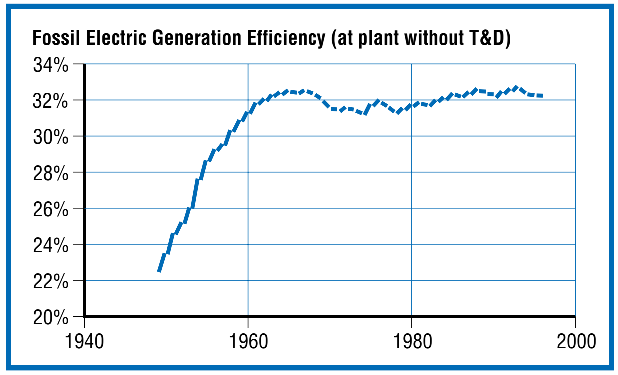
# COMBINED HEAT AND POWER

A Special Supplement to *Energy Matters*

## Combined Heat and Power—Power Production for the New Millennium

**What is CHP?**

Did you know that two-thirds of the energy required to make electricity in the United States never reaches its destination? This two-thirds is the heat that is vented in conventional power plants, which is why average efficiency of power generation in the United States has held steady at 33% since 1960 (see graph). The thermal losses in power plants total approximately 23 quadrillion Btus of energy, representing one-quarter of total energy consumption in the United States, enough energy to fuel the nation's entire transportation fleet. Industrial combined heat and power (CHP) systems utilize this waste heat for productive purposes. While this usually means heating and cooling buildings, CHP systems can also provide heat, mechanical power, dehumidifying systems, or compressed air for industrial and commercial applications. By making productive use of this wasted energy, CHP can achieve overall efficiency levels of 70% or greater. Productivity can be enhanced without a concomitant increase in energy consumption, pollutant emissions, or fossil fuel imports.



Source: Annual Energy Review (International Energy Agency, 1996)

*Figure 1*

So why aren't more plants installing CHP systems? Because the market and regulatory barriers are formidable. Interconnect requirements that vary by state or utility are one such barrier. This lack of standardization results in costly custom engineering efforts to make the CHP system compatible with the local grid. It also makes it difficult for equipment manufacturers to design and produce modular CHP packages. The Institute of Electronic and Electrical Engineers (IEEE) is examining interconnection standards to facilitate safe and easy connection of CHP to the grid.

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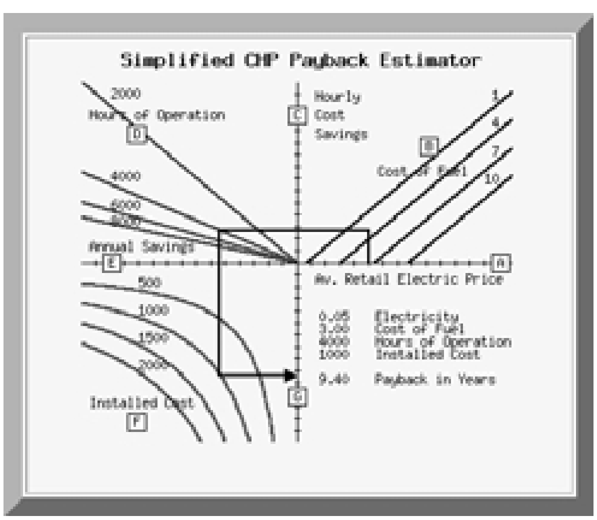
## Is CHP Right for Me? Find Out with the New CHP Web-based Screening Tool

Developing a CHP installation requires significant time, effort, and investment. It's prudent to approach the task in a series of steps. The beginning steps require less work, typically only one to two days, and help determine whether further efforts are justified. To help, a new analysis tool has been developed as part of the DOE CHP program. This tool, a self-operating nomograph, is available on the Internet at DOE's Office of Energy Efficiency and Renewable Energy's (EERE) CHP homepage (www.eren.doe.gov/der/chp/chp-eval.html) and will let you screen a potential CHP site to decide whether a detailed analysis is appropriate.



Source: Annual Energy Review (International Energy Agency, 1996)

*Figure 1*

This Web site also features a tool to help you assess the following feasibility issues:

- **Technical issues**—Are thermal and electrical loads sufficient to support CHP? Are these loads above a minimum size threshold? Are the electric and thermal loads coincident? Are thermal requirements compatible with CHP outputs?
- **Site conditions**—Can the facility infrastructure support a CHP system? Does it have the available space, fuel availability, and zoning limitations?
- **Economics**—Do the fuel and electric rates support CHP? What is the average retail electric price, fuel cost, and required return on investment or payback?
- **Environmental issues**—Are there any environmental limitations that would preclude CHP?

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## How DOE's Combined Heat and Power Challenge—an Industry and Government Partnership—Can Help

What was needed to increase the use of CHP systems was the development and nurturing of an energy infrastructure more conducive to the installation and operation of CHP systems than that which currently exists. In 1998, DOE Assistant Secretary for Energy Efficiency and Renewable Energy Dan Reicher issued the *CHP Challenge.* Its goal: Double the amount of power generated with CHP by 2010—an increase of 50 GW. This will result in a net energy savings of 1,276 Tbtus, 37 million metric tons carbon reduction, almost one million tons of sulfur dioxide emissions reductions, half a million tons of nitrogen oxide emissions reduction, and national savings of $5.5 billion. To make these phenomenal national benefits a reality, DOE's EERE and the U.S. Combined Heat and Power Association (USCHPA) responded to the charge. In collaboration with the Environmental Protection Agency, the International Cogeneration Alliance, the International District Energy Association, and the Distributed Power Coalition of America, a vision and a roadmap process for achieving the nation's CHP goals were launched.

The USCHPA Vision, established at last year's Vision Workshop, projects the hope that by 2020, industry and government collaboration will have created conditions favorable to CHP use throughout the country, including a CHP contribution of at least 200 GW to the nation's energy portfolio. A new fleet of energy generation technologies will be available, a large percent of which will be located in urban and suburban facilities. Open access will prevail, allowing for the open trade of energy and ancillary services for centralized, distributed, and on-site applications.

Since the Vision Workshop, a series of regional CHP roadmap workshops have been hosted by DOE. These workshops bring together key state and local officials with CHP developers and users to identify near-term actions to accelerate the use of CHP. Regional workshops have already been held in the midwest and northeast. A southern regional CHP meeting is currently being planned and will take place in Texas in May this year. Also underway are outreach efforts to inform key regional, state, and local decision-makers about the siting, permitting, and interconnection barriers that raise the costs of CHP development. Outreach activities have occurred in New York, Massachusetts, and Maine, and others are planned for New Mexico (May 2000) and Texas (September 2000). In addition, Washington, California, Indiana, New York, and Vermont have received grants from the Department of Energy to determine the potential and feasibility for CHP in their states.

The CHP Web site is rapidly becoming a national clearinghouse for information on CHP policies, markets, and technologies. One of the new features being developed is the *CHP Registry,* which will recognize CHP systems that have been installed since the announcement of the *CHP* goal. In addition to providing national recognition for these developers, the registry also tracks progress toward the goal. DOE established an online discussion database where interested parties or members of the CHP community can post questions and comments. The database address is http://eelndom1.ee.doe.gov/support/oitreg.nsf/HP?openform.

The U.S. Environmental Protection Agency is a critical partner in addressing the regulatory barriers to the use of CHP. There is now an Energy Star certificate and award program to recognize high efficiency applications and uses of CHP. Winners are expected to be announced within the next few months. Regional EPA offices have started to work with the states to address siting and permitting issues for CHP systems. EPA Region V was an active participant at the Lake Michigan Regional CHP Roadmap workshop as well.

On February 1 and 2, the First International Symposium for CHP was held in Washington, DC. A total of 265 participants from 20 countries attended the symposium showcasing cogeneration, distributed power, and district energy activities throughout the world. Interactive panels, facilitated discussions, case studies, and exhibits provided opportunities for all participants to meet and expand their knowledge on the barriers and successes of CHP internationally.

### Is CHP Right for Me?

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Considering the complexities of adding a combined heat and power system to your plant, how can this new tool be so simple? Remember that this is a screening tool, not a detailed evaluation. To make it simple, this tool includes many assumptions and simplifications. For example, it uses average fuel and electricity prices, thus neglecting the seasonal variations and demand charges that you may incur (and that a combined heat and power installation might help you avoid). It further assumes that: (1) your new equipment will produce electricity with a 30% efficiency, (2) your thermal load is equal to your electrical load and is currently met with a 95% efficient furnace or boiler, and (3) your operating and maintenance costs will be unchanged by the installation of the new equipment.

If your proposed application looks promising after the initial screening, the next step is a more detailed feasibility analysis. Also there are many publications and computer programs available to help. A summary of such resources can be found on the CHP Web site. If the results of the feasibility analysis are positive, the next step is to begin preliminary design. At this point, the cost projections should be sufficient to allow you to make an informed decision about whether a full CHP project design effort would make sense for your application.

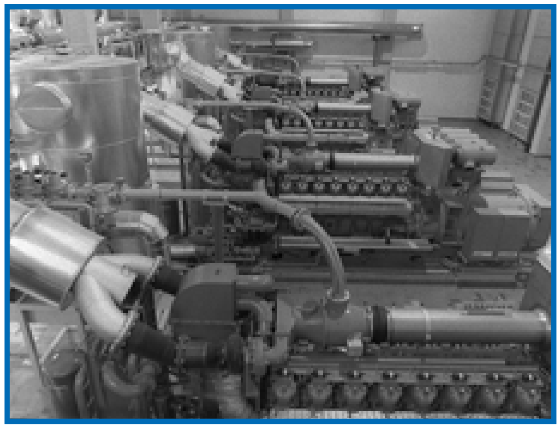
## The Technologies That Make CHP Tick

CHP technologies are numerous. Some of the more common are advanced turbines, reciprocating engines, microturbines, and fuel cells. In combustion turbines, heat in the exhaust is recovered by a boiler that generates steam, creating electricity or mechanical energy. Advanced turbines used for generation requirements of 500 kW or greater already boast high levels of efficiency and low emissions. Newer "microturbines," used for generation requirements below 500 kW, are more compact, lightweight, reliable, and fuel-flexible. By 2005, the goal for these combustion turbines is 40% efficiency and single-digit emissions, with system costs below $500/kW and equivalent reliability. Additional technologies include BCHP, or Building Cooling Heating and Power, which includes:

- **Absorption chillers:** improved in terms of efficiency, reliability, and costs, making absorption chillers a high added-use of recovered heat
- **Engine-driven chillers:** proven to be the most efficient direct-drive machines on the market, have improved in reliability and operating ease through use of microprocessor controls. Similar advances have been made in **engine-driven air compressors.**
- **Desiccant dehumidification:** ventilation air conditioning technology is becoming recognized as a key solution to indoor air quality problems and can effectively be incorporated into building a CHP system.

**Reciprocating Engines**

Of the micropower technologies, reciprocating engines were commercialized first, over a 100 years ago, and have long been used for electricity generation. They are the fastest selling distributed-power technology in the world today. Engine manufacturers are enhancing production capabilities in anticipation of new orders as distributed


Courtesy Clark University

*Reciprocating Engine*

generation technologies are chosen by more manufacturers both here and abroad. Institutions, large industrial establishments, and commercial buildings have used reciprocating engines with fractional horsepower all the way to 60 MW. Existing engines achieve efficiencies in the range of 30% to greater than 40%. Further improvements are possible in efficiencies and lowered emissions, and there are opportunities to use bio-based fuels in place of petroleum and liquids and gases derived from natural gas. The CHP goal for this technology is natural gas-based engines with greater than 50% efficiency and single-digit emissions by 2006.

Reciprocating engines are generally 4-stroke engines; cars, generators, and industrial plant machines use this technology. In the compression cycle, as the piston moves downward in its cylinder, the intake valve opens and the upper portion of the cylinder fills with fuel and air. When the piston returns upward in the compression cycle, the spark plug emits a spark to ignite the fuel. This explosion causes a downward motion of the piston, creating power output. In the exhaust phase, the piston moves back up to its original position as the exhaust is expelled.

**Fuel Cells**

Fuel cell power systems are an emerging class of technologies that convert chemical energy directly into electricity, producing almost no pollution. Heat is a by-product of the reaction and can be recovered in much the same way as in combustion-based systems. The CHP technology focus for fuel cell systems is for application in buildings. CHP goals for fuel cells include operation at higher temperatures and pressures through the development of new membranes and catalysts and the ability to operate using natural gas or methane, made possible by new reformer technology.

There are four types of fuel cells: Proton Exchange Membrane (PEM), Phosphoric

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Courtesy Plug Power

*A home equipped with fuel cells*

Courtesy Solar Turbines

*Advanced Turbines*

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Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), and Solid Oxide Fuel Cells (SOFC). The main differentiation among fuel cell types is in the electrolytic material. Each electrolyte has advantages and disadvantages based on cost, operating temperature, efficiency, power-to-weight ratio, and other operational considerations. PEM fuel cells, the most ubiquitous of the bunch, are being tested in homes to support residential loads. These fuel cells are also most commonly used in testing for transportation efforts. Its power-to-volume ratio makes it appealing for hybrid electric vehicle research and development. The PAFC and MCFC fuel cells are primarily used for larger scale power production.

**Advanced Turbine Systems**

A gas turbine is a heat engine that uses a high-temperature, high-pressure gas as the working fluid. Part of the heat supplied by the gas is converted directly into mechanical work of rotation. In most cases, the hot gases reduced to operating a gas turbine are obtained by burning a fuel in air, which is why gas turbines are often referred to as "combustion" turbines.

Because some are compact, lightweight, and simple to operate, gas turbines have been widely used, notably in jet aircraft and electricity generation. Gas turbines are used in industrial and utility settings to produce electricity and steam. (Many industrial processes require steam in addition to electricity.) In such cases, "simple cycle" gas turbines convert a portion of input energy to electricity and use the remaining energy to produce steam in a steam generator. For utility applications, requiring maximum electric power, a "combined cycle" steam turbine is added to convert steam to electricity.

**Microturbines**

Microturbines are machines ranging in size from 30 kW to 500 kW, which include a compressor, combustor, turbine, alternator, recouperator, and generator. They have the potential to produce power on sites that have space limitations. Waste heat recovery can be used with these systems to achieve efficiencies greater than 80%. Microturbines offer a number of potential advantages compared to other small-scale power generation technologies. These advantages include a small number of moving parts, compact size, light weight, opportunities for greater efficiency, lower emissions, lower electricity costs, and the use of waste fuels. Microturbine technology is still relatively young and testing is not at a point where precise emissions and efficiency can be derived. Estimated efficiency is approximately 26%-30% when not accompanied with a heat recovery or combined heat and power module.

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. The machines generally rotate over 40,000 rpm, which can lead to very high stress areas. The bearing selection, whether the manufacturer uses oil or air, is dependant on usage. Generally, oil bearings last longer and are less prone to catastrophic failure, especially when the power is being ramped up and down frequently. Air bearings require less maintenance and do not require an oil system and pump. Single shaft or split shaft is another design consideration. 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 power.

Courtesy Capstone Turbine Corporation

*Model 330 MicroTurbine*

### Malden Mills

*(as featured in July 1999 issue of* Energy Matters*)*

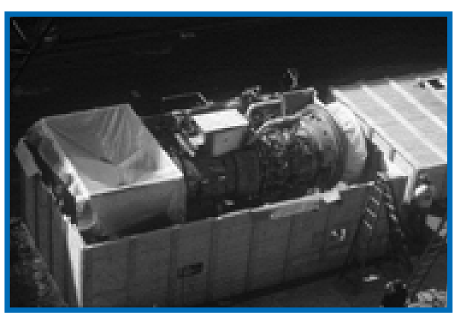
Courtesy Malden Mills

*Malden Mills Textile Plant*

In 1987, Malden Mills, a 2-million-square-foot Massachusetts textile plant that manufactures Polartec™ fleece clothing, was purchasing its steam and electricity from a source recovery facility. Unfortunately, the facility was unreliable, subjecting the plant to occasional power loss, made even more unacceptable by an increasing market demand for Polartec™ products. Additionally, new pollution emission limits endangered the source recovery facility's continued viability. The company began to consider generating its own electricity, steam, and heat on-site. By 1992, Malden Mills had developed a plan for a 12-megawatt CHP system based on combustion turbines and fired by natural gas, for heating and possibly cooling. Over the next several years, the company waded through the discouraging permitting process with the Massachusetts Department of Environmental Protection (DEP), who rejected Malden Mills' application and further required the plant to use an expensive, ammonia-based exhaust-gas after-treatment technology to meet the states new nitrogen oxides emissions standard. This prospect was both economically and environmentally unattractive to Malden Mills, and they appealed the DEP decision in 1993.

In 1995, fate changed everything. A fire ravaged the plant, leaving it almost inoperable. Company CEO Aaron Feuerstein, whose grandfather started Malden Mills in 1907, drew national attention to the plight of his company by pledging to keep all the plant's employees on the payroll and rebuild the plant. Reporters, politicians, and even President Clinton focused on Malden Mills, and many local and national leaders offered assistance. DOE stepped in and advised Malden Mills that an ultra-low nitrogen-oxide CHP system based on advanced turbines would meet the state's new requirements. DOE then helped Malden Mills negotiate an agreement with the DEP by calling use of the CHP systems a "technology demonstration" program. The plant was able to obtain hundreds of state, federal and local permits in record time. Massachusetts restructuring legislation, passed in 1997, removed the final hurdles to installation. In late 1998, Malden Mills installed two 4.3 MW commercial turbines manufactured by Solar Turbines, a partner of DOE's Office of Industrial Technologies Advanced Turbine System (ATS) Program. A year later, both turbines were retrofitted with a ceramic combustor liner, also developed by ATS, that reduces nitrogen oxide emissions by an additional 40%. The project is currently in a two-year demonstration period for assessment of the technology. An independent analysis found that the CHP system, compared to Malden Mills' old system, will virtually eliminate sulfur dioxide emissions, reduce overall nitrogen oxide emissions by 75%, and cut carbon dioxide emissions by 25%.

### Massachusetts Institute of Technology



Courtesy MIT

*22 MW Natural Gas CHP System*

In the late 1980s, the Massachusetts Institute of Technology (MIT), faced with rising electricity costs and increased demand, as well as a desire for reliable power for research facilities, decided to install a CHP system on its Cambridge campus. At that time, MIT was purchasing electricity from the local utility and generating steam for heating and cooling with oil and gas fired boilers at a total annual cost of $14 million. The university selected a 22-MW natural-gas-fired CHP system that would be 18% more efficient than the technology it replaced. The system was designed to meet 94% of MIT's power, heating, and cooling needs while cutting its annual energy bill by 40%. In addition, by making it possible to retire old, inefficient boilers, the CHP system would reduce annual pollutant emissions by 45%.

Despite these clear environmental benefits, MIT still had to overcome the objections of state regulators who required further reductions in nitrogen oxide emissions in order to comply with standards designed for much larger power plants. The project was allowed to move forward only after the university completed a sophisticated life-cycle assessment showing that its innovative system had lower net emissions relative to the state-approved technology. After completing construction in 1995, further roadblocks emerged in the form of a "customer transition charge" of $3,500 per day levied on MIT by the local utility to recoup the revenue lost as a result of the university's switch to self-generation. Fortunately for the university, Massachusetts restructuring legislation eventually exempted CHP generators from such exit charges. After three years of operation, the system continues to produce clean, reliable power while saving MIT $5.4 million a year.

### Walgreens

Energy USA-TPC, a subsidiary of NiSource, wanted to provide a complete energy service that included electricity and thermal energy for heating, air conditioning, and hot water. Therefore, at a meeting with executives from Walgreens, the nation's leading drugstore chain, an agreement was made to install an experimental microturbine with CHP. This unit, installed on the roof of one of the retail pharmacy's buildings in Chesterton, Indiana, was thought to be the nation's first of its kind.

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## CHP—Power Production for the New Millennium

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Restructuring of the electric utility industry plays a large role in two barriers to widespread deployment of CHP systems. First, the customer-sited power generation that CHP makes possible typically requires a backup source of power, for which utilities currently charge high and sometimes arbitrary fees. In a restructured environment, these fees will be open to competition, which will drive them down and make installation of a CHP system a more attractive option. The second restructuring-related issue is stranded costs, which entitle the utilities to recover some or all of the costs of stranded assets via fees charged to their customers. If these fees are applied to CHP facilities, the economic appeal of CHP systems will be reduced, delaying widespread implementation.

An additional financial barrier to CHP installations is existing tax policy in many states. On-site generation systems do not fall into a specific tax-depreciation category, resulting in depreciation periods ranging from 5 to 39 years. Such policies discourage certain types of ownership for some and increase the difficulty of raising capital for others. The U.S. Treasury Department is investigating the possibility of a tax credit for CHP installations.

CHP's potential to reduce overall emissions of greenhouse gases and other air pollutants is mistreated by current environmental regulations that reward existing generation facilities for limiting emissions and/or reducing their concentration in exhaust streams from specific sources. This approach does not credit CHP with the emissions reductions associated with decreased consumption of electricity from the grid offsetting emissions at the central station plant.

Another environmental barrier to be overcome is treatment of CHP projects by air quality and permitting agencies. Permitting requirements and air quality standards vary widely from one jurisdiction to another and the permitting process is usually lengthy, complicated, and expensive. Site permitting for CHP facilities is equally frustrating, due to location-specific and inconsistent rules, regulations, and procedures. Permitting requirements, including analysis of impacts on water, noise, land use, and fire safety, have been developed for large baseload projects or backup generators. These requirements are completely inappropriate for small CHP systems and reflect a general unfamiliarity with CHP technologies and applications.

Unfamiliarity with CHP technologies is a barrier in its own right. Although CHP technology is hardly new, it has historically been used in large industrial applications. Smaller-scale industrial, commercial, institutional, and residential systems need to be tested and improved. Systems integration of these smaller systems will expand the possibilities for market applications. Improvement of information and communication systems and other enabling technologies will help expand potential CHP markets by enhancing grid operations through the use of remote and automated controls.

There is a tremendous opportunity to greatly increase the use of CHP over the next twenty years, bringing about substantial economic, energy, and environmental benefits for the nation as a whole. Although the technical performance and affordability of CHP systems have greatly improved, significant barriers limit widespread use of CHP in the United States. In order to address the regulatory and market barriers associated with CHP, DOE's Office of Energy Efficiency and Renewable Energy, in partnership with industry, established the CHP Challenge. *See related story on page 2.*

## Conclusion

Clearly CHP is a potentially ubiquitous technology capable of dramatically changing the way we produce and use energy. The Department of Energy and its industrial partnerships' continued support of this program has allowed for auspicious growth in a variety of settings, from large industrial facilities to small commercial establishments. The regional workshops and road-mapping efforts that these partnerships have sponsored will continue to facilitate the implementation of CHP both nationally and internationally. Moreover, there is a bright outlook for this exciting area of energy production and utilization. These energy-efficient, economical, and environmentally friendly units will streamline and modernize the way we use energy in the future!

## CHP Sucess Stories

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Courtesy: NiSource

*28kW CHP Microturbine System*

NiSource and Walgreens are on the cutting edge of developing the next generation of BCHP systems.

NiSource Inc. installed a 28-kW microturbine and since August 12, 1999, the natural gas-fired unit has provided 33% of the buildings electric, heating, air conditioning and hot water needs. The system started with an exhaust heat powered absorption chiller and heating system; now an exhaust heat powered desiccant dehumidification unit is currently being integrated. NiSource paid for the initial costs of the unit and installation for the system. Walgreens has been responsible for no more than the cost of fuel, a charge they were paying before. Power outages can be costly for establishments like Walgreens; this new system, which operates around the clock, could maintain power during an outage.

While this example pertains to a commercial building, microturbines that utilize CHP can also be used in industrial settings. Industrial demonstrations are expected as microturbines emerge into the market this year. Fuel cells are also in a prototype developmental stage and are expected to become commercially available by 2005.