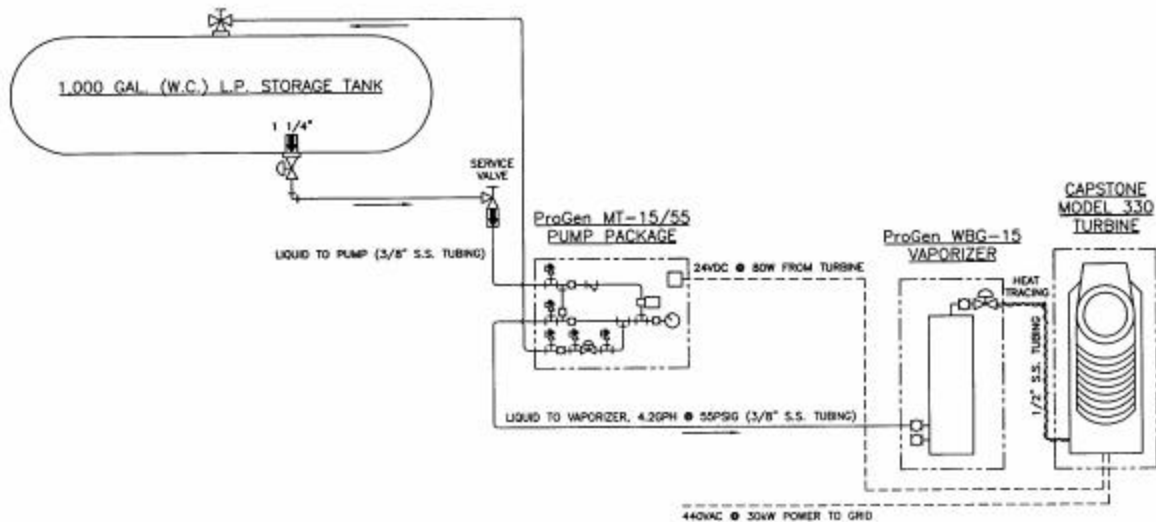
Most low pressure, small volume applications (i.e., domestic applications) use the storage tank as the vaporizer and, in most cases, it is entirely satisfactory. The smallest microturbine (Capstone C30) is rated at 30 kW output, which translates into approximately 4 gallons per hours of propane and a minimum storage requirement of 1,000 gallons. The Capstone C30 also requires a minimum of 52-55 psig vapor pressure at the inlet to the fuel manifold. A minimum outdoor temperature of 35°F is required to maintain the 55 psig vapor pressure off the top of the tank. Larger microturbines would require correspondingly larger storage tanks and will also normally have higher pressure requirements.



Propane Storage Tank Connected Directly to Microturbine Generator

LIQUID PUMP AND GAS VAPORIZER

For those locations with a minimum temperature below 35°F, a pump and external vaporizer are required to operate a microturbine. In this case liquid propane is taken from the bottom of the propane storage tank and piped to a nearby (within 2 feet) small pump that insures that a minimum of 55 psig pressure will be provided to the microturbine. The Superior Gas Plants Corporation standard pump operates on 24 VDC and can start from the Capstone C30 battery if black start capabilities are required. The pressurized liquid propane is then piped from the pump to the propane vaporizer, which is normally located close to (within 3 feet) the Capstone C30 generator. The vaporizer adds heat to the liquid propane (approximately 800 Btu/gal) and converts it to a vapor form that can be used by the microturbine generator. Just downstream of the vaporizer outlet a pressure regulator is installed. The regulator provides a constant 52 psig to the Capstone C30. The piping downstream of the vaporizer must be heat traced and insulated to prevent propane recondensation in this line.



Propane Pump & Vaporizer with Microturbine Generator

TANK HEATERS

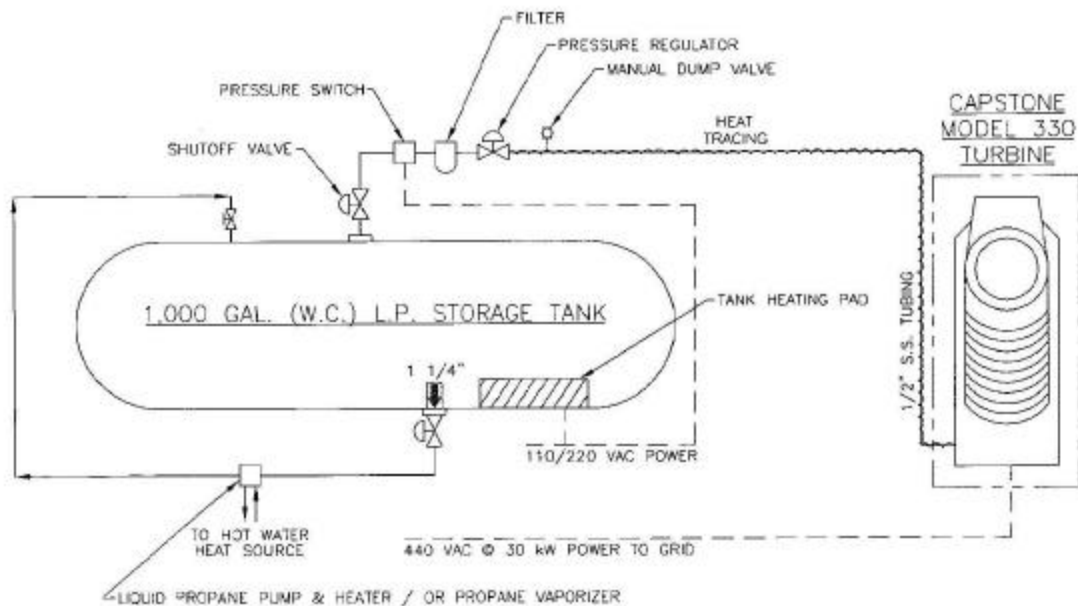
Another option when using propane for microturbines is to use a device that adds heat directly to the storage tank, thereby supplementing natural vaporization and saving energy. This method of vaporization is called a tank heater and is used more extensively outside the United States where butane-propane mixtures are more common. There are several types of tank heaters, such as;

1. A traditional small vaporizer, either gas fired or electrically heated, where the liquid is removed from the bottom of the tank, heated and then returned to the top of the tank. The propane circulation in this type of tank heater is set up by the temperature difference in the

propane through a thermosiphon action. The vaporizer must be mounted below the bottom of the tank and very close to it in this configuration.

2. A tank heater blanket consists of a thermostatically controlled electrically powered heating pad that is attached to the bottom of the tank.
3. A tank heater that uses a water pressure driven pump to circulate liquid from the bottom to the top of the tank. During the recirculation process the liquid is heated with hot water from a small remote hot water heater.

All of the above described tank heaters can be controlled with a pressure switch, thereby only requiring outside power when the tank pressure is low. The 2nd and 3rd type of tank heater listed above are especially effective for underground tanks where the ground temperature is always 45°F-50°F. The biggest negative of the tank heater applications for above ground storage tanks is the difficulty when trying to heat the tank above the ambient temperature in order to build pressure. In these cases it would be necessary to insulate the tank; which would, in turn, add complexity and negate the energy saving effects of natural vaporization.



Tank Heater Schematic

ASSESSMENT OF EQUIPMENT OPTIONS

A microturbine owner will need to assess these options based on their specific requirements. The following table illustrates the different positive and negative attributes of each fueling option for comparison purposes.

Propane Fueling Options

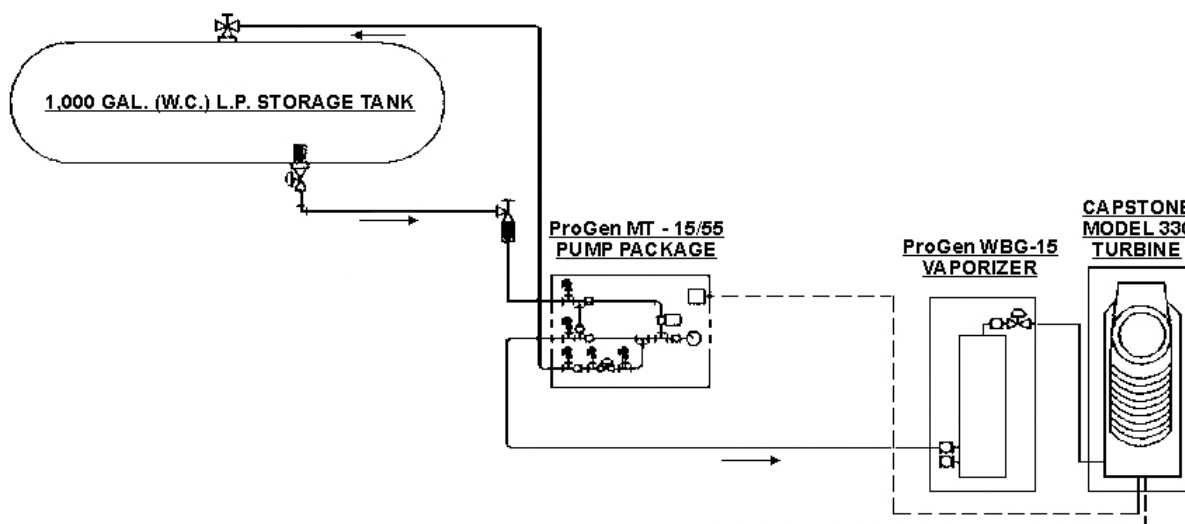
Criteria	Natural Tank Vaporization	Pump & Gas Vaporizer	Tank Heaters
Performance	Cannot provide the pressure required by microturbines in most of the U.S. during winter conditions	Can provide pressure and flow for all sizes of Microturbines	Requires aboveground tanks to be insulated to build required pressure. Performance not proven for aboveground tanks
Reliability/Durability	Very reliable since there is almost no equipment – regulator and heat tracing of vapor piping is all that's required	Least reliable because of complexity – the pump is the primary moving part; while the vaporizer has a number of components to it.	Electric heating pad is very reliable because of simplicity. Other type of tank heaters are more complex and thus less reliable
Energy Efficiency	Has the best energy efficiency since the energy to vaporize the propane is free	Moderate energy efficiency - pump has very little electrical use and gas vaporizer no electrical power, only propane	Can be very energy efficient if pressure is controlled and tanks are underground
Initial Cost	Lowest initial cost since very little equipment is needed. \$200-\$500 uninstalled	Highest initial cost – pump + vaporizer is \$4,000-\$6,000 uninstalled.	Low to moderate cost – electric blanket is \$1,000-\$1,500, while other types are \$1,500-\$3,000 uninstalled

For this demonstration project, the pump and vaporizer configuration was chosen because it is the only solution capable of ensuring only propane vapor will reach the microturbine system at the required pressure in all weather conditions throughout the U.S.

Equipment Demonstration Results

DESCRIPTION OF THE DEMONSTRATION SITE

The propane-fueled microturbine demonstration is located at Superior Gas Plants Corporation at the Columbia Station, Ohio manufacturing plant. The installation includes an above ground 1,000 gallon propane storage tank, a liquid pump located near the storage tank and a gas-fired waterbath vaporizer located near the microturbine. The figure below illustrates the equipment layout, including the pump and vaporizer that were tested as part of this demonstration.



Equipment Layout Schematic at Ohio Facility

EQUIPMENT DESCRIPTION

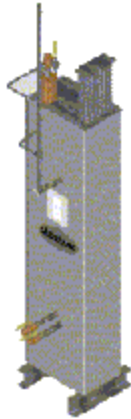
Three primary pieces of equipment were tested as part of the propane microturbine demonstration.

- Vaporizer
- Liquid pump
- Microturbine

The following describes in more detail the equipment demonstrated for this case study.


Vaporizer: The *ProGen Propane Vaporizer Model #WBG-10* was designed specifically to provide propane vapor for microturbine generators. It has a waterbath heat exchanger, requires no electricity, and includes a propane liquid carryout valve at the outlet of the vaporizer to prevent liquid propane from reaching the microturbine. See the table below or www.superiorenergysystems.com for the vaporizer design and performance specifications.

ProGen Propane Vaporizer Specifications

Specifications	English Units	Metric Units	Vaporizer
Propane Vaporization Capacity	1.4 MMBtu/hr (15 Gal/hr)	0.349 KCal/hr (2.62 Kg/hr)	
Burner Fuel Input	20,000 BTU/hr	5060 KCal/hr	
Waterbath Volume	3.5 Gallons	13.3 Liters	
Shipping Weight	177 Lb	80 kg	
Heat Exchange Design Pressure	250 Psig	17.5 Kg/cm ²	
Electrical Requirements	None	None	

Liquid Pump: The *ProGen Propane Pump Model #MG-10/55* is designed specifically to develop sufficient propane pressure for microturbine generators. It is a magnetic drive gear pump packaged with a back pressure regulator, check valve, strainer, and bypass piping. The pump is operated only when additional pressure is required. See the following table or www.superiorenergysystems.com for specifications.

ProGen Propane Pump Specifications


Specifications	English Units	Metric Units	Pump
Propane Pumping Capacity	15 gal/hr	28.8 kg/hr	 <p>Attached below propane tank</p>
Pressure Capacity	55 psig differential	3.87 kg/cm ²	
Power Requirements	85 watts @ 24 VDC	---	
Voltage Connections	24 VDC	---	
Shipping Weight	57 lb	26 kg	

Optional Equipment: Additional equipment that may be used with this pump includes:

- The pump voltage may be 12 or 24 VDC, 110 or 220 single-phase AC, or 230-480 three-phase AC. The standard voltage is 24 VDC.
- If black start capabilities are required, a 24 VDC (100 watt) battery power source must be installed on the Capstone C30.
- An automatic control system can be added to allow summer operation that draws vapor from the top of the tank and winter operation using liquid propane with the pump and vaporizer. The system consists of a pressure switch and solenoid that introduces the pump and vaporizer into the piping arrangement when the tank pressure falls below 60 psig. Alternatively, a manual summer/winter changeover arrangement can be installed with manual ball valves.

Microturbine Generator: The *Capstone C30 Microturbine Generator* was provided by the Capstone Turbine Corporation for use in the demonstration program. The *Capstone C30 Microturbine* has a high pressure fuel system configuration designed to operate on propane vapor. Electrically, it is a parallel system for operating in conjunction with the electrical grid rather than as a stand-alone unit. See the table below or www.microturbine.com for selected specifications.

Capstone C30 Microturbine Generator Specifications

Specifications	English Units	Metric Units	Microturbine
Power Output	30 kW	30 kW	
Fuel Pressure Req'd	52 psig	3.66 kg/cm ²	
Fuel Flow	4.2 GPH at full power	8.4 kg/hr	
Dimensions	75"x28"x53"	190cmx71cmx134cm	
Shipping Weight	1052 lb	478 kg	

INSTALLATION DESCRIPTION

First Energy of Ohio, the local power company, was contacted regarding connecting the microturbine generator to the grid. Personnel at First Energy were helpful, though it appeared they were unsure of how to handle the request to connect a 30-kW generator to their system. It turned out that our request was the first for a small, distributed power generator, therefore, the utility was feeling their way. The main interconnection issues for this demonstration were:

- ✓ Parallel installation vs. stand alone – the microturbine generator that Superior received from Capstone required grid connection to operate. That is, it didn't have the electronics and battery system necessary to act as a stand-alone generator. Thus, the grid would be used both to start the generator and provide the 60 hz frequency signal necessary to operate the generator.
- ✓ New meter requirement – First Energy required the installation of a new meter that would allow power to go both ways; from the grid into the plant, and then from the microturbine generator back to the grid.
- ✓ Modem connection requirements – First Energy also required that Superior have a telephone line to connect to the modem on the new meter.
- ✓ Power rates – First Energy offered several options for how the generated power would be accounted for in their billing system. All the power generated and sent back to the grid could be sold to First Energy by Superior at a rate of approximately one cent per kilowatt-hour. Another option was to use the power generated strictly to offset incoming power that was not required.

RESULTS OF THE DEMONSTRATION PROGRAM

The microturbine generator was operated for a total of 1,756 hours over a period from April 2002 until June 2003. The table presents a summary of the operational test data recorded during this time. The unit was operated during work hours so that personnel could start and stop the unit and monitor operation. Additionally, power from the generator was only able to be used by the site during work hours.

Summary of Test Data

Month	Run Hours	Vaporizer & Pump Incidents
April 2002	183	Pump electronic failure, fixed and restarted
May 2002	95	Vaporizer vapor filter plugged, changed filter & restarted
June 2002	163	No incidents
July 2002	100.8	No incidents
August 2002	178.3	No incidents
September 2002	163.1	No incidents
October 2002	172.1	No incidents
November 2002	143.2	No incidents
December 2002	102.4	Vaporizer vapor filter and fuel valve replaced. Problems with pump operation.
Total for 2002	1317	April through December 2002
January 2003	127.1	Problems w/pump during cold weather
February 2003	35.5	Vaporizer fuel filter replaced
March 2003	130.4	Turbine giving fuel fault diagnostics, shut down 3/26/03
April 2003	0	Shut down for repairs to Microturbine, after many consultations with Capstone service determined that needed to replaced fuel manifold assembly
May 2003	175.4	Restarted 5/9/03 after manifold replaced
June 2003	86.3	Problems with Turbine fuel control valve, replaced
Total for 2003	554.7	
Grand Total	1871.7	

Conclusions

The overall focus of the project was to demonstrate the operability and reliability of operating a microturbine on propane in a typical U.S. location. The demonstration site, located near Cleveland, Ohio, operated through a complete winter season showing that propane could reliably power a microturbine generator in most U.S. locations, given appropriate vaporization equipment.

Measuring the performance of the Microturbine generator was not the purpose of demonstration project. There have been many well documented tests of Capstone C30 microturbines. The particular microturbine generator used in the demonstration testing was an early production model, serial number 35. Some of the electronic failures of the microturbine appear to be related to its position as an early production unit.

Near the end of the demonstration testing the Capstone microturbine did have recurring problems during startup. A fuel inlet train was replaced by Capstone at the end of April 2003 and that solved the problem for about 2 weeks. However, startup problems continued until the demonstration test was completed on June 17, 2003

The results of the propane microturbine demonstration are as follows:

- The microturbine generator and associated propane equipment operated with a minimum of problems for much of the demonstration.
- Most of the operational problems during the demonstration period were associated with the microturbine electronics or fuel inlet train.
- The pump package developed the needed microturbine pressure when tank pressure was insufficient to operate the microturbine.
- The pump and vaporizer provided the required vapor flow and were appropriately sized to match the demands of the microturbine.
- A minimum of electric power was required to operate the propane equipment. The pump only needed 85 Watts of 24 VDC power, and the vaporizer didn't required any outside power to operate.
- Battery power to operate the pump during startup was not required for the microturbine generator used in the demonstration test. The microturbine was a grid-parallel unit, thus it could only operate when line power was available.
- No safety problems occurred with the propane system. The liquid safety valve worked to prevent any liquid propane carryover to the microturbine.
- The reliability of both the pump and vaporizer need to be improved to meet the desired reliability of the microturbine generator package. However, it should be noted that the propane equipment was, in general, more reliable than the microturbine generator during this demonstration.

- Operational problems occurred with the vaporizer and pump at low temperatures (<15°F). Occasionally the pump would shut down. Also, the vaporizer burner regulator would severely frost up during low ambient temperatures, though not causing any equipment shutdowns.
- Another issue was plugging of the vaporizer vapor filter. This happened 3 times, until, in February 2003, the filter was replaced with a unit with much greater surface area. No further plugging problems were observed after this change.
- The estimated cost of the propane equipment at \$4,000-\$6,000 is higher than desired. The primary factors in reducing the costs are continued product development and increasing production quantities.