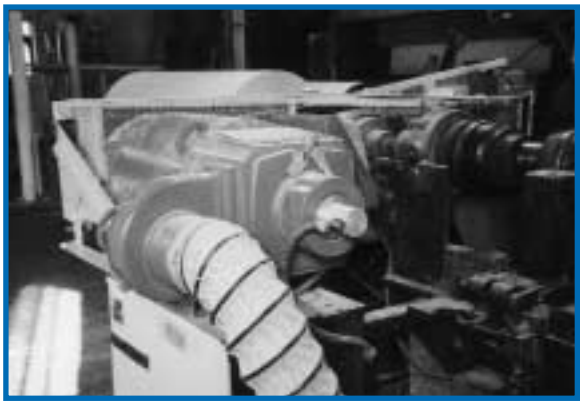
ENERGY MATTERS

March/April 2000

Putney Paper Company Becomes More Energy Efficient with Help from Green Mountain Power



Regenerative drive system on #4 rewinder.

A major rebuild of your processing plant may seem like a daunting endeavor, but Putney Paper Company did just that and is now saving energy and money. The Vermont-based paper-recycling mill upgraded many of its older motors and installed variable frequency drives (VFDs) on its pump and agitator system. The upgrade also entailed rerouting water flow, which eliminated the use of one pumping system. The project is saving the company 400,000 kWh of electricity, or $30,000 annually.

To offset costs and increase efficiency, Putney took advantage of technical assistance and rebates from its electric utility, Green Mountain Power Corporation (GMP), an OIT Allied Partner.

Using original equipment installed in the 1930s was costing Putney Paper Company a heavy price in high energy bills. In an effort to lower costs, in the early 90s, Putney learned of energy efficiency incentives offered by GMP and replaced 27 motors with high efficiency ones that meet or exceed EPAct requirements. The positive results led to further upgrades and opportunities to work with GMP on the recent major plant rebuild.

By 1997, Putney planned to rewind about 13 of the plant's motors driving the mill's pumping process. GMP's review of the plans led to the mill changing the project plan. Instead of rewinding, Putney decided to replace the motors and include upgrades to the agitator systems. "Putney was already committed to upgrading their older equipment to improve productivity. What we were able to bring were recommendations for getting the maximum possible energy savings out of the upgrades," said Dan Gaherty, Green Mountain Power Corporation. GMP provided MotorMaster+ software to help Putney analyze motor replacement options. As a result, Putney installed 15 premium efficient motors and 2 VFDs to operate its pump system. Putney also changed the routing of tray water from the paper machine. The rerouting enabled the company to shut down one pump and use gravity flow in its place, which offered more reliability and cost reductions.

Benefits

In addition to cost savings and energy efficiency, the upgrade has other benefits. For instance, the VFDs have given the operators more control of the process. "We're saving energy by using inverters [VFDs] to achieve the pumping capacity we need. We've eliminated valves and the waste associated with throttling back," said Don Sellarole, plant engineer at Putney. Without throttling back, the operating life of the pump is extended. Also, pressure adjustments have been converted to a digital mode, which allows greater precision and saves time on maintenance. The only drawback is the more complicated drive system that requires greater technical knowledge and expertise to run effectively. To address this, Putney has provided staff training in maintenance and troubleshooting.

Incentives from GMP for the two VFDs reduced payback time from 1.2 years to less than a year.

Working together, Putney Paper and GMP prove that energy efficiency, lower costs, and technological advancement can be affordable realities.

An Office of Industrial Technologies Bimonthly Publication Focusing on Energy Efficiency Opportunities for Today

www.oit.doe.gov
www.motor.doe.gov

Issue Focus: Adjustable Speed Drive (ASD) Technologies

In This Issue

Insert:

Combined Heat and Power Supplement

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Learning to Use Bifocals

By Don Casada and John Kueck, Oak Ridge National Laboratory (ORNL)

Both of the authors of this article are learning to use bifocal glasses. The general idea with bifocals is that they provide two general zones of focus—the lower portion for close up (e.g., reading) and the upper for distance. Leaning your head back while driving or looking out the bottom part of your glasses while descending stairs are recipes for disaster.

There are many demerits associated with our condition (not the least of which are egotistical factors), but like most of life's difficulties, the lessons we learn here have analogs in other arenas.

Take the case of adjustable speed drives, for example. We'd like to discuss two common aspects of drives from a couple of different focal lengths.

Efficiency or Power?

A common way of comparing device A with device B in the energy domain is to compare efficiencies. After all, efficiency is a sort of universal standard that is used in everything from hog farming to haute cuisine, defining the value of the product in proportion to the cost of the input.

Figure 1 shows typical combined drive and motor[1] efficiencies for a new, pulse-width-modulated (PWM) drive and an older eddy-current (EC) drive when connected to a centrifugal load, such as a pump or fan. There is obviously a dramatic difference in drive efficiency at reduced speeds.

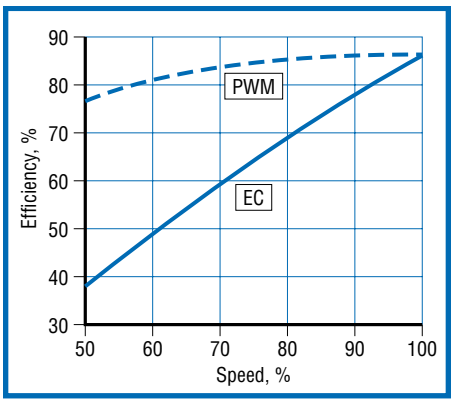

Figure 1. Combined motor and drive efficiency vs. speed.

Consider a situation where we have a fan load that operates at full speed 75% of the time and at half speed 25% of the time. Table 1 shows the combined motor and drive efficiencies at those speeds and calculates an average efficiency.

Table 1. Motor and Drive Efficiency Comparison

Drive Type	*Full-speed efficiency*	*Half-speed efficiency*	*Average efficiency*[2]
PWM	86%	77%	84%
EC	86%	38%	74%

The average electromechanical efficiency with the EC drive is only 88% of that with the PWM drive, certainly a noteworthy difference.

Now let's extend our point of focus to include the electric meter. Does our electric bill include an average efficiency term? Of course not—we pay for energy[3]. Let's assume that the fan requires 50-hp shaft output power at full speed and behaves according to the centrifugal load affinity laws (flow rate is proportional to speed, and power is proportional to the speed cubed). For this assumed load, the electric input power vs. speed shown in Figure 2 applies.

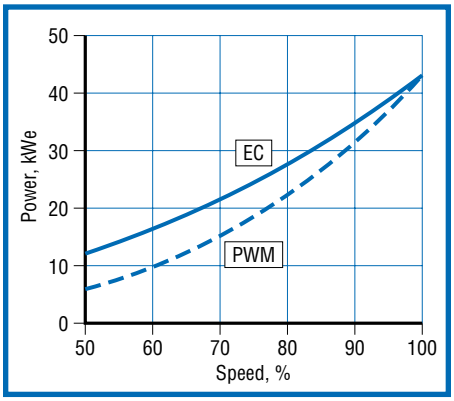

Figure 2. Electric power vs. speed.

(continued on page 7)

Guest Column

Using ASDs with Variable Torque Applications

By John Malinowski, Baldor Electric Company, Fort Smith, AR

Operating energy costs continue to be a major concern for plant managers. Recent studies of electric motor applications show that pumps require 31% of the energy used, 18% for compressors, 18% for blowers and fans, and about 14% for conveyors.

Variable torque applications are the best candidates for adding an adjustable speed drive (ASD) to save energy. Centrifugal pumps and fans are variable torque loads where the amount of power required drops off by the cube of the speed decrease. Thus, the actual savings come from reducing the motor speed, resulting in lowering the motor's power requirements. Constant torque applications such as conveyors often use ASDs, but generally this is not for reasons of energy savings, rather it is for production flow improvements.

Let's look at a pump application with varying flow requirements. Typically, control valves are used to regulate flow from a pump with the motor and pump operating at fixed speed with the motor driven directly from the power line. As the valve is closed, the amount of energy that is wasted is increased. If instead of throttling, an AC inverter (a type of ASD) is employed, considerable savings can be achieved. To illustrate, assume we have a centrifugal pump that requires 100 hp at design flow. Let's further assume an electrical cost rate of $0.07/kWh, an equipment and installation cost of $8,800, and required flow rate that varies from 40% to 90% of design capacity, per Table 1.

Table 1. Load Profile

% of flow rate	*% of year*
40	10
50	20
60	40
70	15
80	10
90	5

As shown in Figure 1, the purchase and installation costs would be recovered from energy savings in less than 5 months, with annual savings of about $22,000.

Caution needs to be taken in this inverter retrofit. Inverters not only reduce the speed by adjusting the voltage and frequency, the motor can also be made to operate above its base speed. Since horsepower requirements on a centrifugal pump increase by the cube of the speed change, it doesn't take much more speed to overload the motor and risk premature failure.

Operation of an AC induction motor from a pulse-width-modulated (PWM) inverter causes extra motor heating due to harmonics. The signal of the inverter to the motor is an artificial sine wave. Motors operating from inverters may experience extra heating resulting in premature failure. Newer high efficiency (EPAct) and premium efficiency motors often have low temperature rise. A rule of thumb is that for every 10°C cooler a motor operates, its insulation life is doubled. Newer motors will also have insulation capable of handling the higher temperatures at which the motor operates when powered from an inverter. Many new motors have a Class F (155°C) insulation system whereas older motors may only be Class B (130°C). Most *inverter-ready* motors have a Class H system rated for 180°C operation.

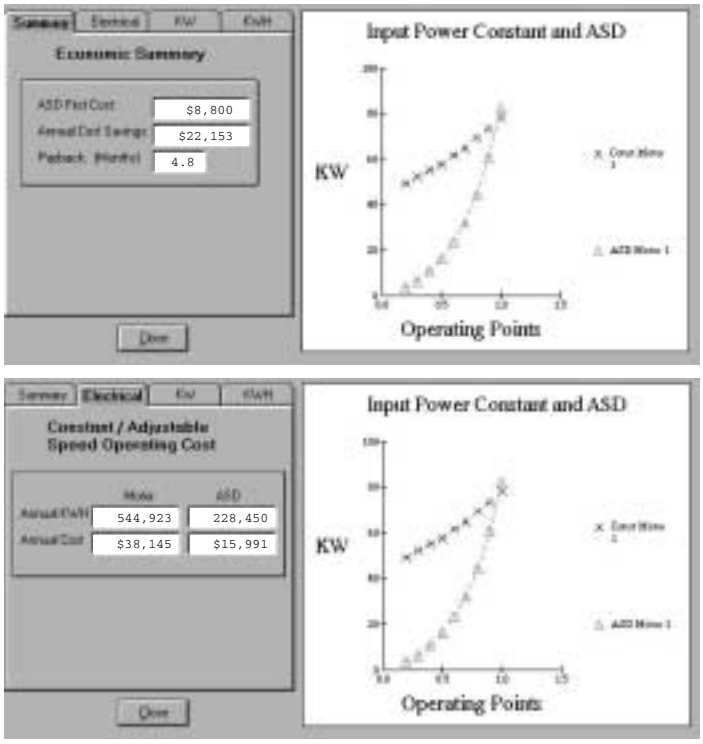

Figure 1. On variable torque applications, ASDs can offer significant energy savings and quick payback periods.

Although the inverter will operate any three-phase AC induction motor, it is wise to purchase a motor with an insulation system that will handle the troublesome voltage spikes, which may be 1600 volts or more in applications with long motor-feeder cables. New inverter spike-resistant magnet wire provide more than 100 times more resistance to high-voltage spikes than standard magnet wire. Long wiring runs between the motor and inverter increase the high-voltage spikes by a condition called "voltage ring-up". To mitigate this situation, line reactors or harmonic filters can be placed between the motor and control.

NEMA addresses operation of inverter-fed motors in its MG 1-1998 standards. Part 31 discusses specific-purpose motors for inverter-fed power supplies. It would be wise to select a motor that complies to MG 1-1998, Part 31.4.4.2 for voltage spikes as a minimum requirement.

Addition of inverters to power motors may provide reduced maintenance and production improvements as well. Instead of starting the motor across the line, the inverter will "soft-start" the motor. By increasing the speed gradually, mechanical stresses on the motor, pump, couplings, and pipes are reduced. Any water hammer (heard as a banging noise in the piping system) should be eliminated. If required, the inverter speed may be adjusted automatically via a process control loop, providing a more precise flow of water from the pump as required by the production process.

(continued on page 4)

Guest Column

continued from page 3

Since most variable torque applications are similar, HVAC installations offer similar savings.

Constant torque applications such as conveyors don't offer the same energy savings as variable torque applications because power is only linear with speed. Again production improvements may be seen with the addition of ASDs. Changing out older, less efficient motors to current premium efficiency designs will reduce energy usage.

Many older conveyors are already adjustable speed, but powered by DC motors and SCR (thyristor) controls. Typically these DC drive systems have efficiencies in the 80-85% range compared to newer AC drives with efficiencies in the mid-90s. Power factor on DC drives may be in the 50% range whereas power factor for AC drives is approaching unity. Changing an older DC SCR system to an AC Vector Drive can provide better performance than the old DC drive. The AC Vector with encoder feedback can provide constant torque from base speed all the way to zero speed. Besides the energy savings, the maintenance required by the brushes and commutator of the DC motor is eliminated (downtime and costs). A larger motor is sometimes required for low-speed, constant-torque applications.

Energy savings translate directly to the bottom line of any manufacturing facility. All of these technologies are proven, in use for 10 years or more. Many different suppliers build inverters, vector drives, and inverter-ready motors. Most difficulties encountered are simple and easily resolved.

Local distributors can help estimate savings and initial investment in equipment costs. Most manufacturers also have free cost/analysis software available to help calculate these savings. These computer programs calculate payback details based on the actual motors you have in your plant, duty cycles, and energy costs.

For questions or comments, contact John Malinowski at (501) 648-5909 or send e-mail to John_Malinowski@baldor.com.

Performance Optimization Tips

Field Measurements in Pumping Systems—Practicalities and Pitfalls

By Don Casada, BestPractices Motor Systems, Oak Ridge National Laboratory

This article is the 4th in a series dealing with practical considerations and pitfalls of field measurements needed to understand pumping systems.

One by one, we're addressing the individual elements critical to understanding pumping system operation. But remember the importance of maintaining a system perspective, not just elements in isolation. In the words of Robert Browning (from A Grammarian's Funeral):

"Image the whole, then execute the parts—
Fancy the fabric
Quite, ere you build, ere steel strike fire from quartz,
Ere mortar dab brick!"

Does Your Car Have a Speedometer?

I recently led a PSAT[1] workshop, and we discussed a scenario where no flow instrumentation was installed. Tom Angle, Director of Technology for Envirotech Pump, offered this insightful simile: "A pumping system without a flow meter is like a car without a speedometer."

Tom further noted that we wouldn't buy a car without a speedometer, but we routinely see pumping systems without flow meters. To see how out of whack this is, let's do an operating cost comparison between a mid-size car and a small industrial pump.

Energy Cost Comparison

	Automobile	*25-hp pump*
Fuel unit cost	$1.40/gallon	5 ¢/kWh
Annual usage	15,000 miles	6,132 hours
Power source effectiveness	25 miles per gallon	93% (motor efficiency)
Annual cost	$840	$6,150

Quite a contrast! If I doubled the gas mileage of my automobile to 50 miles per gallon, I'd save only a third of what I'd save if I dropped my pump load from 25 down to 20 horsepower. Doubling my car's gas mileage would be a challenge, but a 20% improvement is often achievable in pumping systems—if system performance and requirements are well understood.

I suspect that 99% of the time you use your speedometer simply to avoid getting the "blue light special." Consider how big a fine you pay to the local electric utility every day because you don't know your pumping system's speed.

I'm Appalled—No Meter's Installed!

Pumping systems with no flow meters are very common, even in large industrial systems. Because energy costs usually overwhelm capital costs for pumping systems, the wisdom of building an unmetered system may be questionable. But given this reality, we'll identify alternative approaches to estimating flow rate in such systems[2]. Beginning with this issue, we'll discuss three methods:

1) Use of head-capacity curve.
2) Volume change rate measurement.
3) Velocity head deduction.

As we begin to discuss these techniques, here is one final automobile analogy.

With my car on cruise control, I occasionally compare my odometer-indicated distance and speedometer-indicated speed with the distance and speed deduced from mileage markers and my wristwatch. Doing this, I can verify that my speed and mileage indications are reasonably accurate (assuming that my watch and the mileage markers are dependable).

Similarly, these flow-estimating techniques, though far from perfect, are worth considering, *even when a flow meter is installed.*

(continued on page 5)

continued from page 4

Using the Head-Capacity Curve

Pump manufacturers develop head-capacity curves for generic pump models, based on test performance data. These curves are useful in selecting a pump for a particular service; they can also be used to estimate flow rate based on measured head.

Consider the pump configuration in Figure 1, and the head-capacity curve in Figure 2.

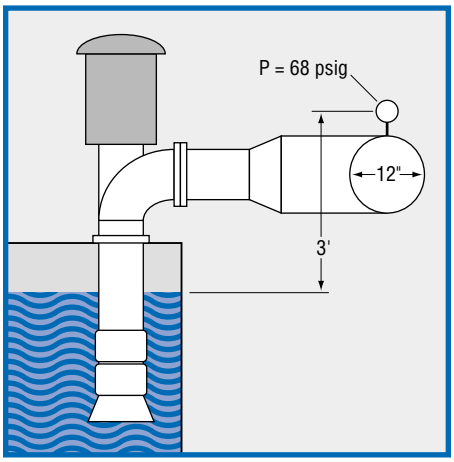

Figure 1. Example pump configuration.

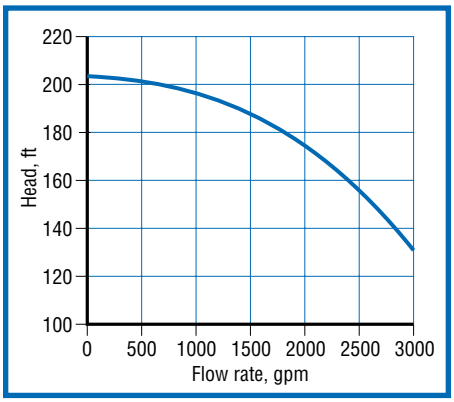

Figure 2. Generic head-capacity curve (1750 rpm).

If this system is handling ambient temperature water, the 68-psig discharge pressure and the 3-ft elevation difference from the vented suction tank to the discharge pressure gauge equates to a developed head difference of about 160 ft. From Figure 2, the flow rate deduced would be about 2400 gpm.

Pretty straightforward, right?

But What About?…

Now let's flag a few assumptions inherent in this approach:

1) This pump's original performance curve is identical to the generic curve.
2) The field performance is identical to the test facility performance.
3) Pump performance is not degraded from service wear or foreign material.
4) The actual rotating speed is 1750 rpm.

How many of these assumptions are likely to be valid?

For the first assumption, consider the Hydraulic Institute's (HI) acceptance test tolerances for a pump in this general category[3], which allows the measured head to be up to 8% above that specified at the rated flow rate. Alternatively, the flow rate can be up to 10% above that specified at the rated head. This tolerance range alone gives an indication of the potential variability from pump to pump, and highlights the value of a certified test curve for the specific pump.

Field and test facility performance can differ for a variety of reasons; in this example, the discharge pressure is measured downstream of an expander and discharge header tee. There are losses across these components that would need to be accounted for.

The potential effects of service wear can be extremely variable, but the longer a pump has been in service, the less likely it will perform like new.

Fortunately, speed equality can be checked (for example, with a strobe light as shown in Figure 3) and accounted for, if different. We'll illustrate how speed can be accounted for with ASDs. This is important, even when operating on a fixed speed motor.

Figure 3. Strobing pump shaft speed.

Assume we find the rotational speed of the pump is 1780 rpm. Using pump affinity laws, the head-capacity curve can be adjusted upwards, as in Figure 4.

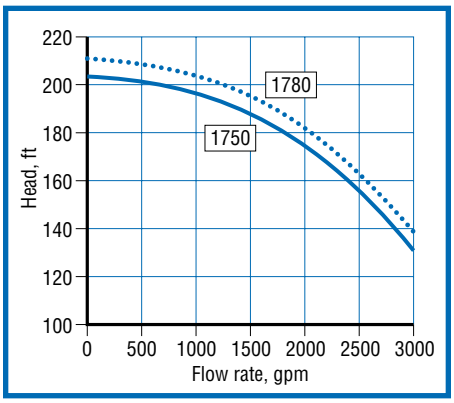

Figure 4. Head-capacity curves for 1750 rpm and 1780 rpm.

The flow rate at 160 ft on the 1780 rpm curve is 2570 gpm, about 7% more than estimated from the 1750 rpm curve. If the measured head had been 200 ft, the speed-related error would be dramatically greater—over 75% (700 vs. 1240 gpm)!

One last potential "gotcha" in using pump head to estimate flow rate is that the velocity head component must be included. But since the velocity head can only be determined once the flow rate is known, we must use an iterative solution[4]. In this case, the velocity head component is small (about 0.7 ft), but that is not always the case.

In the next issue, we will cover the other two methods of estimating flow rate in unmetered systems.

Comments/questions welcome by e-mail: a85@ornl.gov

1 PSAT– Pumping System Assessment Tool, a DOE software product available as a free download at: http://public.ornl.gov/psat.

2 Clamp-on, ultrasonic flow meters are available that are non-intrusive. My experience with externally mounted ultrasonic meters has been mixed. I'm not aware of a report on independent testing of such flow meters under real-world conditions, but encourage readers to provide feedback in this regard.

3 See ANSI/HI 2.6-1994, Vertical Pump Tests, Section 2.6.5.3.

4 There is a way to avoid the iteration – but we'll leave that for a future column.

Maximize Your ASD Application with ASDMaster

Control of process equipment using electronic adjustable speed drives (ASDs) offers significant opportunity to save energy and improve operations. However, the effects of ASDs on process systems are not always well understood. To simplify the process of learning about, analyzing, and specifying an ASD application, the Electric Power Research Institute (EPRI) Adjustable Speed Drive Demonstration Office (ASDO), in cooperation with the Bonneville Power Administration, developed the ASDMaster software. Designed with the layperson in mind, ASDMaster provides a suite of educational materials and software tools for people with little or no experience applying ASDs, to experienced ASD application engineers looking for accurate, user friendly analysis software.

How Does it Work?

ASDMaster is a windows-based software package consisting of six different modules designed to educate and assist users in the proper application of ASDs. A software instruction module and text are included to educate users on the process effects, technology, and power quality issues associated with ASDs. Analysis tools assist users in the accurate, total systems-based analysis of the energy and production benefits associated with ASDs. A simultaneous analysis is performed on constant speed controls for comparison. ASDMaster also contains a specification tool that assists users in writing a solid performance specification for an ASD, just by answering the appropriate questions and filling in the blanks. Finally, ASDMaster's database module directs users to manufacturers with ASDs that can meet their needs, generating a bid-list and contact information with just a few button-clicks.

Where to Get Your Copy

To order your copy of ASDMaster, or to receive more information about the product, call the EPRI ASDO today at 1-800-982-9294.

Adjustable Speed Drive Application Workshops

If you are an end user, utility, or motor manufacturer, the Adjustable Speed Drive Application workshops can help you in your job. These workshops address the fundamentals of ASDs and offer a demonstration of the ASDMaster software. The workshops are offered in co-sponsorship with OIT Allied Partners.

Attend one of the following:

- April 25 in Marlboro, MA, MA Toxics Use Reduction Institute.

  Call Ann Berlin Blackman at (978) 934-2124.
- May 9 in Greensburg, PA, PA DEP Allegheny Power.
- May 23 in Manchester, NH, State of NH Wastecap Resource Conservation Network.

  Call Erin Wheeler at (360) 754-1097, ext.104.

Soliciting Help

OIT's Industrial Assessment Center (IAC) program is soliciting ABET accredited engineering schools across the country to help small and medium size manufacturers save money and improve productivity. The Industrial Assessment Centers, at present, are located at 30 universities across the country. Teams of engineering faculty and students from the centers conduct, at no cost, industrial assessments and provide recommendations to small and medium size manufacturers to help them identify opportunities to improve productivity, reduce waste, and save energy. Recommendations from industrial assessments have averaged about $55,000 in potential annual savings for these manufacturers.

Solicitations will be sent to the Department Heads and Deans of Engineering at all ABET accredited schools. Call Gwen Looby at (215) 387-1535, ext. 221, for more information.

Mark Your Calendar for…

…the 4th OIT Industrial Energy Efficiency Symposium and Exposition. Set for February 19-22 in 2001, this event will help U.S. industry prepare to compete globally. Learn from recognized experts who will share their perspectives on the competitive challenges awaiting U.S. manufacturers and hear their potential solutions for success in global markets. The exhibit hall will feature over 150 booths highlighting technologies under development, emerging cutting-edge processes, and other results of collaborative partnerships. Join other manufacturers, government R&D managers, corporate R&D directors, university researchers, national laboratory scientists, representatives from the financial community and many more at this exciting Expo, to be held in Washington, D.C.

How to Register

You may register online at www.oitexpo4.com or call (877) OIT-7967 to obtain a registration form.

Learning to Use Bifocals

continued from page 2

Table 2 shows the power for the two load conditions, and annual electrical energy and expense, assuming an energy cost of $.05/kWh.

Table 2. Power, Energy, and Cost Comparison

Drive Type	*Full-speed kWe*	*Half-speed kWe*	*Annual MWh*	*Annual cost, $1000*
PWM	43	6	296	$14.8
EC	43	12	309	$15.4

The energy consumed by the PWM drive is only 4% less than the EC drive. Why is this? The simple reason is that the affinity laws are the dominant factor—the shaft power required at 50% fan speed is only 1/8 of what it was at full speed. With this load profile, it would be very difficult to justify replacing a functional, less efficient EC drive with a new PWM drive. A different conclusion might be reached with a different load profile; the point is that efficiency comparisons don't tell the whole story.

Beyond the Affinity Laws

Now that we've shown why the affinity laws tend to dominate the picture in centrifugal loads, it is worth extending our focal length a bit more to see a system picture. A very common mistake made in developing rough estimates of energy reduction by applying adjustable speed drives is to simply use the affinity laws.

Assume we have a pump that is operated simply to fill a tank. The tank supplies the system (by gravity) continuously, but the pump only has to run 12 hours a day to keep the tank full. According to the affinity laws, if we slowed the pump down to 50% speed, the flow rate would drop to half and the power would drop by a factor of eight. If we ran the pump at half speed for 24 hours a day instead of at full speed for 12 hours a day, the energy consumption would go down by a factor of four, right? *Wrong.*

If the system had *no* static head, the logic would be fine; but in many pumping systems, static head is a significant part of the overall system head. For example, as shown in Figure 3, the pump operates at about 3350 gpm and 50 ft of head when operated at full speed. However, when it is slowed to half speed, the flow rate is 0 gpm; in other words, the pump function has switched from a water mover to a water heater. The simple reason is that the system has static head—in this case, about half of the head at full speed is static.

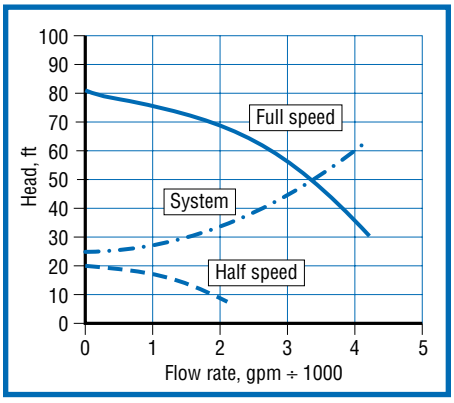

Figure 3. Electric power vs. speed.

Looking Out the Top of the Lens

In many industrial operations, adjustable speed drives can be beneficial. There are many details that must be considered in implementing drives. But these examples have illustrated how too narrow a focus on individual component performance and the failure to see the system as a whole can lead to significant errors.

While the examples used here are just that—examples—they are in their essentials identical to situations that are commonly encountered. Don't be misled by the details—look out the upper part of the lens and see the system as a whole.

[1] The PWM data for Figure 1 is average performance of three drives tested with an older, standard efficiency, 50-hp motor at ORNL. The eddy current efficiency curve assumes 3% loss at all speeds combined with measured direct, across-the-line efficiency for the same motor (full-load motor efficiency was 89%).

[2] Weighted according to the percentage of time operated at the two speeds.

[3] Some electric billing structures also include demand charges and/or power factor penalties; PWM drives do improve power factor.

Letters to the Editor

Energy Matters *welcomes your typewritten letters and e-mails. Please include your full name, address, association, and phone number, and limit comments to 200 words. Address correspondence to:*

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Golden, CO 80401
e-mail: michelle_sosa-mallory@nrel.gov

We publish letters of interest to our readers on related technical topics, comments, or criticisms/corrections of a technical nature. Preference is given to letters relating to articles that appeared in the previous two issues. Letters may be edited for clarity, length, and style.

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ENERGY MATTERS EXTRA
MORE COVERAGE OF ENERGY EFFICIENCY OPPORTUNITIES FOR YOUR INDUSTRY

Find more articles and resources on this issue's theme—ASD Technologies—by visiting the Energy Matters Extra Web site. From here, you can also link to a Web-based Combined Heat and Power (CHP) analysis tool to screen a potential CHP site. Then, access the Office of Industrial Technologies' (OIT's) new online discussion database to post your comments or questions about CHP. Universities will find a new solicitation announcement with the details on applying for participation in OIT's Industrial Assessment Center program. **Go to Energy Matters Extra at www.motor.doe.gov/emextra.**

Naming Names

David Gaw of the Washington State University Energy Program took the Name Game Challenge (November/ December issue of Energy Matters Extra) and correctly identified 19 of the 25 historical energy champions hidden within a story by Don Casada. Our thanks and congratulations to Mr. Gaw for his effort. Check out the answers in the current edition of Energy Matters Extra—and watch for other energy-related quizzes in future editions.

Coming Events

Fundamentals of Compressed Air Systems

- April 19, in Northhampton, MA, New England Electric, MA Electric.

Call Anita Hagspiel at (508) 421-7221.

Adjustable Speed Drive Application Training

- April 25 in Marlboro, MA, MA Toxics Use Reduction Institute.

Call Ann Berlin Blackman at (978) 934-2124.

- May 9 in Greensburg, PA, PA DEP Allegheny Power.
- May 23 in Manchester, NH, State of NH Wastecap Resource Conservation Network.

Call Erin Wheeler at (360) 754-1097, ext.104.

Pump Systems/Pumping System Assessment Tool Workshop

- April 26 in Marlboro, MA, MA Toxics Use Reduction Institute.

Call Ann Berlin Blackman at (978) 934-2124.

- May 1 in Westbrook, CT, BJM Corp.

Call Anna Maksimova at (360) 754-1097, ext. 100.

NC State University, Industrial Extension Service Workshops

- Cooling Tower Operations, April 25 in Atlantic Beach, NC.
- Energy-Efficient Lighting, April 26 in Atlantic Beach, NC.
- Preventive Maintenance, April 27 in Atlantic Beach, NC.
- Energy-Efficient Motors, May 5 in Atlantic Beach, NC.
- Certified Energy Manager, May 8-9 in Raleigh, NC. (2 days, 8:30 a.m.-4:00 p.m.)

All events last from 9:00 a.m. till 4:00 p.m. For more information, contact Jim Parker at (919) 515-5438, or at jim_parker@ncsu.edu.

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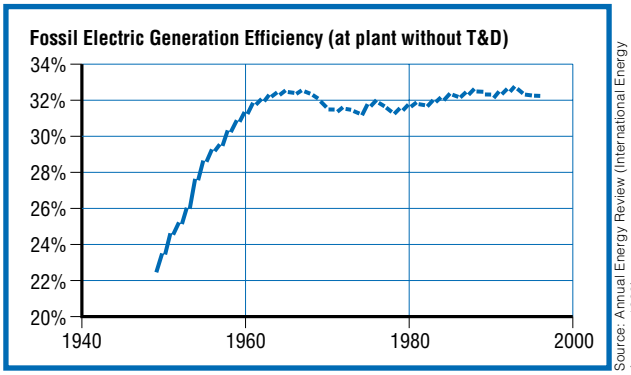
COMBINED HEAT AND POWER

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)

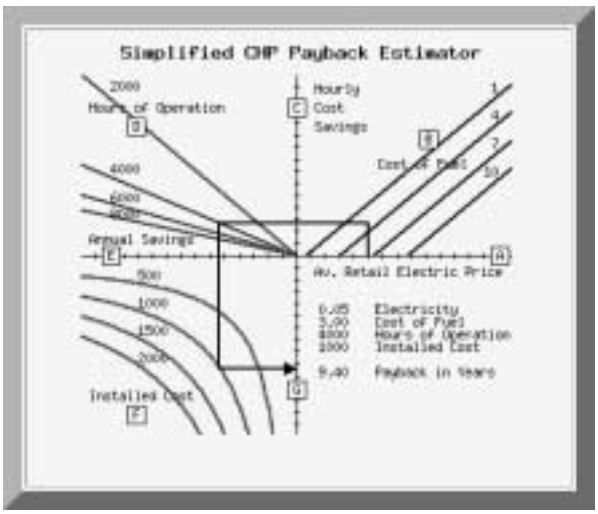
Figure 1

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.

(continued on page 6)

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.oit.doe.gov/chpchallenge/screeningtool.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?

(continued on page 2)

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?

continued from page 1

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 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.

Courtesy Clark University

Reciprocating Engine

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

(continued on page 4)

Courtesy Plug Power

A home equipped with fuel cells

Courtesy Solar Turbines

Advanced Turbines

continued from page 3

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

CHP Success Stories—Paving the Way for the Future

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.

(continued on page 6)

CHP—Power Production for the New Millennium

continued from page 1

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 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

continued from page 5

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.