U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ADVANCED MANUFACTURING OFFICE

Industrial Distributed Energy R&D Portfolio Review Summary Report

Washington, D.C. • June 1-2, 2011

TABLE OF CONTENTS

Introduction to the Industrial Distributed Energy R&D Portfolio Review

Reducing industrial energy intensity is essential if the United States is to meet national energy and carbon goals. The Advanced Manufacturing Office (AMO) within the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) works to improve national energy security, climate, environment, and economic competitiveness by transforming the way U.S. industry uses energy. (AMO was formerly known as the Industrial Technologies Program.) Within AMO, the Industrial Distributed Energy activity conducts research and development (R&D), technology demonstrations, and market transformation activities designed to accelerate deployment of innovative and efficient combined heat and power (CHP) solutions that can play a major role in reducing industrial energy intensity.

To assess the value and effectiveness of its current distributed energy (DE) research, AMO held a Distributed Energy R&D Portfolio Review in Washington, D.C. on June 1–2, 2011. The review brought together principal investigators and team members from industry, national laboratories, and research institutes representing 15 projects within the program's R&D portfolio.

The purpose of the review was for project recipients to report on their project goals, approach, and results to date. Although projects were not formally scored, DOE and National Energy Technology Laboratory staff will use information gathered at the review to support any needed changes to the work being done by the project teams.

The agenda comprised a review of the AMO DE R&D projects, with principal investigators presenting PowerPoint slides and answering questions from attendees. (See Appendix A for agenda.) The review began with a presentation by Dr. Robert V. Gemmer, AMO Distributed Energy Technology Manager, about the AMO DE activity and importance of AMO DE research. Additional presentations addressed reciprocating engines and absorption cooling (linked to an engine), turbines, fuel cells, a CHP system for the food processing industry, and a heat recovery project.

About AMO's Industrial Distributed Energy Activity

The Industrial Distributed Energy activity within the Advanced Manufacturing Office (AMO) provides cost-shared support for collaborative research and development to accelerate the deployment, testing, and validation of novel distributed energy and combined heat and power (CHP) applications for industry.

Program activities build on the success of predecessor U.S. Department of Energy programs on distributed energy and CHP while leveraging proven AMO technology delivery initiatives.

Welcome and Opening Remarks

Dr. Robert V. Gemmer, Technology Manager, Advanced Manufacturing Office, U.S. DOE

Dr. Gemmer presented an overview of the AMO DE and CHP activities at DOE and also highlighted the potential for rapid growth in small-scale and mid-sized CHP and DE systems. Appendix B contains Dr. Gemmer's complete presentation.

Dr. Gemmer explained that industry plays an important role in U.S. energy consumption. Industrial energy intensity must be reduced in order for the United States to meet national energy and carbon goals. DE and CHP, which are much more efficient than existing global power generation technologies, provide a tremendous opportunity to reduce emissions while maximizing the competitiveness of U.S. industry.

The AMO DE program strives to spur widespread commercial use of CHP and other distributed generation solutions, such as waste heat recovery (WHR) and district energy (which utilizes both CHP and waste heat recovery). To support this goal, the program conducts technology research and development, technology demonstrations, and market transformation activities. Additional fuel-cell-related CHP activities are underway in EERE's Fuel Cell Technologies Program. Ongoing Industrial Distributed Energy activities also include American Recovery and Reinvestment Act of 2009 funding of $150 million to implement DE and CHP demonstration projects.

To achieve long-term commercial success, DE and CHP technologies need to achieve a lower first cost, a lower life cycle cost, and reliable performance.

PRESENTATION SUMMARIES

Advanced Natural Gas Reciprocating Engines (ARES)—Caterpillar, Inc.

Martin Willi, Caterpillar, Inc.

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/ares_willi.pdf*

Mr. Willi explained that Caterpillar, which has been a part of the Advanced Natural Gas Reciprocating Engines (ARES) program since it began, has developed improvements in power density and fuel consumption that have delivered substantial improvement in owning and operating costs, thereby improving the economics of distributed power generation using reciprocating gas engines. Caterpillar's Phase I technologies have been commercialized in the G3500C/E engines. As of 2009, more than 3.84 gigawatts of ARES technology have been deployed worldwide, and the demand for gas reciprocating engines continues around the globe.

Mr. Willi highlighted system and component technology development that aims to address efficiency, fuel flexibility, and ownership and operating cost issues. Testing currently underway will help gather valuable data on performance and operation. Key challenges relate to economics and the low cost of gas and electricity. The path forward is for the team to deploy commercial components to gain operational experience now, and when the economics change (i.e., fuel and electricity prices become more favorable), the team will be poised to offer a system solution.

Key Points Raised During Question & Answer (Q&A) Period

- The economics for the technology are not competitive yet. The potential for technology advancements exists in the Organic Rankine Cycle, including the development of better intermediate heat transfer fluids, which are not available today. Lower-cost expander units and the lack of need for intermediate heat transfer would decrease the cost.
- The working fluid used is R245FA.
- Biomass/producer gas will not be available at many sites (customers would need to have the feedstock available and may need to have a pipeline for it). However, customers who do not have readily available pipeline gas will still need to reduce carbon; using reciprocating engines fueled by biogas as a prime mover can be a way to reach greenhouse gas emissions targets.
- Caterpillar is considering the compatibility of these technologies (gasifier, treatment system, engine, and switchgear) to be packaged together.
- Regarding the marketability of ARES products, the natural gas picture was much different in the early 2000s than it is today. The need for much higher efficiency engines is not as great. However, as we continue to pursue higher and higher efficiencies, we are learning more and will be prepared if and when the market changes. The value proposition may not be there right now, but it does not mean that it will not be in the future.

Advanced Natural Gas Reciprocating Engines (ARES)—Cummins, Inc.

Edward Lyford-Pike, Cummins, Inc.

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/ares_lyford-pike.pdf*

Mr. Lyford-Pike explained that through its work in the ARES program, Cummins is developing advanced gaseous fueled engines and technologies for power generation that combine high efficiency, low emissions, fuel flexibility, and reduced cost of ownership.

Cummins has successfully completed ARES Phase 1, developing advanced lean burn technology that increases brake thermal efficiency (BTE) from 36% to 44%, with more than 200 megawatts (MW) of commercial installations. For ARES Phase 2, Cummins has demonstrated ultralow emissions of 0.023 grams of nitrogen oxide (NOx) per brake horsepower-hour with stoichiometric combustion, exhaust gas recirculation, and advanced three-way catalyst technology. Cummins is also working toward the efficiency demonstration. Cummins has also developed advanced technologies, modeling tools, and capability to operate with nonstandard gases (renewable fuels). Cummins expects to complete ARES Phase 3 by the third quarter of 2013.

Key Points Raised During Question & Answer (Q&A) Period

- The technical approach is based on the same size platform (19-liter), and testing is conducted on the same size platform. All comparisons are based on a larger platform.
- Cummins has used combustion modeling and analysis-led design for technology development.

- Cummins has not been that successful with reforming. Problems were encountered with the stability of the reforming catalyst. Because of this, Cummins is taking a new path that involves fully integrated heat recovery with the engine.
- The 60-liter engine will be based on work done using a 19-liter engine in order to conserve costs.
- In achieving the ultralow NOx goals, Cummins did not see deterioration with the catalyst. Just measuring the NOx at 7 parts per million (ppm) can be a challenge. Every evening, Cummins ran the engine to see how it was maintaining the NOx. Results were good, but Cummins has not met 8,000 hours yet.
- Cummins notes that this project is a technology demonstration that should be distinguished from products in deployment, and noted that it has moved into the early stages of Phase 3 even before completing Phase 2.

Advanced Natural Gas Reciprocating Engines (ARES)—GE Dresser Waukesha

Dr. James Zurlo, GE Dresser Waukesha

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/ares_zurlo.pdf*

Dr. Zurlo reported that Phase I of the GE Dresser Waukesha ARES project is complete, and a commercial product was released in 2006 with strong export sales. Phase I yielded six patents, six American Society of Mechanical Engineers technical papers, and numerous trade publication articles.

Phase II was completed with 47% BTE achieved in a laboratory demonstration without exhaust heat recovery, preserving the heat for CHP use. The initial cost increase was minimal, with a payback period of 6 months. Phase II yielded four patents, with one additional patent pending. The ultralow emissions combustion technology has been transferred to the CHP project. Many of the developed technologies represent no cost increase or a low initial cost increase. With 25% lower engine friction, wear rates are dramatically reduced, and oil consumption is cut in half.

Phase III started in October 2010. Additional efficiency improvement technologies have been identified, and testing is ongoing.

Key Points Raised During Question & Answer (Q&A) Period

- One example of a system issue to be addressed relates to friction. While gains from lowering the exhaust temperature are limited by the heat recovery system performance, gains from reducing friction are one-to-one. A reduction of 1 kilowatt (kW) of friction in the crank shaft would yield a full 1 kW gain in energy delivered.
- Twenty percent of the cost of CHP is operations and maintenance (O&M) costs. Although a 1 year period between required oil changes may be feasible, it would not reduce full service O&M costs by 50%. O&M costs are high in part due to the high cost of oil/waste disposal.
- Oil and spark plugs would be major drivers of the cost for a full-service annual contract.
- A long-term goal is to create an engine that requires no maintenance of any kind for 12 months.
- The ARES product is a 1 MW engine. However, the technology is a generic technology that is applicable to any kind of engine (whether it is a 500 kW to 300 MW Waukesha engine or a 500 kW to 9.5 MW GE engine).
- In this size range, some kind of exhaust recovery (turbo-compounding or appropriate alternatives) is important. Larger engines' efficiency is pretty high (e.g., 48.5% electric efficiency for a 9.5 MW system). Within 5 years, these engines can reach 50% efficiency; larger-size engines can do so without recovering energy from the exhaust, while smaller-size engines can reach this efficiency only with exhaust energy recovery.
- The systems approach is interesting. For example, if friction is 5% and is reduced by 1%, this yields a full 1% reduction. Energy is mostly a small piece of a company's cost, maybe 10%, and companies usually operate at a 1%–2% profit margin. Instead of focusing on making more products, what if the company reduced its energy consumption by 10%? That would go right to the bottom line. Reducing the bottom line is an important way of thinking about efficiency improvements. "Product-izing" is not DOE's business, but DOE recognizes that moving from a technology that works to a marketable product that is cost-effective for the customer is (or can be) difficult.

Advanced Reciprocating Engine R&D

Dr. Sreenath Gupta, Argonne National Laboratory

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/ares_gupta.pdf*

Dr. Gupta explained that Argonne National Laboratory is developing technologies to improve the efficiency and reduce the emissions of reciprocating engines that use natural gas/opportunity fuels. The research aims to develop in-cylinder technologies for emissions and performance improvement of natural gas fueled engines, improve the performance of both existing as well as newer engines, develop prototypes for high-risk/high-return concepts for both lean-burn as well as rich-burn engines, develop advanced diagnostics for combustion assessment in production engines, and research the use of opportunity fuels such as synthesis gas, digester gas, and landfill gas.

Argonne National Laboratory's Distributed Energy Research Center is a user facility to develop/test technologies to improve DE performance. Its Advanced Laser Ignition System was shown to extend lean ignitability of methane-air mixtures, improve ignition probability, and enable efficiency improvements up to 3%, and/or NOx emissions reductions up to 70%. Argonne National Laboratory has developed a prototype laser ignition system for a six-cylinder engine; the demonstration is pending completion of the engine test cell.

Nitrogen-enriched air is a clean alternative to exhaust gas recirculation (EGR); hardware durability is improved as particulate and acidic species are avoided. Initial laboratory testing in a single-cylinder engine demonstrates that NOx emissions can be reduced by up to 50% with a modest efficiency penalty.

Diagnostics for engine combustion metrics have been developed, including advanced diagnostics for in-cylinder temperature, rate of heat release, local equivalence ratio, and in-cylinder EGR fraction.

Key Points Raised During Question & Answer (Q&A) Period

- The objectives were developed in the 2000–2002 timeframe, but the objectives are still valid today. An industry consortium is supporting these goals.
- In the 1990s, there was a lack of spectroscopic data. Sandia National Laboratories' research on natural gas engines might not be readily available in the open literature, but it would be a good resource.
- Laser ignition as a concept is not new; managing high-power laser beams in order to reduce laser ignition to practice is the challenge.
- Argonne National Laboratory has held several workshops on this technology. An ignition workshop in November was specifically requested by the manufacturers.

Combined Heat and Power Research and Development

Dr. K. Dean Edwards, Oak Ridge National Laboratory

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/chp_rd_edwards.pdf*

Dr. Edwards reported on Oak Ridge National Laboratory's (ORNL's) R&D efforts to address improved efficiency and optimization of CHP systems and components as well as expanded use of opportunity fuels. ORNL has established a comprehensive program and is addressing the challenges of improving component- and system-level performance of future CHP systems. Its work has included developing a large-bore, single-cylinder engine research facility; performing thermodynamic evaluation of reciprocating and turbine-based CHP engines and systems; and conducting advanced combustion studies. As part of this work, ORNL is examining the potential of advanced concepts such as closed Brayton cycle and supercritical carbon dioxide (CO_2) systems. ORNL is also developing advanced materials for engine valves and turbines.

The state-of-the-art, single-cylinder research engine was installed and commissioned at ORNL. The engine suffered a bearing seizure in March 2011. Failure assessment and redesign and repair efforts are underway, with the goal of returning the research engine to operation this fiscal year.

Thermodynamic evaluations are providing insight to efficiency opportunities on a component and system level. The team presented its assessment of practical internal combustion (IC) engine efficiency limits, is evaluating IC engine data for efficiency opportunities, and is continuing to exercise CHP system models.

Combustion studies on the single-cylinder engine will resume following engine repairs. The team is shifting its focus to the proposed modeling study for the remainder of fiscal year 2011.

Key Points Raised During Question & Answer (Q&A) Period

- The maximum efficiency of 60% takes heat transfer losses into account.
- Different advanced materials technologies, such as barrier coatings and "castable" stainless steel, can be used to conserve heat energy.
- Although the study on engine efficiency is modeled, the team is doing more than modeling work. The Materials Group is looking at ways to address controlling the engine (to vary EGR or fueling in the engine itself).
- If electricity is created at 70%, then the overall efficiency would be 70%. But we are not so efficient with electricity. Even with reciprocating engines (which may be the most efficient) or fuel cells, the efficiency can be only 60%. It is often possible to use thermal energy better than electricity, so CHP may make more sense than just making electricity. As far as operating at 47% efficiency vs. 50% efficiency, the owner and operator economics may be better at 50%.

Low-Cost Packaged Combined Heat and Power System with Reduced Emissions

John Pendray, Cummins Power Generation

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/chp_emissions_pendray.pdf*

Mr. Pendray reported on Cummins Power Generation's effort to develop a flexible, containerized 330 kilowatt electric (kWe) unit that simplifies installation, reduces total cost of ownership, and meets all U.S. emissions regulations. The system will use remote monitoring and control to reduce operation and maintenance costs; the system's modeled efficiency is calculated at 74% (higher heating value). The engine utilizes cooled EGR with a three-way catalyst to achieve aggressive emissions requirements. Intended markets for the 330 kWe unit include small industrial, commercial, and institutional customers with hot water and electrical needs. The system should provide a lower-cost option as a result of mass-market engineering development.

The team has completed customer interviews to determine product requirements. In addition, the base engine is operational in a test cell. When commercialized, the 330 kWe system will be the first product in a family of Cummins Power Generation packaged CHP systems below 1 MW, covering four to six sizes.

Key Points Raised During Question & Answer (Q&A) Period

- The thermal-to-electric ratio is 1.1 kW thermal to 1 kW electric; this can be improved.
- The engine is developed in Indiana and shipped to Minnesota. A test site has not yet been selected; several options are under consideration.
- Cummins Power Generation is not yet calling the system an "integrated energy system," "packaged energy system," "containerized system," etc. because the marketing department has not yet decided upon the formal product name.

Ultra Clean and Efficient Natural Gas Reciprocating Engine for Combined Heat and Power

Dr. James Zurlo, GE Dresser Waukesha

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/ultra_clean_zurlo.pdf*

Dr. Zurlo reported on the development and commercialization of a 1.1 megawatt electric CHP package featuring high electrical efficiency and ultralow emissions. The key technical challenge for the project will be the requirement to meet the California distributed generation emissions rules. The key business challenge for the project is to broadly popularize CHP. The project's commercialization plan includes focusing on five states that have the greatest potential and targeting industries with coinciding electrical and heat demand (such as hospitals, industrial facilities, commercial real estate, and greenhouses).

Preliminary technical systems evaluations (the first Phase 1 milestone) are complete. Market opportunity definition (the second Phase 1 milestone) is approximately 80% complete. The team expects to exit Phase 1 in June 2011.

Key Points Raised During Question & Answer (Q&A) Period

- This project offers a turnkey package, incorporating the design and installation of the equipment, steam, hot water, and so on.

Advanced Low Temperature Absorption Chiller Module Integrated with a CHP System at a Distributed Data Center

Richard Sweetser, EXERGY Partners Corp.

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/chiller_sweetser.pdf*

Mr. Sweetser reported on the development of an advanced low-temperature heat recovery absorption chiller module that could accelerate the deployment of CHP systems into high-reliability data centers of the future. The project will performance-test an absorption chiller beyond previous thermal boundaries to create performance algorithms, create a performance calculator for the chiller series covering all relevant major engine manufacturer model sizes, modularize the system to reduce cost and increase reliability, and test the system in the field for 1 year.

Mr. Sweetser explained that CHP for data centers represents a tremendous untapped market for CHP applications. The critical nature of data center loads elevates many design criteria—chiefly reliability, high power density capacity, and speed to market—far above energy efficiency. CHP systems could provide the reliability and power density—especially if power and thermal systems are properly integrated.

The project addresses key barriers to the adoption of advanced CHP and cooling in data centers, including the following:

- The lack of performance testing to optimize chiller/prime mover performance
- The lack of modularization of chillers with prime movers in current practice
- The inability of field engineered solutions to meet construction schedule requirements for data centers

As for the status of the project, the contract is now signed, and project plans are being developed. The team plans to drive commercialization of the technology by demonstrating it at the Great Lakes Center for Energy Smart Communities—the nation's first carbon-neutral all-digital community.

Key Points Raised During Question & Answer (Q&A) Period

- The engine coolant systems require water temperature of 180°F; most hot water lithium bromide absorption chillers are rated for higher temperatures.
- The projected installed savings with the modular system is 20%.
- For a Tier III data center, two independent power sources are needed. A CHP system could cost-effectively replace the second utility feed.
- The team is going to start small, with a 325 kW engine and 80-ton chiller. This can be scaled up to the practical limits of packaging.
- The practical limit for packaging the chiller is about 400 tons, which yields a 2 MW CHP modularized system size.
- The project team members are part of the Mid-Atlantic Clean Energy Application Center.

Combined Heat and Power Integrated with Burners for Packaged Boilers

Carlo Castaldini, CMCE, Inc.

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/packaged_boilers_castaldini.pdf*

Mr. Castaldini reported on the CMCE effort to engineer, design, fabricate, and field demonstrate a Boiler-Burner-Energy System Technology (BBEST) to replace less efficient low NOx burners on packaged boilers (5–50 million British thermal units per hour) while providing a return on investment (ROI) to the user. BBEST is the integration of a 100 kW simple-cycle microturbine with an ultralow NOx burner into one assembly with integrated controls that complies with California Air Resources Board (CARB) 2007 CHP and boiler emission limits while cogenerating power with a heat rate of 3,800 British thermal units (Btu) per kilowatt-hour (kWh), with corresponding reductions in CO_2 of 0.18–0.64 tons/megawatt-hour (MWh) (0.40 tons/MWh average).

The team has completed significant portions of the design and engineering work and secured the host site for the demonstration. Fabrication of the microturbine combustor, burner, and system interface will be completed by September 30, 2011. Subsequent steps will include developing and fabricating the integrated burner-microturbine controls, assembling and laboratory testing BBEST on a commercial boiler, installing and field testing the unit at the host site, and finalizing commercialization. With the host site secured, the team is on track to complete the project by the end of 2012.

Key Points Raised During Question & Answer (Q&A) Period

- BBEST is built on core technologies for the microturbine and the boiler burner that are already commercially proven. BBEST integrates these technologies using proprietary controls and designs into one assembly for plug-and-play retrofit and new burner applications on commercial and industrial boilers.
- The BBEST concept can easily be adapted to steam and hot water boilers with heat input capacity in the 5 to 50 million Btu per hour range.
- The technology has the commercialization support of a large firetube boiler manufacturer and several boiler/burner installers and service organizations, providing a rapid pathway to commercialization.
- The BBEST target market in the United States includes 130,000 burner replacements on existing boilers, 4,000–5,000 of which are in California.
- The microturbine and burner are currently designed for natural gas fuel only. However, both have the potential for burning renewable biogas.
- The power conversion efficiency of the microturbine is the lowest practicable at approximately 3,800 Btu/kWh with all waste heat from the engine recuperated in the boiler. This efficiency provides a rapid ROI to the boiler's owner/operator for the replacement of burners with BBEST.
- BBEST was designed to minimize the system's footprint, consistent with the space constraints at many sites.
- With a proprietary combustor and boiler burner, the project is demonstrating that the microturbine meets the CARB 2007 CHP NOx limit of 0.07 pounds/MWh in CHP mode, and the burner meets the 9 ppm at 3% oxygen boiler emission limit required in Air Districts in California. The technology has the capability to meet the 5 ppm NOx boiler limit required in the South Coast Air Quality Management District with additional combustion controls.
- Air Districts do not yet have an established standard for permitting of the BBEST technology as one integrated assembly. This project's demonstration of BBEST will provide the performance data to precertify the microturbine and streamline the boiler permit for streamlined deployment of the technology.

Flexible CHP System with Low NOx, CO, and VOC Emissions

David Cygan, Gas Technology Institute

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/flexible_chp_cygan.pdf*

Mr. Cygan reported on the development and deployment of a flexible CHP system (FlexCHP-65) that can deliver power and steam while holding emissions below the CARB 2007 standard targets for microturbines. The project will develop and field test a novel, ultralow NOx supplemental burner for conventional turbines and microturbine-based CHP applications and integrate the burner into a cost-effective CHP package. The Gas Technology Institute (GTI) is collaborating with the California Energy Commission and other partners on this project.

Recent progress includes the following:

- GTI transitioned to a new host site for installation of the FlexCHP-65 system: Inland Empire Foods in Riverside, California, a legume processor that operates 24 hours a day, 7 days a week.
- The burner has achieved the emission target goals in the laboratory; operation may be extended to lower loads based on site specifics.
- Full commissioning will occur at the site, including installation of a control system.
- The site integration package design is underway.
- Benefits of the FlexCHP-65 system include 84% system efficiency, recovery of 10%–14% of boiler output (with comparable reductions in fuel use and greenhouse gas emissions), reduced load on the power grid, and reduced installation costs.

Key Points Raised During Question & Answer (Q&A) Period

- The equipment at the user's site can be moved closer together. This would involve retubing the boiler to make the space better and more efficient. This strategy applies to other types of spaces.
- Inland Empire Food has three boilers. Because the company is expanding and will add another line, it is going to keep all three boilers. It will decide what to remove and what to keep as backup.
- Customers can contact the following for support/questions: GTI; Cannon Boiler Works, New Kensington, Pennsylvania; Integrated CHP Systems Corp., Princeton Junction, New Jersey; Capstone Turbine Corporation, Chatsworth, California; and/or Johnston Boiler Company, Ferrysburg, Michigan.
- Capstone often hears feedback from customers indicating confusion about who to contact for CHP system repairs—The turbine guy? The heat recovery steam generator guy? The boiler guy? Capstone recognizes that it has to be integrated, with "one" guy.
- While the strictest emissions standards are in California, such standards may be possible across the country (e.g., Massachusetts is considering more stringent regulations).
- The project team intends to scale the technology up to larger sizes, but it does not know what the upper limit is right now (i.e., the largest-size burner this can be used on).
- Applying this technology to a water tube boiler is not a major technology challenge.

Flexible Distributed Energy and Water from Waste for the Food and Beverage Industry

Aditya Kumar, GE Global Research

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/flexible_chp_kumar.pdf*

Mr. Kumar reported on GE's efforts to develop a wastewater treatment process for the food and beverage industry that uses an anaerobic digester and an active sludge/membrane bioreactor. The immediate focus is on a brewery due to the high chemical oxygen demand (COD), easily digestible waste, and large plants. However, it is important to note that this research is applicable to other food and beverage segments.

Phase 1—development of online monitoring and supervisory controls—is complete. The project team has developed and validated anaerobic digester and membrane bioreactor models using laboratory-scale and plant operation data. The team is performing online monitoring using sensors and model-based estimation for the anaerobic digester and membrane bioreactor, including simulation with validated models and a laboratory anaerobic digester perturbation experiment. Models and monitoring/control algorithms have been implemented and validated.

Phase 2—a pilot plant demonstration of the online monitoring and controls—is now starting. The team is currently implementing monitoring and controls technology in order to demonstrate improved process robustness and efficiency.

Key Points Raised During Question & Answer (Q&A) Period

- Regarding the market segment, a brewery is lower risk than a municipal plant because brewery wastewater has a high COD content that is more readily digestible. Municipal wastewater has a low COD content and is not practically suitable for direct digestion. The project is focused on industrial wastewater from the food and beverage industry, with an initial focus on brewery wastewater.
- A wastewater plant with a million gallons per day with 5,000 ppm COD can generate enough biogas to generate 600 kW electricity. The team is moving in the direction of higher spark spreads and a Jenbacher engine.

- One of the sensors provides CO_2 and methane content in biogas readings every 2 minutes. At some sites, the methane content can be 80%, depending on food content. If the content is primarily carbohydrates, the methane level is lower. If the content is primarily fats or alcohols, the methane level is higher.
- The tanks are well-agitated (but not over-agitated). There is a fair amount of natural mixing (bubbling, etc.).
- Typical wastewater treatment plants are expected to have roughly $200,000 in annual savings from reduced chemical use, increased biogas, reduced effluent disposal costs, and reduced energy use in aerobic systems. Large plants can have annual savings up to $600,000 or more.
- Anheuser-Busch does not have a membrane bioreactor in place, but it is looking for more opportunities.
- Breweries have high expenses; wastewater treatment plants are expensive. For a 1–2 million gallon plant, the payback period is approximately 2 years.

High Efficiency Microturbine with Integral Heat Recovery

John Nourse, Capstone Turbine Corporation

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/integral_heat_nourse.pdf*

Mr. Nourse reported on progress in developing the next-generation Capstone C250 and C370 engines. While current technology operates at 33% efficiency, the C250 engine has the potential to operate at 250 kW and 35% efficiency, and the C370 engine has the potential to operate at 370 kW and 42% efficiency (or higher).

The team has developed a dual-property, high-temperature turbine with high-pressure compressors and recuperator (11:1). The dual generators are both low-pressure and high-pressure spool, with dual spool control development. The team has also developed technology for a high-temperature, low-emissions combustor and interstage compressor cooling.

Next steps in the C250 engine design will include bearing housing and shroud-line definition, compressor impellor stress and aeromechanical analysis validation, and nozzle and compressor drawing release. Next steps for the team also include development of the C370 combustor conceptual design and C370 turbine rotor design concepts. The first C250 engine test is scheduled for the first quarter of 2012.

Key Points Raised During Question & Answer (Q&A) Period

- This is a high-efficiency microturbine that is building on an earlier 200 horsepower microturbine (the Capstone C200).

Ultra Efficient Combined Heat, Hydrogen, and Power System

Pinakin Patel, FuelCell Energy, Inc.

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/ultra_efficient_patel.pdf*

Mr. Patel reported on the FuelCell Energy effort to reduce gross utility costs for copper powder manufacturing by up to 25% and to reduce energy use by 50%. The proposed solution is to co-produce low-cost reducing gas, power, and heat on site for surface treatment of copper powder. The benefits include an ultraefficient, on-site generated hydrogen and CO_2 mixture that replaces currently imported liquid hydrogen and liquid nitrogen and reduces purchased power, as well as high-value co-products (hydrogen and CO_2) that make the process very competitive.

The laboratory testing by the manufacturer has been successful, and commercial furnace test equipment is now being installed. Near-term markets for the technology include the industrial hydrogen market and clean distributed power market. Future applications and markets for the technology may include backup/load-following power and transportation.

Key Points Raised During Question & Answer (Q&A) Period

- Low-temperature NOx reducing catalysts can provide a good source of hydrogen.

Combustion Turbine CHP System for Food Processing Industry

Kevin Chilcoat, Frito-Lay North America, Inc.

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/chp_food_chilcoat.pdf*

Mr. Chilcoat described the Killingly, Connecticut, CHP project, which has installed a Solar Centaur 50, 4.6 MW natural gas turbine/generator with heat recovery steam generator/duct burner at the Killingly Frito-Lay plant. Installation of the CHP system has reduced emissions and operating costs (total energy costs) in an area with high electric rates and excessive electric grid congestion. The system is parallel to the grid, and is a proven, highly reliable turbine/generator package. Since the system was commissioned in 2009, the plant has experienced a 94% reduction in electricity purchased from the grid, a 25% increase in natural gas use, and a 15% reduction in greenhouse gas emissions. The system provides 100% of the plant's electric needs and 80% of its thermal needs.

The Killingly plant operates two potato chip lines, as well as corn chip lines, Doritos®, and popcorn (approximately 12,000 pounds of product per hour). The company could lose $2 million/day if the plant went down.

Key Points Raised During Question & Answer (Q&A) Period

- The CHP system is 75%–78% efficient. The load drops off in the winter when the turbine is the most efficient.
- The company is exploring the possibility of doing similar projects at other Frito-Lay plants. However, low electricity prices in other geographic areas make this less feasible; incentives and a strong relationship with the power company are both required to make the project successful.
- ICF International is still involved in the project. A draft report on the project is under review. The report will document all of the utility incentives and issues that Frito-Lay has addressed during the project.
- This project is strong from both a technical and product standpoint.

Battleground Energy Recovery Project

Daniel Bullock, Houston Advanced Research Center

Presentation: *http://www1.eere.energy.gov/industry/distributedenergy/pdfs/battleground_bullock.pdf*

Mr. Bullock discussed an upcoming project that will recover waste heat from hazardous waste incineration at Clean Harbors Energy Services in La Porte, Texas. The project will prove the feasibility of the technology and provide low-cost electricity and steam using waste heat.

The system will include a 9 MW steam turbine-generator, condenser, and cooling tower; a 12 kilovolt (kV) electrical interconnect to a substation; and a 600 pounds per square inch gauge (psig) steam pipeline, with condensate return. The system will be able to produce up to 93,000 pounds per hour of steam at 600 psig/750°F and up to 9 MW of power at 12 kV (by condensing steam turbine generator).

With no steam sales, this project will produce 9 MW of "zero emissions" electricity, demonstrating that baseload clean electricity can be produced on commercial scale without fossil fuels. This project will reduce the cost of energy for both Clean Harbors and Dow Chemicals, will create a "showcase" WHR demonstration project, and will help prove the viability of WHR in a "dirty" flue gas environment.

The project is on hold as the team works to resolve issues related to equity financing and execution of commercial commodity sales agreements. If financing is resolved by the end of 2011, engineering procurement and construction execution will begin in early 2012.

Key Points Raised During Question & Answer (Q&A) Period

- Archeological studies had to be done in the historic Battleground area.
- This project has strong potential. The bottoming cycle is a big opportunity for waste heat utilization.
- The Louisiana Public Service Commission has put WHR into its Renewable Portfolio Standard—dispatchable, firm, and right where you need it.
- It will be difficult to advance WHR in Texas with the current low price of natural gas.

CLOSING REMARKS

Wrap-Up/Conclusion

Dr. Robert V. Gemmer, Technology Manager, Advanced Manufacturing Office, U.S. DOE

Dr. Gemmer noted that in order to reach the Obama Administration's goal of 80% carbon reduction by 2050, the United States will need to be nearly all-electric. Carbon production through burning fossil fuels will have to be a very small percentage of overall energy production.

As far as chemical to electrical energy, fuel cell efficiency is about 60%, but this is still not good enough. In the near term, as the United States pushes toward the Obama Administration's goal, CHP will be a necessary bridge technology. CHP remains the best way to achieve the goals that have been set for the next 40 years. (CHP can be cooling, as seen at this review.)

Dr. Gemmer concluded that the projects in the Industrial Distributed Energy R&D Portfolio, as described during this review, are producing valuable and credible results. The principal investigators and their project teams are encouraged to continue on their various R&D paths. DOE looks forward to continued success.

APPENDIX A: AGENDA

DAY 1 - WEDNESDAY, JUNE 1	
8:30 a.m.–8:45 a.m.	Check-In
8:45 a.m.–9:00 a.m.	Welcome and Introductions • **Bob Gemmer, Advanced Manufacturing Office, *U.S. DOE***
9:00 a.m.–9:45 a.m.	Advanced Natural Gas Reciprocating Engines (ARES)—Caterpillar, Inc. • **Martin Willi, *Caterpillar, Inc.***
9:45 a.m.–10:30 a.m.	Advanced Natural Gas Reciprocating Engines (ARES)—Cummins, Inc. • **Edward Lyford-Pike, *Cummins, Inc*.**
10:30 a.m. - 11:00 a.m.	BREAK
11:00 a.m.–11:45 a.m.	Advanced Natural Gas Reciprocating Engines (ARES)—Dresser Waukesha • **James Zurlo, *Dresser Waukesha***
11:45 a.m.–12:30 p.m.	Advanced Reciprocating Engine R&D • **Sreenath Gupta, *Argonne National Laboratory***
12:30 p.m. - 1:30 p.m.	LUNCH
1:30 p.m.–2:15 p.m.	Combined Heat and Power Research and Development • **Dean Edwards, *Oak Ridge National Laboratory***
2:15 p.m.–3:00 p.m.	Low-Cost Packaged Combined Heat and Power System with Reduced Emissions • **John Pendray, *Cummins Power Generation***
3:00 p.m. - 3:30 p.m.	BREAK
3:30 p.m.–4:15 p.m.	Ultra Clean and Efficient Natural Gas Reciprocating Engine for Combined Heat and Power • **James Zurlo, *Dresser Waukesha***
4:15 p.m.–5:00 p.m.	Advanced Low Temperature Absorption Chiller Module Integrated with a CHP System at a Distributed Data Center • **Richard Sweetser, *EXERGY Partners Corp***
5:00 p.m.–5:15 p.m.	Wrap-Up • **Bob Gemmer, Advanced Manufacturing Office, *U.S. DOE***
5:45 p.m.	Optional No-Host Dinner **Location:** L'Enfant Plaza Hotel, 480 L'Enfant Plaza SW, in hotel restaurant. Meet at hotel restaurant at 5:45 p.m.

DAY 2 - THURSDAY, JUNE 2

8:30 a.m.–8:45 a.m.	Check-In
8:45 a.m.–9:00 a.m.	Welcome and Introductions • **Bob Gemmer, Advanced Manufacturing Office, *U.S. DOE***
9:00 a.m.–9:45 a.m.	Combined Heat and Power Integrated with Burners for Packaged Boilers • **Carlo Castaldini, *CMCE, Inc.***
9:45 a.m.–10:30 a.m.	Flexible CHP System with Low NOx, CO, and VOC Emissions • **David Cygan, *Gas Technology Institute***
10:30 a.m. - 11:00 a.m.	**BREAK**
11:00 a.m.–11:45 a.m.	Flexible Distributed Energy and Water from Waste for the Food and Beverage Industry • **Aditya Kumar, *GE Global Research***
11:45 a.m.–12:30 p.m.	High Efficiency Microturbine with Integral Heat Recovery • **John Nourse, *Capstone Turbine Corporation***
12:30 p.m. - 1:30 p.m.	**LUNCH**
1:30 p.m.–2:15 p.m.	Ultra Efficient Combined Heat, Hydrogen, and Power System • **Pinakin Patel, *FuelCell Energy, Inc.***
2:15 p.m.–3:00 p.m.	Combustion Turbine CHP System for Food Processing Industry • **Kevin Chilcoat, *Frito-Lay North America, Inc.***
3:00 p.m.–3:45 p.m.	Battleground Energy Recovery Project • **Daniel Bullock, *Houston Advanced Research Center***
3:45 p.m.–4:00 p.m.	Wrap-Up • **Bob Gemmer, Advanced Manufacturing Office, *U.S. DOE***

APPENDIX B: Presentation by Dr. Robert V. Gemmer, Advanced Manufacturing Office (AMO), U.S. Department of Energy

Industrial Distributed Energy R&D Portfolio Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

June 1-2, 2011
Washington, DC

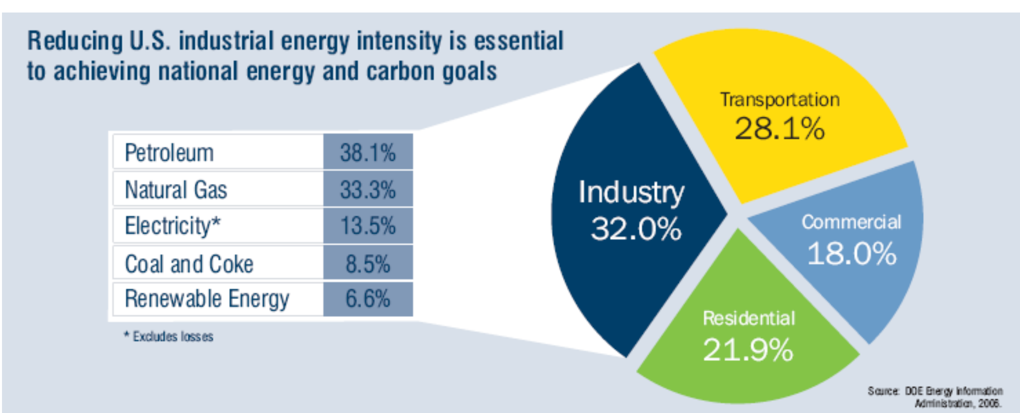
Bob Gemmer
Industrial Technologies Program
U.S. Department of Energy

www.eere.energy.gov/industry/distributedenergy

DOE - Industrial Technologies Program

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Mission: Improve national energy security, climate, environment, and economic competitiveness by transforming the way U.S. industry uses energy.



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ITP Role in Industrial Distributed Energy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Leads Federal efforts to implement innovative DE and CHP technology solutions
- Includes a robust research and development and demonstration portfolio
- Leader and primary catalyst for partnerships to eliminate institutional and market barriers to CHP
- Supporter of applied technology development to improve efficiency, reduce waste heat, utilize alternative fuels, create green jobs, reduce GHG emissions, and maximize competitiveness of U.S. industry

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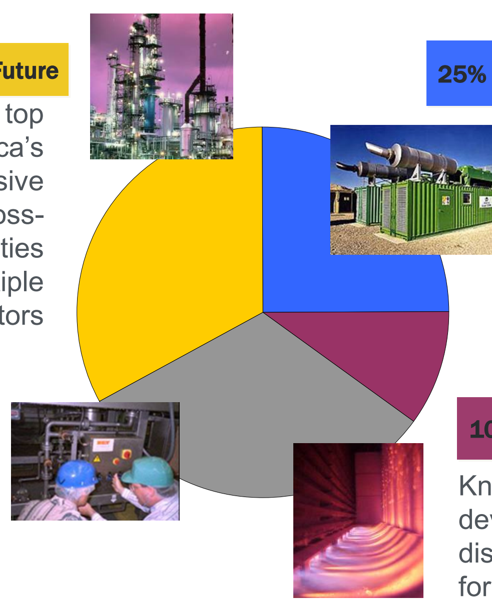
DOE ITP FY11 Budget: $100M

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



33% Industries of the Future

R&D addressing top priorities in America's most energy-intensive industries and cross-cutting activities applicable to multiple industrial subsectors

25% Industrial Distributed Energy

Activities to spur widespread commercial use of CHP and other distributed generation solutions

32% Industrial Technical Assistance

Helping plants save energy today using efficient energy management practices and efficient new technologies

10% Manufacturing Energy Systems

Knowledge development and dissemination centers for rapid innovation of new products and processes

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Clean Distributed Energy Technologies

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

CHP

The sequential production of electric and thermal power from a single dedicated fuel source

Waste Heat Recovery

Captures heat otherwise wasted in an industrial process and utilizes it to produce electric power. These systems may or may not produce additional thermal energy.

District Energy

Central heating & cooling plants that incorporate electricity generation along with thermal distribution piping networks for multiple buildings (campus / downtown area)

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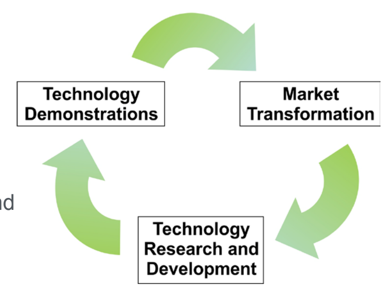
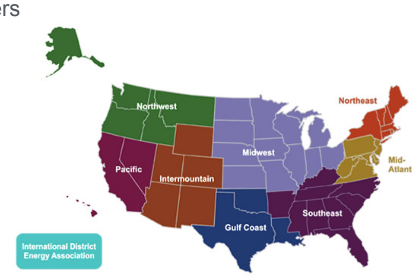
Portfolio Strategy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Three Major Areas**
  - Technology Research and Development
    - Significantly improve efficiency, decrease emissions, optimize fuel flexibility, and decrease capital and operating costs of CHP systems
  - Technology Demonstrations
    - Support installation of innovative technologies and applications that offer greatest potential for replication
  - Market Transformation
    - Remove barriers to CHP, primarily through eight DOE Clean Energy Regional Application Centers (RACs) and the International District Energy Association
- **Open & Competitive Solicitations**
- **Public-private partnerships**
- **Joint research teams**
  - Industry
  - Academia
  - National labs





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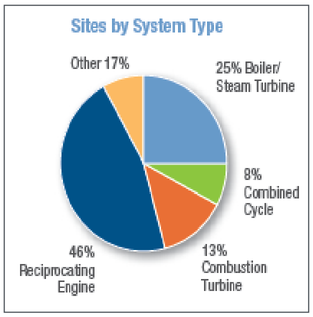
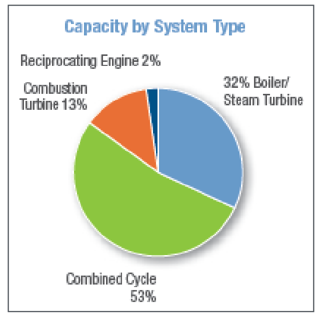
Market Segmentation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Over 90% of existing CHP capacity consists of systems >20 MW
  - Market for large systems relatively mature
  - Mid-range market (1-20 MW) underexploited with potential for major growth
  - Small system market (<1 MW) ripe for expansion with new packaged technologies



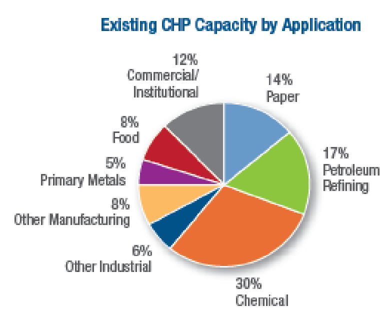


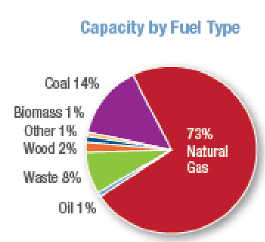
Source: *Combined Heat and Power - Effective Energy Solutions for a Sustainable Future*, Oak Ridge National Lab (ORNL), 2008

Transition and Deployment

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Long-term commercial success requires
  - Market need
  - Acceptable cost
    - Lower first cost
    - Lower life-cycle cost
  - Reliable performance
- Target markets
  - Industrial sector (large and mid-size)
  - Commercial sector (mid-size and small)
  - Institutional sector (mid-size and small)
- Risk mitigation strategy
  - Actively track and measure project performance
  - Pursue multiple parallel research paths
- Externalities
  - Natural gas price and availability
  - Regulatory environment
    - Not fully supportive of CHP implementation
    - Impact of potential greenhouse gas policies unknown





Source: *Combined Heat and Power - Effective Energy Solutions for a Sustainable Future*, Oak Ridge National Lab (ORNL), 2008

Portfolio Review Day 1 Projects

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Advanced Natural Gas Reciprocating Engines (ARES)
- **Caterpillar, Inc.** and Colorado State University
- Conducting R&D on lean combustion and selective catalytic reduction (SCR) of NOx

Advanced Natural Gas Reciprocating Engines (ARES)
- **Cummins, Inc.**, Wisconsin Engine Research Consultants, and Argonne National Laboratory
- Conducting R&D on stoichiometric system with exhaust gas recirculation and three-way catalyst with organic rankine cycle heat recovery

Advanced Natural Gas Reciprocating Engines (ARES)
- **Dresser Waukesha** and Oak Ridge National Laboratory
- Conducting R&D on natural gas engines with increased use of computer simulations and statistical analysis

Advanced Reciprocating Engine R&D
- **Argonne National Laboratory** and Cummins, Inc.
- Developing advanced laser ignition systems for a multi-cylinder engine in which mixtures much leaner than those limiting conventional ignition can be ignited

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Portfolio Review Day 1 Projects cont.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Combined Heat and Power Research and Development
- **Oak Ridge National Laboratory**, Dresser Waukesha, Energy Systems Group, Inc., Solar Turbines, Inc., and Thermal Centric Corporation
- Conducting research on lean burn combustion, thermodynamic analysis and modeling, and improved materials

Low-Cost Packaged Combined Heat and Power System with Reduced Emissions
- **Cummins Power Generation** and Cummins Engine Business Unit
- Developing a flexible, packaged CHP system that produces 330 kW of electrical power output and 356 kW of thermal output while increasing efficiency and reducing emissions and cost

Ultra Clean and Efficient Natural Gas Reciprocating Engine for Combined Heat and Power
- **Dresser Inc., Dresser Waukesha**
- Developing a 1.1 MW CHP system consisting of a natural gas-fueled reciprocating engine with advanced combustion and engine system technologies

Advanced Low Temperature Absorption Chiller Module Integrated with a CHP System at a Distributed Data Center
- **EXERGY Partners Corporation**, Carrier Corp., and Integrated CHP Systems Corporation
- Developing and demonstrating an advanced single-stage lithium bromide absorption chiller module s specifically designed to use low-temperature waste heat from clean and efficient natural gas engines

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Portfolio Review Day 2 Projects

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Combined Heat and Power Integrated with Burners for Packaged Boilers

- **CMCE, Inc.**, Altex Technologies Corporation, and AHM Associates, Inc.
- Developing the Boiler Burner Energy System Technology (BBEST), a CHP assembly of a gas-fired simple-cycle 100 kW microturbine and a new ultra-low NOx gas-fired burner

Flexible CHP System with Low Nox, CO, and VOC Emissions

- **The Gas Technology Institute**, Accu Chem Conversion, Capstone Turbine Corporation, Coen Company, Integrated CHP Systems Corp., and Johnston Boiler Company
- Developing a Flexible Combined Heat and Power (FlexCHP) system that incorporates a supplemental Ultra-Low-NOx (ULN) burner into a 65 kW microturbine and a heat recovery boiler

Flexible Distributed Energy and Water from Waste for the Food and Beverage Industry

- **General Electric (GE) Global Research**, GE Water & Process Technologies, GE Fanuc, and Sentech, Inc.
- Developing a systematic plant-wide automation for online monitoring and supervisory control to enhance the robust and reliable operation of the waste-to-value plant

High Efficiency Microturbine with Integral Heat Recovery

- **Capstone Turbine Corporation**, Oak Ridge National Laboratory, and NASA Glenn Research Center
- Developing a clean, cost-effective 370 kW microturbine with 42% net electrical efficiency and 85% total CHP efficiency

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Portfolio Review Day 2 Projects cont.

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Ultra Efficient Combined Heat, Hydrogen, and Power System

- **FuelCell Energy, Inc.**, ACuPowder International, LLC, and Abbott Furnace Company
- Developing a combined heat, hydrogen, and power (CHHP) system that utilizes reducing gas produced by a high-temperature fuel cell to directly replace hydrogen and nitrogen used in a bright annealing process at a copper production facility

Combustion Turbine CHP System for Food Processing Industry

- **Frito-Lay North America, Inc.** and the Energy Solutions Center
- Demonstrating and evaluating a CHP plant at a large food processing facility in Connecticut

Battleground Energy Recovery Project

- **Houston Advanced Research Center**, Integral Power, LLC, and Clean Harbors, Inc.
- Developing a steam and power generation plant fueled by hot exhaust produced in hazardous waste incineration

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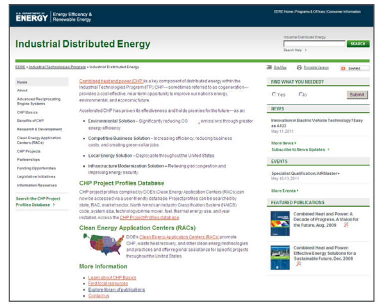
Website

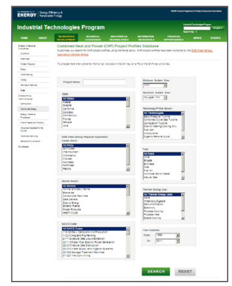
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Industrial Distributed Energy**
  www.eere.energy.gov/industry/distributedenergy

- **R&D Projects Fact Sheets**
  www.eere.energy.gov/industry/distributedenergy/rd
  - ARES (links to separate section of Website)
  - CHP R&D
  - CHP Demonstration



- **CHP Project Profiles Database**
  www.eere.energy.gov/industry/distributedenergy/chp_database
  - Created in January 2011
  - Project profiles compiled by RACs (currently 130)



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Thank You

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Industrial Technologies Program: www.eere.energy.gov/industry
Industrial Distributed Energy: www.eere.energy.gov/industry/distributedenergy

Bob Gemmer
Technology Manager
Industrial Technologies Program
U.S. Department of Energy
Phone: 202-586-5885
E-mail: bob.gemmer@ee.doe.gov

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The Advanced Manufacturing Office (AMO) is the lead government program working to increase the energy efficiency of U.S. industry—which accounts for about one-third of U.S. energy use. In partnership with industry, AMO helps research, develop, and deploy innovative technologies that companies can use to improve their energy productivity, reduce carbon emissions, and gain a competitive edge.

Advanced Manufacturing Office (AMO)
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