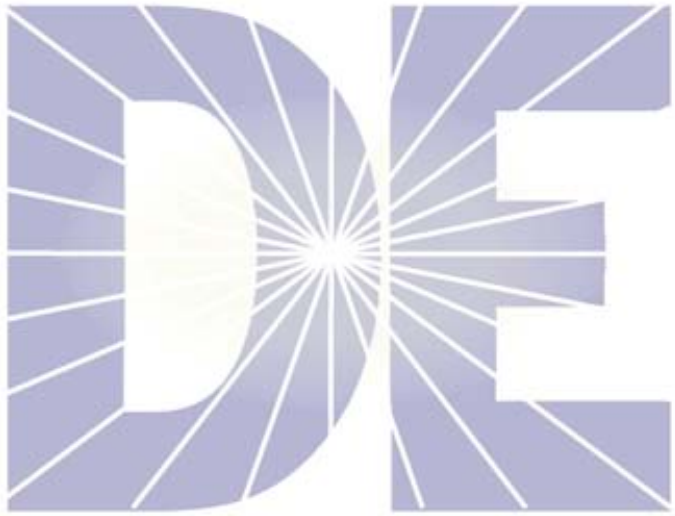
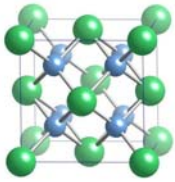


Distributed Energy Program

DE Quarterly Progress Report
For the Period
April 1, 2007 – June 30, 2007



OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Subtask 4.1.1 - Lean NO_x Trap (LNT) Development

Jim Parks, parksjeii@ornl.gov, (865) 946-1283
Oak Ridge National Laboratory

Objective

The main objective of this project is to study lean NOx trap catalysis for emissions control from natural gas (NG) engines. Key emission control areas of interest include: NOx reduction efficiency, operational (fuel) penalty, durability, and cost basis of lean NOx traps for ARES applications. Experiments for the study are performed on a Cummins C8.3G NG engine dynamometer platform at ORNL.

- In FY04, NOx reduction in engine exhaust was demonstrated. **ARES program target emission levels of <0.1 g/bhp-hr NOx were demonstrated**, and NOx reduction efficiencies of >90% were obtained with the lean NOx trap catalyst.
- In FY05, full characterization of the utilization of NG (**fuel efficiency**) for catalyst regeneration was performed. Methane oxidation and reforming chemistries were characterized for various conditions.
- In FY06, the focus shifted to **durability issues** and the impact of sulfur on the *partial oxidation and reforming catalysts* was investigated. Results indicated levels of sulfur commonly found in NG could be tolerated.
- In FY07, a catalyst service process will be investigated as a potential solution of the negative effects of sulfur on the durability of *lean NOx trap catalyst system*.

Highlights

Engine-based experiments for the FY07 task to study servicing of lean NOx traps to remove sulfur accumulated during accelerated aging were completed in Q1. Results were positive and indicated that catalyst washing is a feasible technique for maintaining catalyst durability against sulfur poisoning. Reporting of the results is in progress.

Technical Progress

The goal for FY07 is to determine the feasibility of increasing catalyst durability and lifetime via a catalyst wash service process for the removal of sulfur poisons. Experiments toward this goal have been completed on the Cummins C8.3G+ engine dynamometer platform at ORNL. The following experimental phases were conducted:

1. Baseline Characterization: Lean NOx trap catalyst system performance characterization.
2. Rapid Sulfur Aging: Accelerated Sulfur aging of the catalysts with bottled SO_2.
3. Catalyst Washing: The lean NOx trap catalysts were washed with aqueous solutions, and new sorbate media were applied to refurbish the sulfur poisoned components.
4. Post Characterization: Repeat of catalyst performance characterization.

Results show that the catalyst washing process is extremely effective in restoring lost NOx reduction performance due to sulfur poisoning. The sulfur aging degraded NOx performance from >90% NOx reduction efficiency to ~50% NOx reduction efficiency, but the washing process recovered performance to >90% NOx reduction efficiency levels. ***Thus, the washing process is a feasible technique for maintaining catalyst durability against sulfur poisoning in lean NG engine applications.***

In Q3, efforts have focused on data analysis and reporting of the results.

Status of Milestone(s)

(1) Complete the Lean NOx Trap (LNT) development work with the conclusion of the sulfur poisoning study and disseminate the results to the engine community (September 2007): - On Track (engine experimental work and data analysis completed; reporting in progress).

Industry Interactions

- A draft paper entitled “Mitigation of Sulfur Effects on a Lean NOx Trap Catalyst by Sorbate Reapplication” has been submitted for the ASME Fall Technical Conference on Internal Combustion Engines in Charleston, SC on October 14-17, 2007.

Subtask 4.1.2 - Spark Plug Erosion and Failure

Mike Brady, bradymp@ornl.gov, (865) 574-5153
Oak Ridge National Laboratory

Objective

Spark plug lifetimes in advanced natural gas (NG) engines are on the order of only 1000-4000 h, which result in loss of performance and necessitate frequent, costly downtime maintenance. Spark plug durability will become even more critical as future engines are pushed to leaner-burn conditions to reduce emissions. The goals of this effort are to gain insight into spark plug life-limiting wear processes, and to use this understanding to develop new electrode alloys to achieve lifetimes of ≥ 8000 h.

Highlights

Spark plugs manufactured with ORNL Cr-base alloy have been successfully tested for 200h via a laboratory-modified gasoline engine at Federal Mogul. Electronic microscopy studies on those 200h lab engine test plugs were also completed. These results provide details of the effect of alloy composition and microstructure on the spark plug oxidation/corrosion resistance and thus long-term durability performance under the engine conditions.

Technical Progress

Microstructure characterization of spark plug electrodes, manufactured with ORNL Cr-6MgO base alloy, standard 95% Ni-base alloy, and Haynes 214, after 200h laboratory gasoline engine was completed during this reporting period. SEM examinations of polished cross sections showed that the copper-cored standard 95% Ni-base alloy suffered from internal oxidation and cracking, similar to that observed in the other type of engine tests. Similar cracking was also observed in the Haynes 214 insert pad alloy. In both the standard 95% Ni-base alloy and Haynes 214, the internal attack and cracking were associated with internal penetration of oxygen and sulfur. In sharp contrast, there was no cracking observed in the Cr-6MgO base alloy insert. The surface of the Cr-6MgO insert was smooth, with little evidence of significant oxidation or loss of material. This supposition is consistent with the similar appearance and distribution of the MgO dispersions at the surface and within the insert pad alloy, as significant material loss would be expected to alter and redistribute the MgO dispersions. Results thus suggest that the Cr-6MgO base alloy could be a promising candidate as an alternative to Pt and Ir insert pad alloys. Nonetheless, the longer term engine tests are needed to confirm this observation, as well as more fully demonstrate the low erosion rate and cracking immunity of the Cr.

Status of Milestone(s)

(1) Submit an open literature paper reporting on the engine test results of developmental spark plug electrode alloys (September 2007): On schedule.

Industry Interactions

1. Conference calls and email communications with Dan Tribble of Woodward regarding the status of manufacturing of Woodward NG spark plugs from ORNL alloys.
2. Conference calls and email with Jim Lykowski at FM to discuss progress in collaborative work at FM, and also provide updates on the SEM analyses of those 200h engine tested plugs.

Subtask 4.1.3 – Siloxane Mitigation for Advanced Natural Gas Engines

John Storey, storeyjm@ornl.gov, (865) 946-1232
Tim Theiss, theisstj@ornl.gov, (865) 946-1348
Oak Ridge National Laboratory

Objective

Reciprocating engines remain the most logical distributed generation choice for reducing the peak demand on an electrical feeder due to their ease of siting and good economics. Increasingly, however, the high cost of natural gas is focusing attention on lower-quality fuel sources, such as landfill gas (LFG) or anaerobic digester gas (ADG) from waste-water treatment plants. These fuels often offer a low cost alternative to natural gas that in many cases, have environmental concerns that require their disposal anyway. A key impediment to the more pervasive use of low quality fuels is contaminants in the fuel, specifically siloxane. Siloxanes are a group of silicon-based organic compounds that are prevalent in LFG and ADG and can form silica compounds (sand) in an engine. The increased maintenance costs and/or increased fuel pre-treatment costs can hamper the economics of using these lower quality fuels. The state of the art for siloxane mitigation is quite low; the industry recognizes the issue and has anecdotal information about siloxane formation but the problems has not been carefully studied. This project seeks to provide fundamental insight into the formation of silica-based compounds from siloxane to assist industry mitigate the engine damage. Effort will be focused on a developing an understanding of the extent of the damage and mechanics of formation of siloxanes; development of a low-cost siloxane sensor to replace costly fuel pre-treatment technologies; and consideration of in-situ strategies to avoid the silica formation in the engine.

Highlights

- Work began during this reporting period on a real-time sensor for siloxanes in a LFG or ADG matrix with the University of Tennessee.

Technical Progress

Through feedback control, a real-time sensor could dramatically lower treatment costs (and energy consumption) for the feed gas. For instance, the treatment loop would only be used when siloxanes reached some threshold level. Desired specifications for the sensor include:

- Sensitivity < 1 ppm
- Response time (t_{90}) : < 60 s
- Recovery time (t_0) : <300 s

Researchers have begun testing microcantilever arrays with hexamethyldisiloxane. Early results look promising for sub-ppm detection.

Status of Milestone(s)

- Letter report that will Investigate the engine conditions when burning landfill/digester gas in reciprocating engines that produce siloxane deposits that damage the engine. (September 2007): On Track

Industry Interactions

- Waukesha Engine Dresser (WED) has expressed interest in the siloxane issue in reciprocating engines and discussing potential mitigation strategies with ORNL.
- ORNL is discussing the siloxane issue with a design firm who specializes in the design of waste-water treatment plants.

Subtask 4.2.1 – Microstructural Characterization of CFCCs and Protective Coatings

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Oak Ridge National Laboratory

Objective

During the past several years, SiC/SiC continuous-fiber ceramic composite (CFCC) combustor liners with a BSAS-based environmental barrier coating (EBC) have been exposed in several Solar Turbines engine tests for >10,000 h. The engine-exposed combustor liners have been characterized microstructurally and mechanically at ORNL to evaluate degradation of both CFCC liner materials and the EBC system. Simulated exposures of analogous materials systems were previously conducted in ORNL's Keiser Rigs at high water-vapor pressures.

More recently, an oxide/oxide outer liner, A/N720 CMC + FGI, and a GE SiC/SiC MI pre-preg + BSAS inner liner, have been exposed in a Solar Turbines Centaur 50S gas turbine at the ChevronTexaco engine test site in Bakersfield, CA. The primary objective of this project in FY2007 will be to characterize damage and elucidate degradation mechanisms of the two long-term engine-exposed CFCC liners for comparison with previous engine-exposed liners.

Highlights

The engine-exposed ATK-COIC oxide/oxide ceramic matrix composite outer liner, designated hybrid A/N720 CMC+FGI, was received at ORNL for sectioning and subsequent microstructural and mechanical characterization on March 14, 2007. This hybrid liner was exposed in the Solar Turbines Centaur 50S turbine for a total of 25,404 h with 109 starts. Thus far, the thickness variations across the fully-intact outer liner and a quarter arc of a similarly-processed (but not engine-exposed, i.e., baseline material) have been measured using a coordinate measurement machine (CMM). The entire liner has also been sectioned for extensive microstructural and mechanical characterization, which has just been initiated.

Technical Progress

The sectioning plan for the hybrid outer liner included representative samples from areas exhibiting surface recession of the FGI, regions of exposed CMC, "patched" FGI areas that show improved behavior, and a through-thickness hole, and was approved by each of the project collaborators (Solar Turbines, SiemensWestinghouse, ATK-COI Ceramics). To date, the liner has been fully sectioned and cross-sectional samples for microstructural analysis have been metallographically prepared. Each region of interest will be examined closely using scanning electron microscopy and tensile tests from representative areas will also be conducted and compared to the baseline material. The CMM thickness measurements and liner sectioning tasks are completed.

Status of Milestone(s)

(1) Report results from the analysis of >25,000 h engine-exposed ceramic matrix composite combustor liners (oxide/oxide+FGI and/or GE Pre-Preg) and compare with data for similarly-exposed composite material in the Keiser Rig (August 2007): In progress

Industry Interactions

1. Conference call with GE Global Research Center on June 11, 2007 to discuss sectioning of inner liner and liner characterization at ORNL.

Subtask 4.2.2 – Mechanical Reliability Evaluation of Ceramic Composites and Components with Environmental Barrier Coatings

H-T Lin, linh@ornl.gov, (865) 574-8857
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Objective

The objective of this subtask is to evaluate the protection performance of oxide-based EBC systems with ceramic composite substrates under a combined applied stress and steam environment. The results of this work will allow end users to verify their component design and probabilistic lifetime prediction methodologies, facilitate the implementation of ceramic and composite components, and further optimize the EBC long-term durability performance.

Highlights

High-temperature steam jet studies on directionally solidified eutectic (DSE) oxides, i.e., Al_2O_3-$GdAlO_3$ (GAP) and Al_2O_3-$Y_3Al_5O_{12}$ (YAG)-YSZ, at 1300°C for 500 hours were completed. These DSE oxides are potential candidates for environmental barrier coating (EBC) systems as well as structural material applications due to their mechanical stability at temperatures up to 1600°C in air. These DEC oxide specimens were provided by Ube Industries, Japan as well as University of Zaragoza, Spain through research collaborations. Results obtained from these studies provide important understandings on the long-term material stability (both in microstructure and chemical composition) under a simulated combustion environment. It also provides important database allowing one to develop alternative EBC systems for applications at much higher temperatures up to 1600°C than the limit set by current EBC materials.

Technical Progress

Characterization of surface and polished cross section of Al_2O_3-GAP DSE oxide after 500h exposure at 1400°C under the steam jet environments was completed during this reporting period. Results showed that localized material recession occurred in the Al_2O_3 component region, whereas the GAP region exhibited little or no recession, resulting in a porous GAP layer of ~ 20 μm from the exposed surface. Previous study conducted by Opila et al. on sapphire showed that there were apparent weight losses at temperatures between 1250 and 1500°C under a steam containing environment. The weight loss measured mainly resulted from the primary volatilization reaction of alumina in water vapor, i.e., formation of $Al(OH)_4$ gas specie. Results obtained in the present studies, consistent with previous results obtained for sapphire, suggest that alternative oxides needed to be employed to replace the Al_2O_3 component in the current DSE oxide. On the other hand, the 2000h long-term steam test under a low cyclic fatigue condition with externally applied stress levels of 110 and 165 MPa was initiated for the SiC-SiC CMC samples with EBC. The stress level employed was below or equal to the proportional limit of SiC-SiC CMC substrate.

Status of Milestone(s)

(1) Complete characterization of EBC-composite systems under a combined stress and steam jet test condition (September 2007): On track

Industry Interactions

1. Communications and conference calls with David Jarmon and Venkata Vendula of UTRC on the progress of 2000h testing status of SiC-SiC CMC specimens with EBC.
2. Communications with Dr. Waku at Ube Industries, Japan on the SEM characterization of Al_2O_3-GAP DSE oxide after 500h steam jet exposure at 1400°C.
3. Communication with Prof. Orera at University of Zaragoza, Spain on progress of steam jet testing of Al_2O_3-$Y_3Al_5O_{12}$ (YAG)-YSZ DSE oxide.

Subtask 4.2.3 – Environmental Protection Systems for Ceramics in Microturbines and Industrial Gas Turbine Applications

Beth Armstrong, armstrongbl@ornl.gov, (865) 241-5862
Kevin Cooley, Mike Brady, and H.-T. Lin
Oak Ridge National Laboratory

Objective

In order to be cost competitive, microturbines will have to meet aggressive durability targets. Currently ceramic components without an EBC will not be able to meet the goals of > 20,000 operation hours. An EBC may enable these components to meet the expected lifetimes provided the EBC can be applied at low cost. The goal of this project is to continue to develop a low cost, slurry-based process to apply protective coatings for silicon based ceramic materials for use in microturbine and/or industrial gas turbine applications. This effort will be coordinated with industrial partners to assist in the development of an ideal coating material or material system for steam and high velocity resistance.

Highlights

A study of the effect of contamination(s) upon slurry and coating properties has been initiated. Slurry development of a partners' material systems will continue.

Technical Progress

Due to contamination issues identified previously on collaborators' material system development, the focus of the slurry development for the remainder of the fiscal year will be on evaluating the effect of common elements of contamination from water and additive sources on zeta potential, rheology, dipping behavior, coating thickness, and coating microstructure. Previous equipment issues have been resolved, and work (rheology, dipping, and sintering studies) on the contamination studies ramped up. This work is comparing the effects of deionized and distilled water as well as the effects of varying and known concentrations of contaminant species. Two coating material systems are being used to evaluate the sensitivity of the material system's structure with contamination. The material systems selected are yttrium monosilicate and yttrium disilicate. Early results show that the stability of the material phase in aqueous solution is the dominant factor in controlling the effects of contamination upon slurry flow behavior and coating microstructure. The effects of the contamination species (sodium, potassium, barium, calcium, chlorine and fluorine) are dependent upon the changes in the surface phases and zeta potential.

Status of Milestone(s)

(1) Evaluate the effect of contamination upon slurry and resulting coating properties for a doped rare-earth silicate system (September 2007): On track.

Industry Interactions

- Collaboration with Honeywell continues.

Subtask 4.2.4 – Spark Plug Electrode Alloy Development

Mike Brady, bradymp@ornl.gov, (865) 574-5153
H.-T. Lin and Mike Kass
Oak Ridge National Laboratory

Objective

Spark plug lifetimes in advanced natural gas (NG) engines are on the order of only 1000-4000 h, which result in loss of performance and necessitate frequent, costly downtime maintenance. Spark plug durability will become even more critical as future engines are pushed to leaner-burn conditions to reduce emissions. The goals of this effort are to gain insight into spark plug life- limiting wear processes, and to use this understanding to develop new electrode alloys to achieve lifetimes of ≥ 8000 h.

Highlights

Spark plugs manufactured with ORNL Cr-base alloy have been successfully tested for 200h via a laboratory-modified gasoline engine at Federal Mogul. Electronic microscopy studies on those 200h lab engine test plugs were also completed. These results provide details of the effect of alloy composition and microstructure on the spark plug oxidation/corrosion resistance and thus long-term durability performance under the engine conditions.

Technical progress

Microstructure characterization of spark plug electrodes, manufactured with ORNL Cr-6MgO base alloy, standard 95% Ni-base alloy, and Haynes 214, after 200h laboratory gasoline engine was completed during this reporting period. SEM examinations of polished cross sections showed that the copper-cored standard 95% Ni-base alloy suffered from internal oxidation and cracking, similar to that observed in the other type of engine tests. Similar cracking was also observed in the Haynes 214 insert pad alloy. In both the standard 95% Ni-base alloy and Haynes 214, the internal attack and cracking were associated with internal penetration of oxygen and sulfur. In sharp contrast, there was no cracking observed in the Cr-6MgO base alloy insert. The surface of the Cr-6MgO insert was smooth, with little evidence of significant oxidation or loss of material. This supposition is consistent with the similar appearance and distribution of the MgO dispersions at the surface and within the insert pad alloy, as significant material loss would be expected to alter and redistribute the MgO dispersions. Results thus suggest that the Cr-6MgO base alloy could be a promising candidate as an alternative to Pt and Ir insert pad alloys. Nonetheless, the longer term engine tests are needed to confirm this observation, as well as more fully demonstrate the low erosion rate and cracking immunity of the Cr.

Status of Milestone(s)

(1) Submit an open literature paper reporting on the engine test results of developmental spark plug electrode alloys (September 2007): On schedule.

Industry Interactions

1. Conference calls and email communications with Dan Tribble of Woodward regarding the status of manufacturing of Woodward NG spark plugs from ORNL alloys.
2. Conference calls and email with Jim Lykowski at FM to discuss progress in collaborative work at FM, and also provide updates on the SEM analyses of those 200h engine tested plugs.

Subtask 4.2.5 – Alloy Development and Optimization for Increased Corrosion Resistance in High Temperature Exhaust Gas Environments

Bruce Pint, pintba@ornl.gov, (865) 576-2897

Objective

The goal is to finalize experimental work designed to improve the understanding of alloy composition effects on corrosion resistance of stainless steel components used in microturbine recuperators. Due to the linear kinetics of Cr loss by evaporation in the presence of water vapor in the exhaust gas, the maximum operating temperature and lifetime of high-alloy steels is limited. Encouraging results have been obtained with Al additions to Fe-base alloys. The focus is on acquiring sufficient laboratory experimental results on Al additions and/or low-cost Al coatings for this application.

Highlights

Exposures of model FeCr and FeCrNi alloys have demonstrated that ~0.1wt%B addition improved resistance to water vapor containing environments at 650°-800°C. This work demonstrated another possible route to improving the oxidation resistance of recuperator alloys. Also, characterization of Fe-20Cr-25Ni foils exposed to 17bar steam environments at 800°C was completed and showed significantly less Cr loss than in humid air testing at 800°C.

Technical Progress

Model Fe-16Cr-0.1B and Fe-20Cr-20Ni-0.1B alloys were fabricated to examine the role of B in water vapor environments. As shown earlier for other alloys, there was some beneficial effect on the oxidation behavior with a delay or prevention of accelerated corrosion with the addition of B. Boron may interact with H or OH in the alloy or oxide. More work is required to determine a mechanism and assess the effect of B in commercial alloys and on the alloy mechanical properties.

Characterization also was completed on a series of foil specimens exposed to 17bar steam at 800°C in conjunction with a Fossil Energy program. The reduced rate of Cr consumption observed in steam, compared to humid air, tends to confirm the mechanistic model of Cr loss by formation of an oxyhydroxide. The lower oxygen partial pressure in steam limits the formation of the oxyhydroxide.

Status of Milestone(s)

(1) Submit an open literature publication reviewing the potential for Al alloying additions and/or low-cost coatings to improve oxidation lifetimes of recuperator alloys (September 2007): (a) B. A. Pint, J. P. Shingledecker, M. P. Brady and P. J. Maziasz, (2007) "Alumina-Forming Austenitic Alloys for Advanced Recuperators," ASME Paper #GT2007-27916, presented at the International Gas Turbine & Aeroengine Congress & Exhibition, Montreal, Canada, May 14-17, 2007.
and
(b) Y. Yamamoto, M. P. Brady, Z. P. Lu, P. J. Maziasz, C. T. Liu, B. A. Pint, K. L. More, H. M. Meyer and E. A. Payzant, "Creep-Resistant, Al_2O_3-Forming Austenitic Stainless Steels," *Science*, 316 433 (2007).

Industry Interactions

Presented paper on alumina-forming austenitic alloys at IGTI 2007 Turbo Expo in Montreal, Canada in May 2007

Discussed applications for Al-containing alloys with various companies at IGTI meeting.

Subtask 4.2.6 – Materials Selection for Hostile Microturbine/Engine Environments

Jane Howe, howej@ornl.gov, (865) 241-9745
Rosa Trejo and Edgar Lara-Curzio
Oak Ridge National Laboratory

Objective

The project is to carry out corrosion and mechanical property studies as a function of the test environment (i.e. natural gas byproducts, and with additional contaminants, such as SOx), and report gas sampling of exhaust gases as a function of operation time.

Highlights

The ORNL Microturbine Recuperator Test Facility with Fuel-Flexible Environment (MRTFFE) is designed to perform the following tasks for a given type of fuel:

- Measure the temperature and gas species at selected locations inside the microturbine
- Evaluate materials degradation by placing coupons inside the microturbine
- Measure the SOx, NOx, CO/CO_2, etc in the exhaust
- Evaluate the degradation of candidate turbine/microturbine structural materials by exposing samples in a natural gas exhaust stream that is maintained at the desired test temperature, and doped with toxic species or components that make the gas stream characteristic of the exhaust when nontraditional fuels are burned.

Technical Progress

A 1000-hour recuperator material test started in May 2007 to continue the long term evaluation of 2025-3.2mils, HR120-3.2mils, and AL-625-4mils. The Controlled Environment Test Chamber (CETC) is an extension to the microturbine, as a slip stream of the exhaust gas will be diverted out of the microturbine from the aft removable dome, controlled by a gate valve, then into a 2"-dia test chamber. Machining of the sample holders of CETC is on-going. Gas sampling and analysis were carried out with assistance of NTRC collaborators.

A preproposal entitled, "In situ Electron Microscopy of Alloys in Pressurized Water Vapor" was prepared and selected for the submission of an LDRD full proposal. We proposed to study the initial stages of oxidation of Fe-Cr-based model alloys in simulated combustion environments using in situ electron microscopy with sub-nanometer spatial resolution and sub-second time-resolution.

Status of Milestone(s)

(1) Complete a report summarizing the results of corrosion and mechanical property studies as a function of the test environment (September 2007): On track

Industry Interactions

Communication with Chinese Coal Information Institute (CCII) regarding the proposal entitled, "Demonstration of Power Generation Using Low Quality Coal Mine Methane, Emission Monitoring, and Engine Performance Analysis". We decided not to participate in the research as a subcontractor because EPA only honored a third of the budgeted funding.

Interaction with Capstone Turbine Inc. regarding the energy output of the modified microturbine.

Subtask 4.2.7 – Siloxane Mitigation for NG Reciprocating Engines

Ted Besmann, besmanntm@ornl.gov, (865) 574-6852
Oak Ridge National Laboratory

Objective

Siloxanes are volatile silicon compounds formed in landfills as the result biological processes on silicone-containing products such as shampoos, silicone elastomers, toothpaste, among others. Combustion engines using landfill gas for fuel thus suffer from the formation of silica in the combustion environment which is abrasive to components and can severely limit life. Thermochemical modeling will be used to describe the formation of silica from representative landfill gas compositions. Areas of pressure-temperature-composition will be identified where silica will and will not form. The thermochemical model will then be used to explore possible mitigation schemes for controlling or preventing silica formation within the combustors without inlet gas cleanup systems.

Highlights

A thermochemical data base was developed that can be used to determine the equilibrium state within the combustor environment.

Technical Progress

A thermochemical database for a combustor environment containing siloxanes was developed based on an assessment of gas compositions provided in the literature.
Standard database thermochemical values were used as well as additional silicon-containing gaseous species data obtained from recent work on silicon carbide and nitride corrosion performed at NASA. A typical landfill gas gas composition was generated, including siloxane concentration, and used in thermochemical calculations. The parameter space 500-2200K at 5, 35 and 75 bar was explored for stoichiometric and 150% stoichiometric air ratios. Plots of major gas content and solid silica amounts were prepared showing the formation of silica under the various conditions. Higher temperatures and pressures serve to suppress silica formation, although it is apparent that at the more moderate component surface temperatures in engines that silica will inevitably form.

Status of Milestone(s)

(1) Perform a thermochemical assessment of silica formation from siloxane containing landfill gas combusted in power generation equipment (September 2007):

Industry Interaction

Communications with Mark Andrews of Caterpillar Corp. have been ongoing. Caterpillar provided a document that discusses siloxane deposits that come from landfill gas applications

Subtask 4.2.8 – Advanced Materials for NG Reciprocating Engines

Phil Maziasz, maziaszpu@ornl.gov, (865) 574-5082
Oak Ridge National Laboratory

Objective

Higher power density and efficiency, and lower emissions demand higher in-cylinder pressures and temperatures for NG reciprocating engines. Such conditions can shorten the lifetime and cause failures of critical components, like exhaust valves. In 2006, TRW-Automotive, Waukesha Engine-Dresser, and ORNL engaged in a collaborative project to address the potential to create exhaust valves with more reliability and higher temperature limits through manipulating valve design, applying coatings, and optimizing processing for Ni-based superalloy strength at high temperatures. Limited funding curtailed activities, but funding was provided in FY2007 to finish these efforts.

Highlights

Aging of various commercial Ni-based superalloys used for exhaust valves at 1400^{o}F and above to 5000h was completed. A sub-contract with TRW for tensile testing of those aged materials after 1000h was initiated this quarter. Oxidation testing in 10% water vapor at 800^{o}C to 1000h was completed for discs of bare metal and with various commercial oxidation-resistant coatings. Waukesha Engine, Dresser, initiated and funded a Work-for-Others proprietary project at ORNL to extend the oxidation testing of coated specimens, and to complete the tensile testing of materials aged for 5000h at 1400^{o}F and above.

Technical Progress

All tensile properties measurements on unaged superalloy specimens in various as-processed conditions has been completed. All aging of various Ni-based superalloys rods processed and heat-treated to represent the condition of valves to 5000h at temperatures of 1400^{o}F and above were completed, and all aged materials were sent to TRW for mechanical testing. A subcontract for mechanical testing of materials aged for 1000h was initiated this quarter.

ORNL began oxidation testing of disks of several different Ni-based superalloys with a variety of commercial coatings at 800^{o}C in air + 10% water vapor. One particular coating showed outstanding resistance to water-vapor enhanced oxidation after 1000h exposure relative to bare metal. Microstructural analysis on these specimens began this quarter and will be completed next quarter. Oxidation testing continued under a WFO project funded by Waukesha Engine, Dresser at ORNL.

Status of Milestone(s)

Complete preliminary oxidation testing to identify the best coatings for resistance to moisture enhanced oxidation. Evaluate the Ni-based superalloys with best strength after aging. Recommend the best alloy/coating combination for trial valve production for engine testing. (complete by September 30, 2007). Milestone is on track.

Industry Interaction

Regular data updates and conference calls with TRW and Waukesha-Engine, Dresser to coordinate this project.

Subtask 4.3.1a – Packaged/Modular IES Development

Robert DeVault, devaultrc@ornl.gov, (865) 574-2020
Oak Ridge National Laboratory

Objective

The objective of this proposed subtask is to develop and deploy highly efficient IES and include these as an essential element within the scope of the OE/DE Program. IES focuses on technologies that have broad utilization potential such as cooling, dehumidification, humidification, water heating, steam heating, drying, and shaft power from heat energy. Key program elements are packaged/modular IES development, DG thermal recovery research, IES field evaluations and end-use integration, and analytical tools/validation.

Highlights

UTRC – A system level feasibility demonstration to characterize and quantify performance and reliability of the integrated reciprocating engine and hybrid absorption chiller CHP system has been performed. The Engineering Check Sample (ECS) tri-generation chiller is expected to arrive at UTRC in August.

Technical Progress

The objective of Task 12.6 (Critical Risk Reduction) is the identification, analysis and selection of system modifications to enable simultaneous generation of electricity, cooling and heating from a microturbine/chiller CHP system. This "Trigeneration" capability would be advantageous for buildings with multiple zones having independent thermal loads, e.g., buildings where some zones have constant cooling loads while other zones of the building have seasonally-varying thermal loads. Another application benefiting from this technology would be buildings that are located in climates requiring daytime cooling and nighttime heating.

The Engineering Check Sample (ECS) tri-generation chiller is expected to arrive at UTRC in August once tests are completed at Carrier Korea (CKO) in June. UTRC will use the Capstone C60 microturbines for power generation and to provide thermal energy into the new chiller.

In Task 13.3 (Technology Readiness), a system level feasibility demonstration to characterize and quantify performance and reliability of the integrated reciprocating engine and hybrid absorption chiller CHP system selected for development in Task 12 has been performed. The new system has been named the PureComfort-R system (R stands for Reciprocating Engine). As a summary, the recip engine/hybrid chiller system has demonstrated a cooling capacity of 115 RT at ARI rated conditions. Cooling water return temperatures have been varied from 61 °F to 105 °F. Chilled water return temperatures have been varied between 61 °F to 51 °F. Transient tests have been performed where the cooling water has been ramped from 85 °F to 68 °F in 23 minutes to determine if the chiller control system can maintain stable operation during this rapid thermal transient. Chiller operation has been verified from 25% to 100% of rated capacity. UTC Power has worked with Carrier to migrate the control algorithms from the development platform to provide a common control platform among all Carrier chillers. This migration was funded by UTC Power as part of commercializing the technology developed under this contract.

The performance of the Cummins QSK19 engine has been verified at engine air inlet temperatures ranging from near 60 °F to 105 °F. The data collected has shown that engine outlet power and efficiency is not affected by the inlet air temperature in the range tested. In applications where the prime mover would be operating at high ambient temperatures, such as in tropical regions, the system performance would not be adversely affected.

UTRC has undertaken an exhaustive performance validation test program for the new C65 microturbines, two of which will be used in evaluation of the tri-generation chiller demonstration. Along with the new microturbines, Capstone has developed "rapid transfer" software and hardware that will allow the turbines to switch from grid-parallel operation to "Stand-Alone" operation in less than ten seconds. The previous package required up to two minutes for the

power transfer. With this new capability, the PureComfort-M package can be utilized in more applications where continuous, uninterrupted power is needed.

Status of Milestone(s)
(1)Complete draft report on the UTRC Phase II readiness assessment of performance, cost, and reliability for a reciprocating engine/hybrid chiller system (September, 2007): On schedule.

(2) Draft case study Seton Dell Children's Hospital IES system (September 2007): On schedule

Industry Interactions
N/A

Subtask 4.3.2a,b – DG Thermal Recovery and Integration Research at University of Maryland

Patti Garland, garlandpw@ornl.gov, (865) 574-0738
Dr. Reinhard Radermacher, University of Maryland

Objective

The objectives of the integration research being conducted at ORNL and at the University of Maryland are:

- Demonstrate the benefits of integrated CHP systems in commercial building applications
- Identify and help resolve problems that occur when combining different components into an integrated system
- Identify, develop and demonstrate system improvements
- Provide educational opportunities

This project will be completed in 2007, with the following work activites:

- Completion of testing of the newly designed low-flow conditioner components for liquid desiccant dehumidifier [work to be done in partnership with NREL]
- Completion of testing of the newly installed Broad absorption chiller with internal cooling tower
- Development of course material on absorption chiller systems operation and integration into CHP Systems for Buildings

ORNL works closely with the project team at the University of Maryland to analyze system data, to prepare presentations on test results and lessons learned, to write peer-reviewed technical papers, to provide project updates to DOE, to update the U of M website, and to find opportunities to disseminate lessons learned to the public. ORNL will facilitate cooperation and test plan development with other DOE national labs.

Highlights

- The contract was modified to include the final closeout work.
- The biannual Consortia Meetings are scheduled for the week of September 18th.

Technical Progress

- ORNL's comments are being incorporated into the FY06 annual report.
- The contract was modified on March 27th to include the closeout plan. All equipment (microturbine, absorption chiller, engine, liquid desiccant system and supporting equipment and instrumentation) will be disconnected, removed and disposed of or returned to the original owner.

Status of Milestone(s)

Complete close-out plan for system shutdown (April 2007): completed in March 2007.

Industry Interactions

Partners include members noted above.

Subtask 4.3.2c,d – DE Integration Lab and Analysis

Abdi Zaltash, zaltasha@ornl.gov, (865) 574-4571)
Oak Ridge National Laboratory

Objective

It is essential to industrial partners that we understand technical issues related to optimal integration of components as well as optimal operating conditions for DE and HVAC equipment and systems. ORNL offers the unique capability of benchmarking equipment throughout the full range of operating conditions in a closely controlled laboratory environment or in precisely controlled environmental test chambers. Equipment from manufacturers can be operated and tested in precisely controlled environmental conditions to assist those manufacturers in optimizing equipment and component matching and operational control of the equipment. This work can also be used to help develop or test rating/certification test procedures and standards.

Highlights

Completed the emissions during the air/fuel ratio (A/F) sweep (from rich to lean conditions) of GEDAC #16 at 17, 95, 120ºF outdoor temperatures in April 2007. Draft report on the results of this study is currently under review. The revised report will be submitted to our industry partner.

On May 29, 2007, the new 10-ton packaged rooftop GEDAC heat pump unit with R410A refrigerant (GEDAC #23) was received. The instrumentations on GEDAC #23 have been completed. Currently, preliminary tests are being conducted in both heating and cooling modes to troubleshoot the unit and the instrumentations.

The report on the performance of the Rotartica unit entitled "Performance Evaluation of a 4.5 kW (1.3 Refrigeration Tons) Air-Cooled Lithium Bromide/Water Solar Powered (Hot-Water-Fired) Absorption Unit" has been reviewed, revised, and then submitted to the 2007 ASME conference for publication in the Proceedings of this conference. Future plans are to document performance improvement for rotating heat (and heat/mass) exchangers based on the Rotartica unit and then assess the technical potential for using rotating heat exchangers in other applications.

Technical Progress

Completed the emissions during the air/fuel ratio sweep of the engine used in GEDAC #16 at 17, 95, 120ºF outdoor temperatures in April 2007. A/F ratio was used to determine the effectiveness of increasing air/fuel ratio to lower NOx emissions over a set of operating points. Adding more air to the cylinder acts to suppress combustion temperature and therefore lowers NOx formation. This process, known as leaning, adds oxygen to the combustion process and also the exhaust. The set-points selected for this evaluation are shown in Table 1. Emissions data consisting of NOx, total hydrocarbons (THC), CO and formaldehyde were collected with the outdoor temperature set at 17, 95 and 120°F. For each outdoor temperature an air-fuel sweep was performed at speeds of 1900 and 2250 rpm. Draft report of this study is currently under review. The revised report will be submitted to our industry partner.

Table 1. Air-fuel sweep test conditions.

Outdoor Temp. (°F)	Speed 1900 rpm	Speed 2250 rpm	Mode
17	X	X	Heating
95	X	X	Cooling
120	X	X	Cooling

Instrumentations on GEDAC #23 have been completed. Currently, preliminary tests are being conducted in both heating and cooling modes to troubleshoot the unit and the instrumentations and to optimize the controls.

The revised report on the performance of the Rotartica unit entitled "Performance Evaluation of a 4.5 kW (1.3 Refrigeration Tons) Air-Cooled Lithium Bromide/Water Solar Powered (Hot-Water-

Fired) Absorption Unit" has been submitted to the 2007 ASME conference for publication in the Proceedings of this conference.

Status of Milestone(s)
(1) Completed air/fuel ratio sweep of the engine used in GEDAC #16 (April 2007).

(2) Revised report on the performance evaluation of the InterRotex technology (Rotartica unit) was submitted to the 2007 ASME conference for publication in the Proceedings of this conference (May 2007).

Industry Interactions
• Partners include: Southwest Gas, Team Consulting, BME, and Rotartica.

Subtask 4.3.3 – CHP Economics/Modeling

Mike MacDonald, macdonaldjm@ornl.gov, (865) 574-5187
Oak Ridge National Laboratory

Objective

The economic evaluation of proposed installations of combined cooling, heating, and power (CHP) systems requires calculations that consider building heating, cooling, hot water, and electrical loads, the costs of power and natural gas (including block rates, demand and standby charges, and ratchets), and the simulated performance of generators, chillers, boilers, and water heaters. Ideally this is done on an hour-by-hour basis so thermal loads and electrical generation can be matched in time and so energy cost savings can be calculated correctly for time-of-day rates. The BCHP Screening Tool is a sophisticated building energy modeling tool, smoothly executing DOE2.1e in the background to model all the required parameters.

Experience with this tool has indicated both its amazing strength to model building energy simply and some features that do not operate as expected. This task will update the User's Manual for this tool to better inform users how to take advantage of both basic and advanced capabilities of this tool, as well as change descriptions of some features that are not correct. The update will also allow definition of the next set of improvements needed for this tool.

Highlights

Completed transfer of all documentation and source code to Mike MacDonald from Steve Fischer. Fischer is also under a support contract to provide limited assistance over the next year on technical issues that arise in defining and developing code improvements.

Have identified all changes needed for the User's Manual and will complete revision of the manual next quarter as a draft for review.

Technical Progress

Over the past two years, extensive testing and debugging of the current version of the BCHP Screening Tool has been conducted in actual projects. This effort has also led to development of extensive annotation of changes needed in the User's Manual. These changes will be implemented in a new draft manual next quarter for user review.

Review of the program flow process and methods for controlling program flow have been completed.

Status of Milestone(s)

(1) Complete user manual on BCHP screening tool (September 2007): the update of the manual, including corrections, clarifications, and suggestions for advanced use of the BCHP Screening Tool will be completed as a draft next quarter for review.

Industry Interaction

None this quarter. User comments will be sought on the updated User's Manual.

Subtask 4.3.8 – Industry Collaboration, Crosscutting Activities

Robert DeVault, devaultrc@ornl.gov, (865) 574-2020
Oak Ridge National Laboratory

Objective

ORNL will monitor the progress of the various CHP projects and provide technical direction to the subcontractors. As the tasks progress, lessons learned and technical results will be compiled and disseminated to the stakeholder community. In addition, ORNL will facilitate dialogue with industry stakeholders to encourage the consideration and use of DE in high-tech applications. Barriers to application of DE/CHP will be identified with the intent of reducing or removing them. ORNL will continue working with existing CHP design and evaluation software tools and will work with stakeholders to ensure their awareness of the tools and to assist in their use in studying potential DER/CHP applications. ORNL will continue to assist DOE with participation at crosscutting conferences and events such as PowerGen, ASHRAE, ASHE, etc. This work activity supports the technical guidance and analysis provided by the CHP Group Leader.

Highlights

UTC Power has received orders for two PureComfort-R systems.

Technical Progress

A system level feasibility demonstration to characterize and quantify performance and reliability of the integrated reciprocating engine and hybrid absorption chiller CHP system has been performed (see Subtask 4.3.1a – Packaged/Modular IES Development).

Status of Milestone(s)

Industry Interactions

Meetings were held in May with UTRC to discuss future project plans and System Integration Issues in High Performance Buildings and Hybrid Chiller/Reciprocating engine system status.

Subtask 4.3.13 – Research Survey/History of DOE Program

Mike MacDonald, macdonaldjm@ornl.gov, (865) 574-5187
Steve Fischer [retired]
Oak Ridge National Laboratory

Objective

Over the last few decades, DOE has provided considerable funding in support of development of technologies for improving energy efficiency. There have been several technical analyses completed on potential for energy savings in a variety of technology applications. Although documentation on previous work activities has been completed, it can be difficult to find the relevant work because of passing time or lack of a centralized reference list. In 2006, ORNL created a database that contains over 300 reports. In 2007, the following activities will be completed: an additional 75+ reports on ORNL BCHP work will be included, enhanced search capabilities will be added, and copyright questions will be resolved.

Highlights

This work was completed in December 2006.

Technical Progress

There are abstracts for over 500 reports on-line with links to PDF files for all of the publicly available publications (copyrighted material does not have links to the journal articles, although PDF files for those publications are on-line, they just are not available to the public; they can easily be made available if ASHRAE and ASME gave ORNL/DOE permission to do so).

The publications cover the time frame of 1974-2006 including electrically driven heat pumps, thermally-activated technologies, advanced appliance research, distributed energy and CHP, district heating, and a few lesser categories.

The reports can be accessed at:
http://www.ornl.gov/sci/engineering_science_technology/eere_research_reports/index.html
As well as through Google type searches (turns up better if EERE is included in the search string).

There is a site map as well as a keyword index.

Status of Milestone(s)

Research survey/history of DOE program (April 2007):(1) Add additional ~75 technical papers as requested by DOE sponsor on September 7, 2006 (April 2007): Complete

Industry Interactions

Subtask 4.4.1a – Ritz Carlton Hotel/GTI, San Francisco, California

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

Objective
The FY04 solicitation sought proposals for projects that utilized pre-engineered, packaged IES systems that both generate electricity and make effective use of the thermal energy produced. Target applications for this procurement were healthcare and education facilities, hotels, and supermarkets. Two of these projects, under subcontract to GTI, are included in this subtask: (1) The Ritz Carlton Hotel, San Francisco, California has installed a UTC Pure Comfort System (with four Capstone microturbines) to generate 240 kilowatts and operate a 110 ton absorption chiller. Partners on this project are UTC Power, Pacific Gas & Electric, Carrier Commercial Systems, and Ritz Carlton. (2) Basin Electric, North Dakota will utilize waste heat from an existing pipeline compressor station's gas turbine to generate electricity via an organic Rankine cycle. Due to a change in DOE priorities, two other projects were replaced with a new effort focused on grid integration in a New York utility area with a fully networked (as opposed to radial) grid topology.

Highlights
The draft final report was reviewed by ORNL and revised by the subcontractor.

Technical Progress
The draft final report was reviewed by ORNL and revised by the subcontractor.

Status of Milestone(s)
(1)Complete final project documentation (September 2007): On track

Industry Interactions
N/A

Subtask 4.4.1b – Basin Electric/GTI, Flasher, North Dakota

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

Objective

The FY04 solicitation sought proposals for projects that utilized pre-engineered, packaged IES systems that both generate electricity and make effective use of the thermal energy produced. Target applications for this procurement were healthcare and education facilities, hotels, and supermarkets. Two of these projects, under subcontract to GTI, are included in this subtask: (1) The Ritz Carlton Hotel, San Francisco, California has installed a UTC Pure Comfort System (with four Capstone microturbines) to generate 240 kilowatts and operate a 110 ton absorption chiller. Partners on this project are UTC Power, Pacific Gas & Electric, Carrier Commercial Systems, and Ritz Carlton. (2) Basin Electric, North Dakota will utilize waste heat from an existing pipeline compressor station's gas turbine to generate electricity via an organic Rankine cycle. Due to a change in DOE priorities, two other projects were replaced with a new effort focused on grid integration in a New York utility area with a fully networked (as opposed to radial) grid topology.

Highlights

Data collection is complete and the final report is in progress.

Technical Progress

The site's installation and data collection has been completed.

Status of Milestone(s)

(1) Complete final project documentation (September 2007): On track

Industry Interactions

N/A

Subtask 4.4.3 – Eastern Maine Medical Center in Bangor, Maine

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

Objective
Complete construction and begin testing of a Solar gas turbine to generate 4.4 MW, generate 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.

Highlights
The system was fully operational on October 16, 2006, following a ribbon-cutting open house on site to celebrate completion of construction and startup. Operations data are being collected by CDH Energy, and performance statistics are available for review on the web at http://www.emmccogen.org.

Technical Progress
For the second quarter of 2007, the plant provided 95.8% of the hospital's electricity, generating 6,484 MWh of electricity, while recovering 28,404 MMBtu of useful heat. The overall total CHP efficiency during this period was 74.2 percent.

Status of Milestone(s)
(1)Complete final project documentation (September 2007): As plant operations did not start until October 2006, a final report including a full year of operating data, per the contract, will not be available until the first quarter of FY08. A report on operational results will be prepared in September to cover the period of operations through that point.

Industry Interactions
N/A

Subtask 4.4.4 – East Hartford High School

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

Objective
Install a UTC Pure Comfort system in the East Hartford (Connecticut) High School that will have black-start capability. United Technologies Research Center is the subcontract partner.

Highlights
Project has been completed.

Technical Progress
System performing as expected.

Status of Milestone(s)
(1)Complete final project documentation (September 2007): A project profile has been prepared by SENTECH and has been submitted to NREL for posting on the DOE website.

Industry Interactions
N/A

Subtask 4.4.5 – Madera Hospital/RealEnergy

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

Objective
Install an integrated reciprocating engine and absorption chiller system at the Madera Community Hospital in Madera, California. The system will have capacities of 600 kW and 115 RT. The subcontract partner is RealEnergy, LLC.

Highlights
None.

Technical Progress
None

Status of Milestone(s)
Due to hospital facility expansion (independent of the CHP system), the CHP plant construction has been postponed. It is not known whether the project will ever go forward.

Industry Interactions
N/A

Subtask 4.4.6 – SEMCO Incorporated/Lindale, Georgia

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

Objective

Utilize a 200 kilowatt reciprocating engine generator coupled with an integrated active desiccant system in a high school in Floyd County, Georgia. Partners are C&M Engineering, Floyd County Schools, Deutz Engines, and WW Williams electrical generation equipment. Develop an islanded Integrated Energy System (IES) design that will function independently of the grid to provide adequate building air conditioning and ventilation in the event of a local disaster, blackout, or terrorist attack.

Highlights

The system was commissioned in September, 2006 at the new high school. The rooftop desiccant systems have been running well, but problems with the Deutz engine controls and electronics have resulted in only being able to run the engine for short periods of time. Fortunately, the desiccant units do not require the engine to be operating in order for them to function.

Technical Progress

The system is now operational. Problems with engine controls and electronics are being investigated.

Status of Milestone(s)

(1)Complete final project documentation (September 2007): On schedule

Industry Interactions

N/A

Subtask 4.5.12 – Evaluation of CHP Market Potential As It Relates to Renewable Portfolio Standards

Patti Garland, garlandpw@ornl.gov, (865) 574-0738
Oak Ridge National Laboratory

Objective

This project consisted of several tasks: Collect and summarize opportunity fuels information for fuels that already are or could be used in CHP applications, Evaluate CHP Technology Options, and Analyze Potential Market Impacts and Develop Recommendations. This work was completed in FY05 with publication of the final task report, which can be found on the DOE DE website.

In FY06, one task was added to the contract: Satisfying of Renewable Portfolio Standards with Opportunity Fuels and CHP. In this effort, a state-by-state analysis of the impact of state level renewable portfolio standards will be performed, using state target dates and impacts as well as emerging values of renewable energy certificates (RECs). This analysis will build off of the Phase I work. It will analyze the potential capacity from opportunity fuels that would satisfy the state renewable portfolio standards, based on availability of fuel, economics of opportunity fueled CHP, and prospects for wind and solar renewables.

Highlights

- The following white paper "Project Considerations for Distributed Generation using Opportunity Fuels" has been completed and was issued in April, 2007.
- The report “Potential Impact of Renewable Portfolio Standards on Biomass Combined Heat and Power Applications” has been completed and was issued in April, 2007.
- The following white paper was drafted for comment, “Barriers to CHP with Renewable Portfolio Standards.”

Technical Progress

The report “Potential Impact of Renewable Portfolio Standards on Biomass Combined Heat and Power Applications” has been completed. This report focuses on the potential impacts of biomass combined heat and power (CHP) on 15 leading state’s RPS. Anaerobic digester gas from wastewater treatment and farms, landfill gas, and solid and gaseous biomass are included as biomass. They are labeled “opportunity fuels” because they are not widely used in this country, but they have the potential to be an economically viable source of power generation for certain applications. Each leading state considers these four opportunity fuels as renewable biomass fuels. Based on their RPS and biomass prospects, the leading states are: Arizona, California, Colorado, Connecticut, Illinois, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Jersey, New York, Pennsylvania, Texas and Wisconsin.

Status of Milestone(s)

(1)Complete final paper on barriers to Installing CHP associated with renewable portfolio standards (September 2007): On schedule

Industry Interactions

This project is being completed in partnership with Resource Dynamics.

Subtask 4.5.16 – Coordination of Regional CHP Application Centers
Subtask 4.5.17 – Project Direction and Technical Support

Patti Garland, garlandpw@ornl.gov, (865) 574-0738
Oak Ridge National Laboratory

Objective

ORNL is working the DOE CHP Regional Application Centers and with Power Equipment Associates, Energetics, EEA, Discovery Insights, USCHPA, Sentech, and Resource Dynamics to provide oversight and guidance of continued CHP Projects. ORNL will provide a critical technical review and provide analysis for verification of subcontracted activities. As the tasks progress, lessons learned and technical results will be compiled and disseminated to the stakeholder community. Results of these projects will be disseminated through the use of the DOE DE Website or the DOE CHP Regional Application Centers.

As part of the CHP Roadmap activities, ORNL supports development and updates of the CHP Action Plan in response to the Roadmap.

Highlights

- A CHP RAC face-to-face meeting was held on May 24-25, 2007 in Golden, Colorado.
- A working meeting to discuss RAC activities and metrics was held on June 14, 2007 in Washington, DC.
- A second working meeting on the RAC logic diagram mapping and metrics is scheduled for August 29th in Washington DC.

Technical Progress

The agenda for the May 24th-25th meeting included the following items: U.S. DOE RAC budget update, Regional roundtable discussion, Metrics, U.S. DOE Industrial Technologies Program update, RAC ITP efforts, EPA CHP Partnership, HUD update, FEMP update, Best practices/lessons learned from target market workshops, and U.S. DOE EERE PM Technology Deployment efforts.

Status of Milestone(s)

(1) Complete report on 2006 RAC accomplishments and lessons learned (April 2007): Completed as part of the Historical Metrics Report to DOE.

Industry Interactions

See above.

Subtask 4.5.18 – CHP Regional Application Center Technical Support
Subtask 4.5.19 – Provide Support to HUD on an "As-Needed" Basis

Mike MacDonald macdonaldjm@ornl.gov (865) 574- 5187
Patti Garland, garlandpw@ornl.gov, (865) 574-0738
Oak Ridge National Laboratory

Objective

ORNL is providing technical assistance in performing screening and optimization calculations on an as-needed basis to the CHP Regional Application Centers. ORNL will train CHP Regional Application Center staff on the use of the BCHP screening tool.

ORNL also provides technical support to Bob Groberg at Housing and Urban Development (HUD) on an as-needed basis. Current work includes recommendations on the accuracy of the CHP calculator based on for the Cogen Manual for Multi-Family Housing, Appendix A. Additional work will include collaboration with HUD, and HUD "partners", in identifying and applying the best tools for evaluating CHP in multi-family housing. Among others, these partners include Sebesta Blomberg & Associates of Arlington, Virginia and Dougherty and Associates of Alexandria, Virginia who are under contract to HUD to evaluate combined heat and power for multifamily housing. A data template and utility data files will be produced for use with the BCHP Screening Tool to assess its potential for use in studying combined cooling, heating, and power in multifamily housing.

Highlights

- Bob Groberg presented Version 2 of the HUD CHP screening tool at the CHP RAC face-to-face held in Golden, Colorado, in May.

Technical Progress

- There is a website (http://eber.ed.ornl.gov/HUD_CHP_Guide_version_2a/) for downloading Version 2A of the feasibility screening software that now includes cooling, new screen shots, and new printout capability. HUD is committed to running software on 20 sites. Targeting M-A, NE, MW, and CA. Funding for these software runs has not been identified.

Status of Milestone(s)

(1)Provide technical support to the CHP Regional Application Centers (RACs) (On-going): On going
(2) Provide support to HUD on an as-needed basis (On-going): On going.

Industry Interactions

N/A

Subtask 4.6.1 – Distributed Resources Value to Stakeholders, Including the Grid and Owners

Therese Stovall, stovalltk@ornl.gov, (865) 574-0329
Stan Hadley, hadleysw@ornl.gov, (865) 574-8018
Oak Ridge National Laboratory

Objective
Perform DE benefit analyses to: (1) provide the foundation for informed program management decisions, (2) facilitate the deployment of advanced technologies developed under the program mantle by conveying the full extent of potential benefits and the role of DE in the energy market, and (3) support cooperation and partnership with other DOE offices and other government agencies.

Highlights
Work is ongoing to support multiple utility teams responding to the OE DE solicitation.

Technical Progress
Work is ongoing to support multiple utility teams responding to the OE DE solicitation.

Status of Milestone(e)
(1)Complete a report that considers reliability, power quality, diversity, and market rules to define the value of grid-integrated DE (September 2007): The work to date has focused on the value of plug-in hybrid vehicles.

Industry Interactions
N/A

Subtask 4.6.3 – Coordinate Industry Efforts with the DOE/OE Program

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

Objective
Perform DE benefit analyses to: (1) provide the foundation for informed program management decisions, (2) facilitate the deployment of advanced technologies developed under the program mantle by conveying the full extent of potential benefits and the role of DE in the energy market, and (3) support cooperation and partnership with other DOE offices and other government agencies.

Highlights
Participated in perfect power grid conference in NY as part of coordinating industry efforts with the DOE OE program.

Technical Progress
Participated in perfect power grid conference in NY as part of coordinating industry efforts with the DOE OE program.

Status of Milestone(s)
(1)Complete subcontractor report describing industry coordination efforts (September 2007): Work is underway to meet the milestones.

Industry Interactions
N/A

Subtask 4.6.4 – MADRI Support Activities

Therese Stovall, stovalltk@ornl.gov, (865) 574-0329
Brad Johnson, Consultant

Objective
Perform DE benefit analyses to: (1) provide the foundation for informed program management decisions, (2) facilitate the deployment of advanced technologies developed under the program mantle by conveying the full extent of potential benefits and the role of DE in the energy market, and (3) support cooperation and partnership with other DOE offices and other government agencies.

Highlights
Participated in PJM metering sub-group focused on developing metering interoperability standards in support of DR program settlement activities. Planned workshops with DC, MD, and NJ public utility commissioners to focus on advanced meter infrastructure business case considerations and dynamic pricing.

Technical Progress
Brad Johnson is wrapping up this task before leaving the program to take on a new opportunity at the John Deere Company.Coordinated key MADRI activities through Maryland working group activities regarding advanced meter infrastructure and distributed resources business case and cost/effectiveness criteria.

Status of Milestone(s)
(1) Complete a report describing MADRI advances and how they can be applied to other regions (September 2007): Work is underway to meet the milestones.

Industry Interactions
N/A

Subtask 4.7.1 – Evaluate Methods for Voltage Regulation and Analyze Techniques for Voltage Collapse

John Kueck kueckjd@ornl.gov, (865) 574-5178
Fran Li, and Y. We
Oak Ridge National Laboratory

Objective

Develop methods for local, independent control of Distributed Energy (DE) Resources so that they may provide dynamic voltage regulation with minimal communication requirements for a distributed control system.

Highlights

The June milestone (*Evaluate Methods for Voltage Regulation & Analyze Techniques for Voltage Collapse*) was met ahead of schedule on May 1st. A highlight document on completion of the milestone was prepared and provided to DOE. An induction motor has been installed at the DECC lab to create balanced (when motor starts) and unbalanced (when the motor is single-phased and started) voltage dips for testing the inverter's response to dynamic voltage changes. The initial induction motor configured for the testing is a 7.5hp motor but we have larger sized motors (15, 25, 40, 50, 60 and 75 hp) that we will be testing later on to create more severe conditions. Several technical papers are in preparation or have been recently accepted describing our methods for dynamic, DE-based, voltage regulation. We are proposing the development of a controlled voltage droop characteristic for DE which will actually increase the margin to voltage collapse. We will be testing our methods in the Distributed Energy Communications and Controls (DECC) Laboratory following a test matrix that we have developed.

Technical Progress

The DECC Lab achieved a significant ORNL control milestone on April 30 and May 1 using a unique control algorithm that we developed and tested with the simultaneous operation of three distributed energy (DE) resources in close proximity and connected to the ORNL electric distribution system. Two of the devices were dynamically regulating their end-use voltages using our developed control algorithm for local, independent control. The two devices, SC and inverter, were controlled separately, which was also unique since it didn't involve any central communications and control or the need for the two devices to talk to each other. The third device, a 30-kW Capstone micro-turbine, uses conventional control and cannot regulate voltage. The test was significant from the perspective of showing how conventional DE operates with "smart" DE that can dynamically control its local voltage. The two devices, a 300-kVar synchronous condenser (SC) and 150A (or 125kVar) inverter, use feedback control with our unique control algorithms to adjust their reactive power output based on the measured local voltage at their power panels. One set of tests involved voltage changes of 0.5 to 5V to verify the quick response of the two devices to correct their end-use voltages. A second set of tests involved creating a severe voltage sag (over 55V on the SC panel, which corresponded to ~6V on the inverter panel) with the start-up of the 250hp synchronous motor to assess how quickly and effectively the inverter could respond to a very fast voltage sag. The control algorithms use only a local measurement of voltage and do not require communication between DE. Next steps include the development of independent algorithms that can be used over a wide-spread distribution network (10 miles or more) to support voltage in areas of reactive power shortage and to expand the network's margin to voltage collapse without interfering with existing utility control.

We have developed a test matrix for our path forward that considers a number of operational test scenarios for evaluating our dynamic DE control algorithms. These scenarios involve (1) balanced/unbalanced voltage conditions (i.e., sags), (2) various dynamic load conditions (i.e., motor starts), (3) changing load conditions (i.e., step load changes), (4) severe abnormal conditions (i.e., when there is a fault; we will use several sizes of three-phase motors — single-phased so that they can't start — to produce severe/unbalanced voltage sags for several cycles similar to that due to a fault), and (5) changing voltage schedules for the DEs which involves the use of a voltage-band based control. Based on the results of these tests, general engineering guidelines or "rules of thumb" will be developed along with a control methodology framework that

will provide a streamlined engineering approach for utilities to implement various ancillary services using DE resources.

Status of Milestone(s)

(1) Evaluate Methods for Voltage Regulation & Analyze Techniques for Voltage Collapse: evaluate analytical techniques for using independently controlled DE sources in parallel to supply dynamic reactive power (June 2007): the control milestone was met ahead of schedule on May 1st.

Reports of analysis are in various stages: complete and waiting for publication, in preparation, and only in outline form. A list of is as follows:

Dynamic Voltage Regulation in Multiple Distributed Energy Resources Systems: The paper was submitted to the iREP Symposium 2007 (http://www.ap-concepts.com/irep2007/Index.php, August 20-24) for publication and presentation.

Dynamic Voltage Regulation Using Distributed Energy Resources: International paper accepted for publication and presentation at the 19th International Conference on Electricity Distribution (CIRED, http://www.cired2007.be/), Vienna, May 21-24. The paper was presented by Dr. Fran Li.

The Use of Distributed Energy Resources to Extend the Margin to Voltage Collapse: This paper was previously submitted to the IEEE for review but was not accepted for publication; the analysis in the paper is currently being updated for resubmission to the IEEE Transactions.

Use of a Voltage Schedule and Independent DER Control Algorithm to Increase Margin to Voltage Collapse: This paper will be prepared based on simulations run in PSLF. An outline has been prepared for a paper to be co-authored by ORNL and SCE. The paper will be targeted for policymakers.

Industry Interactions

We are coordinating with Southern California Edison to simulate our DE methods for voltage control using their distribution system model. We will examine the impact of our method on the “micro voltage collapse” events they have had in their system. They have provided us with a number of technical papers they have written on the subject from past events. The most number of these events was experienced this summer.

Subtask 4.7.2 – Conventional Control and New Methods in Parallel

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Objective

The objective of this project is to test the simultaneous operation of multiple reactive power producing distributed energy (DE) resources at the DECC Laboratory with them connected in parallel and providing local dynamic voltage and power factor regulation at their local power panels on the ORNL distribution system. The 150A inverter and 300kVar synchronous condenser at the DECC laboratory will use our control schemes to provide dynamic voltage regulation while operated in parallel with a 30kW commercial Capstone microturbine.

Highlights

Last Fiscal Year (2006), we began operating our 150A inverter in parallel with our 300kVar synchronous condenser and were successful in operating them simultaneously. We have recently operated the inverter to around 75A rms (100A peak) during steady-state operation and up to 150A during transient operation. The temperature of the inverter's heat sink must be kept at or lower than 75C in order to ensure that the integrated bipolar-gate transistor (IBGT) junctions of the inverter are within 100C. Our new inverter cooling system has had no problems maintaining this requirement during our tests.

The induction motor setup for testing voltage dips directly on the inverter panel has been completed. We have motors sized 7.5, 15, 25, 40, 50, 60 and 75 hp available for the tests courtesy of our facilities motor warehouse. The motors have been moved to the DECC lab and the 7.5hp motor installed initially. Fuse blocks and motor logic modules (overcurrent/overthermal protection) were installed to accommodate the full range of motor sizes.

Technical Progress

We are now able to regularly operate the inverter and SC with their independent dynamic voltage controls simultaneously with the Capstone (conventional controls) microturbine. The SC can provide up to 300kVar of reactive power support while the inverter can provide close to 60kVar of reactive power support. The capstone microturbine is operated via a remote control on our desktop computer and can be operated from 1 to 30kW in 1kW steps. The induction motor test rig connected to the inverter panel has been completed and will be used for creating balanced (motor starts) and unbalanced (attempt to start single-phased motor, one phase removed) voltage dips. Also, the single phasing of the motor will create a much higher voltage dip. We are starting out with the smallest motor of 7.5hp and will work our way up to the largest which is a 75 hp motor if possible. The 75 hp motor is operational and its voltage dynamic performance during startup is being accessed before operating the inverter simultaneously with its motor start.

We have developed a test matrix for our path forward that considers a number of operational test scenarios for evaluating our dynamic DE control algorithms. These scenarios involve (1) balanced/unbalanced voltage conditions (i.e., sags), (2) various dynamic load conditions (i.e., motor starts), (3) changing load conditions (i.e., step load changes), (4) severe abnormal conditions (i.e., when there is a fault; we will use several sizes of three-phase motors — single-phased so that they can't start — to produce severe/unbalanced voltage sags for several cycles similar to that due to a fault), and (5) changing voltage schedules for the DEs which involves the use of a voltage-band based control. Based on the results of these tests, general engineering guidelines or "rules of thumb" will be developed along with a control methodology framework that will provide a streamlined engineering approach for utilities to implement various ancillary services using DE resources.

Status of Milestone(s)

(1) Operate multiple DE sources in parallel using the control methods developed in subtask 4.5.1 (September 2007): The milestone is on track. We have been regularly running all three devices (inverter, synchronous condenser and microturbine) and hope to be simultaneously starting/stopping the motor to create voltage dips on the inverter panel shortly.

Reports are in various stages: complete and waiting for publication, in preparation, and only in outline form. A list of is as follows:

Nonactive-Power-Related Ancillary Services Provided by Distributed Energy Resources: This paper of analysis and simulation at the reactive power lab was accepted for publication and presentation at the IEEE Power Engineering Society General Meeting (http://submissions.miracd.com/pesgm2007/Itinerary/TechnicalProgram.asp, June 24-28, Tampa, FL). The paper was presented by Dr. Engin Ozdemir at the Emerging Technologies Coordinating Committee Presentation and Meeting Session on Tuesday, June 26th.

Voltage and Current Unbalance Compensation Using a Parallel Active Filter: This paper was accepted for publication and presentation at the IEEE Power Electronics Specialists Conference (http://www.pesc07.org/, June 17-21, Orlando, FL). The paper was presented by Dr. Engin Ozdemir at the Session T59: Active Filtering on Thursday, June 21st.

Journey to Flexible, Reliable, Laboratory Platform for Simultaneous Control of Multiple Reactive Power Producing Devices: The paper has been published in the Journal of Industrial Technology (Volume 23, Number 2, June 2007, National Association of Industrial Technology, www.nait.org).

A Framework to Quantify the Economic Benefit from Local Dynamic VAR Compensation: We plan to submit this paper to Journal of Electric Power Systems Research (http://www.elsevier.com/wps/find/journaldescription.cws_home/504085/description#description) in the near future.

Industry Interactions

We have developed a complete test matrix for our planned CY07 DECC laboratory testing activities and it has been provided to our industry partners for review and comment. This milestone has been identified as high priority. Southern California Edison (SCE) has continued to provide us with network data and data from last summer's micro-voltage collapses (stalling of air conditioning motors) for analysis. We are proceeding with GE PSLF simulations to understand the dynamics of the SCE network and how voltage dynamic control via DER can mitigate these events.

Subtask 4.7.3 – Instrumentation & Communication Requirements Using Low-Cost Methods

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Objective

The goal is to generate a report that analyzes the scale and granularity of communication architecture requirements for the future power grid. The report will emphasis new requirements that are due to the impact of distributed energy resources (DER) such as renewables and microturbines. DERs require more rapid, highly-distributed, and adaptive control systems to respond in real-time to power system events and pricing. The report will focus on functionally categorizing the existing DER technologies, categorizing available communication technologies, and defining the communication requirements by functionality of DER. Concise simulation will be done to demonstrate the impact of communication network in the operation of grid with DER elements.

Highlights

The outline of the draft report is generated. Focus areas to investigate are identified.

Technical Progress

Different distributed generation technologies existing today are being studied to categorize them functionally. Existing communication architectures in the grid are being studied to understand how we can the address issues like scalability as number of DERs increased, guaranteed Quality-of-Service to satisfy reliability regulations, and available standards to address the large-scale deployment issue.

Status of Milestone(s)

(1) Complete a draft report documenting communication requirements (September 2007): On track.

Industry Interaction

N/A

Subtask 4.7.4 – Fault Current Detection and Mitigation

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Objective

Develop fault current detection, limiting, and protection circuits to protect the modules in the event of an internal fault in the power converter.

Highlights

Types of fault current limiting and detection techniques were studied. The circuit for fault current detection and fault current limiting under Hard Switched Fault (HSF) was designed and tested.

Technical Progress

A literature study was done to identify the type of device faults and to study the techniques to detect, to limit fault current through the device and to protect it. At device level, faults can be characterized as over-current, short circuit, open circuit faults, etc. Short circuit faults are most critical to the device. The two main short circuit fault types are –Hard Switched Fault (HSF) and Fault under Load (FUL). The circuit for fault current detection and fault current limiting under HSF was designed. The circuit was built using commercially available IC chips. The fault current detection is achieved by sensing the Vce across the device. The circuit has the blanking time capability which can be adjusted varying the RC time constant between the gate turn-on signal and the fault detection signal. The blanking time prevents nuisance trips because of transient currents. The circuit has the flexibility to be adjusted for a particular on-state voltage drop between (0-7 V). The output stage of the gate driver circuit is capable of handling 14 A of peak current. The circuit can be adapted for higher gate currents by implementing a complimentary transistor pair at the output stage of the gate driver.

The fault across the device is simulated using a preset voltage across the fault detection circuit, which in the actual device is the on-state voltage drop corresponding to the short circuit current. The gate voltage is clamped to a desired preset voltage as soon as the fault is detected. There is a delay between the fault detection signal and the fault signal output. However, the gate voltage starts to decrease even before the fault signal is active. This change in the gate voltage reduces the peak fault current immediately after the fault. The gate voltage is clamped to the preset voltage until the controller commands the turn-off of the gate signal. The time needed for the gate voltage to be clamped is determined by the short circuit withstanding capability of the device. The protection circuit also has the under voltage gate protection feature which will protect the device from damaging itself because of excessive losses.

The circuit for FUL type of faults has been designed and being built. The FUL circuit will be integrated into the fault protection circuit.

Status of Milestone(s)

(1) Survey existing fault current limiting techniques for power electronic inverters. Develop inverter model in PSIM and Matlab/Simulink (September 2007): The survey of existing fault current detection limiting has been completed. The simulation of inverter has been started.

Industry Interaction

N/A

Subtask 4.7.5 – Develop and Assess Specific Tariff Mechanisms

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Objective

The main objective of this project is to study a range of customer types to see what reactive power needs may be fulfilled by alternate tariff structures. Pacific Gas and Electric has supplied a set of four examples of customers who may potentially supply reactive power to regulate local voltage. We are evaluating the cost and value of supplying reactive power from each customer. We are also working with the California Independent System Operator to gain the system operator's perspective. We are examining existing tariff(s) and evaluating alternative tariff structures.

In FY07, we have visited each of the four PG&E customers and discussed their needs. The customers are highly diverse. We have also visited Pacific Gas and Electric and the CAISO.

Highlights

Some of the customers have the capability to supply significant levels of reactive power for voltage regulation at this time. Some of them would require extensive modification which may not be cost effective. Each of them, if a suitable tariff had been in place, could now be supplying reactive power for local voltage regulation as part of electrical modifications which were performed in the last three years.

Technical Progress

We are in the process of requesting budgetary cost estimates for the needed modifications. We are also developing a value estimate for the benefits of supplying reactive power locally, both from the perspective of the Load Serving Entity and the System Operator.

Status of Milestone(s)

(1) Assess a range of customer types to see what reactive power needs might be fulfilled and will propose and report on alternative tariff structures (September 2007): A technical paper is in preparation.

Industry Interaction

Subtask 4.7.6 – Modeling of Reliability of High Temperature Packaging of SIC

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Objective

SiC-based power electronics can enable module size and weight reductions, operating temperatures of up to 500°C, loss factor reductions of an order of magnitude, and increase power capabilities by two orders of magnitude. Even though the SiC has very attractive electrical capabilities and attributes for power converters, it remains a brittle ceramic (i.e., a class of material in which a deterministic approach to structural design is not reliable) that would be subjected to thermomechanical stresses during device manufacturing and high temperature service - conditions that can limit or decrease device operation and lifetime. The present subtask combines the use of established probabilistic design and lifetime prediction methods developed for structural ceramics, microstructural-scale finite element analysis, micromechanical characterization, and sensitivity analysis methods and adapts them to the analysis of lifetime and design optimization of SiC-containing power converter devices (e.g., insulated gate bipolar transducers or IGBTs)

Highlights

Both a 2-D conventional finite element analysis (FEA) model and a *μ-FEA* model were developed for the cross-section of a 1200V/100A IGBT; they enable either thermomechanical stress analysis or design sensitivity analyses of the IGBT's operational state.

Technical Progress

A conventional finite element analysis (FEA) model of an idealized cross-section of a Powerex 1200V/100A IGBT was constructed. These IGBTs are not capable of operating with junction temperatures above 125-150°C because their diodes are silicon (Si). Such a FEA model enables the consideration of the substitution of Si diodes with silicon carbide (SiC) diodes and the interpretation of how the thermomechanical stress field changes due to property changes of the various subcomponents within the IGBT.

To complement the above conventional FEA, a companion model of the same cross-section was constructed using ORNL's copyrighted *μ-FEA* software that was co-developed by this project's PI. A metallographically prepared cross-section of the 1200V/100A IGBT was imaged with an optical microscope. Its digital picture (which captured the various constituents comprising the IGBT cross-section) was then used as input for the *μ-FEA* software. Unlike the idealized cross-section (with its perfect alignment of the substrates, uniform thicknesses, etc.), the digital picture captured all irregularities (e.g., non-uniform fillet radii of solder bonding, non-uniform thickness of the brazing, etc.), so all these artifacts can be analyzed from the thermomechanical stress results.

Status of Milestones

Demonstrate the use of *μ-FEA* for modeling the thermal-mechanical stresses prevalent in a current SiC-package (September 2007): On schedule.

Industry Interactions

Communications occurred with Kyocera and Brush Ceramics pertaining the candidacy of their Si_3N_4 and BeO insulators, respectively, for use in high temperature power electronic devices.