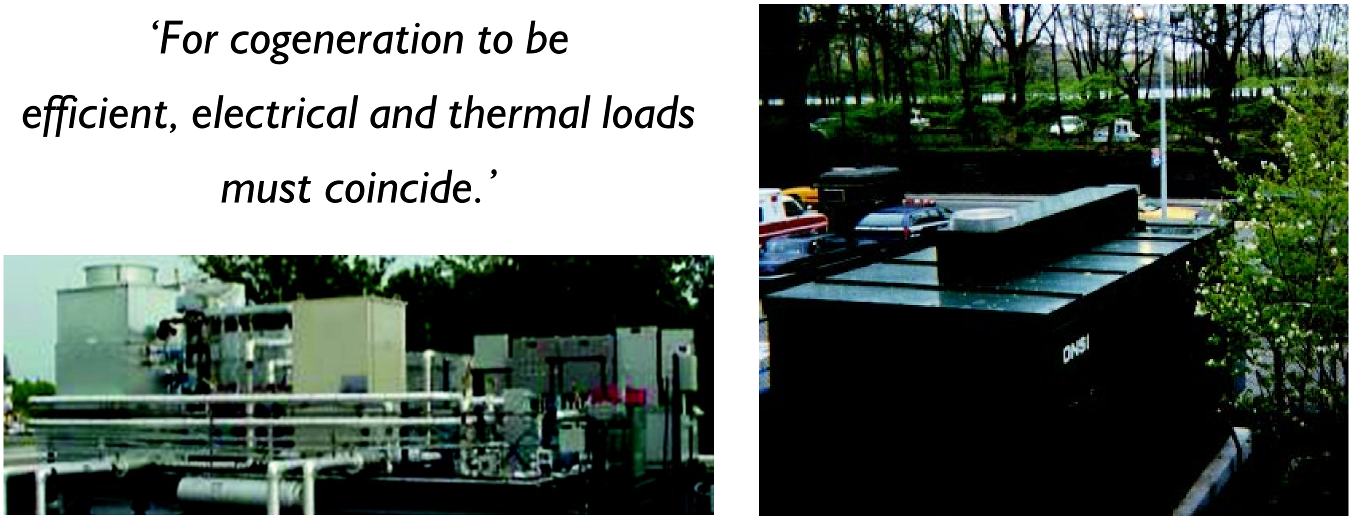
ASHRAE Journal

‘For cogeneration to be efficient, electrical and thermal loads must coincide.’



(Left) Early test of small cogeneration featuring a microturbine and absorption chiller on the roof of an Indianapolis drugstore. (Right) Fuel cell in Central Park in New York.

Economics of Cogeneration

By William Ryan, Ph.D., P.E.

California’s power supply crisis in 2000 alerted the energy industry to the problem of summer peak power supply. Merchant plant developers initiated major capacity expansions, which were expected to solve the problem. However, recent concerns on Wall Street about the energy industry have placed many of these new power plants projects in doubt, and reignited concerns about limited peak summer power supply.

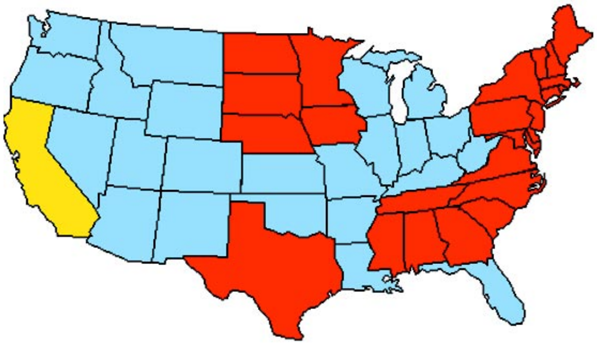


Figure 1: States in red facing less than 10% capacity margin within 10 years (DOE).

These events point to a major defect in current deregulation transition plans. The original concept was that:

- Transitioning to a free electric market would provide price signals that should, in the long term, make the market much more efficient.
- As prices fluctuate freely in response to supply and demand, end users will modify their consumption patterns in response to these price signals.
- Similarly, merchant plant operators will respond by generating more electricity as prices reach desirable levels.

However, merchant plant developers are not motivated to intentionally provide reserve power plants. What was “reserve capacity” in a regulated market (and paid for as part of the rate-base) is “excess capacity” in a deregulated market.

Building power plants that run infrequently will not be economically attractive unless peak power can be sold for a very high price. Therefore, during peak demand periods, power will become very expensive. This effect was predicted as early as 1995.

“Because customers value electricity so much, demand and price during peak periods can be way above average levels.… Hourly prices might fluctuate well above the levels seen to date.[1] and

“During a critical period of peak demand on a hot summer afternoon, for example, the marginal cost of power may increase 20 to 50 times.”[2]

According to the North American

About the Author

William Ryan, Ph.D., P.E., is senior researcher at the Energy Resources Center/Midwest CHP Applications Center, University of Illinois at Chicago.

Electric Reliability Council (NERC), *"Capacity adequacy in North America over the next ten years will be highly dependent upon the construction of new generation resources and innovative use of controllable demand-side resources. Most of the new generation is expected to be constructed by merchant developers."*[3]

However in the same source, *"Capacity additions are increasingly being driven by market signals and not the maintenance of a prescribed capacity margin. This will likely lead to fluctuations in capacity margins that reflect normal business cycles experienced in other industries."*

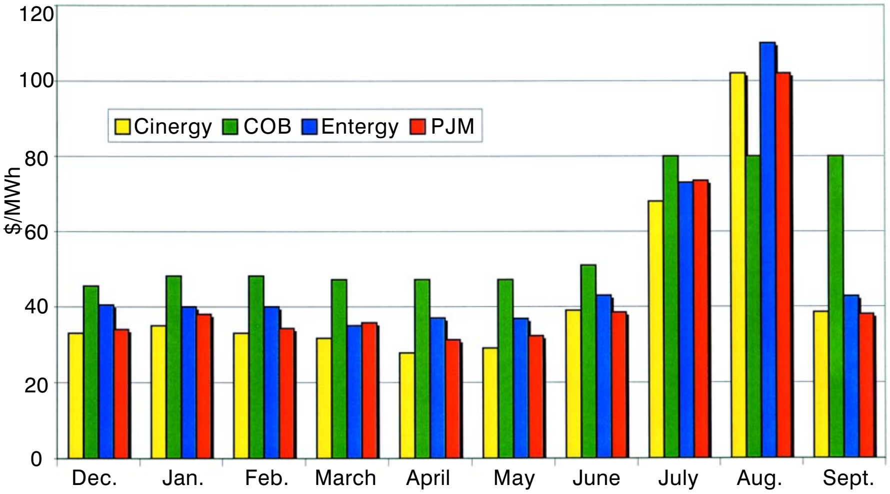


Figure 2: Wholesale prices for electricity as of 11/5/01. The pattern of consistently elevated summer prices has been present for the last three years. Each color represents a differing exchange point.

Why is there so much concern about summer power usage?

Overall power consumption patterns in areas across the country show that summer peaking is nearly universal and is the result of the air-conditioning load. Hot weather brings on all air-conditioning loads in a region nearly *simultaneously*, whereas other loads may be much more randomly timed.

A typical commercial building load can vary significantly. In the cooling season, a commercial building can hit electric loads that are twice that of the peak winter load.

One solution to the summer load is to build peaking power plants. However, from the merchant plant owner's point of view, peak summer periods may be only 500 hours per year (roughly 10 weeks of on-peak weekday service). This results in a fairly high per kWh operating cost just to cover the capital investment.

This high cost has led to concern that large areas of the country will have insufficient reserve capacity margins in the near future (*Figure 1*).

The effect this has on the market for electricity can be seen easily in the futures prices for wholesale electricity (*Figure 2*).

Parameter	Value
Energy Costs Assumed	
Gas Cost	$0.40/Therm
Electric Energy (On-Peak)	$0.05/kWh
Demand Charge (Summer)	$16.41/kW
Demand Charge (Winter)	$12.85/kW
Electric Standby Charge	$2.99/Mo./kW of Generation
Energy On-Peak Period	10:00 – 22:00(M-F)
Demand On-Peak Period	10:00 – 18:00(M-F)
System Operation	Operated During On-Peak Demand Period Only
Equipment Assumed	
Generator Drive	Natural Gas Driven Engine
Base Case Building	Gas Heating and Water Heating by Conventional Boiler, All Electric Chillers
Use for Waste Heat	
DG	None
CHP	Building Space Heating and Water Heating
BCHP	Same as CHP Plus a Single Stage Absorption Chiller Sized for the Available Waste Heat. All Remaining Cooling Load Is Run By Electric Chillers

Table 1: Values used for economic analysis.

The Market Defect

In the long term, end users will learn to reduce consumption during peak summer periods. However, this transition could be difficult and lengthy because:

- End users have developed consumption patterns in response to regulated electric rate-based pricing schemes that traditionally did not heavily penalize peak consumption and poor load profiles,
- The construction industry is entrenched in building practices that reflect current end user requirements, and
- When a new building is constructed, HVAC equipment within that building has a life of 20 or more years.

Therefore, new buildings constructed today will tie end users into a uneconomical pattern of poor load profiles and high summer electric peak power consumption for 20 or more years. Even with the slower, more cautious path to deregulation taken by most states today, transitioning the cooling market to deregulation requires that the construction industry be transformed as quickly as possible. The question is how?

Onsite generation and cogeneration systems have been constructed for large campus or municipal applications for decades. These systems generate power onsite and provide cooling as a waste heat driven by-product, making them a natural for solving the summer peak power problem. Cogeneration also improves overall fuel use efficiency and reduces emission of carbon dioxide. The challenge is to make cogeneration practical for an individual building. These technologies need to be made practical in much smaller sizes.

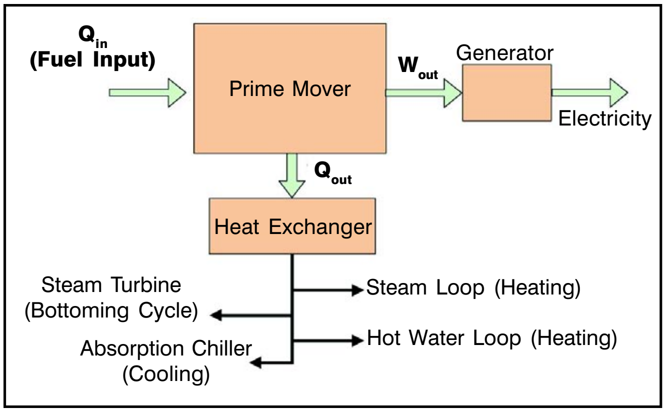


Figure 3: Cogeneration system.

New Small Power Generation Technologies

A wave of new technologies is being prepared or is entering the market. The initial reaction has been the development of small low maintenance electric generating systems to "peak shave" away volatile electric price concerns. Microturbines are sized in the 28 to 350 net kWe range, and unlike larger power turbines, generally use a heat recuperater. This allows these low pressure, and lower cost turbines, to operate at practical efficiencies in the 25% to 30% range.

A more technically challenging approach to small power generation is fuel cell systems. In recent years, fuel cells have been under intense development for automotive applications. With the new interest in onsite generator packages, some of the developers are devoting significant effort to stationary applications.

A far more efficient approach is to fully use the waste heat from these generators to heat and cool. This would bring the additional efficiency advantages of cogeneration systems to these smaller systems (*Figure 3*).

The strength of this approach is the use of the heat normally wasted in the generation process to perform a useful function. This allows the system to have overall efficiencies far higher than any central generated plant (*Figure 4*).

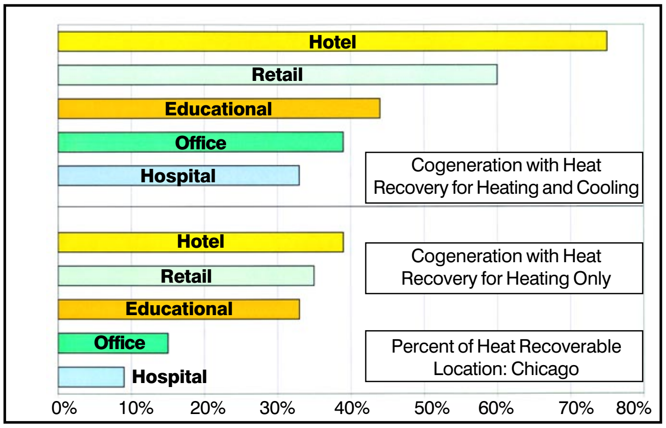


Figure 5: Adding thermally activated cooling makes all the difference. Figure shows how much the recovery heat varies by building function. Values are for typical buildings in Chicago.

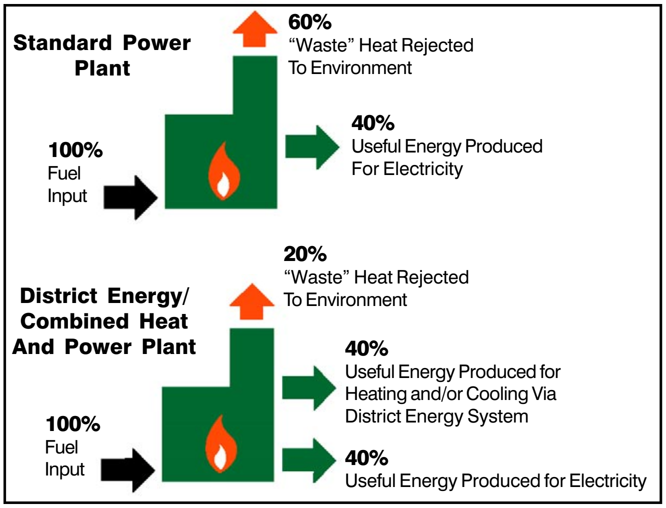


Figure 4: The advantage of efficiency. The overall efficiency of the combined heat and power approach can exceed 80%. This is only possible where the generator is located at or near the facility and waste heat can serve the heating and cooling load. Even the highest efficiency electric utility plant barely exceeds 40% to 45% (figure courtesy of DOE).

Making Efficiency Promises Real

For cogeneration to be efficient in a real application, electrical and thermal loads must *coincide,* and this varies depending on the type of facility and the local climate. This determines how much heat can be productively recovered to serve building loads.

Figures 5 and *6* give a national overview of how much heat could be recovered. The values shown are the percent of waste heat that can be productively used for building thermal loads from a continuously running engine-generator sized to handle building electric demand. Two sets of numbers are shown:

- For buildings where waste heat can only be used for space heating loads, or
- For buildings where waste heat can meet some of the cooling load via a single effect recovered heat-driven absorption chiller.

Chart compares a short operating schedule load, an office building, to a 24-hour load, a large hotel. The greater number

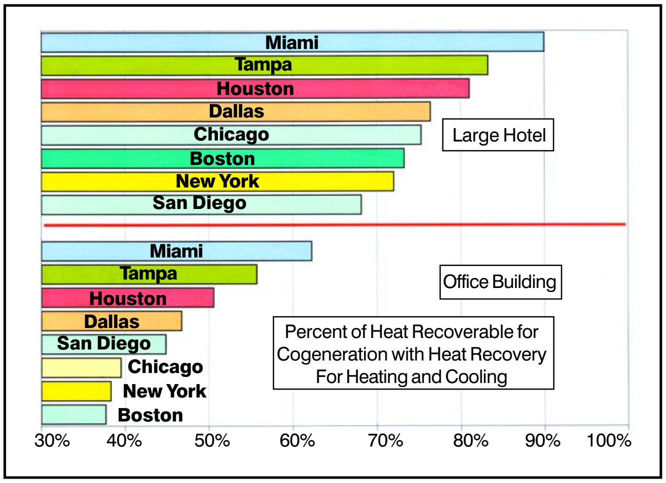


Figure 6: The load's nature is more important than climate.

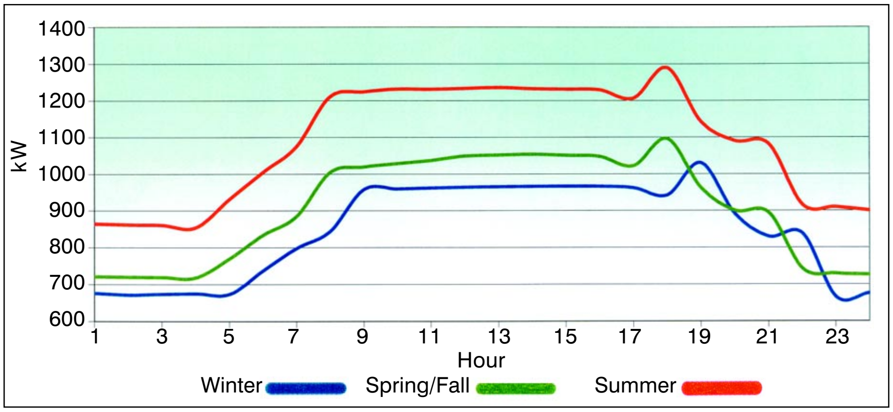


Figure 7: Seasonal load profile for hospital load.

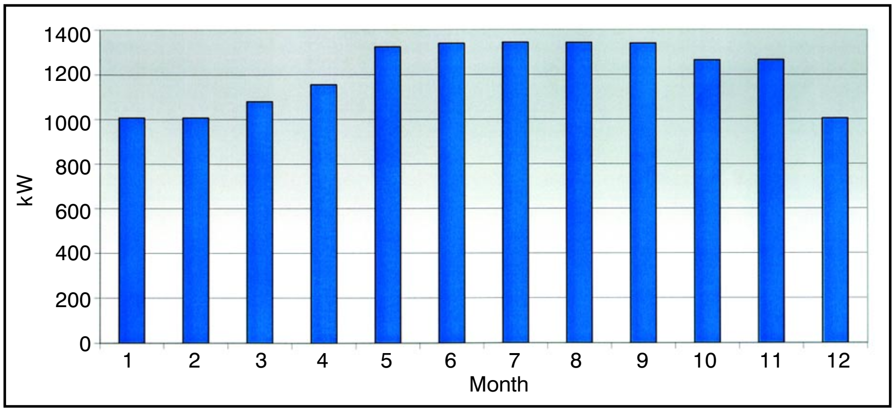


Figure 8: Maximum monthly demand for hospital load.

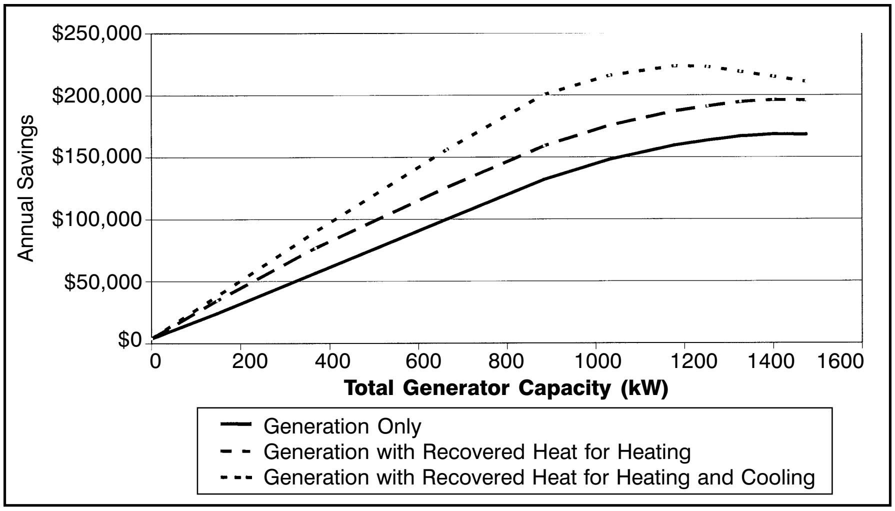
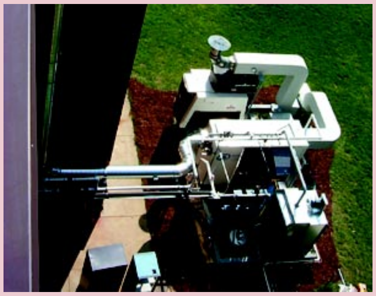


Figure 9: Estimated operating cost savings. DG = Generation with no recovery of waste heat. CHP = Generation with waste heat passing to heating loads. BCHP = Generation with waste heat passing to a single effect absorption chiller and heating loads as required.

of hours of electricity and cooling usage in the hotel makes more difference than the local climate. Heat also is recovered for heating and hot water loads in all cases.

These results point out two issues:

- The type of building application served often makes more of a difference than the local climate. Clearly, buildings with longer operating hours make the system more attractive.



Cogeneration at the University of Maryland consists of a microturbine and a small capacity direct-fired absorption chiller/heater.

Packaged engine cogeneration.

Multiple microturbine installation.

A large capacity microturbine.

- The amount of heat that can be used is substantially greater when the heat can be used throughout the year by adding thermally activated cooling (i.e., absorption chillers) to the building.

Although these conclusions are not new, the charts show how important these issues can be to the overall efficiency of the system. Having some form of thermally activated cooling system will more than double the heat utilization of even the shortest schedule building, even in colder climates. In buildings with around-the-clock operations and warmer climates, the effect can be much larger.

Of course, these efficiency arguments do not directly address operating costs. Although, economics based on current electric tariffs and fuel costs can be calculated, the results become very complex and apply only to a specific locale. Worse, they assume that the current tariff structure will endure for five to 20 years in the midst of dramatic energy industry restructuring. So, what can be said that is geographically universal and enduringly true?

Efficiency is insurance. No matter the future direction of electric or gas prices, a high-efficiency system will guard against future operating cost "shocks."

Fuel diversification is insurance. Cogeneration systems allow the operator to generate power or purchase electricity from the local utility grid. The operator can choose an option on a short-term basis without being trapped into a long-term option.

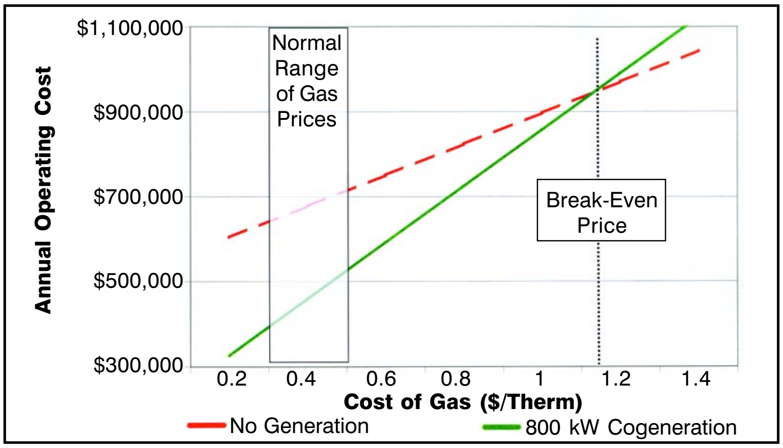


Figure 10:** Annual operating costs over a wide range of gas prices (values from* **Table 1).*

Cooling diversification is insurance. Cogeneration systems use waste heat to cover some of the air-conditioning load. The remainder may be electrically driven. This provides the user with the ability to operate cooling, at least partly, on either the waste heat or electric systems.

Power backup. The ultimate insurance is the ability to operate all, or part of, a facility when the utility power has failed. A cogeneration system can be set up to operate during a blackout, powering the entire facility or only critical loads, thus saving the cost of a dedicated backup generator.

Power conditioning. More high-tech electronic loads are being installed in commercial buildings. These systems often have serious problems with low frequency or undervoltage power, generally caused by electric system overloading. Certain types of onsite generation can be used to supply clean power to these loads. Therefore, a cogeneration system may reduce or eliminate the need for an uninterruptible power or power-conditioning system.

Some of these features can be obtained from a simple backup generation system. However, only a full-featured cogeneration system, designed for continuous operation, can provide all of these benefits.

Economics of Small Cogeneration

Adding heat recovery for space heating and cooling to a generating system will add to the first cost. However, in most installations, the payback for the overall system will be shorter. In addition, heat recovery also reduces the overall exposure of the investment economics to fuel price volatility.

For example, given their need for high quality electric power and emergency backup, medical facilities are attractive applications for cogeneration. A hypothetical 300,000 ft^2 (27 800 m^2) hospital facility in Chicago is evaluated in this example (*Figures 7–11*).

The results in *Figure 9* indicate a number of relationships.

- Given a specific load, the operating cost savings for either a generation or cogeneration system will grow proportionally with system size to a point. This point is well *below* the maximum demand of the building. This strongly suggests that equipping the building with enough generation to be completely independent of the grid is not economical.
- Savings begin to decline on the far right-hand side of the chart for any system where the local utility charges a standby fee based on the size of the generator.
- For cogeneration systems, the optimum size will be smaller than for a generation only (DG) system. As the generator becomes larger, the available waste heat begins to exceed the available thermal loads for some period of the year, in particular, the spring and fall. This reduces the marginal economic return, as the generator becomes large in comparison to the thermal load.
- The optimum size of the cogeneration system with waste heat-driven cooling system is further reduced, as the addition of the absorption chiller lowers the overall electric demand of the building. This means that the same level of annual savings can be reached with a smaller generator. In *Figure 9*, the hospital can reduce operating costs by $150,000/year with *either* 1,100 kWe of generation or 650 kWe of cogeneration, including absorption chillers. In most cases, the second option is lower in first cost.
- For the application shown, the generation/cogeneration system was run only during on-peak hours. Previous experience has shown that running against low ($0.02/kW in Chicago) off-

peak electric charges lowers savings. This may not be true under utility rate schedules in other cities.

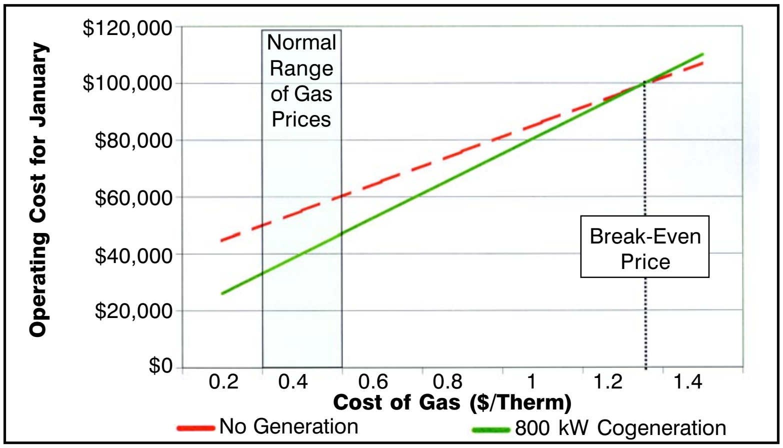


Figure 11: One month of operating costs in the heating season (values from* Table 1*).

Energy Cost Risk

Facility managers have more than operating costs to be concerned about. The tremendous volatility in gas and electric prices over the last few years has made energy budgeting more difficult than ever.

In addition to operating cost advantages, cogeneration can significantly reduce financial risk by lowering the facility's exposure to energy price volatility.

First, cogeneration often is viewed as a natural gas technology. Gas prices in Winter 2000 may make facility owners skeptical about adding another gas use. However:

- The Winter 2000 increase in gas prices seems to have been an abnormal occurrence caused by many producer issues occurring in the same year. The principle issue was insufficient storage set-asides, a mistake that is unlikely to recur soon.
- Immediately following the end of the heating season, the price crashed to values as low as 25% of the peak value. This is not surprising. If a gas price spike is to recur, it will happen in the high demand heating season, and would affect both cogeneration and conventional heating systems.
- In heating operation, a cogeneration system passes its waste heat to the heating load. Therefore, as much as 70% of the gas burned by the generator is used to offset gas that would have otherwise been burned by the heating boiler. Therefore, the *net* increase in gas use in heating is far less than the gas use of the generator.

Advertisement in the print edition formerly in this space.

In *Figure 10,* the effect of fluctuating gas prices on annual operating cost can be seen. However, annual operating cost is not the major concern. Gas prices predictably decline every summer due to low demand. There is little cause to be concerned about gas price spikes in the summer.

Figure 11 focuses on the critical heating season by showing only one typical winter month. In the case shown, the facility has reduced operating cost with the cogeneration system up to an extremely high gas price of $1.40 therm, which was 40% higher price than the peak of the 2000 price spike. In the unlikely event of such an extremely high gas spike, the owner generally is in the position to temporarily turn off the generator, return to normal heating systems, and pass the electric load back to the grid. This would delay the payback period for the cogeneration system for the three to four heating season months. Standby charges, which allow the owner to return the entire electric load to the grid, have been included in the economics.

Price volatility also means periods of prices well *below* the expected average as well as above. As can be seen in *Figures 10* and *11,* the cogeneration system owner is in a better position to profit on low gas prices than a conventional system owner. With cogeneration, the owner has an improved "upside" during periods of low gas prices, while his ability to temporarily shut down cogeneration maintains a very limited downside.

Summary

Much remains to be done to make cogeneration systems a practical and widely used technology for typical commercial buildings. However, in the next 20 years, cogeneration applied on a widespread basis can provide significant improvements in energy efficiency, reductions in carbon dioxide emissions, while providing attractive customer economic and operating advantages.

References

1. Rose, J. and C. Mann. 1995. "Unbundling the electric capacity price in a deregulated market." *Utilities Fortnightly* Dec.

2. 1994. "Buying and selling power in the age of competition." *The Journal of the Electric Power Research Institute.*

3. 2000. *Reliability Assessment 2000–2009: The Reliability of Bulk Electric Systems in North America.* North American Electric Reliability Council. October.

Photo Credits

Page 34. Left photo: Gas Research Institute; Right photo: U.S. Department of Energy.
Page 37. From top to bottom: U.S. Department of Energy, Tecogen, Capstone Turbine and Ingersoll Rand.

Advertisement in the print edition formerly in this space.