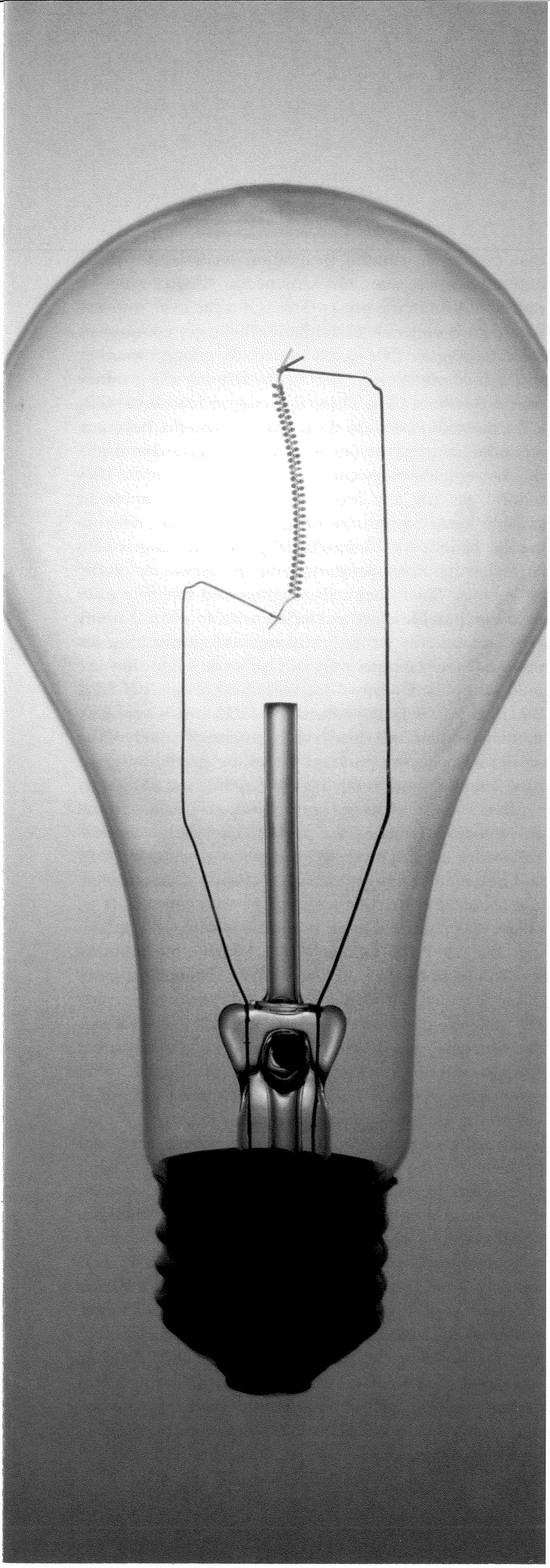


Small-Scale Distributed Generation Technology

By Robert A. Panora

Evaluating projects requires looking at many factors. However, as with most things, cost is the biggest consideration.

The term distributed generation (DG) applies to a variety of technologies that produce electric power in small, factory-assembled packages, designed to operate under an often nearly-continuous duty cycle. Two groups of products fall under this classification: "renewables" like solar and wind-powered equipment, and "conventionally-fueled" devices like reciprocating engines, microturbines and fuel cells. Renewables provide electricity without consuming a conventional fuel, which is their foremost benefit. The operator is spared a monthly utility bill while gaining some reward—not yet in monetary terms, however—in the knowledge that this power is not contributing to global warming, or to the depreciation of the earth's fossil fuels.

The second DG group, which will be reviewed here, includes systems that more commonly use pipeline natural gas, although they may be powered by a non-utility fuel, such as landfill gas. Despite this general dependence on the utility system, the microturbines, engines and fuel cells provide the same compelling advantages as the renewables: reduced energy usage with a substantial benefit to the environment.

DG AND COMBINED HEAT AND POWER

At first glance, it may not be obvious why an engine, microturbine or fuel cell would have an efficiency advantage over a central power plant. In fact, they do not, as far as their relative amount of fuel consumed to electricity produced is concerned. They are all in the 25% to 37% efficiency range, which is more or less the same as a typical power plant. The advantage these small-sized DG units provide is that they can be located close to the electric loads they serve. This allows the large quantity of low-grade waste heat that makes up the 63% to 75% balance of the energy not converted into electricity to be applied to onsite thermal processes. This mode of operation, where the electrical energy and thermal energy is produced concurrently, is referred to as cogeneration or combined heat and power (CHP). The efficiency benefit from a properly balanced CHP installation is approximately 90%, a significant improvement over conventional approaches.

The advantage these *small-sized DG units provide is that they can be located close to the electric loads they serve.*

Utility power plants also could apply this principle of heat reclamation, which was, in fact, common in the early era of power plant design. Their evolution since then has moved consistently toward larger, more centralized power stations that take advantage of their scale to reduce overall capital cost. This centralized nature, almost by definition, isolates these plants from possible heat reclamation opportunities and limits their overall efficiency to that of their single-purpose electrical generation system. For steam-turbine generators, the practical efficiency limit is about 40%. Recent advances in aircraft engine technology have resulted in the introduction of combined-cycle electric power plants that just exceed 50% overall efficiency by driving steam turbines with exhaust heat from gas turbines. Today, this represents the best efficiency of a single-purpose central power plant, still far less than the 90% efficiency level routinely achieved in CHP installations.

EMISSIONS

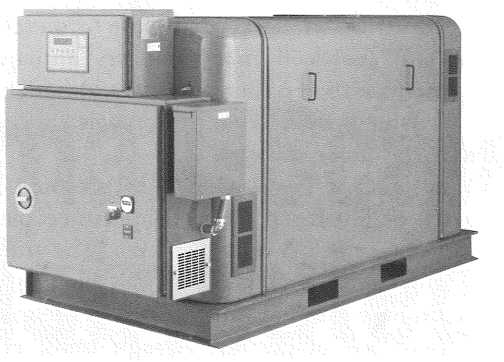
The primary man-made culprit in the global warming debate is carbon dioxide (CO_2). There is a common misconception that certain distributed generation technologies using natural gas can somehow circumvent CO_2 production while still producing power. This is not the case, unfortunately. Each molecule of methane (the major component in natural gas) that is converted to energy, whether through combustion or fuel cell reactions, will produce one molecule of CO_2. There is no way around this—CO_2 is the desired product in these reaction systems, not some secondary byproduct (such as smog-related chemicals) that better technology can correct. When any device uses natural gas (or any fossil fuel) to produce power or provide heat, it produces CO_2. Therefore, the environmental benefit to DG insofar as global warming is concerned is in direct proportion to the efficiency of the technology. Since fuel cells, engines and microturbines have comparable electrical efficiencies to central utility power plants, the strong environmental justification for these DG technologies only can be made when they are used in applications involving waste heat recovery (CHP). When so applied, however, the justification is very substantial, and makes distributed generation one of the most promising methods of curtailing greenhouse gas production without reducing our baseline use of energy.

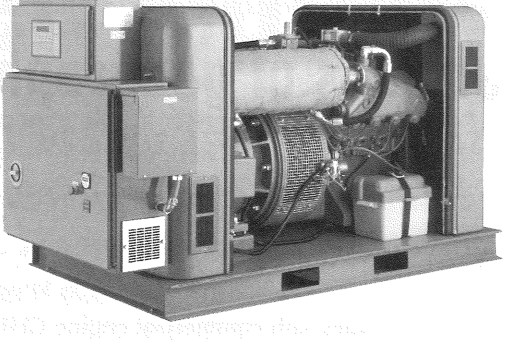
The commonly regulated pollutants from natural gas-fueled equipment—the preventable side reactions—are oxides of nitrogen (NO_x), carbon monoxide (CO) and non-methane hydrocarbons (NMHC). Current regulations in the strictest regions of the country (e.g., California) require that emissions be less than the following: NO_x: 9 PPM, CO: 60 PPM, NMHC: 30 PPM. All the DG technologies do very well in controlling emissions. Engines are able to meet these standards using the well-developed catalyst technology used in vehicles1. Microturbines are likewise able to do so, but without exhaust after-treatment because of their very clean combustion systems. Fuel cells have almost negligible emissions, certainly one of their key features. Future toughening of pollution standards may be a particular problem for the microturbines; exhaust after-treatment with a catalyst to further reduce NO_x is precluded by their lean combustion design, while alternative methods developed for large turbines do not appear to be viable on a small scale. With regard to pollution and DG technologies, however, the real story of their benefit relates to their very high efficiency in CHP applications. Consider, for example, a DG unit producing electricity at a 33% efficiency rate, while emitting 5 PPM NO_x. In this mode, the DG unit is nearly equal to the utility power plant in emissions. However, when the waste heat is recovered, a substantial pollution source—the water heater or boiler—is eliminated.

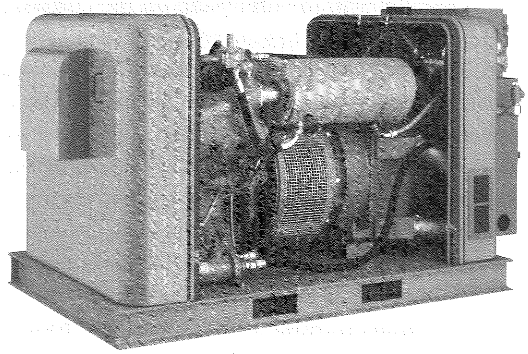
COMPARISON

While the emission benefits of DG are useful arguments for government policymakers for deciding where incentives and research dollars should be applied, real DG customers are, of course, driven by economics. The bottom line for DG projects is their payback—will the equipment save money relative to a conventional energy approach? In this regard, a meaningful comparison of these technologies needs to consider the characteristics that affect a DG project's capital investment operating economics:

- Electrical Efficiency (based on the lower heating value of natural gas, LHV). The published efficiencies of phosphoric-acid fuel cells—the type currently available in a commercial (200 kW) size—are about 37% based on their relative electric output to natural gas consumed, their value being compromised by the energy expense in "reforming" the natural gas into hydrogen, their base fuel. Turbocharged engines are within a few points of fuel cells and about 31% when naturally aspirated (i.e. non-turbocharged). Microturbines are the least efficient at 25%, less than their larger counterparts due to their low pressure ratio designs and frequent need for high pressure natural gas (the pressure booster uses electricity). Electrical efficiency is more important than thermal efficiency because the electrical energy is the "premium" valued product from the DG unit.
- Overall Efficiency (thermal plus electrical, and LHV). Using 200 F as the typical temperature for a heat recovery process, an overall efficiency of 90% is a practical goal for CHP systems. Indeed, engine-based systems are often in this range. The phosphoric-acid fuel cell has about half its waste heat available at this temperature, giving it an overall efficiency of approximately 60%. Higher fuel cell efficiencies are often quoted, but this is achievable only when a use can be found for the remaining heat energy that is available at a cooler, less useful temperature (140 F). Microturbines are about 70% efficient on an overall basis when used in 200 F recovery applications, somewhat less than what would be expected; this is likely due to the high air dilution of the exhaust stream which, although beneficial in reducing NO_x formation, leaves the exhaust effluent from the heat reclaim system carrying a lot of unrecoverable energy in the form of warm air.
- Equipment Cost: Hard-cost numbers generally are not published. However, engine CHP packages are available for less than $1000 per kW. Suffice it to say that newer technologies such as fuel cells and microturbines are still considerably more expensive than engine systems. The basic components used in engine DG systems, of course,







Photos courtesy of Tecogen

are manufactured in extremely large quantities for the vehicle/construction market (gasoline or diesel). Microturbine and fuel cell manufacturers anticipate cost improvements as their volume increases, although this hurdle is substantial, since these technologies are without a related, high-volume industry.

- Maintenance Costs: Generally accepted rules of thumb for engine-based CHP maintenance place these costs to the user at 2-3 cents per kWh. The true maintenance costs of fuel cells and microturbines in the CHP application have not yet been revealed in the true market sense—there are simply not enough units, competing companies and hours logged to really know. The promise of lower maintenance costs is a promised feature of the microturbine and fuel cell technologies due to their minimal moving parts. However, it would be naïve to presume these costs would be insignificant for these new technologies as they really have substantial maintenance-prone components (electronics, fluid systems).

> **Regardless of geography,** *the best applications will be those where lots of low-grade thermal energy is used.*

Gas industry studies with commercial engine CHP systems revealed that the majority of service costs were outside the prime mover (electronics, heat recovery equipment, etc.). Since all the DG technologies share these items, it would seem reasonable that the lower limit for fuel cell and microturbine CHP systems is1.0-1.5 cents per kW.. The best economics for DG systems are when they operate in parallel with the utility and on the customer side of the meter.

Another consideration in selecting a DG system is permitting. The permit most unique to DG is the utility interface permit, often a contentious issue. In the past, DG manufacturers and their customers were often frustrated by inconsistent standards and requirements for power plant grade protection devices.

However, in recent years, due to the undeniable benefits of distributed generation and improvements in the technology, a national interconnect standard to which all DG technologies can be certified was developed under the Institute of Electrical and Electronics Engineers with DOE funding: IEEE P1547. The importance of this standard and its adoption cannot be overstated since it potentially will ease this difficult project step. Customers evaluating DG units for purchase should check for product certification to this standard through a national testing laboratory.

The economics of a distributed generation system with CHP usually hinge on a very high utilization factor for the equipment: 75% or better at full load with purposeful application of the waste heat. In areas of the country with expensive electricity, however, considerably less utilization may suffice. Regardless of geography, the best applications will be those where lots of low-grade thermal energy is used: hospitals, nursing homes, schools, municipal pools, hotels, and certain industrial processes. Methods of utilizing the thermal energy for cooling, such as desiccants and absorption air-conditioners, are becoming more cost-effective and are opening up new CHP applications.

In any case, the best economic strategy is to size the CHP system to meet the base year-round thermal load. While it is often tempting to increase the installation size beyond the thermal needs of the facility, this usually dilutes the economics, except in regions with high-cost electricity. Three forces inevitably will drive DG/CHP in the 21st century: an ever increasing cost of electricity, the need to reduce global production of carbon dioxide, and the difficulties electric utilities will have in expanding their electric transmission systems.

The DG technologies reviewed here offer very viable means to alleviate these ever expanding problems in a way that is positive from any perspective: environmental, conservation of resources and user economics. ■

***Robert A. Panora** is the president and COO of Tecogen Inc., a U.S. distributed generation company. He holds BS and MS degrees, both in chemical engineering, from Tufts University. He can be reached at* rpanora@tecogen.com; 781.466.6401.

HART
ENERGY MARKETS
Global Solutions For Integrated Energy Executives