The Use of Combined Heat and Power (CHP) to Reduce Greenhouse Gas Emissions

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ABSTRACT

Cogeneration or Combined Heat and Power (CHP) is the sequential production of electric power and thermal energy. It is a more efficient way of providing electricity and process heat than producing them independently. Average overall efficiencies can range from 70 percent to more than 80 percent. CHP decisions often present an opportunity to switch to a cleaner fuel. CHP systems are an attractive opportunity to save money, increase overall efficiency, reduce net emissions, and improve environmental performance. Climate Wise, a U.S. Environmental Protection Agency (U.S. EPA) program helping industrial Partners turn energy efficiency and pollution prevention into a corporate asset, has increased awareness of CHP by providing implementation and savings information, providing peer exchange opportunities for its Partners, and recognizing the achievements of Partners that have implemented CHP at their facilities.

This paper profiles Climate Wise Partners that have invested in CHP systems, including describing how CHP is used in their facilities and the resulting cost and emission reductions.

Introduction

Cogeneration or Combined Heat and Power (CHP) is the sequential production of both electrical or mechanical energy and useful thermal energy. CHP can be implemented in any scenario where a reliable and constant supply of steam or heat is needed. This can be for an industrial process or a facility's space heating needs. It is an opportunity to save money and reduce environmental impacts in several types of facilities. The case studies of Climate Wise Partners included in this paper will clarify the many applications and advantages of CHP.

CHP is not a new technology -- this idea has been implemented in the U.S. since the early 1900's. Historically, industry has moved away from the use of CHP because it was not competitive with electricity purchased from large utility-owned generating stations. Today, however, interest in CHP is growing for several reasons.

First, the costs of CHP equipment have decreased. Economies of scale are less important and the size of the facility is not the sole determinant of the rate of return. Deregulation is also a driving factor. Open markets will make excess power transactions easier.

With deregulation, companies are also realizing the value of owning and operating CHP facilities for third-party industrial sites. This allows the manufacturer to concentrate its resources on production while maintaining a reliable and competitive source of energy. Third parties benefit by sharing in the realized energy-cost savings.

Because of its high efficiency, CHP is also being recognized as a means for U.S. industry to take a proactive stance in reducing greenhouse gas emissions. It is this last benefit of CHP that is often overlooked by industry.

CHP allows more useful energy to be extracted from the fuel, increasing the efficiency of the system through waste heat recovery. Less fuel is used (relative to producing steam and electricity directly) and fewer emissions are produced overall because the electricity produced on site displaces electrical generation from a utility. For example, if a 10 MW natural gas CHP system is constructed at a facility (inside-the-fence) in Massachusetts, and the steam produced replaces a boiler system that was burning 44,000 barrels of fuel oil (distillate) each year, total annual emissions would be reduced by 25,000 metric tons of CO_2. Table 1 shows an accounting of emissions by source. It should be noted that the inside-the-fence emissions are increased by almost 14,000 metric tons of CO_2. When emissions avoided by the utility are incorporated, the environmental benefit is recognized.

Table 1: Example CHP System CO_2 Emissions Reductions

System	Power	Estimated Efficiency	Metric Tons of CO_2 Avoided
Fuel Oil Boilers	34 MMBtu/hr	80%	18,738
Massachusetts Electricity	10 MW	33%	39,720
CHP System	10 MW + 34 MMBtu/hr	66%	-32,955
Total Savings			**25,503**

As suggested by the above example, on average, a third of the energy released from combustion is transformed into electricity, a third is used as thermal energy, and the remainder is lost to the atmosphere. CHP can double the efficiency of a standard turbine and decrease emissions by more than 40 percent. The cost-effective, environmentally-sound choice of CHP is an option that many Climate Wise Partners are taking advantage of.

Climate Wise

Climate Wise is a partnership initiative sponsored by the U.S. EPA designed to stimulate the voluntary reduction of greenhouse gas emissions among participating manufacturing companies. Climate Wise hopes to spur innovation by encouraging broad goals, providing technical assistance, and allowing organizations to identify the most cost-effective ways of reducing greenhouse gas emissions. Climate Wise currently has more than 500 Partners, representing about 13 percent of U.S. industrial energy use. As part of their Climate Wise commitment, Partner companies across the country develop comprehensive Action Plans that describe their energy-efficiency and pollution prevention goals, the specific actions they plan to take to achieve these goals, the time frame for implementing commitments, and estimates of future impacts on energy, costs, and emissions from these actions.

Climate Wise encourages Partners to take advantage of CHP through technical support, information exchanges, and promoting legislative action. Climate Wise has developed the "Wise Rules for Industrial Efficiency." This tool kit provides rules and measures for estimating the energy, costs, and greenhouse gas emissions impacts of alternative efficiency measures targeting major industrial equipment. This includes information on several end-uses: boilers, steam systems, furnaces, process heating, waste heat recovery, CHP, compressed air systems, and process cooling. The Cogeneration section of the Wise Rules defines the CHP system and outlines some of the issues surrounding implementation. Also supplied are several "Wise Rules" to help estimate savings. For example:

Heat Recovery/Cogen Wise Rule 1

★ Gas turbines with heat recover equipment typically cost from $600 to $1,000/kW. Larger gas turbines may be available for half the cost per kW.

★ A typical cogeneration project may reduce *primary* energy consumption (including fuel inputs at off-site power plants for purchased electricity) for steam and electricity generation by 10 to 15 percent.

★ Cogeneration systems can save about 9% of a typical *facility's* primary fuel inputs for on-site energy use (i.e., including fuel savings at off-site power-plants for purchased electricity) with an average simple payback of 34 months (Climate Wise 1998).

Climate Wise promotes the exchange of ideas and experiences with CHP between companies and the government. For example, in late January, the New Jersey Climate Wise Partnership held a technical workshop on CHP. This workshop brought together 17 New Jersey manufacturers, representatives from the State government, and several consulting firms. Highlights of this conference included comments from Commissioner Robert Shinn, New Jersey Department of Environmental Protection, an overview of CHP by Dr. Michael Muller from Rutgers University, and a tour of the Trenton, New Jersey, CHP heating and cooling facility. The next workshop will be held in May of this year.

Climate Wise has also been instrumental in bringing the benefits of CHP to the attention of the Congress. They have promoted tax credits and financial support for industries attempting to reduce their emissions through the use of CHP.

The remainder of this paper highlights the Climate Wise Partners who are leading the way by example. Presently, 18 Climate Wise Partners use, or are considering using, 24 CHP systems. These companies are listed in Table 2. Six of these Climate Wise Partners are in the chemical and allied products industry. The rest represent a variety of industries, including breweries, textiles, paper, transportation, equipment, research centers, and a hospital. Cumulatively, annual emissions reductions from the use of these 24 CHP systems exceed 2.3 million metric tons of CO_2, or the equivalent of removing 500,000 cars from the road.

Table 2. Climate Wise Partners Using or Considering CHP

• 3M Austin Center	• King County Wastewater Treatment
• Anheuser-Busch	• Malden Mills
• Bristol-Myers Squibb	• Navistar International Transportation
• Colorado School of Mines	• Polaroid
• Coors Brewing Company	• Pratt & Whitney
• DOW Chemical	• Prime Tanning Company
• General Motors	• Roche Vitamins
• Gillette	• Schering Plough
• Holy Name Hospital	• Weyerhaeuser

Overview of CHP Systems

In a typical CHP, an industrial boiler is replaced by a gas turbine and heat recovery system generator. The turbine is used to generate electricity, and the waste heat is used to generate steam in a heat recovery steam generator (or HRSG). Other CHP configurations combine boilers and steam turbines (often as a back-end system), or gas and steam turbines (combined-cycle units). Other systems integrate absorption refrigeration (chillers) to better serve the host's needs. Two emerging technologies that are applicable to CHP are the use of fuel cells and the Kalina cycle -- a vapor heat engine cycle using an ammonia-water working fluid (Wise Rules 1998).

General Motors (GM) and Polaroid have several CHP systems that demonstrate some of the ways CHP can be implemented. GM currently has four operational CHP facilities and a fifth under construction. At its Delphi plant in Lockport, NY, a 174 MW CHP is providing 60 percent of the facility's electricity demand, and 100 percent of their steam requirements. This CHP, which is operated by a third-party, was constructed under PURPA, and is therefore eligible for avoided cost rates for power sold to the grid. It consists of three gas turbines, three waste heat recovery boilers, and a steam turbine. The steam is sent from the combined-cycle CHP to GM's process, returned to a heat exchanger at the CHP facility, and the remaining water is used in the facility's cooling towers as make-up water.

The second GM facility is a 25 MW back-pressure turbine. This CHP facility is providing steam and electricity to GM's Pontiac North plant in Michigan. Under an agreement with the local utility, electricity is only generated when the utility requires the extra capacity. Under this same agreement, two small 3 and 7 MW facilities in Warren and Romulus, Michigan, are only run as back-up generators. These generators can supply 10 to 20 percent of the plant's electrical needs but 100 percent of the process steam load in Warren.

GM is also committed to a CHP at its plant in Linden, New Jersey. A third party will construct, own, and operate a 20 MW gas turbine system that will supply the assembly plant with 100 percent of its steam and compressed air needs, and 95 percent of its electricity demand. The system consists of gas turbines, waste heat recovery boilers, and a steam turbine. This system is expected to reduce annual CO_2 emissions by 50,000 tons and reduce facility-operating costs.

A key driving factor for this project is GM's need to replace their aging powerhouse. The CHP arrangement allowed them to do this economically by avoiding an initial cost of approximately $15 million while allowing them to realize significant fuel cost savings. This gas-fired system is replacing the oil burning boilers and electricity from the local utility, thus reducing emissions by increasing efficiency and changing fuels (Hildreth 1999).

Polaroid has a coating facility with approximately 400 employees in New Bedford, Massachusetts. To produce low-pressure steam, a 500 kW turbine is running on the process steam system. This has the advantage of utilizing the heat and pressure required for manufacturing while generating electricity and low pressure steam to heat a high temperature hot water system that circulates throughout the facility. The unit provides the facility with approximately 10 percent of its electrical needs. The addition of the turbine and generator saves Polaroid approximately $170,000 and reduces CO_2 emissions by 3,000 metric tons annually. The success of this facility has been key to Polaroid's consideration of other CHP projects.

Polaroid has another site in Waltham, Massachusetts, that is considering the installation of a 6 MW CHP facility using gas turbines and a heat recovery steam generator. The facility would be built on Polaroid property, but the construction and operation would be contracted out. Presently, this project is under review for economic and environmental viability (Borghesani 1999).

The implementation of a CHP system is often dependent on the economic drivers at the launch time and location of the unit, but there are examples of other driving forces. For example, following a fire that destroyed its mill, Malden Mills seized the opportunity to construct a new, energy-efficient facility. With the aid of U.S. Department of Energy and Solar Turbine (another Climate Wise Partner), the company has equipped the facility with a state-of-the-art CHP system that will serve as a demonstration project for additional installations. When completed, this system will consist of three 4 MW gas turbines and associated heat recovery steam generators and will generate most of the power and steam for production operations. This system will use low-NO_x combustion technology utilizing ceramic-lined burner components. The initial installation of two turbines has been completed. This facility is being leased to Malden Mills so that cost savings, as well as emissions savings, are immediate without a large, initial investment (Richards 1999).

Benefits

These Partners have found numerous benefits of using CHP. For every company, cost savings have been the primary benefit, but companies like GM and Roche Vitamins have found that having a redundant electrical and heat source (for companies that keep their retired boiler) is a major benefit.

A good example of CHP benefits is evident at the GM facility located in Lockport. In the early 1990s, GM was evaluating cost savings options at this facility in NY, an area with high electricity rates. A long-term contract for the output of a CHP facility with a third party allowed the facility to maintain one of the lowest costs per kWh among the GM facilities. It has also allowed the facility to remain in operation during several extended weather-related outages experienced by the utility. Other benefits included improved voltage regulation and an increase in steam quality due to the once-through system (Hildreth 1999).

Prime Tanning has a unique CHP opportunity that can lower their electric cost by avoiding wheeling charges (both transmission and distribution) and would allow them to shut down their boilers, avoiding O&M cost and the on-site burning of 33,000 barrels of oil each year. A partnership to construct a 500 MW facility to meet this demand is being considered. Prime Tanning is providing a location for construction by an independent third party. This facility would be a natural gas combined cycle plant. Prime Tanning's 2 MW electric load and 100 percent of Prime Tanning's thermal requirements will be supplied by the CHP. This arrangement required no initial cost for Prime Tanning, providing immediate savings (Allard 1999).

Other companies, such as Coors, decided to sell its CHP to a third party and can now concentrate on its main business line while maintaining reliable energy sources. Coors sold Trigen this facility in 1995 after successfully managing it for almost 20 years. Coors obtains all its steam and 90 percent of its electricity from a 40 MW CHP facility. The system consists of five boilers serving three steam turbines. The steam is then shared by Coors and the Colorado School of Mines (CSM). Trigen estimates that greenhouse gas emissions from Coors and CSM have been reduced by 15 percent compared to emissions from steam generation and purchased electricity.

Due to the size of CSM, they could not justify a CHP plant on campus. The Coors/Trigen arrangement allows them to purchase reliable steam at a reasonable rate. Another benefit is that they no longer use the two existing 40,000 lb/hr boilers, thus reducing their emissions. Overall, this has been an ideal situation for all parties involved (Salehizaed 1999).

Other companies have found that running their own CHP has advantages. Three examples are Roche Vitamins, 3M, and Navistar. Roche Vitamins, Inc., in Belvidere, NJ, brought their new CHP system on-line in June of 1998. This CHP system consists of a 38.2 MW natural gas turbine and a waste heat boiler. The boiler provides up to 350,000 lb/hr of steam. This system is equipped with dry low NO_x combustors; a staged combustion process that controls NO_x rates to 15 parts per million (ppm) NO_x and CO rates to 10 ppm. This new system has allowed Roche Vitamin to maintain production of electricity at a competitive rate. The capital cost of $34 million is expected to be recovered from energy cost savings within 3.5 years (Sorensen 1999).

3M's Austin Center has two 20 cylinder, 8,000-plus horsepower, natural gas engines generating 6 MW of power, and a steam turbine creating an additional 1.5 MW of electricity. The turbine is powered by excess steam from the exhaust of the two natural gas engines. Waste heat is also used to provide steam and hot water for use in the 3M laboratories. The heat transferred to the water that cools the engines provides hot water for heating. After only one year of operation, the system has met cost objectives (3M, Belk 1999).

A CHP facility located at Navistar Melrose Park Plant consists of 12 natural gas engines, which produce in total 9.24 MW. Waste heat is captured from half of the engines to produce 30 psig of saturated steam. Navistar is saving $2 million annually from reduced electric load charges and has avoided down time from interruptions in utility transmission (Shih 1999).

Other facilities have used CHP to take advantage of byproducts of their processes. For example, King County Wastewater Treatment Division has three reciprocating engines with a combined maximum capacity of 3.9 MW. These units burn methane produced from the waste treatment process. On average, 14.5 percent of the facility's electricity use is met by these generators. The waste heat from this system normally produces enough steam to meet 100 percent of the facility's requirements. This heat is transferred to a hot water loop for process and space heating. Savings from this system are estimated to be between $250,000 and $300,000 per year (Sugita 1999).

Though cost savings tend to be the primary motivating factor in CHP decisions, emissions reductions can also be very important. For example, Polaroid was considering burning volatile organic compounds released from their process in a gas turbine to generate electricity. The decision to cogenerate was being driven by the need to stay in compliance with state environmental regulations. This alternative was not implemented when a production change allowed the facility to remain within its emissions limitations (Borghesani 1999).

Lessons Learned

Climate Wise Partners' experiences with CHP have been positive. Each company is satisfied with their systems. Several of these Partners have found that good relationships with the third-party CHP providers are essential to success. For example, one company was able to renegotiate their third-party contract when the electrical pricing method became unprofitable.

Another example, King County, is presently looking to replace their aging system. They are trying to improve their CHP system by obtaining either new, more efficient generators or fuel cells. The new CHP system will better utilize the available methane supply. They have also found their present system to be O&M intensive due to the system approaching the end of its useful life and the difficulty in maintaining the system in its present location, which has very limited workspace. They plan on rectifying this with the new installation (Sugita 1999).

Bristol-Myers Squibb has three CHP facilities, totaling 20 MW of power generation. Through excellence in planning and managing, they have found value in having their own CHP facilities and maintaining a competitive situation with outsourcers. Bristol-Myers Squibb has learned several lessons in developing CHP facilities:

- Take neighborhood concerns into consideration. Gas turbines are often thought of as loud jet engines that could self-launch.
- Pay close attention to "single-point of failure." For example, if losing cooling water would shut down the system, an automatic backup system is recommended.
- Concentrate on value engineering during the conceptual stage, it will pay off.
- Negotiate turbine warranties so that maintenance providers have a stake in profit lost due to CHP down time.

Summary

This collection of case studies represents a wide variety of facilities and configurations where CHP is in use. One third (8 out of 24) of the CHP systems are owned and operated by third parties. The CHP facilities range from newly installed to almost two decades of use. There are examples of topping systems, back end steam turbines, and combined-cycle facilities as can be seen in Table 3. In total, these systems represent almost 900 MW of capacity. All these systems were designed to meet heat or steam demands, but the electrical load may only be partly met. Figure 1 indicates the percentage of electricity the CHP supplies. CHP systems are proven technologies that have not met their full potential. With deregulation of the electricity sector and increased concerns regarding global warming, CHP systems will increasingly become viable alternatives that will increase profit and reduce greenhouse gas emissions. The Climate Wise Program and Partners will continue to be a resource and advocate for this technology.

Table 3. Summary of Selected Climate Wise Partner's CHP Facilities

Implemented CHP	3rd Party	Configuration	Facility Size (number of employees)
3M Austin Center		Gas/Diesel Engine, Combined Cycle, with Waste Heat Boiler	1400
Bristol-Myers Squibb - Lawrenceville		Gas Turbine with Waste Heat Boiler	
Bristol-Myers Squibb - New Brunswick		Gas Turbine with Waste Heat Boiler	
Bristol-Myers Squibb – Wallingford		Gas Turbine with Waste Heat Boiler	
Colorado School of Mines	Yes	Boilers and Steam Turbines	662
Coors Brewing Company	Yes	Boilers and Steam Turbines	4400
General Motors – Lockport	Yes	Combined Cycle	
General Motors - Pontiac North plant		Back Pressure Turbine	
General Motors – Warren		Back Pressure Turbine	
General Motors – Romulus		Back Pressure Turbine	
King County Wastewater Treatment		Methane Burning Engines with Waste Heat Recovery Boiler	135
Malden Mills		Gas Turbine with Waste Heat Boiler	2000
Navistar International Transportation		Gas Engines with Waste Heat Boiler	1400
Polaroid - New Bedford		Back Pressure Turbine	400
Roche Vitamins		Gas Turbine with Waste Heat Boiler	700
Schering Plough	Yes	Gas Turbine with Waste Heat Boiler	2000
Planned CHP			
Polaroid- Waltham		Natural Gas Turbine with a Waste Heat Boiler	1000
Prime Tanning Company	Yes	Combined Cycle	150

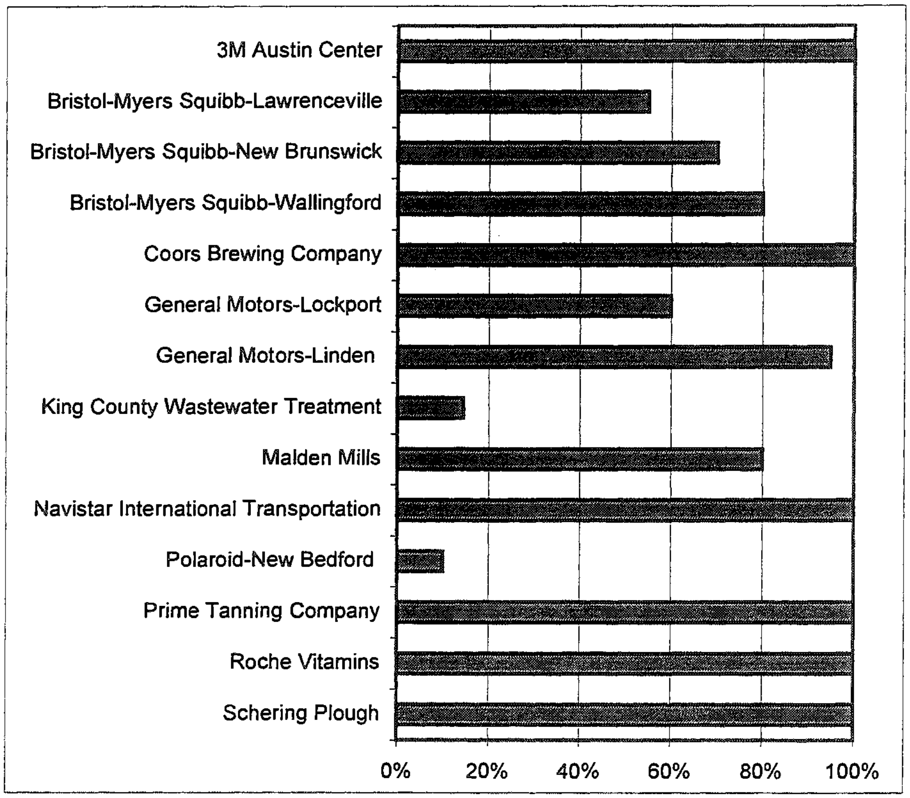

Figure 1: Percent of Facility Electricity Provided by CHP at Selected Facilities

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