

Performance Results and Lessons Learned from Austin Energy's Packaged Cooling-Heating-Power System

*Ed Mardiat, Burns & McDonnell
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ABSTRACT

According to many industry experts, we have already reached the top of our gas bubble—the rate of discovery of future gas reserves is increasing at a pace slower than the rate of increase in demand. These experts paint an unfavorable scenario for the day that the supply and demand curves intersect. Some pundits believe this intersection could be as soon as 2025.

We can have optimism for the long-term prospects of energy because numerous initiatives are under way to replace our dependence on finite supplies of fossil fuels. A multitude of government and private programs promise to increase the feasibility of renewable energy sources such as hydrogen, solar, wind and biogas. Perhaps the energy “wreck” that some experts are forecasting will be forestalled forever by the introduction of renewable energy into the daily routines of our personal and business lives.

An added risk for delivery of reliable power is the electricity transmission infrastructure. While investments in electric generation assets continue to increase, especially since 2000, investments and upgrades to transmission systems continue to decrease year after year.

In the meanwhile, until that 20 to 30 year “wreck” is forecast to occur, we have opportunity to take action that will sustain us while we still have reliable supply of fossil fuels. According to the US Department of Energy (DOE), combined cooling, heating and power (CHP) is an essential element in the distributed generation portfolio often making the

economic and environmental difference between success and failure of a project. CHP has been called the bridge to a sustainable energy future.

INTRODUCTION

In support of the DOE's vision for a clean and sustainable energy future is the Distributed Energy Program. The DOE program emphasizes development of next generation distributed energy solutions that promise to make on-site electric generation an integral part of the electric delivery system of the future.

In 2002 the DOE received proposals in response to their solicitation to create innovative packaged CHP solutions to meet the needs of specific buildings. When responding to the DOE's request Burns & McDonnell had available numerous options for prime movers and for thermally activated technologies but decided early in the process only to consider equipment that would make economic sense in high low electric cost areas such as Texas. If a CHP system makes sense in Texas, then replication potential would be great elsewhere.

To configure a CHP to perform successfully in Texas from a technical perspective places a priority for HVAC cooling, rather than heating, by recycling the exhaust heat. And to raise the stakes even higher, any CHP system must comply with Texas's stringent emissions rules. The only way to have a successful CHP system with such high performance benchmarks will require extra ordinarily high efficiencies from the input fuel. While a 55 to 65% efficient system may be favorable on the west coast and the northeast, efficiencies greater than 75% were required in Texas.

Achieving such high efficiencies (or such a low system heat rate) is a daunting challenge. To get maximum impact from the recycled exhaust energy Burns & McDonnell engineers determined that by indirectly firing an absorption chiller by using all of the recovered exhaust heat was the ticket to higher efficiencies and lowest emissions. And so they picked unique combination of a Solar Turbines Centaur gas combustion turbine that would indirectly fire its exhaust heat into a Broad USA absorption chiller.

With the equipment configuration decided, Burns & McDonnell created a public-private partnership consisting of Austin Energy (contributing \$5.3M), DOE's Oak Ridge National Laboratory (contributing \$3M), Burns & McDonnell of Kansas City, Missouri as design-builder

and system integrator, Solar Turbines Incorporated as supplier of the prime mover and Broad USA as supplier for the absorption chiller. Turbine Air Systems of Houston was added to the team later as an exclusive subcontractor and provided shop fabricated skid packages to reduce installation time during site construction.

On June 14, 2004, a ribbon-cutting ceremony was held in Austin, Texas, to inaugurate the commencement of operations for this unique CHP configuration. The new Austin Energy CHP system is an exciting addition to an existing district energy system at an industrial park called The Domain. The district system provides chilled water, steam and compressed air to more than 1 million sq ft of office, retail, industrial and residential space.

The DOE's vision of a sustainable energy future is emerging with this large scale CHP system that uses waste-heat exhaust from a natural-gas-fired turbine-driven generator as the only fuel source for a chiller providing air conditioning and heating. This innovative plant can be the basis for replication of similar CHP systems while making a significant contribution toward the DOE's effort to double the amount of CHP in the United States from the 1999 level of 46 GW to 96 GW by 2010.

EQUIPMENT SELECTION

Recycling waste heat exhaust from a natural-gas-fired generator is not new. What is new is using waste heat as the only fuel source—without any supplemental fuel—for a chiller providing this much air-conditioning capacity. By indirectly firing the chiller with exhaust heat, any need for waste heat recovery steam boilers is eliminated, see Figure 1.

The prime mover is a Solar Turbines Model Centaur[®] 50 electric generator set that produces 4,600 kW of electricity at 12,470 volts using natural gas, see Figure 2. While its heat rate of 11,628 Btu/kWh may not be particularly attractive for standalone operations in a low-electric-cost state like Texas, the amount of exhaust heat from the turbine is especially attractive for use in the 2,535-ton absorption chiller. The turbine exhaust is supplied directly to the absorption chiller.

Inlet air to the natural gas turbine is cooled to improve power output and electric efficiency using 200-260 tons of the system's chilling capacity during hot ambient temperatures. Heat from the approximately 900°F turbine exhaust is used to boil the refrigerant (water) from a

CHP MODULAR CONFIGURATION

Gas Turbine Exhaust & Indirectly Fired Absorption Chiller

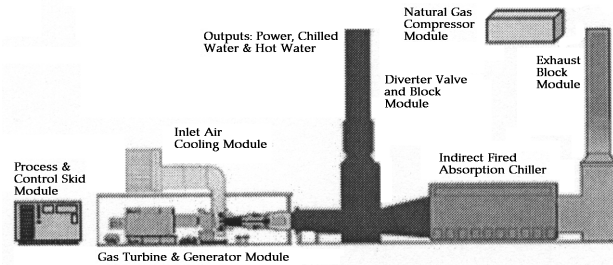


Figure 1. Austin Energy Domain CHP Energy Plant Major Components.

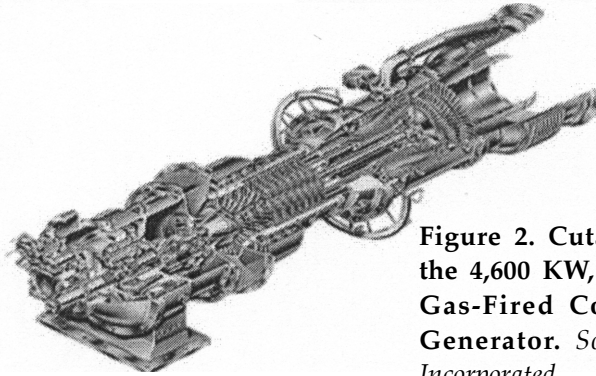


Figure 2. Cutaway Illustration of the 4,600 KW, Centaur 50 Natural-Gas-Fired Combustion Turbine Generator. *Source: Solar Turbines Incorporated.*

natural absorbent, lithium bromide. This high-pressure water vapor is condensed, expanded through a throttling valve and sent to an evaporator that produces the chilled water. This advanced double-effect chiller uses two stages of heat exchange to improve efficiency.

The absorption chiller is a Broad Model BE-1000 rated for 2,535 refrigeration tons, producing 6,073 gpm of 44°F chilled water, see Figure 3. The unit uses only 37 kW of electric power.

While the skid-mounted absorption chiller and gas turbine generator make up the bulk of the plant, ancillary plant equipment is also provided on skids. A Toromont gas compressor increases delivered fuel-gas pressure from 40 psi to 220 psi needed for the turbine generator. Turbine Air Systems shop-fabricated the gas compressor package, turbine exhaust and bypass damper skid, absorption chiller exhaust skid, prefabricated much of the interconnecting pipe, and the control enclosure and pump skid, as shown in Figure 4.

Figure 3. The integrated energy system includes an absorption chiller rated for 2,535 refrigeration tons, producing 6,073 GPM of 44°F chilled water. Source: Burns & McDonnell

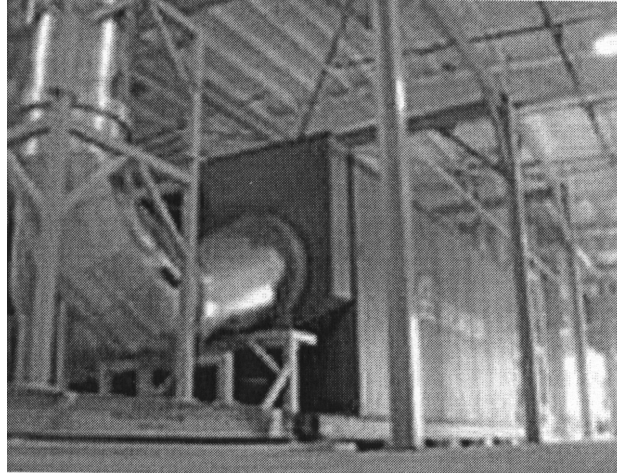
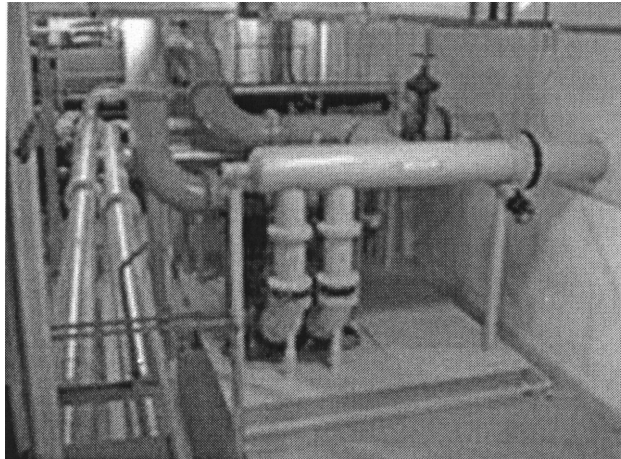


Figure 4. This shop-fabricated chilled water pumping skid includes a local control room to monitor power generation outputs, chilled water supply, and condenser water temperatures. Source: Burns & McDonnell



The use of pre-built, skid-mounted equipment modules offers many advantages that will enable packaged CHP systems to be applied to commercial buildings as well as industrial and institutional applications. By packaging these pre-engineered CHP modules at the factory, field erection time and installation costs are reduced thereby enabling growth of these highly efficient CHP systems. As the penetration of CHP increases, energy delivery will become more secure because of less dependence on central station power plants and transmission lines. Power plant emissions will also reduce because of the higher efficiencies of CHP.

PLANT OPERATIONS

From purchase order to commercial operation, the Austin Energy CHP project took nine months to build—about four months for engineering, materials procurement and fabrication, and five months for site construction.

The system has the capability to vary electric and chilled-water load, but to maximize efficiency, it is primarily intended to operate in a base load configuration. Where electric prices are low, as in Texas, the financial value of thermal demand is more of an economic driver for system operation than electric demand.

At full load, the plant's combined power and chilled-water efficiency is nearly 89 percent lower heat value (LHV), including equipment parasitic loads. A diverter valve installed between the turbine and high-stage generator section of the chiller allows chilled-water temperature control. A remote computer enables plant operators to monitor and control the system from a room 500 ft away from the CHP equipment.

The electrical output is registered with the Electric Reliability Council of Texas and can be remotely dispatched by Austin Energy to provide power to the grid when needed. The turbine generator can be up to full load in less than 15 minutes. However, the chiller requires an additional 30 minutes to heat soak the high-stage generator section prior to achieving full load.

The system was the first to use the Texas air quality standard permitting process for electric-generating units, which provides a thermal credit for CHP applications. The Texas Commission on Environmental Quality (TCEQ) allows a credit against the prime mover's NO_x emissions of 1 MWh for every 3.4 MMBtu of heat recycled. Because the Austin Energy project recycles so much heat, the system surpasses TCEQ's stringent 0.47-lb NO_x/MWh NO_x requirements without any catalyst. Using the 'output-based' emissions formula:

$$\text{Emission Rate} = \frac{\text{Emissions (lb/hr)}}{\text{MWe} + \text{MWt}}$$

The CHP prime mover that has nameplate emissions of 0.66 lb NO_x/MWh falls to 0.23 lb NO_x/MWh. From an emissions perspective, the recycled heat is like adding another 9 MW of power capacity.

Table 1 provides a picture of the plant's initial performance. The data exclude the auxiliary loads associated with the chilled-water distribution pumps and condenser water system. The net plant heat rate (LHV) chargeable to power, when crediting the absorption chillers thermal benefits, is only 4,792 Btu/kWh. This is a significant improvement over (1) the currently operating gas turbine combined-cycle plants, which have an efficiency of about 53 percent or a net plant heat rate of 6,442 Btu/kWh, and (2) coal-based plants with an efficiency of about 38 percent and a heat rate of 8,934 Btu/kWh.

LESSONS LEARNED

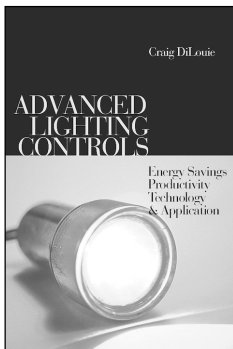
While prepackaged, pre-engineered CHP systems will drive costs down and open opportunities for replication, their full potential will not be realized unless decision-makers are well informed about certain details that can make or break the project. A thorough understanding of energy issues is required, from the supply side to the user perspective. In assessing the feasibility of replicating Austin Energy's CHP concept, the following areas should be considered:

Table 1. Austin Energy CHP Energy Plant Performance

Turbine-Generator Site Output	4,329 kWe*
Chilled-Water Production	2,632 tons at 44 F
Turbine Fuel Consumption	51.7 MMBtu/hr (LHV)
Fuel-Gas Compressor Load	89 kWe
Turbine Parasitic Loads	5 kWe
Chiller Parasitic Loads	37 kWe
Overall Net Plant Efficiency	88.8% (LHV)
Overall Net Plant Efficiency	80.4% (HHV)
Chiller Coefficient of Performance (COP)	1.35

*Full-load continuous duty rating
Source: Burns & McDonnell.

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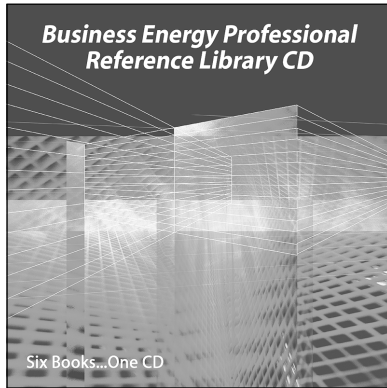
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- **Thermal loads profiles.** Can your host site use thermal energy in the form of chilled water, steam or hot water nearly all year long? Often a CHP installation will not make sense unless the customer places a larger value on the thermal energy than the electrical energy. Note that chilled water at 25 cents/ton-hour or steam at \$12/MMBtu is worth more than \$0.06/kWh for electricity.
- **Value of thermal energy.** What is the thermal energy worth? Will the CHP system simply offset the value of thermal energy currently produced by an efficient electric chiller or a packaged boiler? One will find that the financial proforma is greatly improved when the CHP system is credited for the full value of thermal energy rather than an offset for the fuel costs for an existing chiller or boiler.
- **Emissions permitting issues.** A new gas-fired CHP system will have to be permitted as a generation plant. Many areas of the United States are increasing emissions requirements that may eliminate many distributed-generation prime movers. But for areas using an output-based emission evaluation, the possible choices for prime movers will increase. A creative use for recycled exhaust heat can significantly reduce overall energy consumption as well as have a positive impact on the environment.
- **Grid interconnect.** The weak point of many CHP projects is in addressing interconnection to the electric grid and the costs for gas. When studying CHP feasibility, be sure that costs to physically interconnect to the grid and the optimal electric tariff are applied that will allow the CHP system to operate at optimal capacity. The chosen tariffs may need to allow the grid to serve as backup or standby to the CHP system. The Texas and California interconnection models may serve as examples for areas with outdated interconnection guidelines that are punitive to CHP.
- **Cost of natural gas.** A base-loaded CHP system will consume a constant flow of gas all days of the year. This stable and predictable throughput and capacity allows the CHP provider to negotiate favorable transportation and commodity pricing from the local distribution company and from a competitive gas supplier. Don't forget to ask the gas company about availability of high pressure gas. You don't want to install a gas compressor for your CHP system if the gas company can provide the pressures you need at little or no cost.

- **Ancillary and parasitic loads.** No CHP system can operate without them, but how you pay for the fuel to operate your cooling towers, circulating pumps, gas compressor and other plant support equipment can have a significant impact on the financial performance of your CHP system. Most CHP installations will perform better financially by using the CHP prime mover as the source for power for the plant parasitic loads.
- **Zoning/permitting.** Keep in mind that a CHP installation is more like a power plant than a central utility plant. Local zoning authorities may need to apply different criteria for approval of plans and specifications for prepackaged CHP equipment. Noise issues should also be addressed because the CHP installation will include a gas-fired prime mover.
- **CHP is two base-loaded plants in one—get used to it!** Just because you need don't need all of the chilled water from your CHP does not mean that you should by pass more exhaust heat. No! To do so significantly degrades the system efficiencies and financial performance. An effective CHP must optimize its efficiencies in a base load configuration and the only way to do that is to maximize the use of all of the thermal and electrical output of the system.

Other valuable benefits may factor into your CHP selection such as improved on-site availability of power, improved site reactive power, grid voltage support and elimination of electric transmission and distribution losses. An on-site generator can be the catalyst for creating a micro-grid that distributes premium power to targeted customers. For applications with high spark spreads (the difference between the cost of electric power and fuel cost) and limited transmission and distribution growth potential, these systems would be an excellent option to consider.

MOVING FORWARD

In terms of meeting both the DOE's and Austin Energy's goals, the CHP project is a significant success. The configuration of large-scale absorption chillers in conjunction with combustion-turbine generators was proven to be effective for applications with large electric power, chilled-water and possibly hot water energy needs. With higher heating value efficiencies in excess of 75 percent fuel usage, compared to the U.S.

average generation cost of only 35 percent, integrated energy systems using combustion turbine generators with absorption chillers should find a number of global applications.

Projects such as the Austin Energy CHP experience are proof that by careful selection of system components, the options for replication of highly efficient and sustainable CHP plants is great. The choices for prime movers are increasing every year with new lean burn reciprocating engines as well as highly efficient and low emissions combustion turbines. Each of these prime movers can be mated with thermally activated chillers, desiccant driers or heat exchangers to maximize system efficiencies that will help us to sustain our energy needs.

"Federal officials are hoping Austin's plant is the beginning of a trend," said Ron Fiskum, a technical manager with the DOE. "We're hoping this project sets the stage for other projects like this around the world. Once people see the data, they're going to want to get involved."

ABOUT THE AUTHORS

Ed Mardiat, DBIA, is a principal and director of combined heat and power development for Burns & McDonnell. He has more than 25 years of design and project management experience, the past 10 focused on marketing and business development for utilities and infrastructure projects. He works with industrial, commercial and institutional clients to help them understand the impact of utility deregulation on their facilities. Mardiat serves on the executive board of the U.S. Combined Heat & Power Association. He may be reached at emardiat@burnsmcd.com.

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