On-Site Combined Heat and Power Promotes Energy Efficiency in NYC

The Right

ON FIFTH AVENUE IN NEW YORK CITY, ONE office building has managed to cut its electric usage and cooling and heating needs through the use of a new 1.6-MW on-site combined heat and power (CHP) system. Located in the heart of the Plaza District at 717 Fifth Avenue between 55th and 56th Streets, it is the first of its kind to be synchronously interconnected to the critical midtown network grid of utility provider Con Edison. The new US$4.1 million system, supported by a US$745,000 grant from the New York State Energy Research and Development Authority (NYSERDA), handles 60% of the building's electric usage and 65% of its cooling and heating needs (see Figure 1). The 450,000-ft^2, Class-A office building is owned and leased by Blackstone, once the nation's largest real estate investment trust (REIT) and now part of the Blackstone Group. The system, which was engineered, built, and installed on a turnkey basis by CHP specialists now with Endurant Energy, generates electric power during on- and mid-peak hours and provides chilled water in the summer and hot water in the winter. It is sized to provide nearly two-thirds of the building's peak summer electric demand.

Though its primary function is to increase the building's efficiency, the system can also be configured to provide backup power to keep the building operational during an extended power outage, such as the one experienced by tenants during the August 2003 blackout (in conjunction with the building's existing diesel generator, which powers fire

By John Kelly and Greg Rouse

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Combination

and life safety systems). Whenever the system is operational, the building remains connected to ConEd, running in parallel with the utility's grid.

Setting the Scene: New York City

New York City Power Market Constraint and Supply Shortfall Forecasts

The State of New York as a whole has enough capacity to meet demand on a regular basis, although the New York City area is constrained by a transmission bottleneck through Westchester County. Existing infrastructure is projected to be insufficient for estimated New York City demand growth, and politically fraught transmission construction projects are unlikely to go forward in the near to midterm (see Figure 2).

Given the constrained New York City power market, the New York State Reliability Council (NYSRC) has set a requirement that 80% of electricity used in New York City be derived from in-city generation. This creates additional constraints on electricity supply.

NYISO and Merit Order Bid Stack Pricing

The New York Independent System Operator (NYISO) was created in the postderegulation environment to manage the supply and demand of electricity throughout the entire state. In essence, it acts as the New York electric commodity market maker, aligning the demand of power buyers with the supply of power generators and setting prices for their transactions.

The market is divided into 13 NYISO zones, with the Con Edison territory (New York City and southern Westchester County) comprising Zone J. Relying on historic demand data and daily load projections, the NYISO estimates day-ahead demand for each zone in the market. Generators bid in prices for their capacity based on their marginal costs (e.g., fuel), and the NYISO accepts bids to fill its projected demand requirements in each zone. This is called the locational-based marginal pricing (LBMP) day-ahead market (DAM). In an effort to arrive at the most efficient market price, the lowest bids are considered highest merit and those generators are dispatched first (i.e., base loaded); the highest bids are considered lowest merit. This is called the merit order bid stack. Nuclear and hydroelectric generators tend to bid the lowest due to their low marginal costs (low relative fuel costs), while fossil fuel-based generators generally bid higher (depending largely on variable fuel costs). As a result, nuclear and hydroelectric generators are typically tapped first for base loads while additional demand is satisfied through fossil fuel-fired generation.

Figure 3 illustrates the merit order bid stack for NYISO Zone J, showing generation dispatch by type according to the Zone's annual load duration curve. As expected, nuclear and hydro are the highest merit, supplying base load all 8,760 hours in the year; coal and natural gas are the next highest merit, dispatched more than 7,500 hours (including all peak demand hours); and oil is the lowest merit, dispatched only about 1,200 hours during the highest peak demand periods in the year.

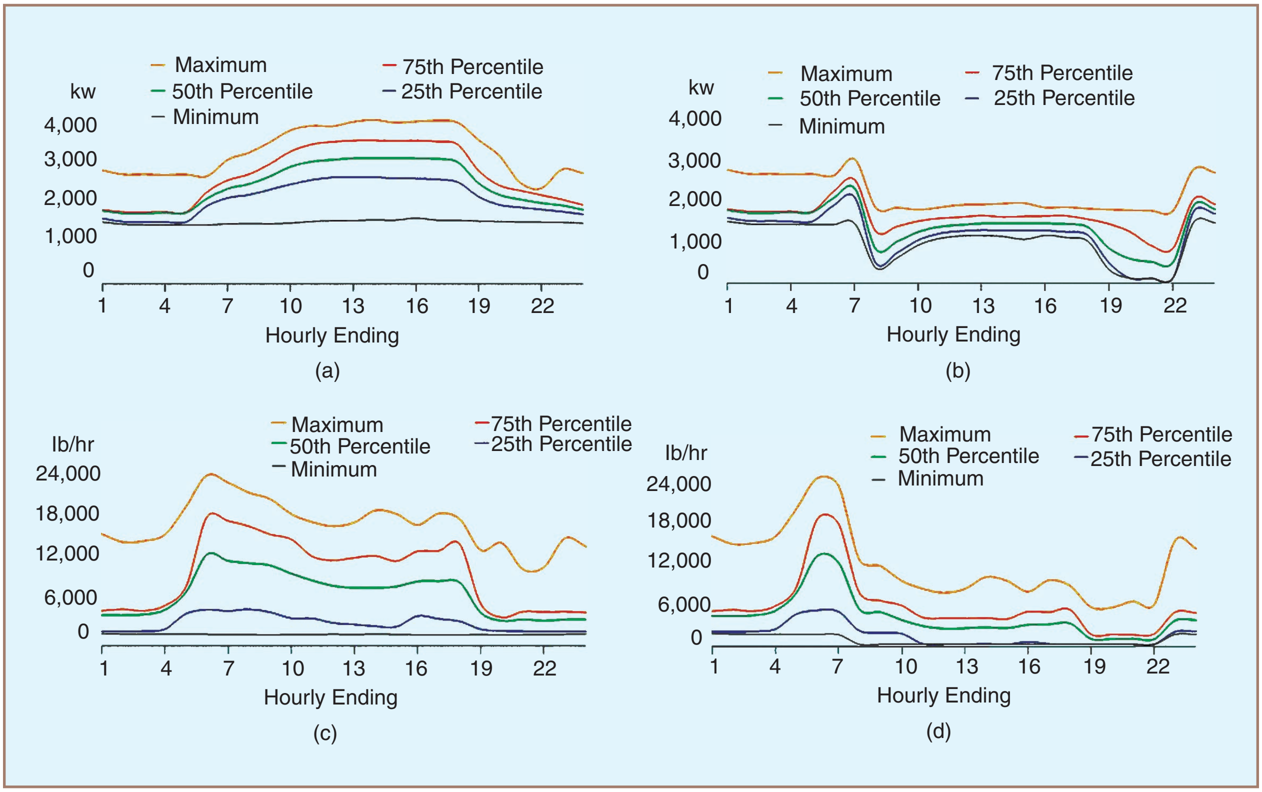

figure 1. Example profiles of 717 Fifth Ave winter electric and steam demand from Con Edison pre- and post-CHP.

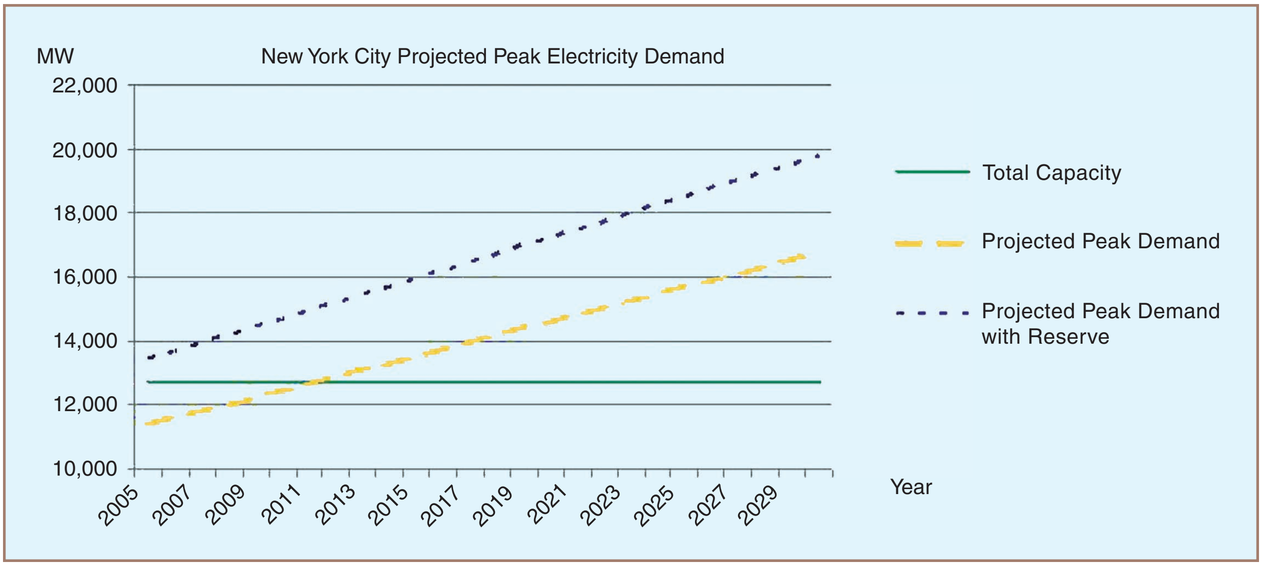

figure 2. NYSERDA, NYISO, and NYC Economic Development Corporation (EDC) projections indicate that NYC peak demand will overtake current capacity between 2011 and 2012. Total capacity includes approximately 9,000 MW of installed capacity in NYC and another 4,000 MW of imported capacity (maximum imported capacity is 5,000 MW, but this has traditionally been impossible due to transmission constraints). In addition, NYISO calls for 18% reserve capacity above demand, which is not currently being met.

Time-Differentiated Electric Commodity Pricing

The price of electricity for any given bid period (every 15 minutes) in the NYISO DAM is set by the highest bid needed to meet demand in a given zone for that period. Due to increasing demand in New York City (and Zone J, generally), coupled with the aforementioned 80% in-city generation requirement, electric commodity pricing for most of the on-peak hours is set largely by natural gas-fired generators and to a lesser extent by oil generators. Of the roughly 4,000 hours of highest on-peak demand in Zone J, oil sets the electric commodity price for about 1,200 and natural gas for the remaining 2,800 or so. Thus, there is a historic link between the average price of natural gas in New York and the on-peak Zone J electric commodity price (see Figure 4).

Due to the commercial nature of New York City, with many large office buildings ramping up power demand around 8:00 to 10:00 a.m. and ratcheting down demand by about 8:00 to 10:00 p.m., daily electricity demand is concentrated during a roughly 12–14 hour peak plateau. The on-peak electricity demand profiles reach their highest during the winter heating

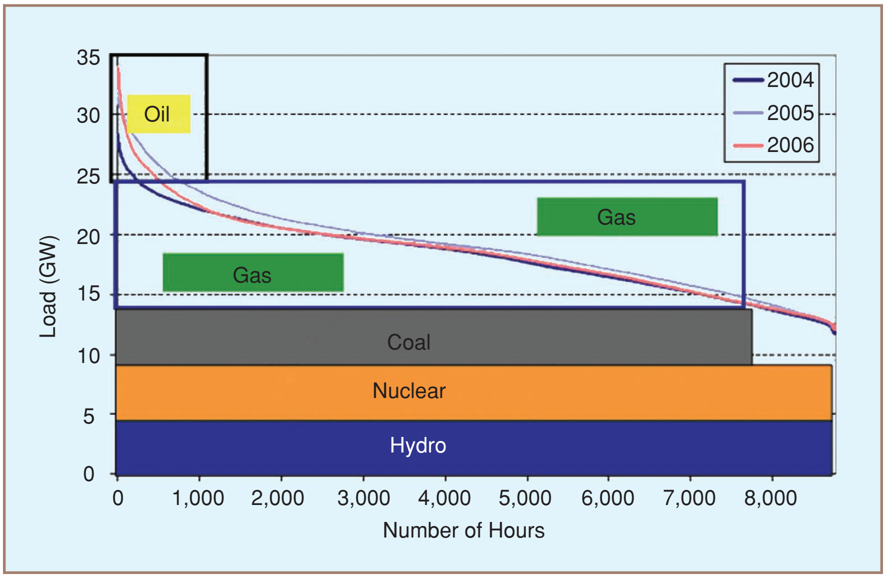

figure 3. The load duration curve for NYC (NYISO Zone J), with an overlay of the "merit order bid stack" for dispatched generation. As demand increases, more expensive and less efficient (i.e., "lower merit") generation sources are necessary. For instance, hydroelectric and nuclear power are base loaded (lowest marginal costs, lowest bid price, highest merit first) while gas and oil are used to supply power in periods of peak demand (highest marginal costs, highest bid price, lowest merit last). These are the generators setting the commodity price for virtually all on-peak power in NYC; however, utility-scale gas generators have the same spark spread as the CHP system proposed for 717 Fifth, but, without waste heat recovery, they generally use the fuel only about half as efficiently and therefore half as cost effectively.

and summer cooling seasons (see Figure 5), but the daily load profile is essentially the same shape throughout the year.

Historically, average on-peak demand is approximately 35% greater than average off-peak demand. Given constrained supply, growing concentrated demand and the reliance on primarily natural gas for on-peak electricity in Zone J, market prices for on-peak power are higher than for off-peak power and generally vary with natural gas costs. Figure 6 illustrates the time-differentiated nature of NYISO's electric commodity pricing in both the LBMP DAM and the real-time market. This creates opportunities for economic savings through on-peak energy demand reduction and more efficient use of natural gas, such as CHP.

Initiatives Encouraging Distributed Generation

With potential capacity shortfalls forecasted for the near- and mid-term, a number of initiatives have been announced to aid in mitigating the situation. In 2003, New York Mayor Michael Bloomberg commissioned an Energy Policy Task Force (EPTF), which issued a report in January 2004 proposing 28 recommendations, of which nine dealt directly with the development of distributed resources throughout the city. These recommendations included directives to

- ✔ determine the types and necessary levels of direct incentives to overcome the initial cost barrier of installing steam and gas chillers and thermal energy storage systems
- ✔ support the use of clean on-site generation systems
- ✔ adopt a standardized and streamlined interconnection review and approval process for clean on-site generation systems
- ✔ support incentives for peak load management enabling technologies.

In 2006 Con-Edison set a three-year target of 675 MW of distributed resources including on-site generation. Finally, in 2007 Mayor Bloomberg's office released PlaNYC, "a comprehensive sustainability plan for the City's future." Among PlaNYC's energy goals are:

- ✔ by 2030 increase the amount of clean distributed generation resources by 800 MW
- ✔ by 2015 increase the total amount of generation capacity in New York City by between 2,000 MW and 3,000 MW
- ✔ promote peak load management programs
- ✔ reduce global warming emissions by more than 30%.

One common form of clean distributed generation is CHP. CHP systems have several advantages over traditional utility generation. In the process of generating electricity at a utility-scale plant, a tremendous amount of heat is created, which generally goes unused. This heat loss combined with

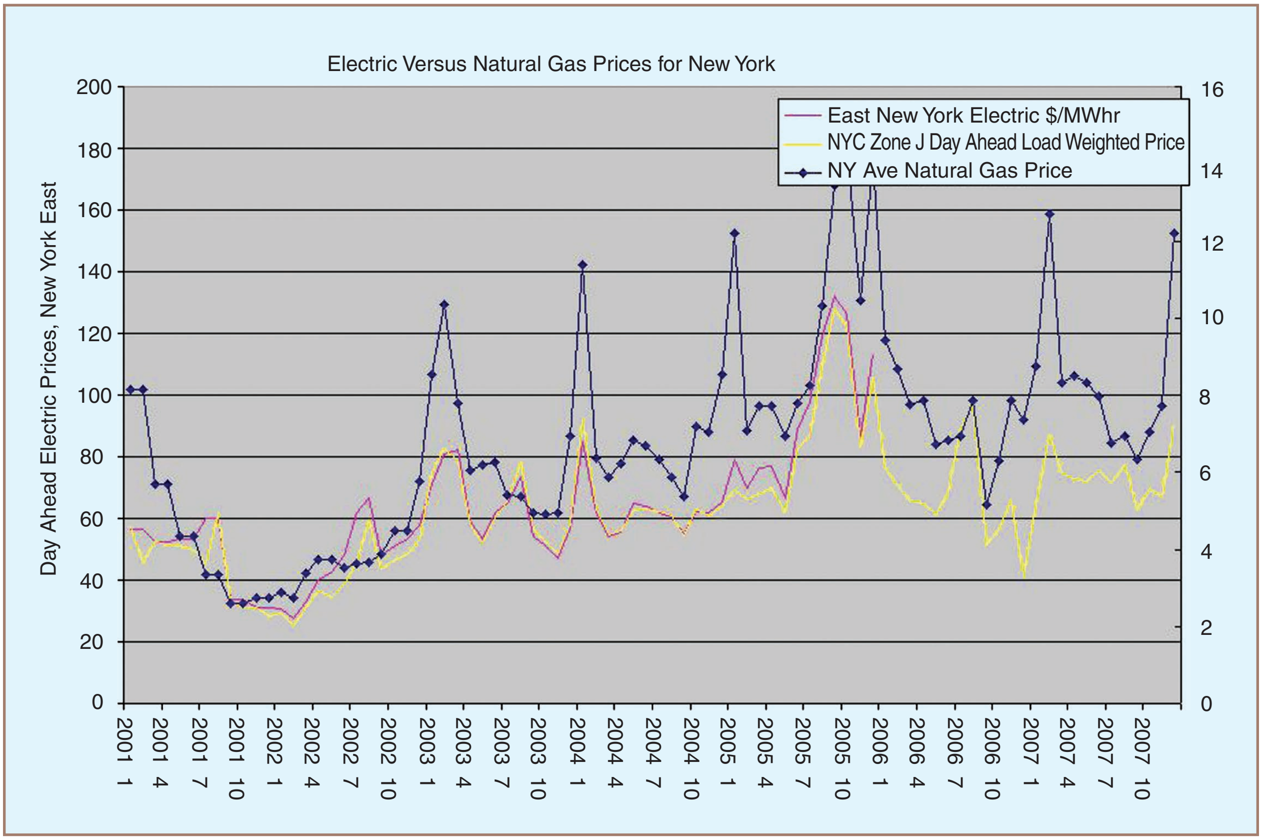

figure 4. Average natural gas prices and day ahead market electricity pricing in Zone J (Con Edison territory) have historically risen and fallen in lock-step, as expected based on gas-fired generation representing the market-clearing LBMP bid during most on-peak hours in Zone J.

electricity lost over transmission lines en route to the end-consumer means that the typical coal, oil, or gas-fired utility can only operate at approximately 33% efficiency (as measured by dividing the potential energy contained within a fuel—i.e., 1 million Btus (MMBtus)—into the actual end-product electricity—MWH). Because CHP systems capture waste-heat and can utilize it productively (in the form of steam-generation for heating and air conditioning as well as domestic hot water production) on-site, along with the lack of long-distance transmission loss, these systems will typically operate at efficiencies above 60%. At the same time, today's new gas-fired generators produce less emissions than their older utility counterparts and can reduce a building's carbon footprint (the impact emissions containing carbon—greenhouse gases—have on the environment) significantly. This reduction in carbon footprint can also increase a building's Energy Star and LEED ratings, contributing positively to a building's reputation and economic bottom line.

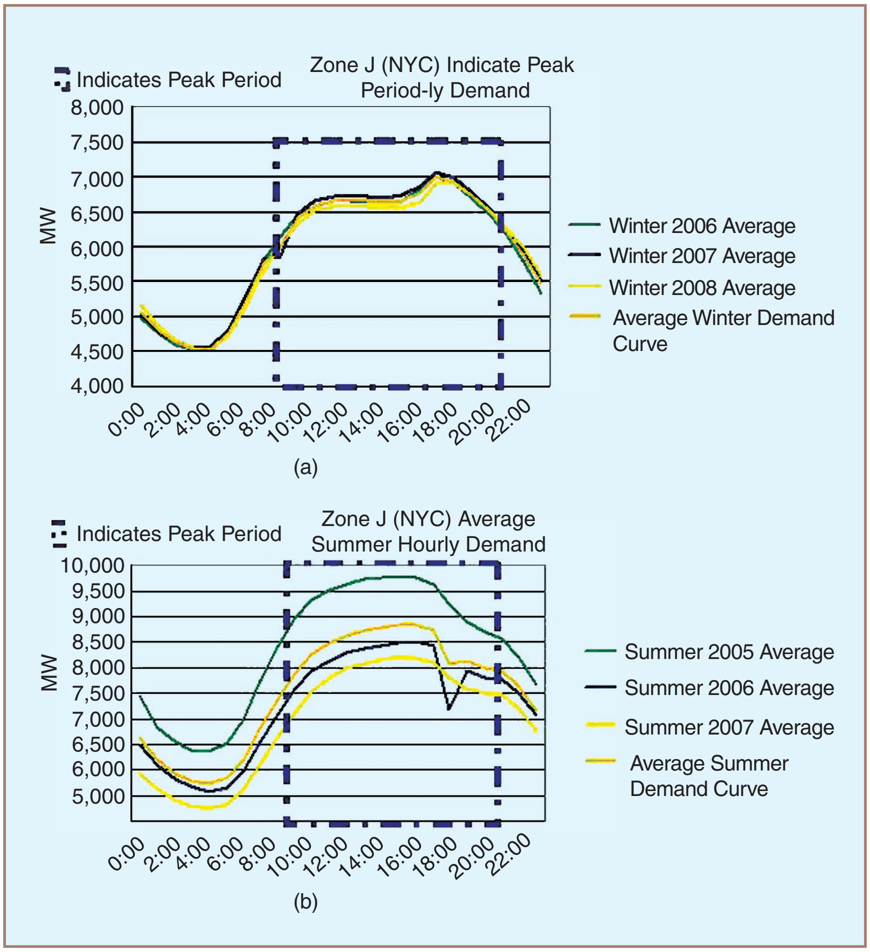

figure 5. Average hourly demand profiles for NYISO Zone J, based on sample winter and summer days from 2005, 2006, and 2007.

A CHP system displaces much of its on-peak electricity expenses with fuel expenses (natural gas) that feed the generator. In New York City, where the price of peak electricity is significantly higher than the price of off-peak electricity, economic benefits can be gained by operating the system during peak load hours. This arrangement is called peak coincident distributed generation (PCDG). Because the cost of operating the generator during peak hours (inclusive of fuel and maintenance charges) is significantly less than the cost of purchasing the equivalent electricity directly from the utility, a building owner can realize maximum economic savings by operating the CHP system only during peak load demand hours. In addition to the electricity produced, many buildings in the New York City market utilize steam-based heating and air conditioning systems. Steam purchased from Con Edison complies with the same peak/off-peak pricing scheme as electricity (see Figure 7). Thus the same economic savings can be realized by utilizing the CHP system to produce steam during peak hours.

The NYSERDA has issued Program Opportunity Notice (PON) 1197 seeking service providers to complete feasibility studies on possible CHP projects in the New York City metropolitan area. Pursuant to PON 1197's requirements, the proposed system described in this study meets the following requirements:

- ✔ facility where the proposed system is installed must utilize 75% or more of the potential output of the system
- ✔ energy efficiency must be greater than or equal to 60%
- ✔ sum of all usable thermal energy must constitute at least 20% of the technology's total usable output
- ✔ system must produce between 100 kW and 5 MW of electricity.

Demand Management Strategy

Equity Office considered the options available for reducing 717 Fifth's overall energy consumption and annual energy costs. As a result of energy market investigation and traditional cost/benefit analysis of various building efficiency measures, Equity Office turned its attention to on-site generation alternatives, ultimately focusing on CHP. Endurant proposed a natural gas-fired reciprocating engine CHP system sized to offset up to 75%–80% of the building's peak electric load and configured to run in parallel with Con Edison Electric and Steam *during on-peak hours*—what NYSERDA calls a PCDG system. In Class

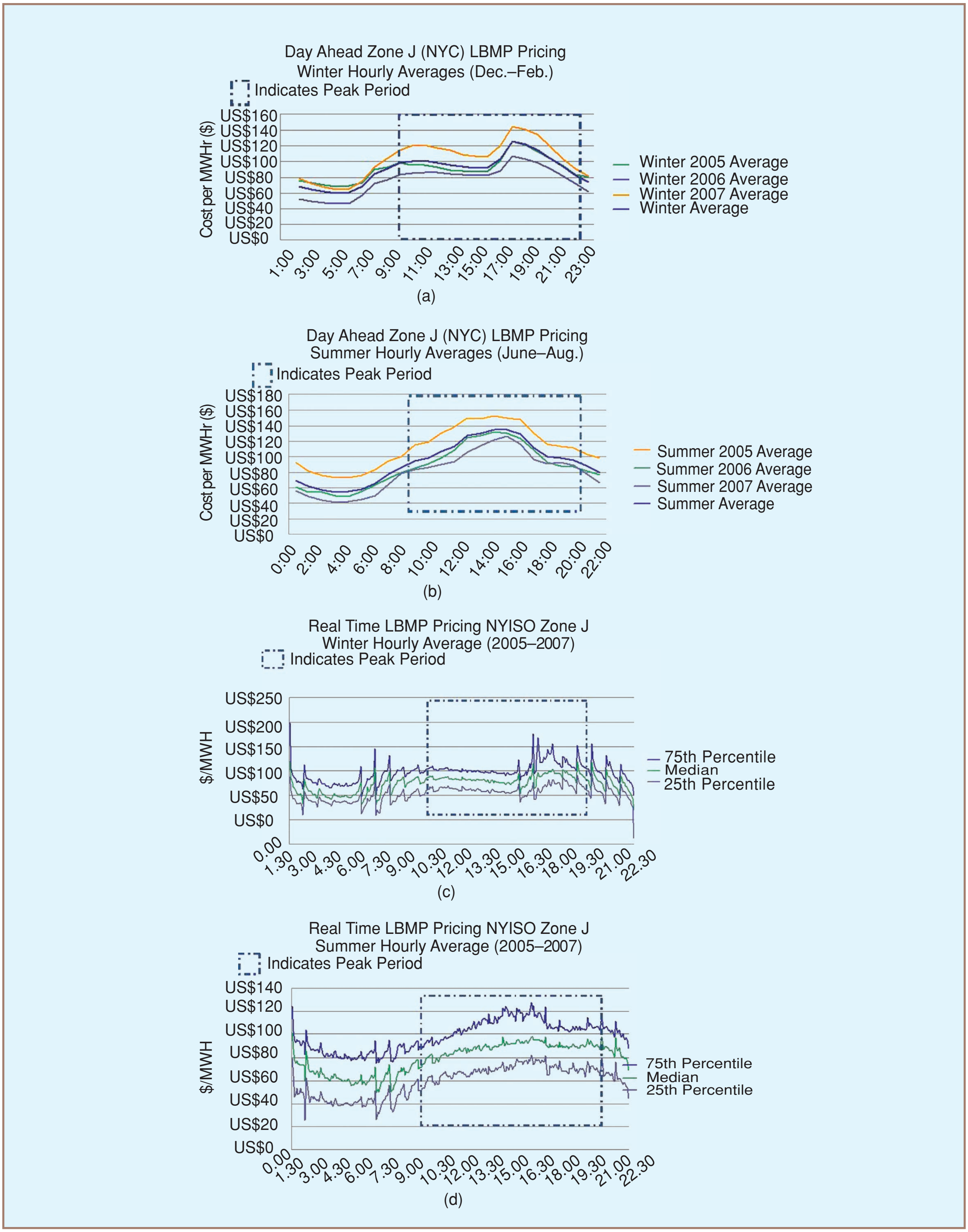

figure 6. Actual NYISO Zone J (Con Edison territory) day ahead and real-time LBMP pricing data, averaged for winter and summer 2005-2007, show that electric commodity prices have a similar peak plateau profile to the load profile of the typical NYC office building. In on-peak hours, when supply is constrained and demand high, Zone J electricity prices are generally significantly higher than in off-peak hours, largely due to the fact that the market-clearing price is typically being set by utility-scale in-city natural gas generators. These are the hours and the prices for which efficient CHP offset of electricity, along with recovered thermal energy, make most sense from the standpoint of effective demand reduction and maximized financial returns.

A office towers like 717 Fifth, such systems achieve the optimal balance between efficiency when energy is most expensive, demand reduction when energy loads are at their peak, and favorable returns on investment by running only when most profitable. The proposed system will operate 8:00 a.m. to 8:00 p.m., coinciding with Con Edison's on-peak hours (8:00 a.m. to 10:00 p.m.) and will provide both electricity and steam to the building. The building expects to purchase standby electricity and steam from Con Edison once the CHP system has been developed.

Analysis Methods

Endurant uses an in-house program for baseline and CHP energy assessments. The energy results from these assessments are transferred and used in a spreadsheet for further energy and economic calculations. Endurant took the approach of using a program for the energy analysis to account for the number of possible CHP configuration options and to reduce the number of spreadsheets required if all of the calculations were to be made in a spreadsheet.

Baseline Energy Assessment

Endurant's energy analysis program is capable of reading electric and steam interval data in a variety of formats and is capable of reading 15-minute or hourly intervals. Prior to the assessment, the raw data are screened for anomalies that might throw off the energy calculations.

The program uses the interval data to determine monthly energy use and demand for on- and off-peak hours. The Con Edison electric on-peak hours are 8:00 a.m. to 10:00 p.m. during weekdays. Steam on-peak hours under the backup/supplemental service class 4 are 8:00 a.m. to 5:00 p.m.. Based on hourly electric and steam data, the program also performs a statistical analysis to determine typical hourly use profiles for each quarter. The statistical analysis includes calculating minimum, maximum, 75th percentile, 50th percentile, and 25th percentile values for each of the 24 hours in a day. The statistical calculations are made for each quarter.

The on- and off-peak energy use and the statistical analysis are then compared to the monthly energy bills to make sure they are in-line with expectations for monthly and annual energy use and monthly electrical demand.

Emissions and Efficiency Calculations

Results from the electric and thermal output calculations are then transferred into a spreadsheet for additional calculations. While the primary purpose of the spreadsheet is economic calculations, additional energy and emissions calculations are also made, as indicated in the spreadsheets. The emissions calculations are made by converting grams per break horsepower (g/bhp) emissions levels from the engine specification sheets to pounds per kilowatt hour (lb/kWh) equivalents. The emissions are then determined

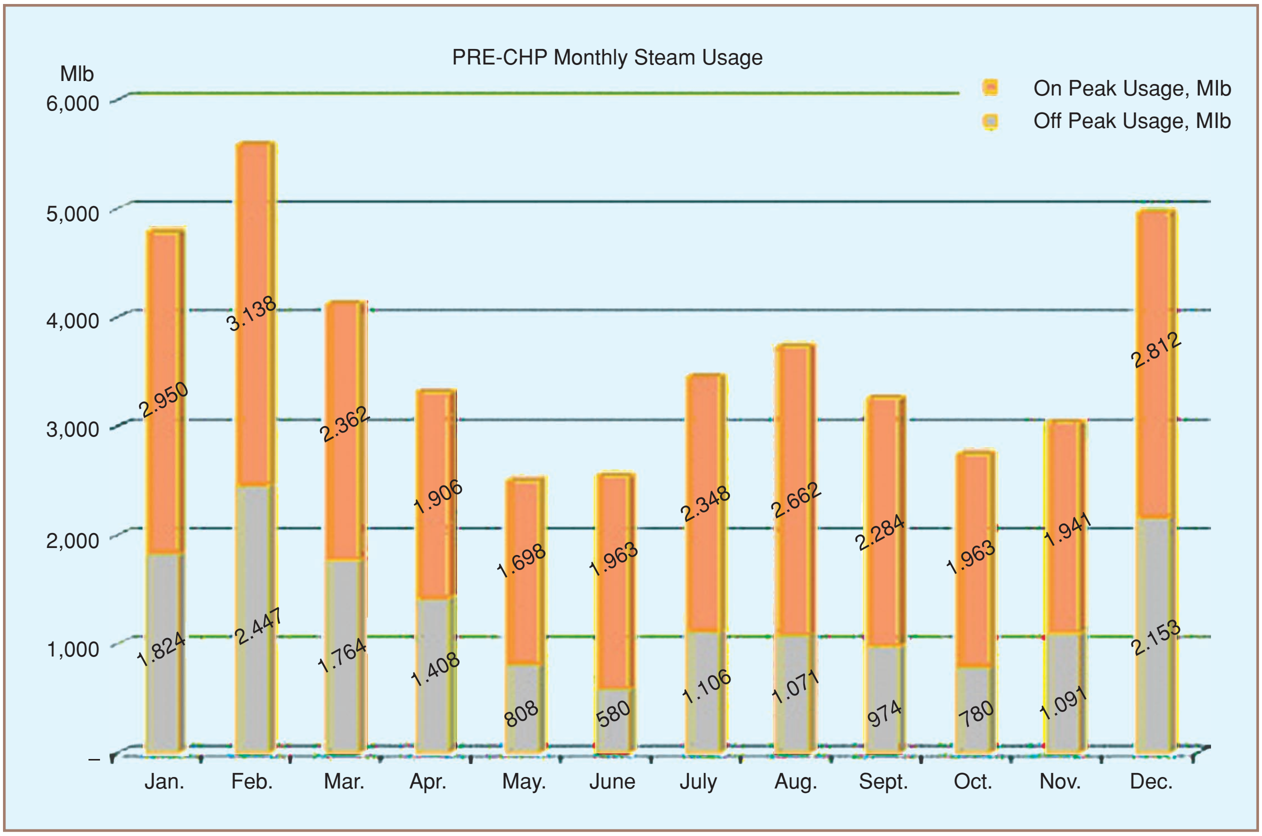

figure 7. The monthly steam usage of the 717 Fifth Ave. building (Mlb, in 1,000 pounds).

by multiplying the monthly and annual generated kilowatt-hours by the lb/kWh equivalents.

Monthly and annual electric, thermal, and system efficiency are determined from the fuel flow, net electric output, and the estimated actual thermal output of the CHP system. When the absorber is used, the thermal input to the absorber (Btus) is used in the recovered thermal energy calculation. Endurant's calculation follows the NYSERDA annual CHP efficiency formula:

$$n = \frac{\sum_{i=1}^{8760} Q_{\text{useful}} + 3412 \cdot \left(\sum_{i=1}^{8760} \text{kwh}_{\text{output}} - \sum_{i=1}^{8760} \text{kwh}_{\text{parasitic}}\right)}{.9\,\text{HHV} \sum_{i=1}^{8760} \text{Gas}_{\text{input}}}.$$

Efficiency Characteristics

Endurant consolidated its hourly electric and thermal (steam, hot water, and chilled water) CHP dispatch projections into monthly kilowatt-hour and MMBtu totals. By converting each month's kilowatt-hours generated (net of 7% parasitic losses) and each thermal output to MMBtus and then computing in Microsoft Excel, the analysis derives a net electric efficiency and a net thermal efficiency for each month, summed and divided by 0.9 to give a monthly overall fuel conversion efficiency in terms of a lower heating value (LHV). The annual total fuel conversion efficiency is calculated the same way, but for annual totals of kilowatt-hours and thermal outputs, all converted to MMBtus according to standard conversions shown in the "Assumptions" tab of the included Excel pro forma spreadsheet.

Description of Systems

Power Generation

The project consists of one Caterpillar model 3516 natural gas packaged generator set. The unit is rated for 850 kW of continuous power at 480 V, 60 H, and 0.5 gpm NOx/BHP-hr. The generator set includes:

- ✔ engine
- ✔ generator
- ✔ structural steel base
- ✔ starting batteries with rack and cable
- ✔ 24-V electric start
- ✔ engine/generator unit mounted control panel (EMCP2+)
- ✔ jacket water heater
- ✔ critical grade silencer
- ✔ vibration isolators
- ✔ gas valve
- ✔ fuel filter
- ✔ lubrication system
- ✔ cooling system
- ✔ electronic isochronous governor, load sharing type
- ✔ engine-driven jacket water and aftercooler pumps (one each).

Engine Jacket and Aftercooler Cooling System

The jacket water circuit and the aftercooler water circuit for the engine will be cooled by a dedicated cooling tower installed on the upper roof of the building. During times of steam production, a slip stream from the jacket water return from the engine is used to preheat the condensate return to the deaerator via a plate and frame heat exchanger.

Exhaust Gas Heat Recovery Steam Generator and Blowdown

The exhaust from the engine passes through an HRSG. The HRSG converts high-pressure feedwater into high pressure (185 psig) steam. The HRSG includes an exhaust bypass mechanism, which acts as the capacity control for the unit, controlling the volume of exhaust gasses that pass over the heating tubes, maintaining steam pressure (and flow) at setpoint. The bypass also allows for 100% exhaust bypass to provide the capability to produce full plant power output without generating steam.

The HRSG includes a continuous blowdown controller to maintain water quality and stable water level. The HRSG continuous blowdown discharges to a blowdown tank; the outlet from the tank will mix with water to reduce the temperature to below 130 °F and will then be routed to the enclosure drain tank.

Condensate and Feedwater

Condensate return is collected from the existing condensate reclamation tank in the 14th-floor mechanical room. The collection from the condensate source will be controlled via temperature and level control. This condensate collection will be combined with a makeup water source and routed through a water treatment skid to ensure that the condensate return to the deaerator is in accordance with the HRSG manufacturer's feedwater quality requirements.

The condensate transfer pump forwards water from the condensate storage tank through the condensate heat exchanger (heated by the engine's jacket water) into the deaerator. The deaerator utilizes low-pressure steam (obtained from the HRSG's output through a reducing valve) to heat and strip out noncondensables. This helps to maintain the water stability and prevent corrosion within the HRSG.

Steam

Steam generated at 185 psig by the engine's HRSG exits the CHP system through a new insulated steam line. The CHP steam piping shall interconnect the existing steam header. The steam system design and controls will prevent the backflow of steam into the Con Edison steam system and maximize the ability of the system to deliver steam to the facility. A revenue-grade flowmeter will be included in the common steam header from the cogeneration plant.

Closed Cooling System
A closed-circuit cooling tower is included and located on the upper roof to provide cooling to the closed cooling water loop that cools the four power distributors in the 14th-floor mechanical room.

Chemical Treatment
Chemical treatment is provided to the jacket water and aftercooler cooling systems via the inclusion of a pot-feeder in the system piping. Chemical treatment skids including the equipment and storage tanks necessary to treat both the cooling water and steam systems are also to be provided.

Water Treatment
A water treatment system shall be included to treat both the city domestic water and building condensate to meet the feedwater quality standards of the HRSG manufacturer.

Condensate
The condensate system is designed such that the entire condensate supply piping drains back to the building's condensate holding tank during periods of nonoperation and freezing weather.

Auxiliary Electrical
The auxiliary electric power system provides power to all cogeneration plant auxiliary loads. The system is comprised of a preferred power feed from a metered source at the building electric service. A backup power source is derived from the 480-V generator bus. An automatic transfer switch selects between the preferred and the back-up sources to ensure that auxiliary power is available for islanded mode operation.

Grounding
The grounding system provides protection for personnel and equipment from the potential hazards that exist during normal and abnormal power system operations and minimizes the damage to equipment during system faults and lightning strikes. The grounding system is designed to:

- ✔ protect personnel from electric shock hazards
- ✔ protect equipment from excessive voltage
- ✔ facilitate isolation of faulted systems
- ✔ permit the dissipation of transient currents
- ✔ provide a stable reference point for instrumentation and control circuit measurements
- ✔ safely dissipate lightning discharges.

Generation and Electrical Distribution System
The generation electrical distribution system provides the means for delivering generator power to the existing electrical system. Overall control and monitoring of the generation and distribution system is directed by the cogeneration system's programmable logic controller (PLC)-based control system.

Control System
The control system is integrated (electrically and thermally) to allow for autonomous operation not requiring site intervention or actions for normal operation in grid parallel mode. The control system consists of the generator controls, generator paralleling, and distribution switchgear, and a central balance of plant (BOP) PLC. The BOP PLC interfaces with all major equipment and system instrumentation for monitoring and control. The remote terminal unit will collect and store data from the BOP PLC. Remote human-machine interface (HMI) terminals in the system and the building's engineering office on the 14th floor will display all essential system data as well as provide supervisory control. Other major control components and functions consist of:

- ✔ cogeneration synchronization and load sharing control and protection cabinet
- ✔ circuit panel powering combination motor starters for cogeneration equipment as well as 480-120/240 transformer and distribution panel
- ✔ monitoring and data logging of all NYSERDA required data points
- ✔ steam flow meters: one for revenue, one at the HRSG, and one to monitor flow to the building chiller steam turbine
- ✔ water meter for city water use
- ✔ flow meter for condensate use
- ✔ parasitic load electric meters in the cogeneration system
- ✔ parasitic load meter for gas compressor/cooler and HVAC loads in the subcellar
- ✔ pulse counting connection to the new utility gas meter supplying the new cogeneration system.

Plant Communication
The generator system shall include a telephone line and DSL high-speed access line. Endurant will run the lines to the telecommunications room located in the building's basement. Connection and service contract are provided by others.

Operation Description

Heat Recovery Operation Modes

100% Steam
When the building needs steam, condensate is pumped through a jacket water heat exchanger for preheating, and into the deaerator. The deaerator takes the condensate, heats it, and removes dissolved oxygen. High-pressure feedwater is then sent from the deaerator to the HRSG. The HRSG uses waste heat from the engine's exhaust to turn high-pressure feedwater into high-pressure steam for the building.

No Steam
If the engine is running and no steam is required, the condensate transfer pump and feedwater pump to the HRSG will be off and the exhaust will bypass the HRSG through

automatic controls located on the HRSG assembly.

Power Generation Operation Modes

Normal Grid Connected Start/Stop

When generator operation is required the generator paralleling and distribution switchgear sends a signal to the BOP PLC to start the auxiliary equipment required to run the engines. Once auxiliary equipment startup is complete the BOP PLC returns a permissive to the generator switchgear. The generator paralleling and distribution switchgear then issues a start command to the Caterpillar engine controller, which starts the engine, warms the engine, and then closes the generator breakers synchronizing to the generator bus. After power is available from the generator, a signal is sent to the power converters from the generator paralleling and distribution switchgear. The power converters enter an automated start-up process and parallel the two sources of power to serve the building loads.

At the end of the generator run period a signal is sent to the power converters to switch to the standby mode. The power converters automatically disconnect from the utility grid and report the event back to the BOP PLC when complete. The BOP PLC then notifies the generator paralleling and distribution switchgear, which opens the generator breakers and terminates the run request to the generator. The generator enters a cool-down cycle and then shuts off. When the generator has stopped the BOP PLC shuts down the auxiliary equipment as required.

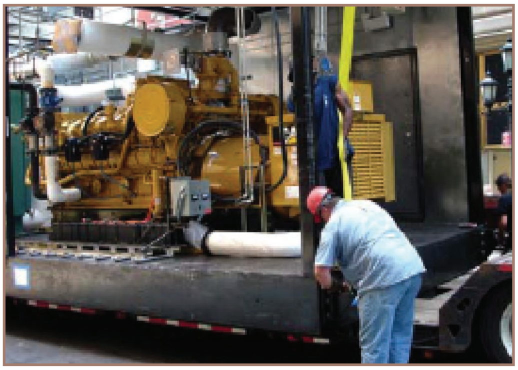

figure 8. An 800 kW reciprocating engine module resting on a flatbed truck to be prepared for delivery.

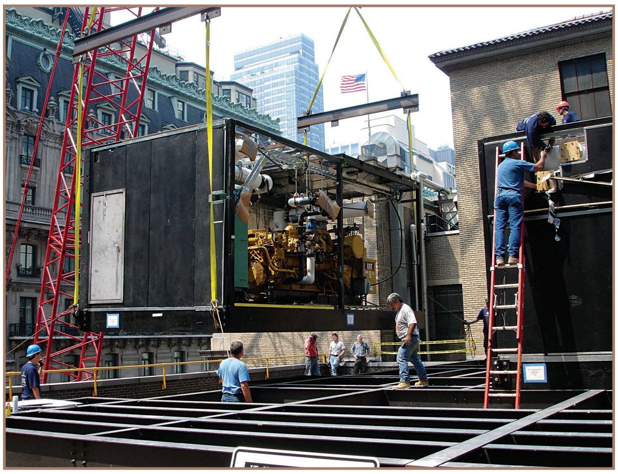

figure 9. A Reciprocating engine module being hoisted on to the 12th floor setback at 717 5th Avenue.

Black-Start

In the event of a utility power failure the cogeneration system has the ability to be black-started and provide power to all building loads connected to the backup power system. A dedicated uninterruptible power supply (UPS) provides black-start power to the gas compressor when operating from its integral battery backup. The fuel gas compressor ensures adequate gas supply for the operation of the engine generator. The engine is started via power supplied by the engine battery. Once the engine is running and the generator output adjusted to nominal voltage and frequency, the UPS and all connected backup loads are automatically provided with power. The BOP PLC monitors and controls all functions necessary to support operations in the black-start mode.

Figure 8 and Figure 9 show the steps during the implementation of the proposed project.

Conclusion

The CHP system at 717 5th Avenue produces electricity, hot water, and chilled water to supplement the buildin's current energy needs and produce electricity at roughly twice the efficiency of the grid, ~60%. This system also reduces the cost of energy while providing backup power. In addition, the building owners receive payments from the NYISO for participating in the NY demand response program. This project confirms that CHP benefits the user, utility, and consumers overall.

For Further Reading

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Biographies

John Kelly is with Endurant Energy, LLC.

Greg Rouse is with Endurant, Energy, LLC.