Distributed Energy Program FY05/06 Accomplishments

ARES

Materials

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CHP

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Oak Ridge National Laboratory

FY 2005/06

Accomplishment Report

Research funded by

U.S. Department of Energy

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Distributed Energy Program

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INTRODUCTION

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On behalf of Oak Ridge National Laboratory's Distributed Energy Program, I am pleased to introduce the FY 2005/06 Accomplishments Report. The objective of the Distributed Energy (DE) Program is to develop the next generation of clean, efficient, reliable, and affordable DE technologies and to successfully integrate them into end-use applications. These systems are powered by microturbines, reciprocating engines, or industrial gas turbines, and they can produce from 30 kW up to about 10 MW of electricity. Waste heat produced by the prime mover is captured and converted to useful energy to heat and cool buildings. The target for these integrated systems is to demonstrate at least 70% total fuel efficiency with a payback period of less than 4 years.

The Distributed Energy Program at ORNL is divided into three areas: 1) Advanced Reciprocating Engine Systems (ARES), 2) Advanced Materials, and 3) DE Systems Integration/CHP. Research is conducted to increase the efficiency of turbines, dramatically reduce the emissions from the reciprocating engines, and optimize the efficiency of the integrated systems. FY 2005/06 featured accomplishments in each of these program areas – 2 in ARES, 5 in Advanced Materials and 8 in DE Systems Integration/CHP. The last section of the report summarizes packaged Integrated Energy Systems (IES) projects that are currently under construction and will be completed during FY2006 or FY2007.

During the past year, DOE's Distributed Energy Program has been moved from Energy Efficiency and Renewable Energy (EERE) to the Office of Electricity (OE). This change has significantly impacted the Program as emphasis has shifted from the efficiency and emissions of prime movers to the security and reliability of the electric grid. The Program's customers or end users have also changed from OEMs and DE system owners to electric utilities. The featured accomplishments at the front of this report describe work that reflect these changes. The first accomplishment documents the benefits of DE installations at municipal utilities in Utah and Tennessee. The second accomplishment describes research on the generation of Reactive Power by distributed energy resources and development of collaborative relationships with numerous electric utilities.

Please feel free to direct comments or questions regarding this report to me or the contacts listed for each project.

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ORNL Investigates Benefits of Distributed Generation at Municipal Utilities

DE Offers "Win-Win" Outcomes to Customers and Utilities

Background

Over the last thirty years, a large number of studies have been conducted to characterize the benefits of Distributed Energy (DE) to system owners. These benefits typically include reduced utility expenses and the provision of back-up power. As the Department of Energy (DOE) established a broader program, however, DE benefits to other stakeholders and society in general were explored. The earliest analyses simply listed potential advantages and their beneficiaries, but the benefits identified were often poorly understood and difficult to quantify. For example, total air emission reductions benefit society at large while voltage support may benefit only electric customers located in close proximity to the DE source. Moreover, as monetary values were assigned to the identified benefits, profits to one group of stakeholders might require additional costs to other stakeholders. It was therefore necessary for broad national estimates to be supplemented with more localized studies. Since municipal utilities are actually owned by their customers, they were poised to offer opportunities for the development of a DE implementation model benefiting both customers and utilities. In addition, municipal utilities are also often motivated by energy security concerns and economic development objectives.

McMinnville Electric System's peaking power diesel generator sets

Assessments

Heber Light & Power (HLP), the municipal utility in Heber City, UT, operates a combination of advanced gas-fired generators, diesel generators, and hydro with a total capacity of 12.5 MW – about half of the local peak demand. The facility actively manages the equipment in response to market fluctuations, dispatching power from their plants when hourly market prices rise above the operating cost. As large homes with huge, peak period air conditioning requirements continue to be constructed in the region, DE capabilities have kept rates from increasing to meet peak demands.

The DE equipment also provides a reliability hedge to HLP. This allows HLP to contract for lower prices from central station plants on a unit-contingent basis and provides back-up capacity in case of outages from the transmission grid. Furthermore, since the utility is located at the end of a 138 kV transmission line, positioning a portion of the power generation close to the load improves the power quality.

In Tennessee, the McMinnville Electric System (MES) operates a block of 11 diesel generators to provide peaking power to the Tennessee Valley Authority (TVA) system and back-up power for the city of McMinnville. When operating, the 20 MW capacity of the installation provides approximately 40% of the city's total demand, and is tied into a critical care feeder circuit serving the local hospital and jail. In contrast to the HLP system, this system is dispatched by TVA and is permitted to run a maximum of only 350 hours per year due to emissions limitations. Although MES does not actively participate in the market as HLP does, fees paid by TVA have helped the utility control costs and subsequently offer retail customers the fourth lowest rates in the TVA system. TVA does not pay for reactive power, but the diesel generators provide voltage support to other power distributors 50 miles away.

MES is also involved in DE research, hosting a collaborative effort to develop and demonstrate a reciprocating engine-generator fueled by a soybean-based, bio-diesel product. An innovative after-treatment emissions system is now being tested in efforts to reduce emissions by 80-90% as compared to a diesel-fired engine. The facility's goal is "Green Power" classification which would allow continuous operation and the potential to charge higher rates.

McMinnville Electric's new bio-diesel system

DE Benefits to Municipal Utilities

- **Cost savings for utility and customers –** At a municipal utility, there is little distinction between the utility and customer. Community members at the utility want to purchase and resell power at reasonable prices in their own neighborhoods.
- **Reduced demand charges –** The utility is charged a fee proportional to its peak load. This revenue is used by larger utilities to build coal-fired or nuclear power plants to generate enough power for peak periods. Without DE capabilities, HLP would be charged for a 25 MW peak load; however, the facility is able to generate 12.5 MW of the peak power and subsequently claims only a 15 MW peak load.
- **Reduced capital costs –** Both the HLP and McMinnville systems are low-cost – approximately $1,000/kW installed. HLP can pay off the cost of the engines in approximately 2 years when running the engines only 30% of the time because the facility profits largely during peak periods and does not operate during off-hours.
- **Improved reliability and security –** Most municipal utilities simply buy electricity at market prices and resell it to customers. Both HLP and MES are atypical in that they generate their own power, making them less grid-dependent. This is particularly important to the citizens of Heber City since the one or two transmission lines into the town can be quickly compromised by a forest fire or major snow storm.
- **Power quality –** Power quality is improved when a portion of the power generation occurs close to the load.

A comprehensive examination of DE advantages may facilitate the deployment of advanced DE technologies as they are understood in the context of the larger energy market. Furthermore, a public discussion may result in regard to who will bear the costs and who will reap the benefits of power generation alternatives.

Future Work

The ongoing study of potential DE applications at customer-owned utilities will contribute to DOE's assessment of societal DE benefits mandated in the 2005 Energy Policy Act and complement technology development efforts. For example, increased examination of the value of reactive power aligns with the expansion of research into methods of production. Similarly, improved meters and controls are being investigated for their potential role in optimizing integration of DE into utility systems.

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ORNL Establishes Reactive Power Laboratory

Distributed Resources and Controls are Implemented to Supply Cost-Effective Reactive Power

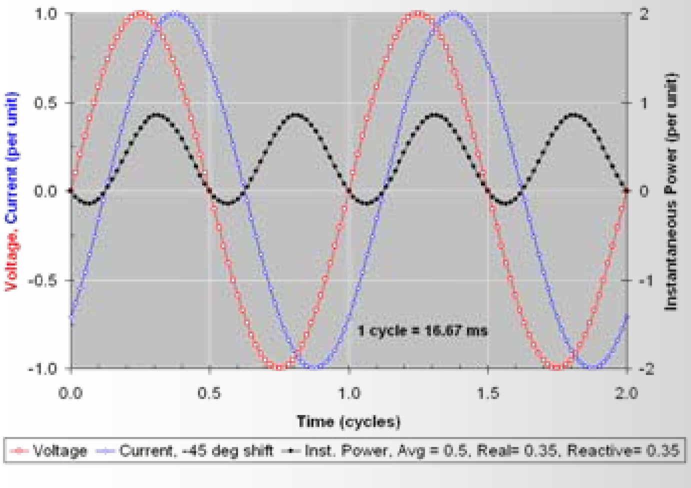
Background

Reactive power is a complex phenomenon that plays a key role in the operation of the electric power grid. Reactive power is that portion of electricity that establishes and sustains the electric and magnetic fields of alternating current (AC) equipment. It is created by capacitors and inductors as they stabilize voltage and current respectively, and it must be supplied to most types of magnetic equipment (such as motors and transformers) for proper operation. Inadequate reactive power reserves can contribute to voltage collapse and wide-scale power outages, so it is necessary to effectively manage reactive power levels.

Reactive power is best applied locally since its transmission from remote sources can cause power lines to experience voltage drops and decreased capacity to carry active power.

Objective

The Reactive Power Lab has been established to demonstrate that distributed resources (DR) can provide reactive power locally for power factor correction and voltage regulation through low-cost controls and minimal communications using either inverters or synchronous machines.



Reactive Power Basics

Current and voltage fluctuate with each AC cycle. When current and voltage are fluctuating together in phase, active power is produced for tangible use; however, when voltage and current are out of phase, reactive power is produced. Although reactive power is not available for end-use consumption, it is required by some electrical equipment for operation.

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Technology

DR with power electronic interfaces can be controlled to produce and absorb reactive power in order to stabilize voltage on transmission networks. Some DR devices, such as reciprocating engines, contain synchronous generators, which can be directly connected to the local power system. Others, such as photovoltaics or microturbines, produce direct current (DC) and therefore must be converted to AC through an inverter. The ORNL Reactive Power Lab has been established to develop the controls allowing both types of device to produce reactive power locally.

250 kVar synchronous motor & 75, 150 & 300 kVar 3-phase inverters

For example, in the synchronous condenser testing area, a 250 hp synchronous motor is overexcited (by DC power provided by a 6.6 kW power supply) and operated unloaded in order to produce reactive power. In the inverter portion of the Lab, three different sizes of programmable inverters are also tested to supply reactive power and can also provide overall non-active power compensation (such as harmonics, unbalance, and flicker).

The test equipment of the Reactive Power Laboratory connects with the ORNL distribution system (owned and operated by ORNL and supplied by TVA) at different electrical locations. This interface allows testing to occur under various scenarios, such as motor starts, relaxation of capacitor compensation and reconfiguration.

Milestones & Future Work

Milestone April 27, 2005

The 300 kVar synchronous condenser was operated for the first time to inject reactive power into the ORNL distribution system. The device has been operated to its full reactive power rating since that time.

Milestone February 23, 2006

The 62kVar (75A) rated inverter was first operated to produce 10% of its rated output. In March, the same inverter operated at 58% of its rated output.

Spring 2006

Feedback control algorithms for both the synchronous condenser and inverter operating independently have been developed and tested for maintaining a local voltage schedule.

By September 2006…

Researchers plan to simultaneously control a 300kVar (volt-ampere reactive) synchronous condenser and a 125kVar (150A) inverter which are connected to two different distribution circuits.

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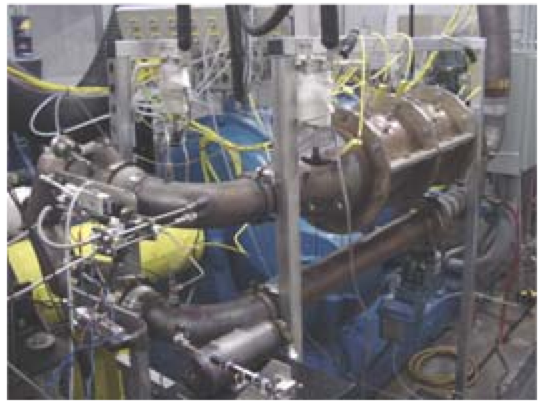
Advanced Reciprocating Engine Systems

Practical Lean NO_x Trap Technology Achieves High Fuel Efficiency and Low Emissions

NO_x Trap Regeneration System Optimized in Gas Engine

Background

Lean-burn combustion (with high air-to-fuel ratio) is used in natural gas reciprocating engines for better fuel economy, enhanced engine durability, and lower emissions levels. In 2004, ORNL lean NO_x trap (LNT) experiments successfully met and surpassed the 2010 target for the Advanced Reciprocating Engine Systems (ARES) Program to reduce nitrogen oxide (NO_x) emissions to less than 0.1 g/hp-hr.

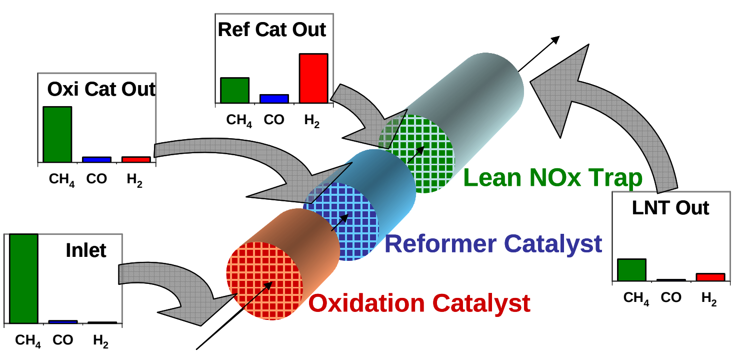


A state-of-the-art lean engine used at ORNL to evaluate a lean NO_x trap.

Hereto, reduction of NO_x required the use of potentially toxic chemicals (such as ammonia and urea) in the selective catalytic reduction (SCR) process. The LNT process eliminates the complexity, costs, and emissions associated with such chemicals by its ability to use natural gas as the sole fuel/chemical source; however, the additional catalysts and natural gas consumption needed for NO_x reduction represent some penalties. FY05/06 research therefore focused on characterizing and improving the catalyst system and fuel controls to optimize fuel efficiency.

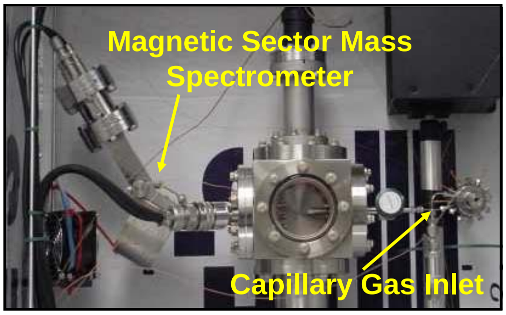
Technology

The LNT is a catalytic surface that adsorbs NO_x from the engine exhaust. When this trap is saturated, most of the exhaust flow is shunted to a parallel and symmetrical path while the "idled" trap is regenerated. Rich-burn conditions are created by briefly introducing a small amount of the engine's natural gas supply into the "idling" fraction of the exhaust flow just upstream of the oxidation catalyst. The oxidation and reformer catalysts break down methane in the natural gas into reactants, carbon monoxide (CO) and hydrogen (H_2), which then quickly reduce the trapped NO_x. This resultant LNT exhaust is harmless N_2, carbon dioxide (CO_2) and water. When the NO_x trap in the other path becomes saturated, the two flows and are reversed.



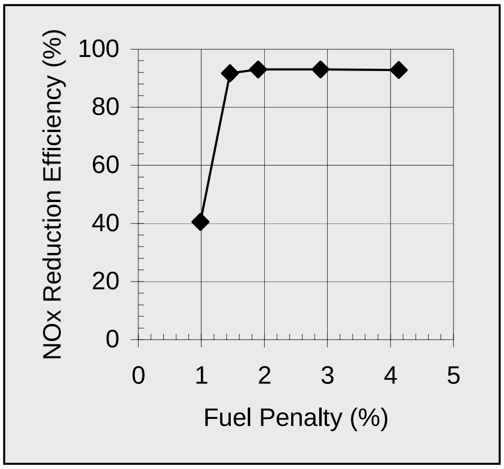
Exhaust Species vs. Position in Lean NO_x Trap Catalyst System. *Oxidation and reformer catalysts are positioned upstream of the lean NO_x trap to convert CH_4 in natural gas to CO and H_2 which are preferred reductants. Sample data shows CH_4, CO, and H_2 at various positions in the exhaust system.*

In FY05, ORNL completed a study characterizing the exhaust chemistry at each position in the LNT catalyst system. The results show the importance of both partial oxidation and reforming processes in the utilization of natural gas for LNT regeneration. The production of H_2 is greatly enhanced by the reformer catalyst that utilizes Rh to catalytically produce H_2 from CH_4 and H_2O. A unique technique developed in a another project at ORNL, SpaciMS, was used to make the H_2 measurements in the study. The SpaciMS technique is highly sensitive and responsive due to a novel method of collecting the gas sample through a hollow capillary that can be inserted into any exhaust stream; a magnetic sector mass spectrometer is then used to detect the hydrogen gas.



SpaciMS Analytical Tool developed at ORNL

The study found that NO_x reduction efficiency is not a linear function of fuel penalty. "Fuel penalty" was defined as the amount of excess fuel delivered for catalyst regeneration relative to the amount of fuel consumed for engine operation. A 12% fuel difference exists between stoichiometric and lean engine combustion, so fuel penalties significantly less than this amount are desired. Results showed that NO_x reduction efficiency increased with increasing fuel penalty until NO_x performance plateaus at >90%. Once sufficient H_2 is produced from the natural gas injected into the catalyst system, additional fuel use does not increase NO_x reduction efficiency. In the example shown to the right, the optimal fuel penalty of 1.4% yields the most fuel effective NO_x reduction performance.



Benefits

Full characterization of the LNT catalyst regeneration process allows the fuel penalty to be minimized. As LNT technology continues to be optimized for maximum efficiency, it will enable reciprocating engines to be sited even in states with the most stringent environmental regulations.

Future Work

Next steps in LNT research at ORNL include

- characterization of oxidation and reforming catalyst durability as catalysts are exposed to varying quantities of SO_2 present in natural gas, and
- collaboration with industry to develop a commercial product which can reliably switch between LNT systems during regeneration.

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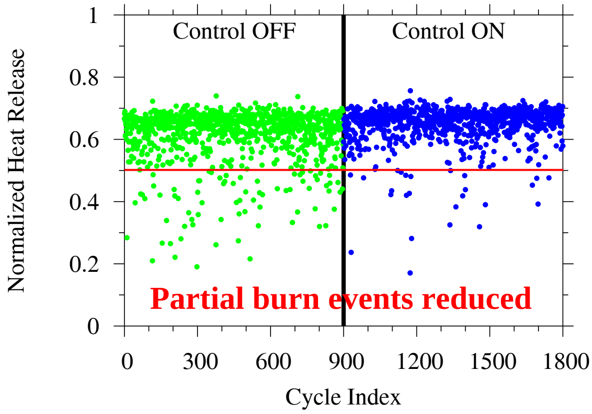
ORNL Adaptive Control Shows Potential for Extending Practical Lean Combustion Limit

Improved Engine Operation Further Reduces NOx Emission Levels

Background & Benefits

Nitrogen oxide (NO_x) emissions can potentially be reduced in spark-ignition (SI) engines by creating ultra-lean-burn conditions. The air-to-fuel ratio during combustion can be increased by introducing fresh air to the cylinder. The diluted mixture results in lower combustion temperatures that inhibit NO_x production. Dilution is also a key component in achieving advanced combustion modes such as homogeneous-charge compression-ignition (HCCI) combustion, which also produces low NO_x levels.



In this example, application of adaptive control to a small NG engine operating at lean conditions results in a 70-75% reduction in the occurrence of extreme partial burns and misfires.

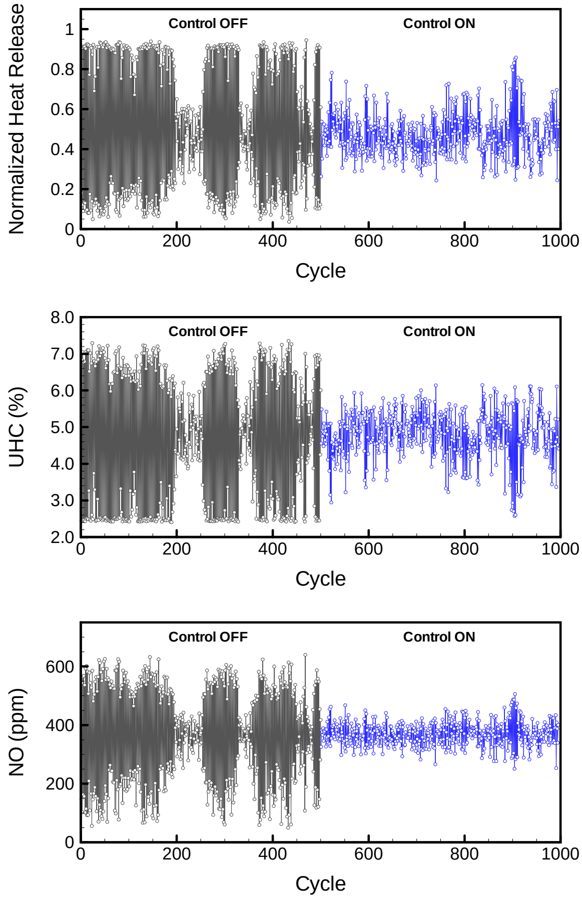
As dilution is increased, however, combustion becomes more and more unstable with increased cycle-to-cycle variability. These instabilities are responsible for decreased engine performance, decreased fuel efficiency, and increased emissions of unburned fuel and NO_x. Subsequently, SI engine operation becomes impractical at dilution levels well within the theoretical limit for sustainable combustion. The goal of this ORNL Advanced Reciprocating Engine Systems (ARES) Program project is to maintain stable combustion using adaptive controls while extending the lean limit as much possible.

Technology

Cycle-to-cycle variations observed in lean-burn conditions occur in a predictable pattern where performance in any given cycle directly effects the performance of the following cycle. The primary feedback between cycles is the residual exhaust gases trapped inside the cylinder when the exhaust valve closes. Following a suppressed combustion cycle, the residual exhaust gases contain significant quantities of unburned fuel which mix with the fresh charge to produce an extra-rich mixture and subsequent enhanced combustion event. ORNL emissions measurements confirm that, in addition to the emission of large amounts of unburned fuel (UHC) during the suppressed combustion events, high levels of NO_x are produced during the enhanced, high-temperature combustion events that follow.

The alternating suppressed and enhanced combustion cycles occur in a predictable pattern that can be controlled through a proactive control strategy. Adaptive controls resolve cycle-to-cycle combustion fluctuations in lean burn engines with active feedback control to make small, but precisely timed, changes to one or more engine parameters. Adaptable parameters include fueling, ignition timing, and possibly valve timing.

ORNL data shows that adaptive controls can indeed reduce the severity of cycle-to-cycle variation in an SI engine operating under lean conditions and allow the practical operating range to be extended. To better estimate the gains in fuel efficiency and emissions reductions which may be achieved through the application of these controls, ORNL researchers developed an analytical SI engine model by adding a detailed combustion model to commercially available engine-modeling software – specifically, WAVE from Ricardo, Inc. The resulting model can predict the development of combustion instabilities and evaluate adaptive control strategies for specific lean-burn SI engine platforms (including large, reciprocating, natural gas engines of interest to the ARES program) without costs associated with actual engine operation.



ORNL analytical model shows reduced cyclic variations and emissions levels using adaptive control and fuel perturbations..

Future Work

HCCI combustion is being aggressively pursued as a promising alternative for the reduction of NO_x production in internal combustion engines, however, it may not be possible to operate in HCCI mode over an entire load range due to dilute combustion instability. One of the most important developments needed to achieve wide-spread HCCI utilization is the ability to rapidly and smoothly switch between HCCI and SI combustion as the power demand changes.

Recent work conducted at ORNL has been focused on operating a single-cylinder research engine in SI and HCCI modes by varying the amount of exhaust gas recirculation. During the transition from SI to HCCI combustion, there are complex but predictable patterns of unstable combustion which can be stabilized with adaptive control strategies. In FY 2006, ORNL will install a state-of-the-art, ARES-representative, single-cylinder engine to further explore the potential benefits of adaptive control to SI and HCCI combustion.

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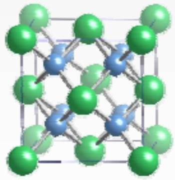


Champion and ORNL Develop Erosion-Resistant Spark Plugs

Better Plugs will Improve the Reliability and Performance of Natural Gas Engines

Background

ORNL is teaming with spark plug manufacturer Federal Mogul (Champion) to develop new electrode alloys to extend spark plug lifetimes in stationary, natural gas (NG) engines. During FY 2005, Champion manufactured a set of 65 test plugs and sent them to ORNL for engine testing and microstructural analysis. The initial set of plugs included five ORNL developmental alloys and three Champion control alloys. Data gathered in this effort will be used in the continued development of new materials that will extend spark plug electrode life.

Spark plug electrode wear is a major issue in enabling industrial NG reciprocating engines to meet cost, performance, and emission goals. Currently, spark plugs have lifetimes of only about 2–6 months, resulting in poor performance as plugs deteriorate, as well as frequent, costly shutdowns for plug replacement. Ideally, spark plugs for NG engines would have year-long lifetimes, and as NG engine operating conditions move closer to lean-burning combustion to reduce emissions, spark plug reliability and lifetime performance become even more critical.

Technology

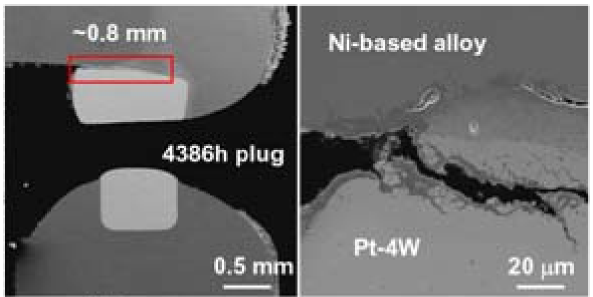
ORNL and Champion are working to identify the key mechanistic contributors to spark plug electrode wear in NG engines and develop improved electrode materials based on this insight. ORNL microstructural and spectroscopic analysis of end-of-life spark plugs from field-operated NG engines identified electrode wear phenomena driven by oxidation and cracking of the electrode materials during engine operation. This finding was unexpected, as wear of spark plug electrodes typically is associated with loss of material due to sputtering, melting, ablation, and particle erosion during sparking.

During FY 2005/06, a range of field- and engine-tested spark plugs at various stages of wear were systematically studied to determine the relative importance of the oxidation/cracking due to

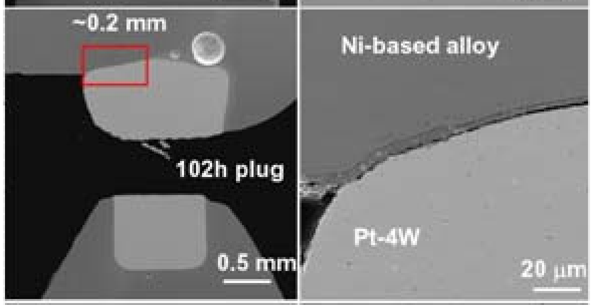
Experimental NG spark plugs manufactured by Federal Mogul using ORNL advanced alloys

CAT G3406 NG engine to be used for spark plug testing electrode wear. The information from these tests will provide a basis for the development of improved electrode materials to achieve longer spark plug lifetimes.

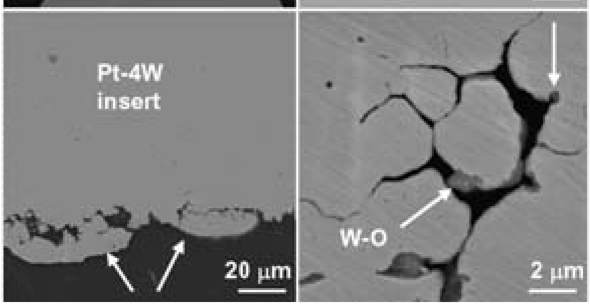
Key Findings



Extensive crack growth and oxidation were seen at the platinum-alloy tip insert and nickel-based electrode interface after 6 months of engine testing (left). This phenomenon would significantly degrade the ignitability and performance of spark plugs and is likely a key life-limiting step.



Crack initiation and oxidation were observed at the platinum-alloy interface after only a few days of engine operation (left). The observations confirmed the importance of these phenomena to the electrode erosion process and confirmed that they initiate at an early stage of plug life.



Substantial intergranular cracks were observed in the platinum-tungsten alloy electrode inserts after only a few days of field service (left). Failed plugs run for up to 6 months were found to have lost up to 40% of their original platinum-alloy electrode material. This cracking was found to result from internal oxidation of tungsten added to the platinum to lower breakdown voltage, followed by volatilization of the tungsten oxide. Coalescence and growth of the cracks associated with this attack would result in flake-off of electrode materials and are likely a major contributor to the loss of platinum electrode material/gap wear.

Future Work

The cracking/oxidation wear mechanisms observed at ORNL establish a basis for developing new electrode alloys. ORNL and Champion will continue to work together to manufacture and engine-test conventional J-type spark plugs using new electrode alloys. Several sets of plugs are planned for the initial series of evaluations. They will include electrode alloys selected for improved oxidation resistance and thermophysical compatibility with platinum electrode insert tips.

Several developmental high-melting-point alloys with high corrosion resistance also will be evaluated in place of platinum alloys for the electrode insert tip. These tests will evaluate the potential to prevent the intergranular cracking and associated material loss observed in the platinum alloys tested.

Engine testing and post-test spectroscopic and microstructural characterization of the developmental spark plugs will be pursued in FY 2006/07.

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New Recuperator Alloy Commercialized

Affordable AL20-25+Nb Alloy Demonstrates Improved Creep and Oxidation Resistance at High Temperatures

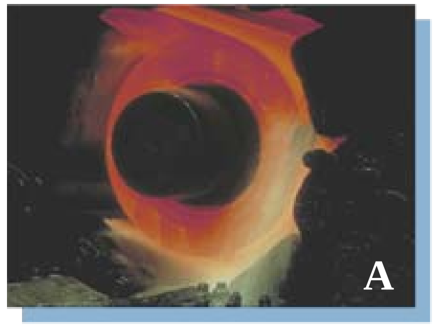
Background

The current DOE Advanced Microturbine Program goal of >40% electrical efficiency will only be achieved as recuperators are enabled to operate reliably at higher temperatures (650-700°C) for extended time periods (>40,000 h). To this end, ORNL has identified a group of commercial alloys for the production of more durable recuperator components. Both lab testing and microturbine experience have shown that standard 347 stainless steel (347SS) is inadequate at 650°C due to moisture-enhanced oxidation and insufficient creep resistance; however, the new Allegheny-Ludlum (AL) alloy, AL20-25+Nb™ (20% Cr, 25% Ni, Nb, and Fe), has outperformed 347SS, demonstrating superior properties in moist, high-temperature combustion environments.

AL20-25+Nb was initially developed in response to the needs of Solar Turbine's new, high-temperature Mercury 50 industrial gas turbine (5 MW) – capable of 38% efficiency. ORNL and AL collaborated to produce and characterize a broad range of AL20-25+Nb commercial sheets and foils for the recuperator needs of microturbine manufacturers. During 2005, the partners modified the alloy processing conditions to optimize the creep resistance of the new alloy.

Technology

During Phase I of this collaborative project, 5000 lb of original hot-band was reduced into over 1000 lb of foils (0.004, 0.005, and 0.008 inch gage thickness) and 800 lb of sheets (0.010 and 0.015 inch gage thickness). ORNL creep–rupture testing and microstructure analysis of the 0.004 and 0.005 inch foils confirmed that AL20-25+Nb alloy strength surpassed that of standard 347SS

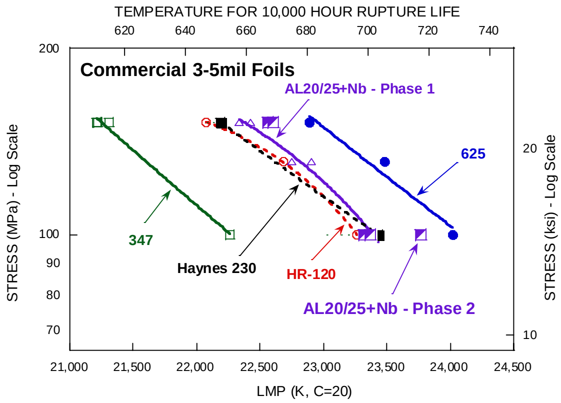


The AL20-25+Nb stainless alloy was melted as a large ingot. It was then formed into foils and sheets through typical commercial rolling of hot-band (A), cold-rolling and annealing (B), and slitting to the exact widths required by each recuperator manufacturer (C).

at 700-750°C and performed as well as foils of HR120, HR230, and other commercially-available, high-performance alloys.

Ingersoll Rand Energy Systems (IRES) received the foils and sheets to fabricate brazed plate-and-fin (BPF) air cells for the recuperators used for the company's new 250 kW microturbines. AL20-25+Nb passed all preliminary IRES tests for BPF air-cell manufacturing and brazed as well or better than 347SS.

In the Phase II effort to further enhance creep-resistance, several hundred pounds of 0.0032 inch AL20-25+Nb foil was produced for Capstone. The foils were used in manufacturing trials for the welded primary surface recuperator (PSR) for their 60 kW and 200 kW microturbines. The Phase II foil strength surpassed that of HR120 and approached that of alloy 625, a Ni-based superalloy. Moreover, AL20-25+Nb is cost-effective upgrade to 347SS when compared to these other more expensive alloys.



Phase II AL20-25+Nb foils demonstrate good creep-resistance when compared to 347SS and other more expensive alloys.

Benefits

- **Improved Strength and Oxidation Resistance** – Foils and sheets of AL20-25+Nb demonstrate better creep and oxidation resistance than those of 347SS at 650-750°C. Rupture ductility of the new alloy is 20-25% (347SS is 3-10%) which further enhances cyclic microturbine operation. In addition, the improved oxidation resistance of the alloy should be more resistant to contaminants present in landfill gas and other alternative fuels.

- **Affordability –** AL20-25+Nb is one of the most cost effective alloys for upgrading recuperator capability, reliability, and performance. The Ni-based superalloy HR230 is strong as a plate, but weak as a foil and 7 times the cost of 347SS. Alloy HR120 and Inconel 625 cost 3.5 times and 5 times the cost of 347SS respectively. AL20-25+Nb is only 1.5 to 2 times the cost of 347SS.

- **Good Manufacturing Properties –** Good welding and brazing behavior should make AL20-25+Nb a promising alternative for many other heat-exchanger technology applications.

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Slurry-Coated Materials Withstand Corrosive Turbine Engine Environment

Successful Environmental Barrier Coatings Formed by Low-Cost Process

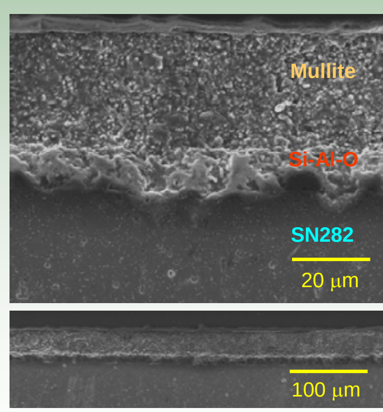
Background

Monolithic silicon nitride (Si_3N_4) ceramics are the primary ceramic material currently used in combustion engine environments. These ceramics are also under consideration for use as hot-section structural materials in microturbines and other advanced combustion systems; however, Si_3N_4 typically forms a surface oxidation layer (silicate) in oxidizing conditions. The silicate layer rapidly degrades in the corrosive and erosive turbine engine environment, severely limiting life of the ceramic. Long-term use of Si_3N_4 material in advanced combustion engine applications will require the development of environmental barrier coatings (EBC) that can withstand high temperature, high pressure, high gas velocity, and the presence of water vapor.

Technology

The slurry (dip) coating process is a promising, low-cost approach for the production of EBCs. For many years, slurry coatings have been used to produce protective barriers in the housing, marine, automotive, and aerospace industries. In contrast to most other coating techniques, slurry coating is a non-line-of-sight process, which coats all surfaces of the part.

Example of an as-coated, rare-earth silicate on silicon nitride

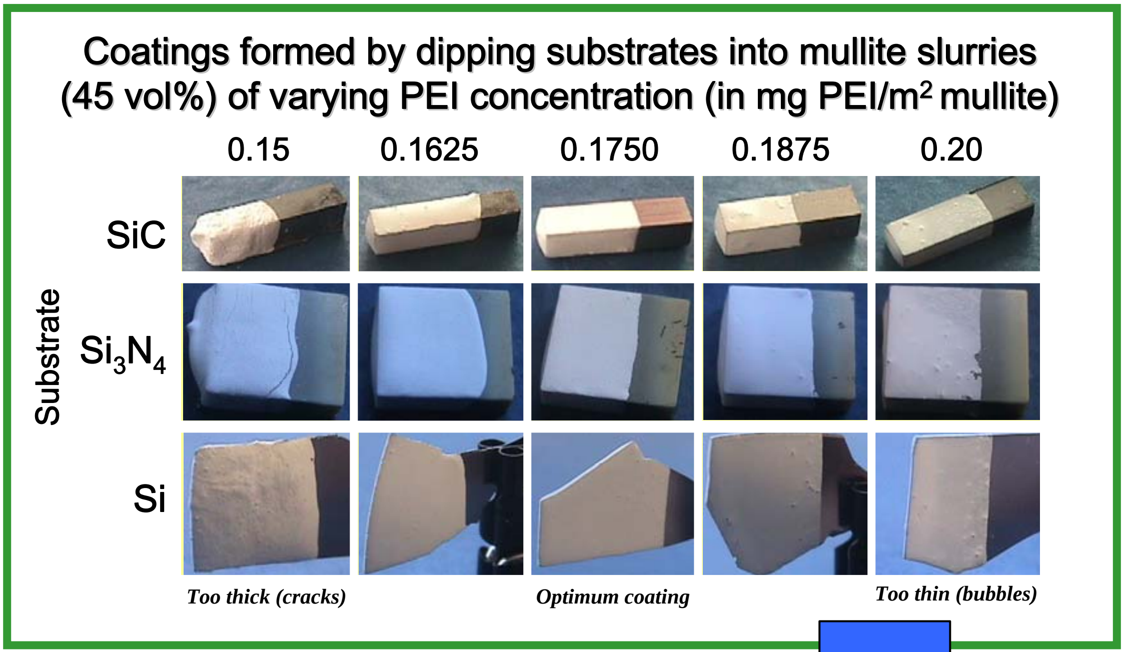


Micrographs of polished cross-sections of densified mullite on silicon nitride

Components with complex shapes can be dipped into a slurry (ceramic particles suspended in a solvent medium), and subsequently dried and heat treated at elevated temperatures to promote densification. Excessive shrinking of the coating upon sintering can cause cracking, and poor adhesion of the coatings to the substrate can dramatically effect the substrate strength. Successful EBCs for Si_3N_4 materials have been developed through the formulation of crack-free and adhesive slurry compounds.

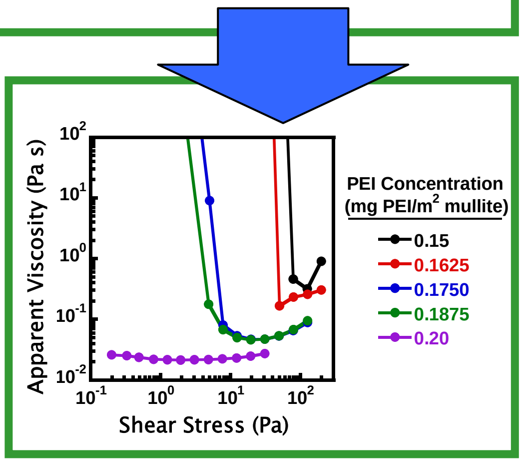
During FY05, coatings of doped alumino- and rare-earth silicates were tested for use on silicon nitride substrates in simulated microturbine environments. A cationic poly-electrolyte, poly-ethylenimine (PEI), was used to tailor the rheological behavior of mullite, doped aluminosilicate, and rare-earth silicate suspensions. Latex emulsions were used to promote improved wetting, drying, and green strength of the ceramic layers. Uniform, crack-free layers were demonstrated on a wide variety of substrates.

ORNL has supplied coatings to collaborators such as NASA, Ceramatec, and Honeywell. Industrial partners are continuing to provide substrate materials, as well as ideas and suggestions for coating compositions, as the optimum processing conditions and best coating compounds are identified.



Benefits

- Non-line-of-sight process for uniform coatings on complex shapes
- No unique equipment required to establish coating capability
- Process flexibility – a variety of ceramic powders can be applied to various substrate compositions
- Technology can be easily transitioned to industrial production



Future Work

The durability and adherence of coatings on complex-shaped substrates exposed to a simulated and actual gas turbine engine environment will continue to be assessed as the slurry coating process is further refined.

Points of Contact:

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Graphite Foams Reduce Size and Weight of Heat Exchangers

Large Internal Surface Area Replaces Conventional Fin Design

Background

High-conductivity, lightweight graphite foams (GF) can potentially increase heat transfer while reducing both the size and weight of heat transfer devices – significantly impacting the cost to dump or recover heat energy. In the past, high-conductivity, low-porosity GF was used as a substitute for other solid materials like aluminum and copper in traditional heat exchanger designs; these attempts yielded only marginal success. Researchers are now achieving significantly better convective heat transfer using flow-through designs that access the extensive internal surface area, but power efficiency losses associated with back pressure must be addressed.

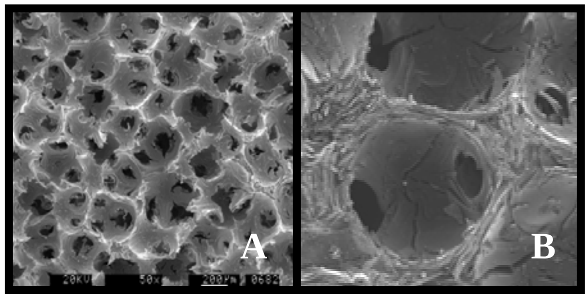
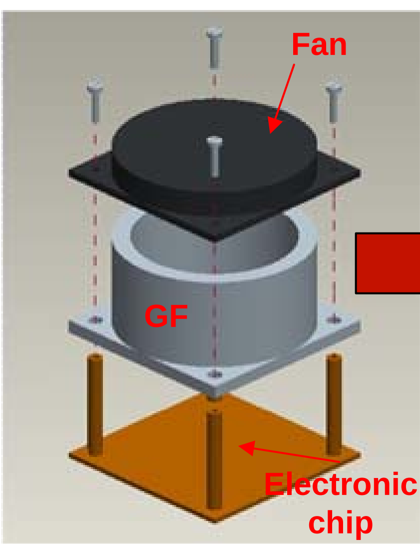


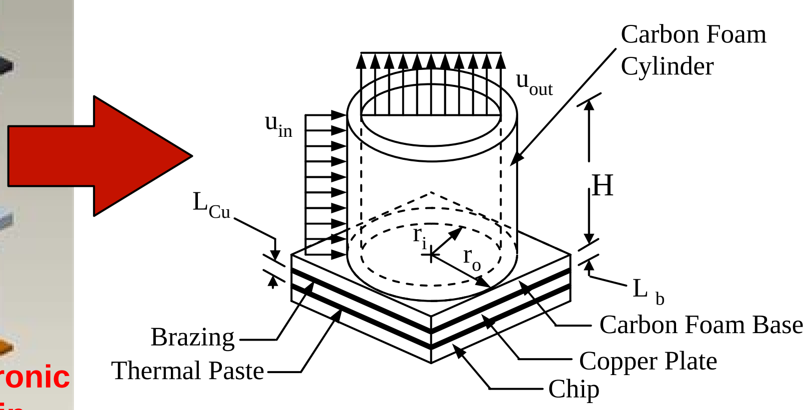
Figure A: Electron micrograph of the GF surface; Figure B: Enlarged view of GF pores and windows; porosity=0.9, pore diameter=400 µm

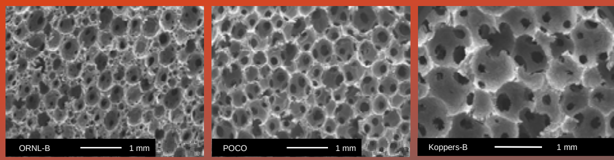
Technology

Properties that make GF well-suited for thermal management applications include its high conductivity, light weight, large internal surface area per unit volume, and low heat storage capacity. The walls of the foam are four times more conductive than copper and six times more conductive than aluminum (approximately 1500W/m·K compared to 400 W/m·k for copper and 250 W/m K for aluminum). This means that the surface of graphite foam will be hotter than metal foam or fins under the same flow conditions, resulting in increased heat transfer. This high thermal conductivity also allows a given amount of heat to be distributed over a larger surface area at the same temperature difference.



Engineering Analysis of Heat Sink to Investigate Potential Enhancements to GF

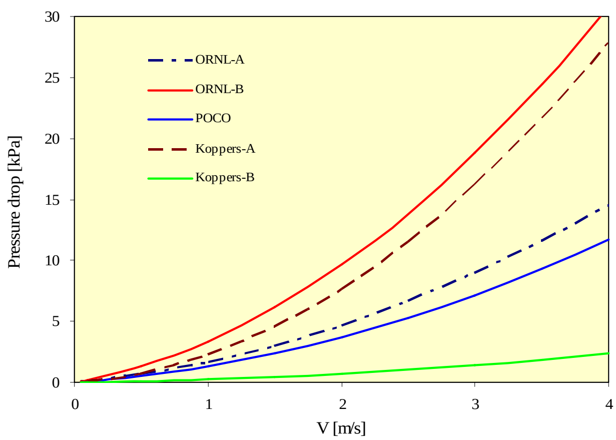




SEM images of graphite foams with varying pore structures

The permeability of the foam also has a positive effect on the heat transfer, but a negative effect on the flow required for adequate cooling. The potential benefits of GF use in electronic heat sinks has led to the use of flow- through designs where all the cooling air flows through GF. As a result, a new generation of GF is being developed – foams with larger pores and inter-pore windows that increase efficiency by better balancing thermal and flow resistances. Flow-through designs allow GF to conduct heat more deeply into the solid structure of the foam, making use of a much larger amount of internal surface area and yielding higher overall heat transfer. This simple configuration was shown to significantly out-perform conventional CPU heat sinks and similarly designed aluminum foam devices.

Empirical models of the pore level heat transfer and pressure drop have been established for a variety of existing ORNL foams (e.g., 219-3) and POCO™ foams on the basis of laboratory experiments and Computational Fluid Dynamics (CFD). CFD models have been extremely useful in elucidating the internal energy transfer and have guided the development of new foams. More recently-developed ORNL graphite foams, with larger pore diameters and more homogeneous internal structures, have confirmed substantial increases in heat transfer with significantly reduced parasitic pressure drops.



Pressure drop as a function of channel velocity, v, for several foams with varying pore structures.

Benefits

- Smaller and lighter thermal management devices
- More efficient thermal management devices
- Simpler design – reduces the machining of fins

Future Work

Future work will focus on the development of processes that control the internal structure of GF so that internal structures can be optimized for specific heat transfer applications. In addition, heat transfer devices for the electronics, automotive, and energy sectors must be designed to take advantage of the unique properties of GF. Efforts are being directed at both single and multiphase heat transfer applications.

Points of Contact:

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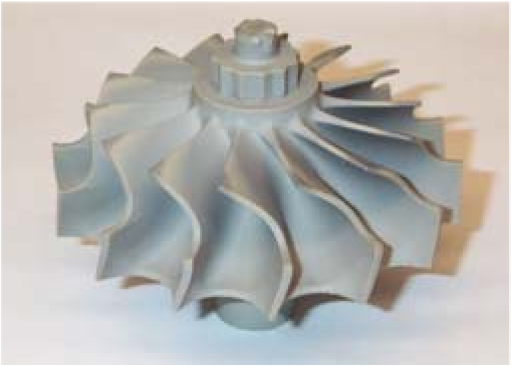
Silicon Nitride-Based Turbine Components Improved Through New Forming Process

As-Processed Surface Strength Increased by 40%

A new forming process developed by Saint-Gobain in partnership with DOE's Distributed Energy Program has increased the as-processed (AP) strength of silicon nitride-based components for use in gas turbines by approximately 40%. The improvements to the AP surfaces will significantly increase the reliability of the turbine components.

Background

For more than a decade, Saint Gobain has collaborated with gas turbine manufacturers in the development, fabrication, and testing of high temperature turbine components. In the early 1990s, the high temperature silicon nitride material, NT154, was found to possess properties making it highly suitable for use in gas turbine operating conditions.

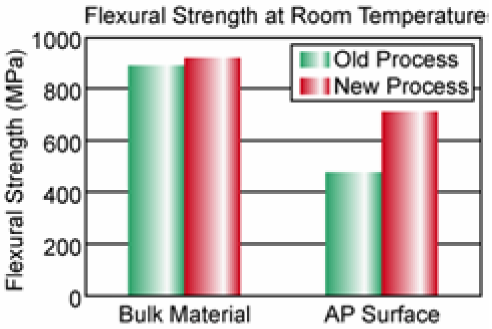


Dense NT154 rotor

The current microturbine program was begun using NT154-based material and process technology. An environmentally-friendly, aqueous closed loop process (CLP) and robust, glass encapsulated hot isostatic press (HIP) densification process were initially employed. The highly reliable CLP was utilized to reestablish the strength retention of NT154 at both room and high temperatures; however, implementation of a proprietary, new HIP process resulted in a 40% increase in the components' AP strength.

Technology

The targeted, room temperature AP strength of 700 MPa was achieved in both the laboratory and production HIP furnaces. Reproducibility of the AP strength directly correlated with the AP surface finish, which in turn, was heavily impacted by the surface finish of the green components prior to HIP processing. The new HIP process helped to retain the green surface finish and minimized the reaction layer formed due to the glass encapsulant.

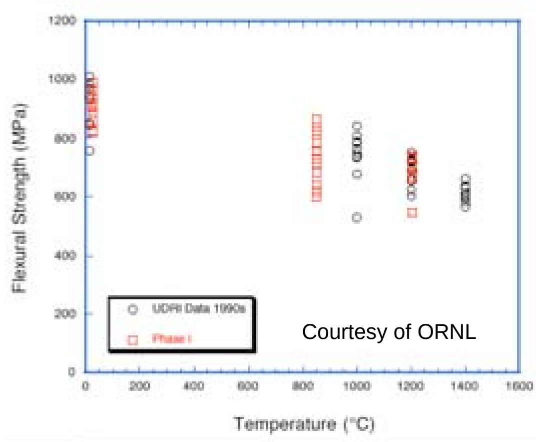


A 40% improvement in the as-processed surface strength has been obtained in the current program.

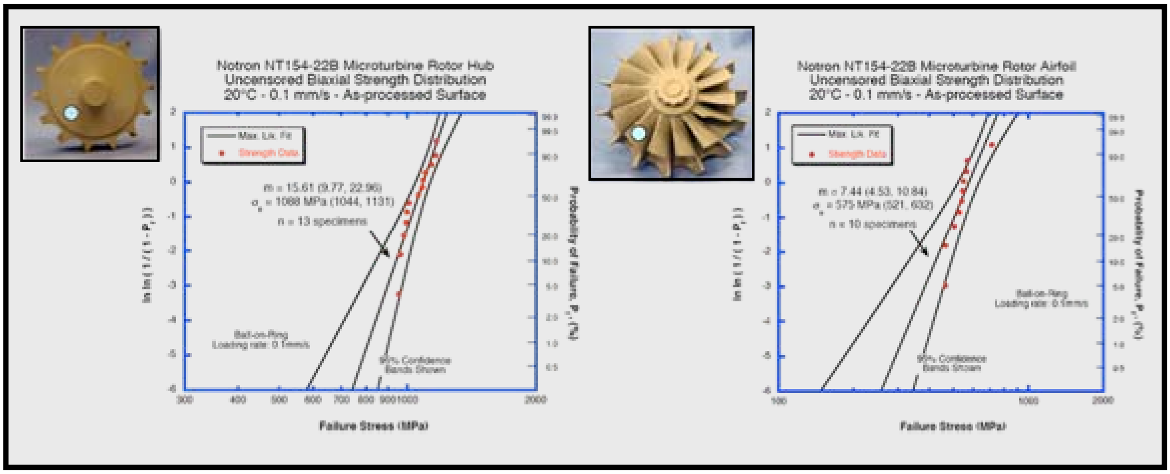
Green-machined rotors of a complex shape were densified with the new HIP process for improved AP surfaces. The rotors had an excellent average surface roughness of 30-33 μin on the AP surfaces. Based on coordinate measuring machine data, the rotors exhibited a maximum part-to-part variation of 0.006 in – an indication of the consistency of the process.

Furthermore, a measured concentricity within 0.003 in for the rotors indicated uniform shrinkage.

The process reproducibility of the selected net shape forming technique was further highlighted by measuring various critical dimensions of the net shape formed rotors prior to densification. All the deviations from the nominal green dimensions were well within the three sigma values for the target dense tolerance. The AP surface strength of one of the dense rotors was evaluated by ORNL. Core-drilled disks from individual blades were tested in biaxial flexure to establish the AP strength of actual components. The average AP strength of 527 MPa is comparable to those of other candidate gas turbine grade silicon nitride materials.



The current mechanical performance of NT154 is consistent with data from the early 1990's.



Benefits

Improved AP surfaces will increase the reliability of turbine components made with NT154. These improvements are a good compliment to the excellent room and high temperature bulk properties of NT154. In addition, the net shape forming technique has been shown to produce dimensionally consistent parts.

Future Work

Future work will involve further optimization of the new HIP process, as well as the net shape forming process, to consistently reproduce high AP strengths on net shape formed turbine components. In addition, effort will be focused on improving the recession resistance of silicon nitride by employing surface modification and environmental barrier coating approaches both in-house and in collaboration with end users. Saint-Gobain will continue to be a key ceramic component manufacturer to original equipment manufacturers of gas turbines. This will involve supplying NT154 samples and components for future engine development and testing.

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DE Systems Integration/CHP

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Integrated Air Conditioning & Dehumidification System Wins R&D 100 Award

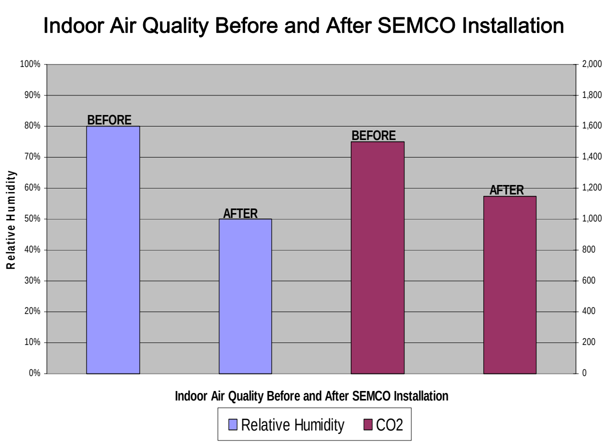
New Technology Improves Air Quality at Georgia Elementary School

The SEMCO Revolution™ was installed at Timber Ridge Elementary School in response to years of problems and complaints related to the building's indoor humidity. The award-winning Integrated Active Desiccant Rooftop (IADR) system now successfully controls humidity, temperature, and air quality at reduced energy costs.

Background

Maintenance of indoor air quality in schools should be top priority. Molds, particulates, and CO_2 levels must be controlled through proper ventilation and humidity control. Otherwise, students and teachers are at higher risk of developing respiratory illnesses leading to increased absenteeism. Damage to books, carpeting, wood flooring, and ceiling tiles can also occur from mold and mildew growth in excessively moist conditions.

Conventional HVAC systems cannot independently control temperature and humidity levels, and this limitation has creates a tension between comfort, air quality, and cost issues. Delivery of fresh, but moist, outdoor air prompts occupants to lower thermostat settings to maintain comfort. At Timber Ridge Elementary, costly over-cooling was followed by reheating. Furthermore, outdoor air louvers in the original unit were sealed, and dehumidifiers were used in efforts to control mold growth. Inadequate ventilation, air quality, and temperature/humidity control compromised the school learning environment.



Technology

In June 2005, Jim Sand of Oak Ridge National Laboratory and John Fischer of SEMCO won an R&D 100 award for their development of the SEMCO Revolution™. The awards are presented annually by R&D Magazine for the year's outstanding technology innovations.

The novel packaged system is compact, cost-effective, and extremely energy efficient. An Integrated Active Desiccant

Wheel offers unique dehumidification capabilities. “Bone dry” air leaving the desiccant wheel mixes with cool bypass air leaving the conventional cooling coil so that cool, dry, comfortable air can be provided at any temperature. A natural gas burner regenerates the desiccant as needed to bring down humidity when the internal humidity set-point level is not being met by conventional vapor compression cooling.

The effective provision of already dry air eliminates the need for overcooling to achieve dehumidified, low-dew-point ventilation air, as well the corresponding low suction pressures and air-conditioning operating efficiencies needed to obtain these low temperatures. The SEMCO Revolution™ uses fewer tons of mechanical cooling capacity to deliver a desired supply air dew point – up to 70% less than conventional systems.

Benefits

- Effective control of space humidity by the Revolution™ system allows school occupants to be comfortable at higher thermostat settings, resulting in energy savings.

- By controlling humidity in all conditions, the chance of mold and mildew growth within ductwork, ceiling tiles, carpeting, and classrooms is greatly reduced.

- Adequate outdoor ventilation air ensures low CO_2 levels during periods of high occupancy. By inference, it can be assumed that other contaminants (such as carcinogenic VOCs) are also reduced.

- Students and staff experienced greater comfort and better air quality as a result of the Revolution™ installation. The improved learning environment at Timber Ridge will promote learning and potentially reduce absenteeism.

Future Work

In 2006, SEMCO, Inc. will install several IADR units in a new, 1,500-student high school in Floyd County, Georgia. In an ORNL cost-shared project, four of the systems will use electric power and waste heat provided by a 200 kW reciprocating generator to operate at significantly higher efficiencies than the retrofitted Timber Ridge Elementary system.

SEMCO INCORPORATED

Points of Contact:

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Novel CHP Technology Wins R&D 100 Award

Trane CDQ™ Enhances Dehumidification Performance of Traditional Air-Conditioning Coil

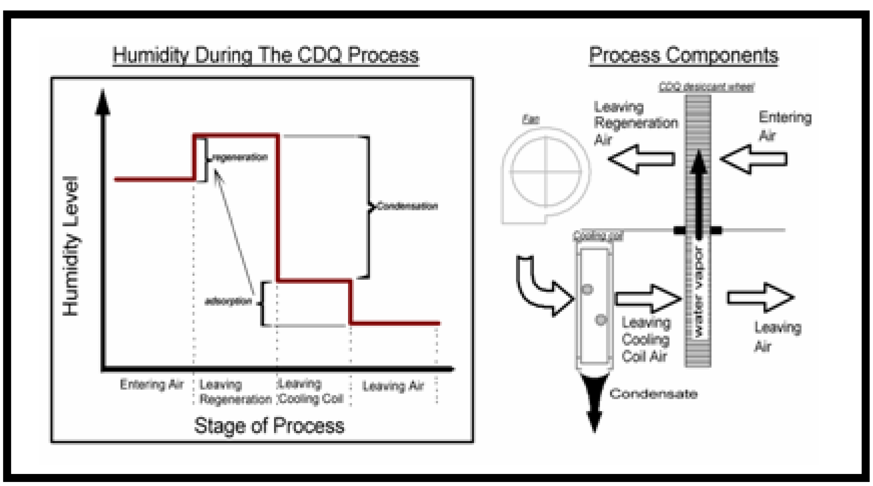
In June 2006, ORNL and Trane Company won an R&D 100 Award for their development of the Trane CDQ™ (Cool, Dry and Quiet) Desiccant System. The system uses an Integrated Active Desiccant Wheel to enhance the dehumidification performance of a traditional air-conditioning cooling coil.

Background

Most rooftop air conditioning units cannot independently control temperature and humidity to standards required for modern, healthy buildings. This limitation in technology has created a tension between comfort, air quality, and efforts to reduce energy costs. Increased delivery of fresh, outdoor air can increase indoor humidity, prompting occupants to lower thermostat settings. In order to meet humidity requirements, oversized vapor-compression systems may be operated for long cycles at low temperatures resulting in a reduction in system efficiency and the need for expensive reheating of the very cold, dehumidified air in order to achieve comfort. This cycle occurs in thousands of buildings across the country everyday, putting an unnecessarily high burden on the electric grid during peak usage hours.

Technology

The desiccant wheel captures water vapor that remains in the air leaving the cooling coil of a conventional air-conditioning system. The wheel then slowly rotates to be regenerated by return or mixed air upstream of the coil – using no additional heat. The activated



The CDQ™ Process

alumina desiccant was chosen especially for this application because it regenerates at low temperatures. The ability of the wheel to adsorb water vapor decreases significantly when in contact with incoming return or mixed air of less than 80% relative humidity; however, the desiccant wheel exhibits high adsorption capabilities when exposed to the air leaving the cooling coil with a typical relative humidity of 90% or greater.

The Trane CDQ™ can be used with existing AC equipment. The technology is ideal for hospital operating rooms, archive storage, museums, libraries, or other buildings where temperature and humidity control are critical. Trane began sales and installation of the CDQ™ in early spring 2005 and will soon incorporate the technology into rooftop applications designed for use by schools, retail stores, restaurants, and supermarkets.

Benefits

- **Efficient, independent control of humidity, temperature, and air quality**
- **Easily retrofitted**
- **Reduced operating costs**
- **Increased comfort for building occupants**

A conventional air-conditioning unit being installed on a standard curb mount fitted with the Trane CDQ™.

Future Work

Simulations are currently being used by industry to compare the Trane CDQ technology to typical alternative moisture control methods. A comparative study of the CDQ™, a free-reheat configuration, and heat pipe enhancement on the same system is desired to serve as a "real world" validation of the product. To examine energy use using a free-reheat configuration, the CDQ rooftop unit can be operated without the desiccant wheel in place, with hot gas bypass providing free reheat. The reheat coil could be isolated and removed from the air stream when not in use. Likewise, a set of heat pipe coils could be built for insertion in place of the wheel, and the systems could be operated under heat pipe enhancement.

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UT-BATTELLE

CHP Capacity Optimizer Identifies "Best Fit" to Maximize Cost Savings

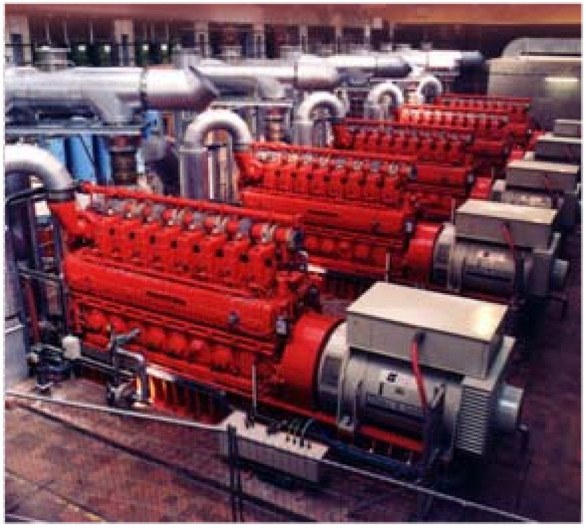
Spreadsheet Tool Determines Optimum Capacities of Distributed Energy Components

Background

Distributed energy cooling, heating, and power (CHP) applications can save both money and natural resources when system components are properly selected and installed. The accurate determination of distributed generator and absorption chiller capacities is critical to optimized system performance, yet a complex task. The electric and thermal demands of a facility are influenced by building size and location and may vary with time of day and season. Improved efficiency due to waste heat recovery must also be taken into account, and the cost of energy provided by the CHP system must be balanced with that of the conventional electricity grid and on-site boiler. The CHP Capacity Optimizer is an efficient, user-friendly tool that allows both system designers and end users to assess the "best fit."

Technology

Electric and thermal energy supply and demand must be modeled on an hourly basis in order to adequately assess the demand behavior at a specific facility or building. Using hourly load data generated by building simulation programs such as the BCHP Screening Tool[1] or Building Energy Analyzer[2], the CHP Capacity Optimizer simulates the operation of a distributed energy system and provides a "make-or-buy" recommendation. For given prime mover and absorption chiller capacities, the optimizer software calculates the life-cycle net present value savings of the CHP system relative to the conventional grid and on-site boiler arrangement. By coupling the operation simulation to a non-linear optimization algorithm, "best fit" equipment capacities that maximize life-cycle CHP system savings can be determined. Both the operation simulation and capacity optimization are displayed in a single Microsoft Excel™ spreadsheet file, which features intuitive user controls for providing input, performing optimization, and assessing the results.



A CHP system with reciprocating engines

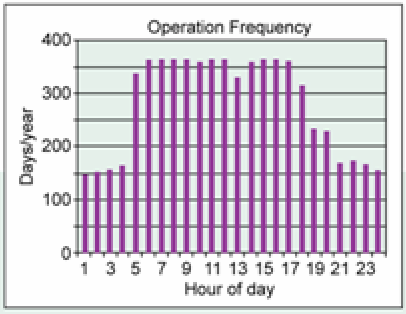
Benefits

- The CHP Capacity Optimizer is an efficient, easy-to-use tool that can benefit both CHP system designers and end users.
- The tool's determination of optimum capacity components in CHP systems will maximize cost savings of a CHP system.
- Contour plot guidance and quick manual entry capabilities allow users to explore the economic impact of alternative equipment sizes.

Results

Demands	Electricity	Heating	Cooling
Annual	12,406,742 kWh	37,074 MMBtu	1,617,306 RT-h
Maximum	2275 kW	17.0 MMBtu/h	808 RT
Minimum	934 kW	0.51 MMBtu/h	0 RT

Installed DG capacity	1130.1	kW (net)
Installed AC capacity	210.5	RT
Hours of DG operation	6,717	h/year
DG generated electricity	7,422,145	kWh/year
DG supplied heating	27,839	MMBtu/year
AC supplied cooling	535,793	RT-h/year

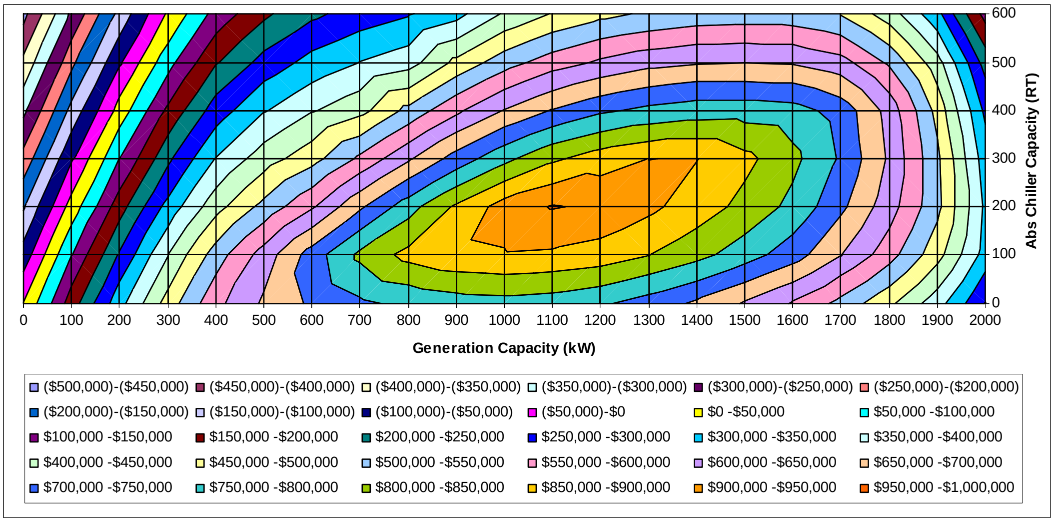


Annual costs (before tax)	With CHP	No CHP
CHP system	$1,056,847	$0
Utility elec	$661,305	$1,785,547
Non-CHP fuel	$125,137	$502,367
Total	$1,843,290	$2,287,913

Annual operating savings (after tax)	$275,666
NPV savings	$954,175

Optimum DG capacity	1130.1 kW
Optimum AC capacity	210.5 RT
NPV savings	$954,175

Example summary output from CHP Capacity Optimizer



Contour plot of total solution space from CHP Capacity Optimizer

Future Work

The CHP Capacity Optimizer is being distributed to interested users and to the Regional Application Centers. Suggestions are being solicited to improve the user-friendliness of the tool.

Point of Contact:

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[1]Available from ORNL (fischersk@ornl.gov)

[2]Available from InterEnergy Software, www.interenergysoftware.com

DE Packaged System Evaluated by Supermarket

System Cuts Energy Use and Costs for A&P

Background

A new A&P Food Market in Mt. Kisco, New York, is enjoying annual energy cost savings of nearly $130,000 with the installation of an integrated microturbine power system developed by DOE's Distributed Energy Program and UTC Power, a United Technologies company. The PureComfort™ system, which provides cooling, heating and power solutions, was installed in 2005 in the 57,000-square-foot facility. The New York supermarket was the first U.S. customer to take delivery of the new system.

The PureComfort system is designed to reduce dependence on the electrical grid; provide cooling for refrigeration systems and space heating or cooling; improve fuel utilization; and reduce emissions associated with power generation, all significant concerns under current economic and environmental conditions. The design can achieve an overall energy utilization level of approximately 80%—more than twice the typical efficiency level of a central power plant.

Technology

The PureComfort system consists of four natural-gas-powered 60-kW microturbines integrated with a Carrier double-effect absorption chiller/heater. The system was developed by United Technologies Corporation (UTC) through cost-shared research with DOE/ORNL.

Energy end use	*Annual baseline energy saved (%)*	*Annual cost savings ($)*
Grid electricity	54	44,000
Refrigeration compression	10	10,000
Space cooling compression	70	45,000
Desiccant refrigeration	50	9,000
Space heating	75	21,000
TOTAL		129,000

The key to outstanding system performance is integration. In the PureComfort system, a pre-engineered assembly carries the microturbines and chiller along with gas compressors, a cooling tower, and a chilled-water pumping system. Heat from the microturbines is not wasted but is used to directly power the high-efficiency double-effect absorption chiller. Energy in the turbine exhaust is directly transferred to the chiller working fluid, a more efficient process that also eliminates the need for a heat recovery unit. The double-effect absorption chiller/heater can cool or heat from the same unit while generating no additional emissions.

Benefits

PureComfort 240M systems provide power generation independent of the electrical grid, which is especially important for businesses that carry large inventories of refrigerated goods. Extended power disruptions caused by events such as blackouts and hurricanes leave tons of spoiled food in refrigerated cases in food stores. Producing power on site is more efficient and avoids the losses that occur during transmission. These factors are especially important considering recent increases in power demands and costs and the large cooling energy requirements of food stores, with their rows of freezers and cold cases.

The systems are also environmentally friendly. PureComfort 240M systems produce 40% less CO_2 and 85% less NO_X per megawatt-hour than conventional fossil fuel utility generation. The chiller uses no ozone-depleting fluorocarbons, and the units are quieter than competing technologies.

Shorter and Less Expensive Installation

Pre-packaged systems can reduce installation time by as much as two-thirds and provide corresponding installation cost savings.

Future Work

UTC is continuing to develop more product sizes and additional features based on the PureComfort 240M system. For example, two larger versions have already been introduced: PureComfort 300M and PureComfort 360M, with five and six microturbines, respectively.

Points of Contact:

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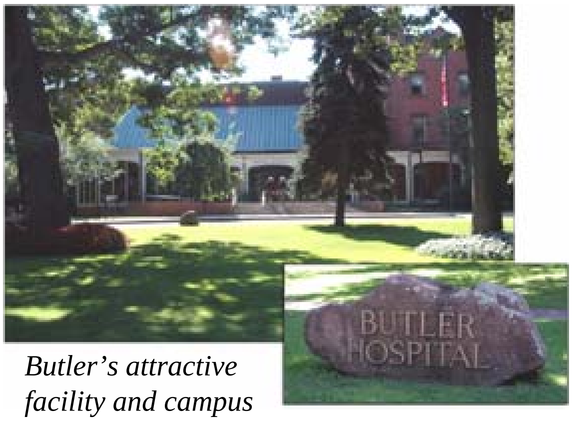
Innovative CHP System Provides Affordable, Clean Energy to Butler Hospital

Annual Savings of $92,000 Projected

Background

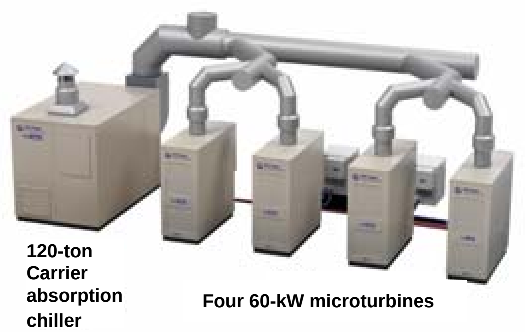
Butler Hospital is recognized as one of the top psychiatric hospitals in the country and has a reputation for outstanding medical care. The well-maintained facilities and carefully manicured, wooded campus in Providence, Rhode Island reflect efforts to provide quality care and comfort to patients. The facility's 500,000 square feet houses the inpatient hospital, day hospital, outpatient programs, as well as programs and departments of other agencies. Last year, 11,200 square feet of space was added to accommodate Butler's state-of-the-art Senior Treatment Center in the new Lippett Building. All together, the hospital was spending about $500,000 annually for heating and cooling prior to the installation of the PureComfort™ cooling, heating, and power system. Electrical power and space conditioning are now provided more efficiently and with less environmental impact.



Butler's attractive facility and campus

Technology

Butler installed the United Technologies PureComfort™ Model 240M packaged system in 2005. This technology was developed under a DOE/ORNL/IES contract and includes four Capstone 60 natural gas–fired microturbines that can generate up to 240kW of electricity. A Carrier chiller uses exhaust heat from the turbines to produce either 120 tons of chilled water for cooling or 900,000 Btu of hot water. Two compressors provide natural gas to the turbines. The system replaced oil-fired boilers and a steam heating system, and supplements the remaining campus heating and cooling system.



Benefits

- ***Cost Savings*** – The hospital projects savings of $92,000 in utility costs annually.
- ***Energy Efficiency*** – The system is expected to reach around 80% efficiency, compared with 33% efficiency for utility power plants.

- ***Environmental Friendliness –*** The PureComfort™ system produces about 40% less CO_2 than an average fossil-fuel central power plant. In addition, for Butler, it ends the handling, storage, and combustion of fuel oil, eliminating the need for an air emissions permit and further reducing costs.

- ***System Simplicity –*** The use of waste heat from the turbines eliminates the need for additional water heating or steam equipment. Butler is able to use the same room-by-room terminal heaters/chillers of the previous system, running water heated by turbine exhaust through the units for heating, and cold water from the chiller through them for cooling.

- ***Energy Security –*** Although Butler's PureComfort™ system is grid dependent, new "black-start," grid independent versions are now available. This technology is ideal for health care facilities that must continue to operate as usual, even during sustained power outages like those experienced in the aftermath of Hurricane Katrina in 2005.

The potential uses and benefits for CHP in the healthcare industry are huge. Hospitals represent a 7-gigawatt market with potential energy savings of 0.38 quad/year. More than 200 hospitals have already taken advantage of the lower costs, decreased environmental impacts, and the increased reliability and power quality that CHP brings.

Future Work

Butler will install a dedicated monitoring system at 19 points within the integrated energy system that will continuously measure power, gas use, and thermal flows at 15-minute intervals over one year. These data will allow evaluation of the performance of the microturbines and chiller-heater over a range of operating conditions, measure how well the CHP system meets key loads, and quantify the system's economic benefits. Furthermore, through ORNL, DOE has awarded similar contracts to other hospitals that will install and test much larger packaged CHP systems.

Points of Contact:

Randy Hudson, Oak Ridge National Laboratory, 865-574-0578, hudsoncrii@ornl.gov
John Fox, UTC Power, 860-727-2889, john.fox@utcpower.com
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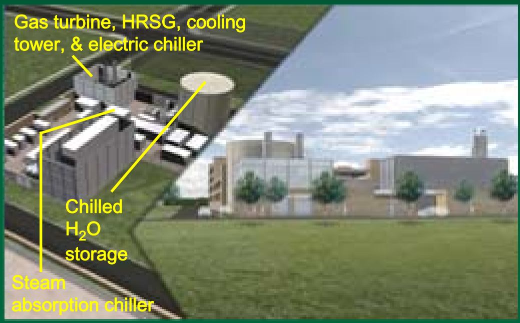
Hospital IES Provides Clean, Secure Energy

Site Makes Gains Toward LEED™ Certification

Background

During FY 2006, ORNL partnered with Burns & McDonnell and Austin Energy to install a state-of-the-art integrated energy system into the Dell Children's Medical Center of Central Texas. The site is undergoing a $175 million redevelopment that includes the incorporation of an integrated energy system (IES) that will provide high levels of energy efficiency, energy security, and environmental protection.

Packaged CHP system construction for the Dell Children's Medical District Energy System



The IES will be part of the first phase of a 35,000 square-foot central utility plant to be built on-site. Environmental concerns of those living in the surrounding Austin, Texas community have been allayed as the reduced NOx emissions of the IES have been publicized. Furthermore, the on-site plant (and use of DE IES) will allow the hospital to operate independently of the electric grid in the worst of circumstances. Sustained power losses on the Gulf Coast following Hurricane Katrina in 2005 resulted in heightened awareness of the critical need for reliable power in medical facilities during disasters. Dell will be one of the first grid-independent hospitals in the state of Texas, and the site is one of the first CHP plants in the nation to be eligible for Energy and Atmosphere Credit 1 (EA-1) points toward LEED™ certification.

Technology

The 4.3 MW IES is owned and operated by Austin Energy and has achieved 80% fuel efficiency (LHV); standard generation plants achieve around 30% efficiency. The packaged system developed by Burns & McDonnell combines a low-emission Solar Mercury-50 combustion turbine, a 1,000-ton Trane Horizon steam absorption chiller, and a 8,000 ton-hr Thermal Energy Storage tank. The use of pre-engineered, modular components created capital cost savings for Austin Energy.

A high-efficiency, natural gas turbine generator produces 100% of the hospital's electrical and thermal energy with excellent part-load efficiency and low emissions. As the turbine produces electricity, its waste heat is used to generate steam and chilled water for space conditioning with no additional emissions. The absorption chiller uses steam from a Heat Recovery Steam Generator (or stand-by boiler) to produce chilled water for air conditioning without using CFCs. Steam is also available for space heating and the hospital's sterilization equipment. An electric centrifugal chiller and packaged boiler are provided for peak demand periods and turbine maintenance down-time. Future phases will include an additional turbine and absorption chiller.

Benefits of IES installation:

Energy efficiency
Energy security
Reduced emissions
Reduced capital costs
Lower fuel costs

Pre-engineeered, modular components create capital cost savings for Austin Energy

Future Work

ORNL will monitor and evaluate system performance at Dell in order to provide feedback regarding improvements to future installations.

Points of Contact:

Patti Garland, Oak Ridge National Laboratory, 202-479-0292, garlandpw@ornl.gov
Ed Mardiat, Burns & McDonnell, 816-822-3344, emardiat@burnsmcd.com
Cliff Braddock, Austin Energy, 512-322-6302, cliff.braddock@austinenergy.com

DE System Provides Power to Critical Verizon Switching Center

United Technology Corporation (UTC) Fuel Cells Provide 1.4MW of Clean, Reliable Power

Background

The tightly-packaged electronics of the telecommunications industry require huge amounts of electricity, reliable high-quality power for 24/7 processing, and large amounts of cooling. These needs provide an ideal opportunity for the application of Combined Heat and Power (CHP) Systems. Under a DOE/ORNL cost-shared competitive procurement, Verizon Communications, Inc. installed a fuel-cell-based CHP system into a 300,000 sq. ft., 880-employee Central Office on Long Island in New York during 2005.

This system allows reliable cell phone operation at all times – even during extended power outages as experienced during the 2001 terrorist attacks and the 2005 aftermath of Hurricane Katrina. Sustained communication capabilities during these types of emergencies can bring help to those in crisis and reassure the families of those who are safe.

Verizon Communications, Inc. CHP System

Technology

The Verizon system became operational in June 2005. Annually, the facility is expected to produce 11,100 MWh of electrical energy, 16,000 million BTU (MMBTU) of useful thermal energy, and will require 105,000 MMBTU (LHV) of natural gas fuel. The resulting overall fuel utilization efficiency at this level of production is over 50%.

The CHP system is a topping cycle with base-load electrical power provided to the building by seven UTC PureCell 200kW fuel cells and a dual-fuel (natural gas and diesel) engine. The fuel cells receive their hydrogen supply from natural gas which is already delivered for the dual-fuel engine. The fuel cell/engine combination generates up to 2.6 MW of electricity to essentially meet all of the facility's electrical needs. The generators are typically paralleled to the grid, but can run in isolation if necessary. Supplemental backup power is supplied by the Long Island Power Authority grid and two standby diesel engines.

Waste thermal energy from the fuel cells drives two 70-ton Thermax lithium bromide (LiBr) absorption chillers for cooling in the summer, and an unfired heat recovery steam generator (HRSG) for space heating in the winter. Cooling demands can range from 50 to 750 RT and the chillers offer flexible operation to meet part-load conditions in off-peak cooling seasons. Avoiding operation of the existing, older and less efficient electrical chillers results in energy cost savings. In addition, the HRSG that reclaims waste heat from the seven fuel cells in the winter replaces approximately a third of boiler fuel usage, significantly reducing NO_x emissions. These reduced emissions plus the reduced emissions of the co-fired engine allow the CHP system to operate longer without exceeding NO_x caps, resulting in more savings from peak-shaving.

Benefits

Verizon customers now have the ability to communicate even when the electrical grid is compromised for extended periods of time. The fuel cell, engine, chiller, and HRSG CHP system were designed to enhance the reliability of Verizon's telecommunications facility while providing an essentially free source of heating and cooling with reduced NO_x and greenhouse emissions.

Seven UTC PureCell 200 kW fuel cells and a dual-fuel (natural gas and diesel) engine generate up to 2.6 MW of electricity and serve as the primary power sources for the Verizon central office facility. Verizon customers can now depend on reliable service even during large-scale emergencies that compromise the electrical grid.

Points of Contact:

Randy Hudson, Oak Ridge National Laboratory, 865-574-0578, hudsoncrii@ornl.gov

Jeremy Metz, Verizon Communications, Inc., 212-338-6405, jeremy.metz@verizon.com

Initial Use of DE Packaged System Evaluated in Hospitality Sector

Ritz Carlton San Francisco Installs PureComfort™ 240M

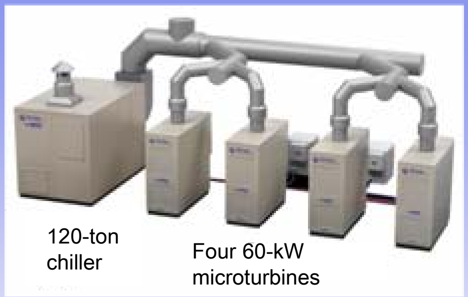
Background

The power, heating, and cooling demands of large hotels are high year-round. The benefits of integrated energy system (IES) use in the hospitality industry are potentially great; however, the hotel industry has typically avoided the financial risk of introducing large-scale technology innovations which affect building design.

The Ritz Carlton San Francisco has become the first hotel in the world to install the PureComfort 240M – a combined cooling, heating, power system developed by UTC Power in partnership with the DE Program. It is anticipated that the IES will provide 240 kW of electricity and 120 tons of cooling to the 336-room hotel at better than 80% efficiency. In addition, nitrogen oxide emissions will be reduced by 90% in support of local and state environmental protection policies.

Technology

The PureComfort 240M is a modular system with four to six, 60-kW Capstone microturbines and a 120-ton Carrier absorption chiller/heater unit. It differs from traditional CHP installations in that the heat recovery unit is eliminated and the chiller/heater is directly connected to the microturbines. Recaptured waste heat is used to drive the chiller/heater with high efficiency, reduced utility costs, and no additional emissions.



PureComfort™ 240M

PureComfort's modular design allows the flexibility required for installation and operation in diverse settings, and the Ritz system is customized to accommodate the facility's year-round air conditioning needs. Kitchen and restaurant heat can elevate cooling requirements to 300RT during summer months. Prior to the PureComfort installation, a 300-ton chiller ran continuously (even when demand would drop to 100 RT) and accounted for 20% of the building's total electricity use. Now the PureComfort™ 240M provides 161RT of cooling year-round and the old chiller supplements its use only during the warmest four to five months of the year. San Francisco's fairly moderate climate makes it unnecessary to switch to the heating mode.

Benefits

- **Energy Efficiency and Reliability**– Combined power, heating, and cooling can significantly reduce energy spending in a large hotel. Microturbine exhaust drives the chiller/heating unit, reducing utility needs. Furthermore, on-site power generation reduces grid dependency.

- **Modularity** – PureComfort™ solutions are available with 4, 5, or 6 microturbines to generate 240kW, 300kW, or 360kW of power respectively. The Carrier chiller is a relatively small commercial unit that is specifically designed to recapture exhaust from these units. The system's modularity facilitates installation in urban areas and simplifies the retrofitting process. In addition, system operations can be more easily customized to meet each building's unique CHP requirements.

- **Environmental Protection** – No fluorocarbons are used and nitrogen oxide emissions are extremely low. The PureComfort™ system easily passed the especially stringent emissions regulations applied to the Ritz Carlton due to its close proximity to a school.

- **Low noise** – Hotel guests are not disturbed by the microturbines located next to the courtyard area.

Collaborators

Gas Technology Institute
United Technologies Research Center

Future Work

Reductions in operating costs will be documented and used to encourage IES installation throughout the Host Marriott system as well as other hotel chains. Distributed energy use in other commercial settings such as grocery stores, hospitals, and schools will also be examined.

The PureComfort™ 240M microturbines quietly operate adjacent to the Ritz Carlton courtyard. Pumps and tanks are located in the equipment room below.

Point of Contact:

Therese Stovall, Oak Ridge National Laboratory, 865-574-0329, stovalltk@ornl.gov

UT-BATTELLE

New CHP Option Made Available to Commercial Markets

UTC Power Offers CHP Package with Reciprocating Engine

Background

During FY04, the DE Program partnered with UTC Power, a United Technologies Company, to commercialize technology for PureComfort™ cooling, heating, and power solutions. Each PureComfort™ system used a microturbine array to generate reliable power year-round and featured a Carrier absorption chiller/heater to provide space heating and cooling. The PureComfort™–M product line is ideal for customers who value cooling efficiency, ultra-low emissions, low noise, and low maintenance requirements. Some customers, however, have needs that could be better met through an alternative technology.

Lean-burn generator (above) and the absorption chiller/heater (below) are integrated to create the PureComfort Model 330R solution.

Technology

Systems commercialized prior to FY06 featured microturbine arrays, but the new PureComfort™ 330R Combined Cooling, Heating, and Power (CCHP) system features a lean-burn reciprocating engine prime mover. Exhaust from the 334 kWe engine drives an absorption chiller/heater to provide domestic hot water, supplemental heating, reheat for HVAC systems, and/or preheating for facilities systems. As a result, grid power consumption is significantly reduced throughout the year and energy efficiencies of more than 80% can be achieved.

With the wide-range of products now available, the customer can strategically determine primer mover attributes. Reciprocating engines are less expensive and can outperform microturbines in hot climates that effect turbine efficiencies; they also can offer better heating efficiencies in cooler climates. The PureComfort™-R systems may also be better suited for regular start-up and shut-down cycles associated with peaking markets. Although the emissions from the new system are low (NOx < 12 ppmV @ 15% O2), they do not meet California CARB 2007 emissions limitations/regulations.

Benefits

- More options for customers
- Lower capital costs
- Energy savings
- Reliable power
- Low emissions

PureComfort™ Product Differentiation

	PureComfort™-M CCHP	PureComfort™-R CCHP
Price	-	+
Availability	+	-
Market E/T	-	+
Temp. Derate Performance	-	+
Emission	+	-
Noise/Vibration	+	-
Cooling Efficiency	+	-
Heating Efficiency	-	+
Peaking Market	-	+
Maintenance	+	-

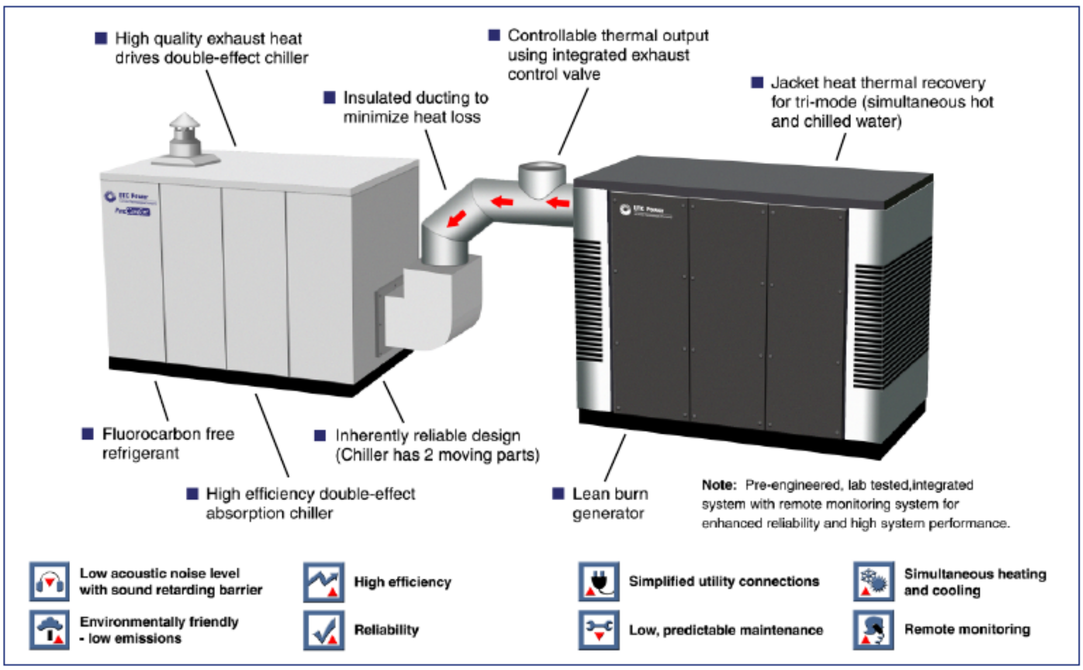
Standard Configuration

1 Lean-burn engine
1 Double-effect absorption chiller
1 Duct system
1 Remote monitoring system

Indoor/outdoor siting flexibility

Generator	Chiller
Dimensions**	**Dimensions**
H: 88" (224 cm)	H: 82" (208 cm)
W: 74" (188 cm)	W: 73" (183 cm)
L: 196" (498 cm)	L: 145" (368 cm)
Weight	**Weight**
12,278 lb (5581 kg)	17,240 lb (7836 kg)

** With sound enclosure and thermal recovery unit



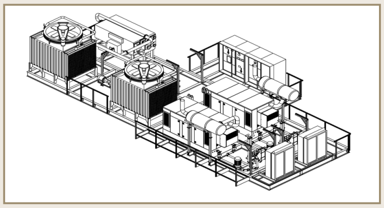
Future Work

The product line will be expanded to incorporate reciprocating engines of different sizes and manufacturers – providing customers with even more choices.

Points of Contact:

Robert DeVault, Oak Ridge National Laboratory, 865-574-2020, devaultrc@ornl.gov
Tom Rosfjord, United Technologies Research Center, 860-610-7418, rosfjord@utrc.utc.com

New Projects



Integrated Energy System in Hospital (Madera Community Hospital)

Benefits of Integrated Energy Systems

Capital Cost Reduction

Pre-engineered systems can cut CHP system capital costs by 15% to 30%.

Shorter & Less Expensive Installation

IES can reduce CHP system installation time by as much as two-thirds, and provide corresponding installation cost savings.

Replicability

System designs are suitable for multiple applications in facilities around the country.

Optimize Facility Energy Use

Pre-engineered systems allow facility operators to manage power generation, cooling, and heating to optimize energy use as well as reduce electricity use during peak periods.

Simplified Systems

The use of a "Standardized" Organic Rankine Cycle generator eliminates the need for a water-based Rankine Cycle, which has experienced freezing problems.

Operational Cost Savings

Produces electric and thermal energy at a 7.5% discount for the host hospital compared to traditional grid-based solution.

System Performance

This technology has the ability to provide electric generating capacity with virtually zero additional fuel usage, and virtually zero additional emissions.

Program Contact:

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http://www.eere.energy.gov/de/

Project Overview

Madera Community Hospital is an independent, community-based organization that has served the residents of Central California since its establishment in 1971. The 106-bed, licensed facility offers inpatient hospitalization, emergency care, laboratory services, radiology, as well as physical, occupational, and speech therapies.

Real Energy, of Yountville, California, will install two, 300 kW Guascor reciprocating engines and a 115-ton absorption chiller at Madera. The integrated system will provide high reliability power, heating, hot water, and chilled water for space cooling with very low and controllable emissions. Furthermore, the modular design on five truckable skids will reduce installation time and costs. The commissioning of the system is slated for the summer of 2006.

Benefits:

- High fuel utilization efficiency (>75%)
- Rapid installation and commissioning
- Skid mounted design capable of hybrid microgrid integration
- A replicable model will be established to promote the use of packaged CHP systems in hospitals and other industrial/commercial settings

MCH
www.maderahospital.org

RealEnergy

Objectives

To facilitate the widespread adoption and implementation of integrated reciprocating engine CHP packages to hospitals by

- Demonstrating the use of an innovative integrated CHP package that requires no cash or balance sheet commitment by the host site through a build/own/operate business model
- Conducting research on improving technical and economic viability of integrated CHP packages
- Accelerating CHP commercialization by preparing and disseminating information on system performance through multiple channels to other hospitals, business leaders, government officials, and the general public.

Project Contact:

Randy Hudson
Oak Ridge National Laboratory
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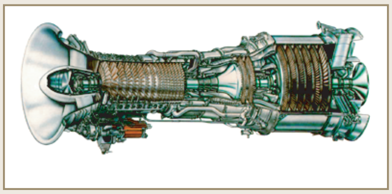
hudsoncrii@ornl.gov



Gas Turbine

Integrated Energy System in Remote Co-op Application (Gas Technology Institute)

Benefits of Integrated Energy Systems

Capital Cost Reduction

Pre-engineered systems can cut CHP system capital costs by 15% to 30%.

Shorter & Less Expensive Installation

IES can reduce CHP system installation time by as much as two-thirds, and provide corresponding installation cost savings.

Replicability

System designs are suitable for multiple applications in facilities around the country.

Optimize Facility Energy Use

Pre-engineered systems allow facility operators to manage power generation, cooling, and heating to optimize energy use as well as reduce electricity use during peak periods.

Simplified Systems

The use of a "Standardized" Organic Rankine Cycle generator eliminates the need for a water-based Rankine Cycle, which has experienced freezing problems.

System Performance

This technology has the ability to provide electric generating capacity with virtually zero additional fuel usage, and virtually zero additional emissions.

Program Contact:

Therese Stovall
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http://www.eere.energy.gov/de/

Project Overview

Gas Technology Institute (GTI), of Des Plaines, Illinois, will partner with Basin Electric to utilize waste heat from an existing pipeline compressor station's gas turbine to generate electricity via an organic Rankine cycle. This project seeks to improve the economics by developing a standardized approach to integrate components of known reliable technologies into a comprehensive configuration that can be replicated and meet market concerns.

Benefits:

- Develop DE ownership and contracting models attractive to utilities, waste heat suppliers, and developers.
- Provide voltage support to the distribution system that serves a local hospital.
- Allow designers to modularize the components, reducing field installation costs and risks, while shortening construction periods.
- Concept could be used at other pipelines and compressor stations, as well as many other locations where waste heat is available.

gti Gas Techology Institute

BASIN ELECTRIC POWER COOPERATIVE

Objectives

- Provide a demonstration of the combined technologies into a prototype, with a real-time, web-based monitoring and control system, which can be replicated at numerous, similar compressor sites.
- Partnering of critical stakeholders—the partnership of the local utility with the pipeline to produce electricity—which would then be integrated into the overall system to produce firm power at a competitive rate.
- Leverage economy of scale by standardizing the modularization and increasing production volumes to reduce unit price.

Project Contact:

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Director, Distributed Energy Group
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john.kelly@gastechnology.org

Solar Centaur® 50

Integrated Energy System in Hospital (Eastern Maine Medical Center)

Benefits of Integrated Energy Systems

Capital Cost Reduction

Pre-engineered systems can cut CHP system capital costs by 15% to 30%.

Shorter & Less Expensive Installation

IES can reduce CHP system installation time by as much as two-thirds, and provide corresponding installation cost savings.

Replicability

System designs are suitable for multiple applications in facilities around the country.

Optimize Facility Energy Use

Pre-engineered systems allow facility operators to manage power generation, cooling, and heating to optimize energy use as well as reduce electricity use during peak periods.

Simplified Systems

Other projects demonstrate the use of exhaust-fired absorption chillers to eliminate the need for steam/hot water generation equipment.

Operational Cost Savings

Projected to save $1.1 million annually in energy costs with a payback of 4 years or less.

Program Contact:

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Project Overview

Eastern Maine Medical Center (EMMC), in Bangor, Maine, will utilize a Solar Turbines gas turbine to generate 4.4 MW of electricity, 24,000 lb/hour of steam, and drive a 500 ton absorption chiller. Partners are Solar Turbines, Cianbro Corporation, Vanderweil Engineers, University of Maine, and International District Energy Association. As a result of this project work, the new CHP system will address the following concerns:

- High energy costs
- Fuel use diversity
- Need for additional chilled water capacity
- The need to deliver services under any climatic condition
- Utility reliability
- Diverse thermal heating load profile
- Emissions compliance

Benefits:

- Reduced emissions.
- Increased thermal and heating capacity and enhanced emergency backup power.
- Savings will directly reduce healthcare costs.
- Power availability during adverse weather conditions

EASTERN MAINE MEDICAL CENTER
The Right Choice, Right in the Heart of Maine

Objectives

- Design a system that responds to a specific energy concern for healthcare – reliability.
- Use an integrated, modular "power island" concept to reduce field labor costs and installation time, while increasing the opportunity for replication.
- Design a system that could be replicated for similar applications with a minimal amount of balance of plant and integration costs.
- Structure the CHP system using advanced information technology to aid in information dissemination.

Project Contact:

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ORNL 06-G00919/abh