# MARKET DEVELOPMENT OF MICROTURBINE COMBINED HEAT AND POWER APPLICATIONS

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## ABSTRACT

Microturbines are gaining market acceptance through continued product development, market education, government incentives, and an improved regulatory environment. This article describes the economic factors driving customer acceptance of microturbine CHP solutions, illustrates several applications, and provides information regarding the regulatory situation in California. The examples sited in this article are from the author's company, Capstone, but are intended to reflect the potential application of similar microturbine products.

## MICROTURBINE TECHNOLOGY OVERVIEW

There is no formal definition for a "microturbine," however the common characteristics of today's products are simple radial compressor and radial turbine designs using a recuperator to preheat the combustion air for improved efficiency. Most designs use a single shaft onto which the radial compressor, radial turbine and generator are all coupled. This assembly is sometimes called the "turbo generator." Rotating speeds are extremely high, in the range of 45,000 to 100,000 revolutions per minute (rpm). The generator output is therefore high frequency alternating current. Figure 1 illustrates a microturbine turbo generator with annular construction recuperator.

Power electronics are used to rectify this alternating current to direct current, then invert to the three-phase 50- or 60-Hertz power fre-

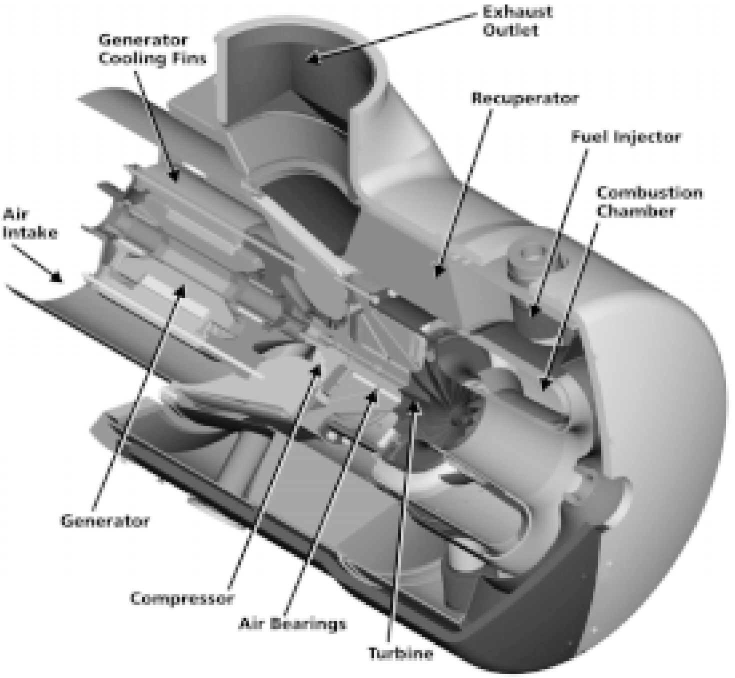

**Figure 1. Turbo Generator Assembly**

quency. Insulated gate bipolar transistors (IGBT's) are commonly used, and the power electronics and controls are similar to technology used in uninterruptible power supplies and variable frequency motor drives. Integral computers control the conversion of power, operation of the turbo generator system, as well as provide convenient man-machine interface and remote communications. Because the designs are often so tightly integrated with the onboard computer, operator interface is convenient and extremely powerful. Protective relay functions are also often built into the system, making microturbines extremely easy and safe to connect in parallel with an electric grid. Figure 2 provides a system diagram showing the key elements of such an electronically controlled microturbine system. One manufacturer uses a gearbox to transform the high-speed turbine output to a more traditional synchronous speed generator. In this case, synchronizing and protective relaying control is done using traditional separate control systems.

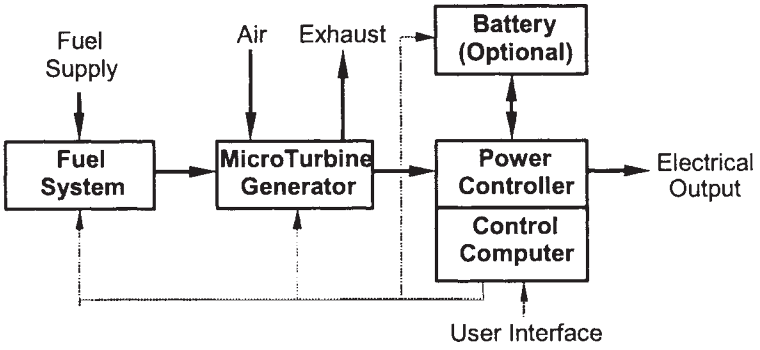

**Figure 2. Typical Microturbine System**

Microturbine turbo generators from most manufacturers are able to operate on a variety of fuel types: natural gas, biogas, diesel fuel, or propane. One of the characteristics of microturbines is that the fuel must be injected into the combustion chamber at relatively high pressure of three to five atmospheres. When using gaseous fuels, this requirement for fuel compression requires significant power, which must be considered part of the microturbine system when calculating net power output. Several manufacturers offer a natural gas compressor either internal to the microturbine package or directly powered and automatically controlled by the microturbine in order to simplify installation.

Current production microturbines range in net power output from 28- to 250-kW. The standard used by manufacturers for rating power and electrical efficiency for microturbines is at ISO ambient conditions of 15°C (59°F) and sea level. Electrical efficiencies relate to the lower heating value of the fuel (LHV), and are typically from the mid twenty to low thirty percent range, depending on fuel type and fuel compressor parasitic load. As with all Brayton cycle engines, the power and efficiency are both reduced with increased ambient temperature, resulting in performance de-rating curves, which can be obtained from the manufacturer for each specific microturbine.

Microturbines do not have reciprocating parts that require frequent change of lubricants. Some microturbines even utilize innovative air bearings, thereby completely eliminating the need to change and dispose of hazardous liquid lubricants. In any case, microturbines are similar to major power plants, able to run for extended periods at full power output, and require little scheduled maintenance compared with traditional reciprocating engines of similar size. This makes them ideal for stationary prime power applications.

The combustion process in a microturbine is continuous and clean burning, similar to modern gas turbine power plants. Microturbine manufacturers have deployed state-of-the- art lean-burn combustion technology to control emissions without the need for expensive catalytic exhaust treatment equipment. The leading microturbine manufacturers publish fewer than 9 parts per million (ppm) for $NO_x$ at full power, and independent third parties have verified that emissions measurements are sometimes much lower. Because their exhaust is so clean, microturbines are relatively easy to site virtually anywhere. In southern California, with some of the strictest emissions standards in the world, most manufacturers have already deployed microturbines. In addition, the California Air Resources Board (CARB) set new emissions regulations for microturbines effective January 1, 2003 that are output based and must be measured over several real-world operating conditions. At least two microturbine manufacturers have now met this strict standard, and have had microturbine emissions certified to meet CARB. It is expected that more microturbine manufacturers will follow, and that future standards will be even more stringent. This type of regulation is already facilitating installation of microturbines in California, and may become more widely accepted in all markets.

## THE MICRO CHP ADVANTAGE

Because the microturbine exhaust is inherently clean, and because almost all of the unused fuel energy is available directly in the exhaust stream, microturbines make excellent components for a combined heat and power (CHP) solution. The exhaust is so clean that some microturbine applications actually port the exhaust directly into a manufacturing process. A more traditional example is to port the microturbine exhaust to a gas-to-liquid heat exchanger, where the exhaust energy is transferred into hot water. In fact, almost all microturbine suppliers today offer a microturbine CHP system, where the heat exchanger is integrated into the microturbine package. Figure 3 shows an example of a 60-kWe CHP system where the heat exchanger is mounted on top of the microturbine for space saving installation. Future developments are focused on integration of microturbines with direct exhaust fired absorption chillers, and an example is included later in this article.

The benefits of combining the thermal and electrical outputs of a system are widely recognized. Extracting the exhaust energy that would otherwise be wasted increases the total system efficiency. This means more useful work from our limited natural resources and less greenhouse gas emissions than using conventional energy conversion technologies. And since microturbines are already extremely clean burning, other exhaust emissions are reduced as well. Figure 4 provides an example comparing efficiency and emissions for traditional and micro CHP systems with 60-kW electric output and 120-kW heat output. Note that total efficiency is significantly higher, greenhouse gas emissions ($CO_2$) are 25% less, and $NO_x$ emissions are an order of magnitude lower for the micro CHP system shown. Reference emissions for the traditional system are extracted from published U.S. Department of Energy data on efficiency and emissions from the average U.S. fossil fuel power plant.

These benefits of combined heat and power systems are significant for the environment and for energy conservation. National and state governments recognize the social values of such CHP systems, and often provide incentives to help develop new installations. For example, in California, AB970 provides up to 30% rebates for CHP installations that

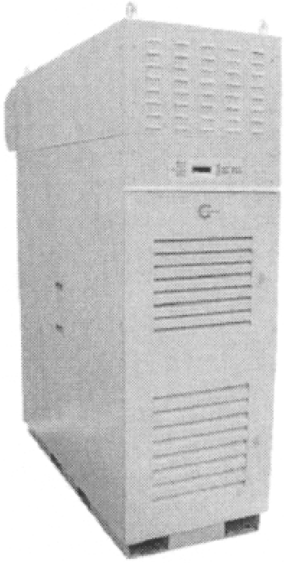

**Figure 3. 60-kW Microturbine CHP System**

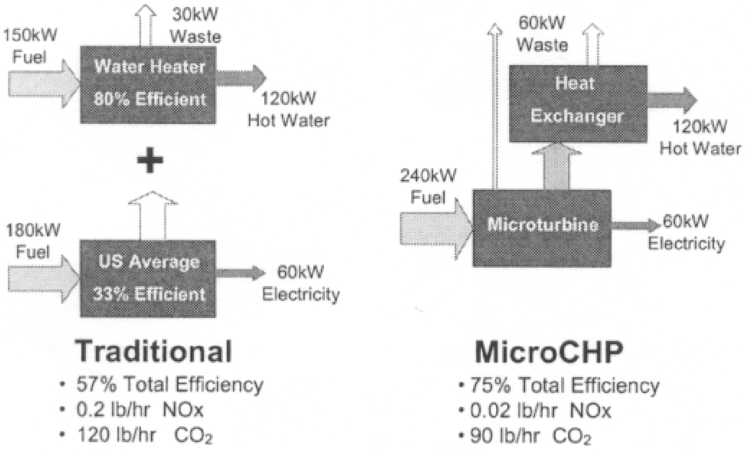

**Figure 4. Traditional vs. MicroCHP System**

meet certain size and efficiency requirements.

To become widespread, however, micro-CHP systems must be economical. End users must be able to realize savings in total electric and gas utility bills; either in the form of reasonable payback on their capital to purchase and install a micro-CHP system, or as monthly utility bill reductions offered through an energy service provider that owns and operates the micro-CHP system. Figure 5 illustrates how a 120-kW micro-CHP system provides these savings. The left bar in the chart shows the annual electric and fuel costs for the system. The right bar shows the cost of operating a micro-CHP system. This includes the fuel cost plus the cost of maintenance, in this example assumed to average one cent per kWh of electricity produced. For the example shown the payback on capital investment is three years, assuming tax depreciation benefits. Of course, actual financial benefits will vary depending on site-specific installed costs, electric and gas rates, hours of operation, tax benefits, government incentives, or other project costs. However, many project developers and microturbine manufactures can quickly estimate the savings for a specific micro-CHP installation using PC software.

One aspect of CHP systems is that they are relatively insensitive to changes in the cost of natural gas. This is because the traditional method of heating water is to use natural gas anyway. In comparison, only a small incremental amount of gas is needed for the micro-CHP system, and with it comes the benefit of offsetting more expensive electricity.

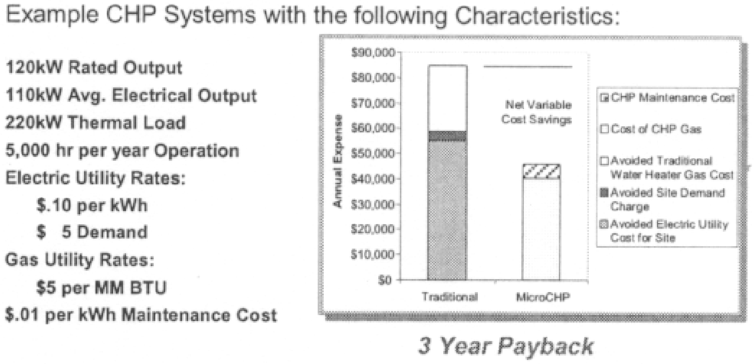

Figure 5. Example MicroCHP Economics

Figure 6 shows how changes in electric and gas rates impact savings. The lines plotted are constant payback values for the example in Figure 5. Note that for any starting point on the chart, an equal percentage change in electric and gas rates actually improves the financial benefit of operating the system—meaning the system can operate fewer hours to get the same payback.

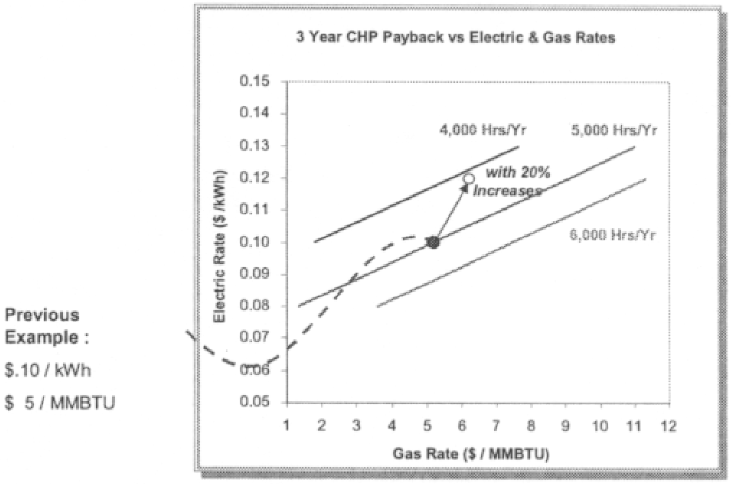

Figure 6. MicroCHP Rate Sensitivity

Due to their economic benefits, microturbine CHP systems are gaining market acceptance, as seen in the examples below.

## DIRECT EXHAUST MUST BE CLEAN

One of the largest microturbine installations in the world is at a chemical factory in Japan. Exhaust energy from a total of forty four microturbines is ported directly into a proprietary chemical drying process. In this case, essentially all of the exhaust energy is utilized in the total process, providing highly efficient use of the natural gas fuel. Figure 7 shows a view of some of these microturbines, which total 2.6 MW of electrical output. The ability to locate these microturbines near their thermal loads exemplifies how micro CHP can offer unique distributed generation solutions. This particular example was also made possible because of the microturbine's extremely clean exhaust—even small amounts of oil could not be tolerated in the drying process. While this specific industrial application may have limited numbers of installations, it is a powerful example of how the use of clean and efficient microturbines can open new opportunities for energy savings.

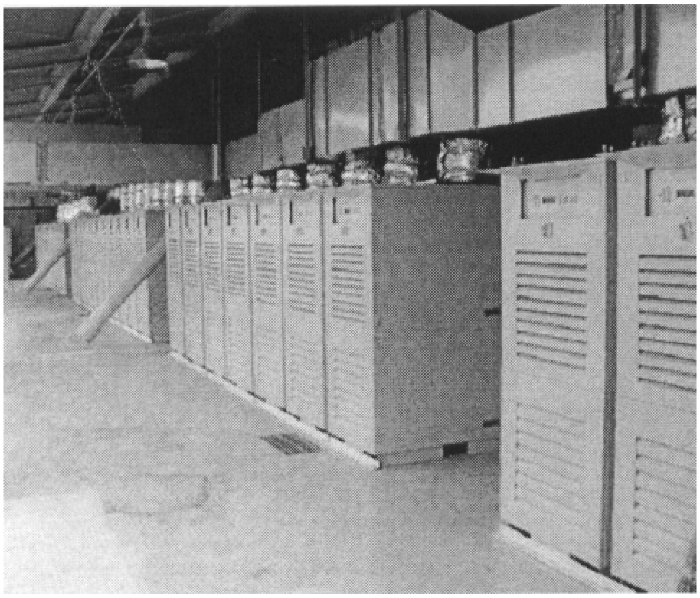

**Figure 7. Direct Exhaust Use for Industrial Process**

## SOME LIKE IT HOT

One recent micro-CHP installation has been the focus of a report by Energy Nexus, with support from the Energy Resource Center, the Oak Ridge National Labs, and the U.S. Department of Energy. The application is at a metal plating facility in Hollywood, California. The company is Faith Plating; an 85-year-old company that claims to be the world's largest electroplater of remanufactured chrome bumpers. In fact, their website is "www.bumper.com."

Faith Plating was in jeopardy of major financial impact due to both unpredictably high electric rates and potentially unreliable power during California's electricity crisis. As a metal plating company located in southern California, they were also subject to strict new environmental regulations on boiler emissions. Faith Plating is also an innovative company, and saw the potential benefit of installing an on-site microturbine CHP system to control utility costs and increase reliability of critical electric power. Faith Plating contacted their local gas utility Southern California Gas Company (SoCalGas) for consultation on the planned micro-CHP system. SoCalGas worked directly with Faith Plating to ensure the company made a successful transition to distributed generation and realized the maximum benefit from their decision. The account executives helped Faith Plating pursue state and federal funding opportunities that are available to users of microturbine CHP technologies. The solution was to install four 28-kW microturbines in their facility, as shown in Figure 8. Exhaust from

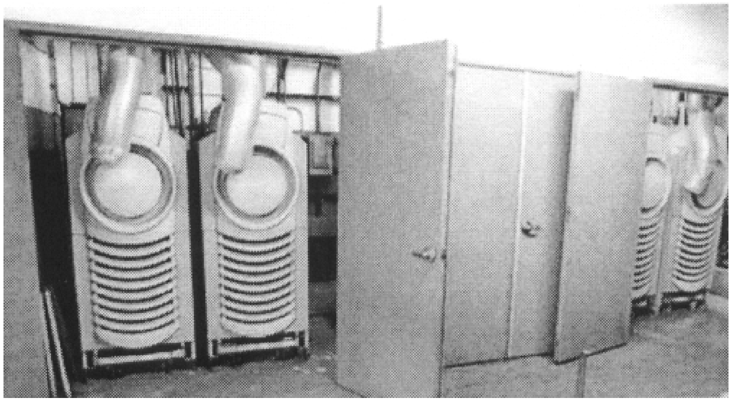

**Figure 8. Four 28-kW Microturbines at Faith Plating**

these four microturbines is ducted into a common heat exchanger to provide energy for their plating process.

All of Faith's plating tanks were converted from conventional boiler operation to the new heating loop from the heat exchanger. The loop runs at 170°F to 190°F. Each 14,000-gallon tank holds plating solution: liquid metal in a sulfuric solution. Faith's production encompasses work with nickel, copper and chrome. Plating tanks must be maintained at 110°F to 190°F, depending on metal content. Thermostat controls on the tanks monitor proper temperature levels. Figure 9 shows one of these electroplating tanks.

The four 28-kW microturbines supply approximately 60% of the facility's power during peak periods, slashing electric utility bills by an average of about $6,000 per month, less a net average of $500 per month for the gas bill.

In addition to supplementing facility electricity and heating for the plating tanks, the microturbines drive a third process at Faith: a patented treatment system for its industrial waste water. Exhaust not used by the heat exchanger is diverted to a sludge dryer. The sludge contains residual metals and wastewater from the plating tanks. Polymers injected into the water bond with the sludge and sink to the bottom. A filter press then creates caked sludge, to which the voluminous, 600°F microturbine exhaust is directly applied. The result is a signifi-

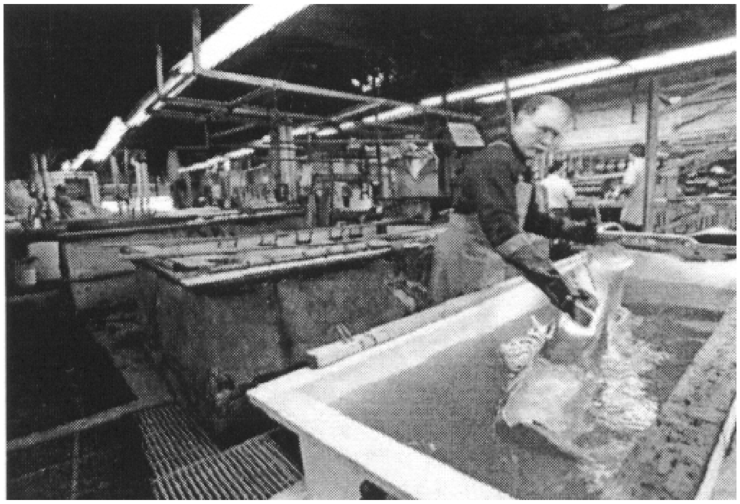

**Figure 9. Plating Tanks Need Hot Water**

cant reduction in waste weight and volume. Electric dryer precipitate processing that used to run $550 to $1000 per month now costs a mere $35, and the treatment cycle has been reduced from 48 hours to about six.

## THE FUTURE IS COOL

The heating examples shown above, and many more like them, are excellent microturbine applications that save energy and money while simultaneously benefiting the environment. However, they all require coincident need for electricity and heat. While there are many types of commercial and industrial facilities that have suitable thermal to electric profiles, even more buildings require energy for air-conditioning. Traditional air-conditioning systems use electricity for cooling, causing the highest peak use during the summer. Many buildings even require some amount of air conditioning during the cooler months as well. So there is a large opportunity for microturbine suppliers to create combined electric and cooling solutions using their clean exhaust to drive absorption chillers; devices that use heat to produce chilled water for air conditioning, rather than using electricity.

The U.S. Department of Energy is supporting several microturbine manufacturers in their efforts to develop cost effective integrated systems for buildings. One example is an installation of a 60-kW microturbine with a LiBr absorption chiller at an office building at the University of Maryland. At this installation, the exhaust from the microturbine is first ducted into the absorption chiller, resulting in about 18 refrigeration tons of chilled water for the building's air handlers. Having extracted most of the available energy from the microturbine exhaust, the remaining energy is ducted to a solid desiccant system for dehumidifying the same building. Figure 10 provides a system overview of the installation, along with some of the performance figures for each system element. More information is available at the websites www.cee.umd.edu/ceee and www.bchp.org/vtour. The system at the University of Maryland ran successfully during the summer of 2002, and is continuing to operate during 2003. This and other similar installations are verifying the reliability and performance of these combined cooling and electric power generating solutions.

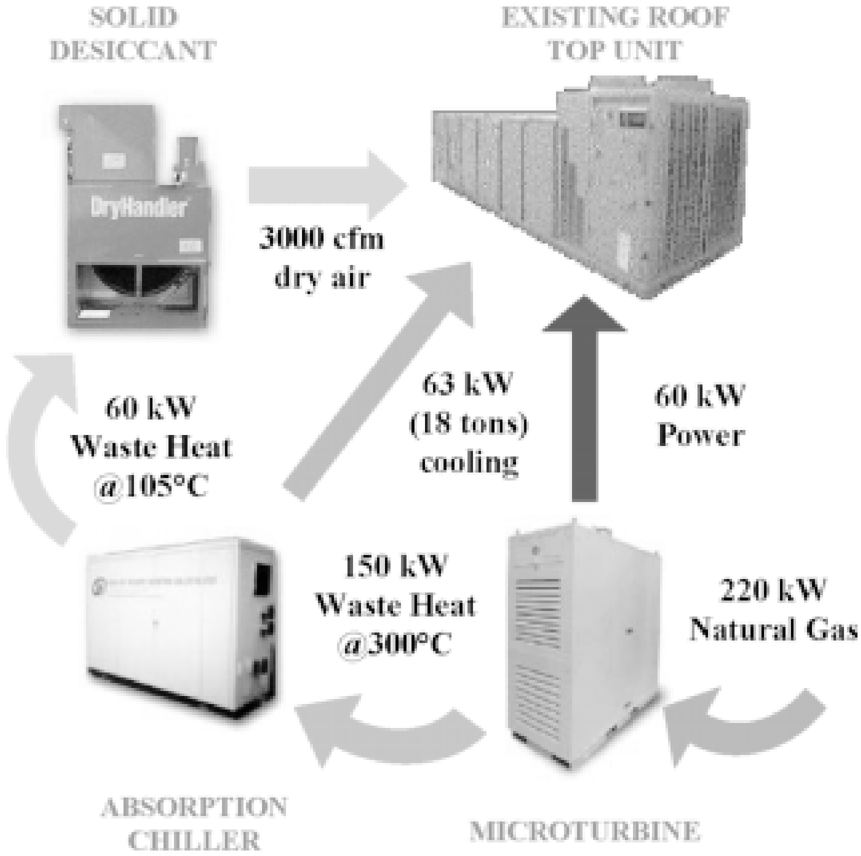

**Figure 10. Microturbine Building Cooling System**

## MAKING AN EASY CONNECTION

One of the obstacles to installing cost-effective microturbine CHP systems has been the ability to quickly and easily interconnect with the electric utility grid. There are a variety of technical and procedural issues that must be resolved for a safe and efficient installation. In the past, electric utilities relied on their years of experience with separate protective relaying and synchronizing equipment to determine what equipment and relaying schemes were needed for each new proposed installation. This highly engineered approach is reasonable when the generators to be connected were relatively large, and could afford the time and expense for such external equipment and detailed engineering review. But for small-scale distributed generation to become common, a quicker and less costly approach was needed. Many states have recognized this problem, and have begun to establish guidelines for expedited interconnection approval.

One example is California, which has established Rule 21 as their accepted process for utility interconnection. This process is one of the first attempts to define the conditions under which an expedited process is allowed. By answering a series of questions, a potential distributed generation installer can quickly determine how difficult a given site installation will be, and can therefore plan accordingly. In the simplest case where no power is exported by the microturbine, the utility grid is a simple radial system, the microturbine protective relay system is certified to meet the technical requirements of Rule 21, and several other conditions are met, the interconnection permit for a microturbine can be completed in just a few weeks.

Figure 11 shows the interconnection application process used by Rule 21. More information is available from the website "www.energy.ca.gov."

## CONCLUSION

Microturbines are continuing to find economic applications in a growing market. Combining the use of exhaust energy with the microturbine's reliable, continuous, and low maintenance attributes makes for a simple solution that saves money, increases power reliability, and has the added social benefits of clean emissions, reduced greenhouse gas production, and more efficient use of our limited natural resources. Technical and procedural improvements are still ongoing that will allow micro-CHP systems to grow into a significant market, with associated benefits for all.

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ABOUT THE AUTHOR

**Steve Gillette** is director of CHP Applications for Capstone Turbine Corporation, a company focused on the commercialization of microturbine power generation technology. Originally founded in 1988,

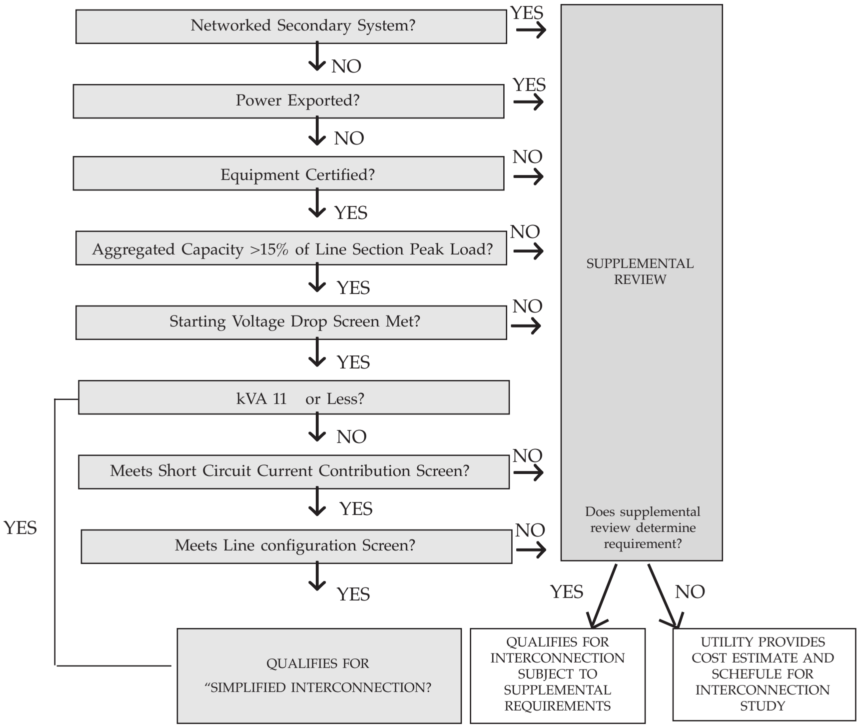

**Figure 11. California Rule 21 Process**

Capstone is a leading microturbine manufacturer. Prior to joining Capstone in 1999, Mr. Gillette served as president and chief executive officer of Statordyne LLC, a power quality equipment company in Texas. His experience also includes leadership positions at Siemens Energy and Automation. During his time at Siemens, Mr. Gillette managed marketing and application engineering functions for several business units including the company's protective relay business, advanced electronic development and switchgear and motor control centers. He also held managerial and engineering positions at the General Electric Company. Mr. Gillette holds a master's degree in electrical engineering from RPI and a bachelor's degree in mechanical engineering from Union College. Mr. Gillette can be contacted by electronic mail at sgillette@capstoneturbine.com.