ORNL/TM-2000/250

OAK RIDGE NATIONAL LABORATORY DISTRIBUTED GENERATION CAPABILITIES

Edited by Therese K. Stovall

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Oak Ridge, Tennessee 37831
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Contents

Introduction

Distributed generation is recognized as a strategy to meet local energy needs while reducing energy losses associated with electricity transmission. Distributed generation also provides the opportunity to augment overall system efficiency by productively using thermal energy in a combined heat and power system, or to productively use direct shaft power, thus avoiding the mechanical/electrical energy conversion losses. These system efficiency improvements also reduce the environmental impact of energy production and use. Another distributed generation advantage is its substantial potential to improve the reliability of the nation's electricity grid.

However, expanding the use of distributed generation poses several challenges. First, it represents a significant change from the status quo. Electricity consumers are accustomed to purchasing utility services, not to accepting local responsibility for construction, operation, and maintenance. The hardware and regulatory/economic structure already in place is designed to support central station generation.

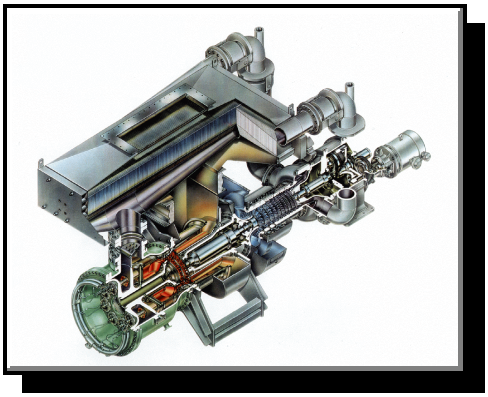
Second, system control and system reliability are interdependent functions. During the transition to distributed resources, we need to learn how to best integrate distributed resources to improve the overall system. This challenge includes appropriate efforts to balance local needs with system needs.

Third, all energy use must consider the environmental impacts of the technology and of the fuel selection. Current post-combustion clean-up of pollutants is economic only for large scale operations, restricting distributed generation to very clean fuels. To expand the fuel choices for distributed generation to include biomass and abundant coal will require small-scale gas clean-up technology development. The efficiency of the system also has a direct effect on the environmental impact. System efficiency has historically been a function of system size where the larger systems were more efficient - this new paradigm requires very efficient small systems.

Fourth, heating and cooling systems in buildings have not traditionally been optimized for efficient low-temperature thermal energy use, and the load density is often too low to support related distribution piping systems. Distributed generation can be used more effectively in buildings if improvements are made to thermally-driven cooling systems and analysis/assessment programs that help to identify economic applications.

Oak Ridge National Laboratory is well positioned to contribute to a comprehensive DOE distributed energy resources program. This summary provides an overview of the many areas of energy research at the laboratory that can directly contribute to the nation's needs in this important arena.

Gas Turbine Development



Opportunity

Due to the low-cost availability of natural gas and its low-emissions characteristics, most new large distributed generation installations are projected to be gas turbines. Considering their widespread use, efficiency improvements for this technology will have significant impacts on national energy consumption and environmental goals. Also, high efficiency gas turbines permit higher electric/thermal load ratios, thus making cogeneration a viable option for a broader industrial market.

Current Research

The advanced turbine systems program has the goal of developing and demonstrating ultra-high efficiency, natural gas turbine systems for commercial offerings to electric utilities, independent power producers, and US industry. One of the critical parts of the advanced turbine systems program is base technology development on materials and manufacturing technologies. Key needs were identified with extensive industry input and are currently the focus of on-going research activities. These key needs are (1) single-crystal airfoil manufacturing technology, (2) coatings and process development, (3) ceramic development, and (4) materials characterization.

Successful Parntership

ORNL has worked with Howmet Corp and PCC Airfoils to develop their capability to manufacture single-crystal airfoils. Although their yield have not yet reached commercial production levels, they were able to manufacture the single-crystal airfoils for the ATS demonstrator engines. Both partnerships have also resulted in the development of a melt-desulfurization process for the nickel-based superalloys.

ORNL has partnered with Westinghouse Power Generations and Pratt and Whitney to develop dependable thermal barrier coatings to enable increased turbine inlet temperatures while maintaining reduced airfoil substrate temperatures. These new systems have been bench tested and are moving on to product line gas turbine testing. programs.

Solar Turbines and Rolls-Royce Allison have tested monolithic vanes and blades for use in industrial gas turbines. Solar Turbines has conducted over 10,000 hours of testing on continuous fiber ceramic composite combustor liners.

Materials characterization efforts have focused in two areas: (1) measuring long-term tensile creep in ceramics and ceramic composites for gas turbines in support of programs at Solar Turbines, Allison, and Westinghouse, and (2) the development of characterization techniques for thermal barrier coatings used by all gas turbine manufacturers. With the University of Dayton Research Institute, long term testing on monolithic ceramic materials has extended to over 10,0000 hours, providing the manufacturers with a database to use for their life prediction programs.

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Microturbines

Opportunity

One key to expanding distributed generation is to expand the technology choices and provide the best possible fit for each customer's energy needs. Micro-turbines (defined here as less than 1 MW) with increased reliability, efficiency, durability, along with reduced emissions and lower cost, will be attractive to a broad market. This market will include industrial customers who wish to place and control electricity and thermal energy production at precise steps in their manufacturing process. Other customers for this technology include small commercial, institutional, and service businesses. In addition to local electricity production, this system is available for cogeneration.

Current Research

The microturbine program at ORNL is charged with leading a national effort to design, develop, test, and demonstrate a new generation of microturbine systems that will be cleaner, more efficient, fuel-flexible, more reliable and durable, and lower cost than the first generation products that are entering the market today. Detailed program planning efforts are nearly complete.

Successful Partnership

Microturbine systems are just entering the market and manufacturers are targeting broad applications in the industrial and buildings sectors including combined heat and power, backup power, continuous power generation, and peak shaving. So far, four U.S. manufacturers have make commitments to enter the microturbine market. Honeywell (AlliedSignal) is offering a 75 kW product, Capstone has a 30 kW product, Elliott has 45 and 80 kW products, and Northern Research and Engineering Company will have several products in the 30 to 250 kW size range. ORNL is working with several of these equipment manufacturers on advanced materials.

In fact, a big jump in microturbine efficiency can be achieved with significant increases in engine operating temperatures, and the most likely materials to accomplish this are ceramics. Current microturbine designs use metallic components without air-cooling, and the resulting high metal temperatures result in shortened lifetimes.

Structural ceramics have long been considered primary candidates for hot section components in advanced gas turbines. Initial property limitations, such as low strength, low Weibull modulus, and poor creep resistance, were successfully addressed in a number of materials development programs. Despite these advancements, recent tests have shown that the long-term performance of ceramic components may still be limited by environmental degradation and foreign object damage. In addition to these technology barriers, several manufacturing challenges including high component costs and unacceptable product yields remain.

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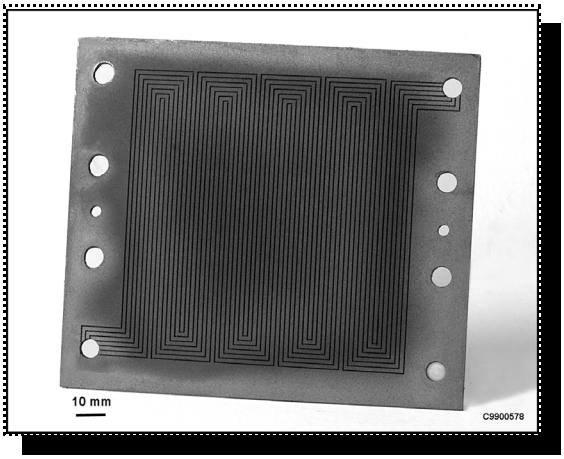
Proton Exchange Membrane Fuel Cell Electrode



Opportunity

The significant and growing interest in fuel cells for stationary power applications has been demonstrated by the attention these technologies are receiving from both government and industry. Interest in the proton exchange membrane fuel cell is related to its low-temperature operation and thus rapid start-up, and to the inherent efficiency and low emissions of fuels cells in general. Their modularity make them ideal for small appliance operation and other residential and commercial applications.

Current Research

One of the key components is the bipolar plate, which is the electrode plate that separates individual cells in a stack. The reference design uses a bipolar plate made from high-density graphite with machined flow channels. However, both material and machining costs of this plate are prohibitively high. Developmental efforts to improve the performance and reduce the cost of this component are the focus of the current project at ORNL. A process has been developed which uses a low-cost, slurry-molding process to produce a carbon-fiber preform. The molded, carbon-fiber component could have an inherent volume for diffusing fuel or air to

Current Research (continued)

the electrolyte surface or impressed, flow-field channels. The bipolar plate is made hermetic through chemical vapor infiltration with carbon. The infiltrated carbon also serves to make the component highly conductive.

Successful Partnerships

Currently, Plug Power, LLC and Honeywell Corp. are both testing prototypical components developed at ORNL. The issues of interest to these manufacturers are cost, thickness, weight, adequate mechanical properties/hermeticity, and corrosion resistance. The commercially available competitor is machined, high density (POCO™) graphite. Current costs for the components are ~$27 per plate. This should be compared to an expected cost for the composite bipolar plate of less than $2 per plate.

For many applications weight is a very important factor. Using carbon composite bipolar plates of the same geometry, the weight is reduced by one-half.

High density graphite is also very brittle, with a single crack resulting in leakage and failure of the system. Mechanical testing of the carbon composite material revealed that it can tolerate substantial cracking, due to its fiber reinforcement, without any through-thickness leakage. Biaxial flexure testing of plate material to a 100 N load resulted in detectable acoustic emissions indicating cracking. Subsequent leak testing under a differential pressure of 2 bar of hydrogen revealed no detectable leakage. Thus the material has significantly more damage tolerance than high density graphite, which cannot tolerate a single crack.

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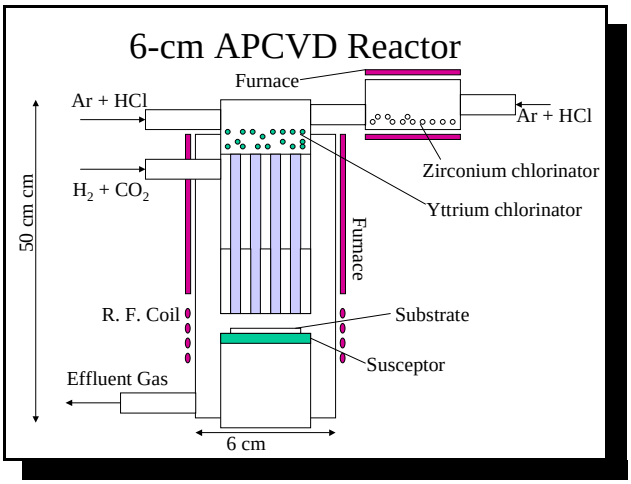
Efficient Solid Oxide Fuel Cell Electrolyte Fabrication



Current Research (continued)

The process utilizes halide-based precursors flowing over a heated substrate in an atmospheric pressure reactor. The elimination of the typically required low pressure reactor will substantially reduce fabrication costs. Development of the process is needed because the higher pressures generally cause poor coatings to be deposited and significant homogeneous nucleation that results in the formation of powder.

Opportunity

Solid oxide fuel cells represent the most fuel-efficient means for producing electricity. They are low-emission, low-noise systems and can accommodate a wide spectrum of fuels ranging from hydrogen to various hydrocarbon liquids. As such they are ideal for distributed generation with sizes from household to medium-scale industry.

Current Research

The current major fabrication method for solid oxide fuel cell yttria-stabilized zirconia electrolyte layers is electrochemical vapor deposition . The process requires low pressure operation with the oxygen source on one side of the porous support electrode and halide precursors of yttrium and zirconium on the other side. This complex arrangement allows for highly uniform yttria-stabilized zirconia coatings to be deposited, yet is quite costly due to low throughput and capital equipment requirements. The effort at ORNL is to develop an atmospheric pressure chemical vapor deposition process for fabricating yttria-stabilized zirconia electrolytes for a solid oxide fuel cell.

Successful Partnerships

This project was initiated just this year and has already shown some initial progress. A thermochemical analysis of the atmospheric pressure chemical vapor deposition of yttria-stabilized zirconia has been performed. This analysis has indicated the approximate values for several major processing variables that promise success. An atmospheric deposition reactor of unique design has been developed that uses stagnation flow. The reactor was specifically designed to allow design scale-up to wide area, commercial systems. Computational fluid dynamics are being used to support the reactor design in terms of maintaining uniform deposition over such large areas.

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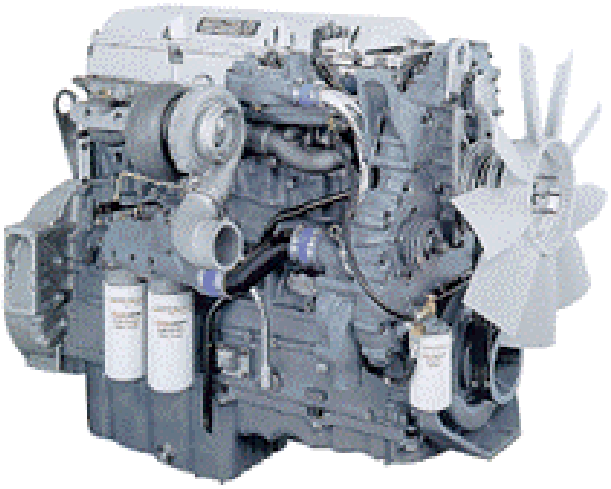
Materials for Reciprocating Engines



Successful Partnerships

ORNL has partnered with Cummins Engine Co., Caterpillar Inc., Detroit Diesel Company, and the University of Southern Illinois to develop new materials for high-efficiency diesel truck engines. Ceramic valves have been evaluated in a cooperative venture with Detroit Diesel. Separate efforts are underway with both Cummins and Caterpillar to develop improved methods for precision machining ceramic fuel injection plungers. Another partnership with Caterpillar is focused on the development of advanced steel for diesel engine components. Our cooperative efforts with the University of Southern Illinois center on processing ceramic components.

Opportunity

Reciprocating engines dominate in the small scale distributed generation market, making up about 48% of all installed combined heat and power sites. Significant increases in this installed capacity would be possible if engine emissions were reduced. Many of the proposed emissions reduction methods rely on exhaust gas recirculation, which creates a harsh operating environment, and a need for materials that can perform well in that environment.

Current Research

Most of the current research is aimed at reciprocating engines used in vehicles, especially in heavy vehicles. Some of the materials work is focused on the fuel system, including the development of carbon storage materials for gaseous fuels and the development or wear and scuff resistant materials for fuel injection systems. Advanced materials, including high-temperature metal alloys, intermetallics, cermets, ceramics, amorphous materials, metal and ceramic-matrix composites, and coatings are investigated for critical engine applications.

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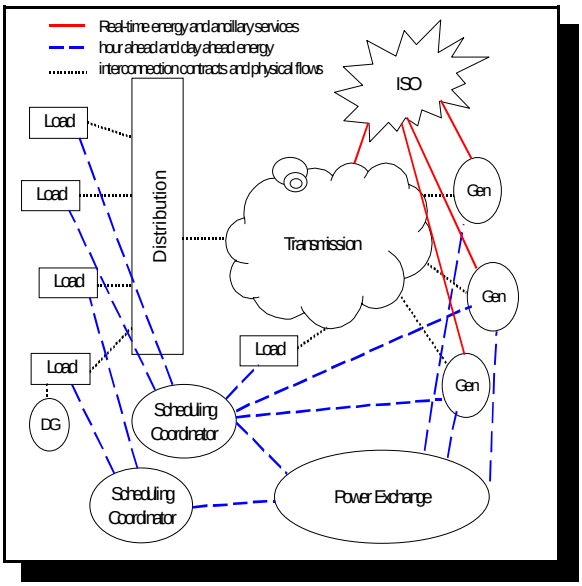
Integrating Distributed Generation into the Electric Power System



Opportunity

Both the distributed generation owner and the power system benefit when distributed generators are interconnected with the power system. Reliability for both can be increased since they can support each other. Successful interconnection of distributed generators requires that careful attention be paid to numerous technical issues including system stability, safety, and system protection.

Current Research

Research is progressing in two areas, interconnection standards and system simulations. ORNL is actively participating in the IEEE effort to draft interconnection standards for all distributed generation up to 10 MW. ORNL is also collaborating with the Consortium for Electric Reliability Technology Solutions in an effort to model the expected behavior of multiple distributed generators connected to the power distribution system. Both efforts are aimed at lowering the cost and maximizing the benefit of using distributed generation resources as an integral part of the electric grid.

Successful Partnerships

ORNL is working with Northern Indiana Public Service to find ways to mitigate the impact of highly varying industrial loads on control area performance. ORNL worked with Anchorage Municipal Light and Power to evaluate the application of Superconducting Magnetic Energy Storage to enhance the stability of the Alaska Rail Belt system.

As a result of its close links with the utility industry, ORNL has acquired a significant capability for system analysis using utility standard, commercially available software codes. North American Electric Reliability Council(NERC) regional data combine with ORNL's own model development capability to provide an unparalleled ability to perform large scale system studies. The use of industry standard databases and codes assures high quality repeatable results that are widely acceptable to industry, while in-house modeling expertise assures appropriate handling of unusual requirements. A sampling of available analysis codes includes Power System Simulator, Production Costing(In-house models and DYNASTORE), Electromagnetic Transient Program, Power System Harmonic Simulation and Analysis, System Reconfiguration Analysis Program, and the Powerdat Database System.

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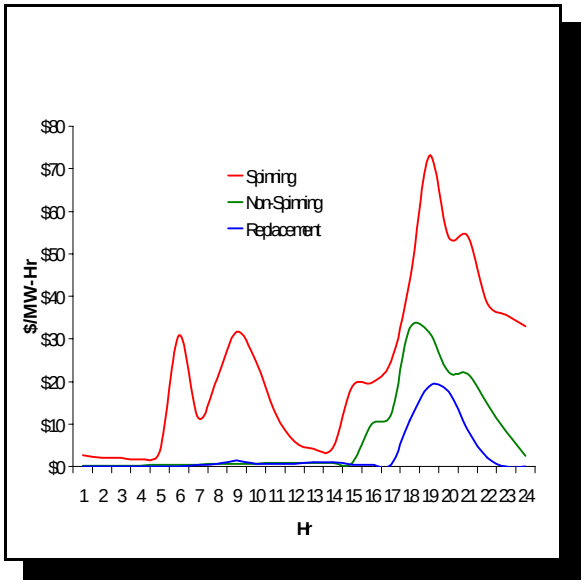
Electric Utility Restructuring, Reliability, and Ancillary Services



Opportunity

Electric industry restructuring provides both challenges and opportunities for distributed generation. Energy markets have become quite dynamic with significant volatility in real-time energy prices. In addition, there is more to sell from distributed resources generation than just energy. There is a set of services, called ancillary services, that the power system requires to operate reliably. By participating in these dynamic markets, DG customers can reduce their electricity costs. This also increases the reliability of both the power system and the customer's supply.

Current Research

The Power Systems Research program conducts research aimed at integrating increased electric system reliability with industry restructuring and the introduction of competitive markets. Electric power reliability markets are in the form of ancillary services. The services of greatest interest are spinning reserve, non-spinning reserve, backup supply, and voltage support. The first three represent real-power reserves that can be deployed with different speeds and for different durations. The last

Current Research (continued)

represents the reactive power available from the generator. Research is underway on defining and measuring the services in technology-neutral ways to facilitate market participation. Research is also being conducted on the communications and control technologies required to support distributed generation participation in real-time energy markets.

ORNL is developing a model of generator/market interactions for the complex situation where energy and ancillary services are all competitively provided. This model can be used by both generators and system operators to study how they can best prosper in the restructured market while still maintaining system reliability.

Successful Partnerships

ORNL is working with the North American Electric Reliability Council on policies governing reliability and ancillary services. This is a technical effort as well as a consensus-building effort involving all sectors of the electric power industry; vertically integrated utilities, independent system operators, transmission companies, independent power producers, and power marketers.

ORNL is working with the California Energy Commission to determine how loads and distributed generation can participate more fully in ancillary service markets. ORNL has also worked with Detroit Edison on ancillary service definitions and requirements.

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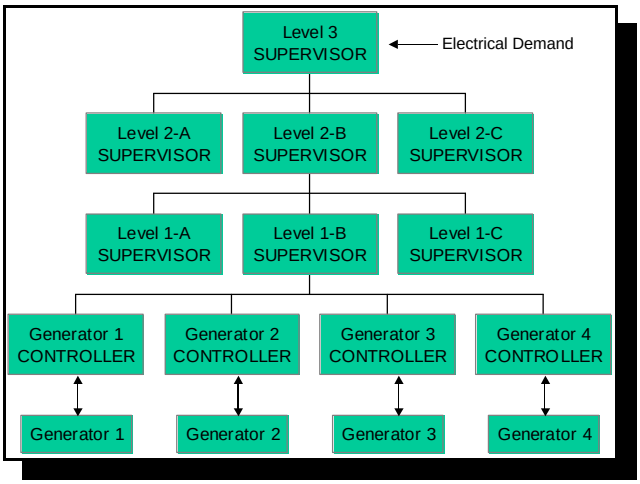
Advanced Controls and Simulation

Supervisory Control Hierarchy for Distributed Energy Resources



Opportunity

Distributed energy Resources (DER) will present a very challenging control and optimization problem. The DER system will consist of highly interdependent components and high expectations for reliability and availability. In addition to control, there will be a strong desire to optimize system efficiency and minimize the cost of operation. A hierarchical supervisory control system, as depicted in the figure, could optimize performance of the DER system. Each level of the hierarchy can control and monitor the systems below it to optimize availability and maintenance while meeting the demand for power. Only the lower level controllers operate the individual generation units, while higher level controllers work to meet the electrical demand and maintain overall system performance.

Current Research

Supervisory control system research being conducted at ORNL aims to automate highly complex systems. Automation is achieved by combining subsystem control with higher level intelligent supervisory control. The appropriate control algorithms

Current Research (continued)

are developed for lower level subsystem controllers. The subsystem controllers are then directed and coordinated by the supervisory control system. The supervisory controller can have objectives to control to a desired operating condition, but also to optimize the resources available, respond to upsets, and meet economic objectives. Current projects include a supervisory control system for a steel plant and a 21st century fully automated nuclear power plant.

Successful Partnerships

ORNL has worked with General Electric Nuclear Energy on developing a supervisory control system for the Advanced Liquid Metal Reactor. This is a unique nuclear plant design because it has nine nuclear reactors driving three turbine generators. ORNL developed subsystem control algorithms, the supervisory control, hierarchical architecture, and simulations for this project. The supervisory control system balanced power demands with plant capabilities (including adapting to system faults). The supervisory control system worked in conjunction with a plant operator to allow for manual control as desired.

In a Cooperative Research and Development Agreement with the Electric Power Research Institute, ORNL developed control system architecture simulations and specifications for a Plant Window System. The Plant Window System was to specify the interface requirements for a power plant operator interface.

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Power Electronics

Opportunity

Distributed generation brings with it a host of challenges related to control and stability, especially as grids are operated near their limits. The Multi Level Converter appears to be an excellent solution. This device provides total control over the frequency and voltage output, including phase angle. The converter will connect any generator to the grid in a way that not only handles synchronization, but also provides rapid control over real and reactive power.

Power electronics permits the use of alternative power supplies, including renewable technologies, to meet electrical load demand. This technology makes the distributed resource more useful and valuable to the grid, thereby enhancing grid reliability.

Current Research

High-efficiency electric power inverters convert direct current to alternating current at reduced cost, volume, and weight compared to previous technology, while improving reliability and performance. They show a high efficiency over a wide operating range with very low electro-magnetic interference. Other designs are under development to produce multi-level inverters for use in high-voltage applications. These could be used to integrate power from photovoltaic cells or wind turbines with the higher voltage utility grid.

Successful Partnerships

ORNL developed and introduced the multilevel topology for converters having more than three levels as part of a 1992 to 1996 government/industry collaboration to reduce the cost of high voltage dc conversion stations. The new multilevel configurations, for which ORNL has received patents, were so successful that they not only cut station costs in half by eliminating transformers, but also provided technology to control power transfer between providers and users, for whom transfer had been difficult or impossible. This technology was demonstrated at a 10kW power level. The photo on this page shows a suitcase demonstration of a 5-level multilevel converter configured to drive a house fan using 110 voltage ac synthesized from five 30-volt dc power sources, which represent five photovoltaic cells.

ORNL is collaborating with Southern States, Inc. to develop bi-directional powerline conditioners that may be connected between a utility provider and an industrial user. An industry with DG may be contracted to provide emergency power to the utility grid, which may be the emergency user.

ORNL has had significant experience in collaborating with private industry, mostly in areas of inverter or motor technology. These companies have included GM, Delphi, Lockheed Martin Control Systems, Advanced Vehicle systems, Chattanooga Area Regional Transportation Authority, Nartron Corp., Detroit Diesel, and Stereotaxis, Inc.

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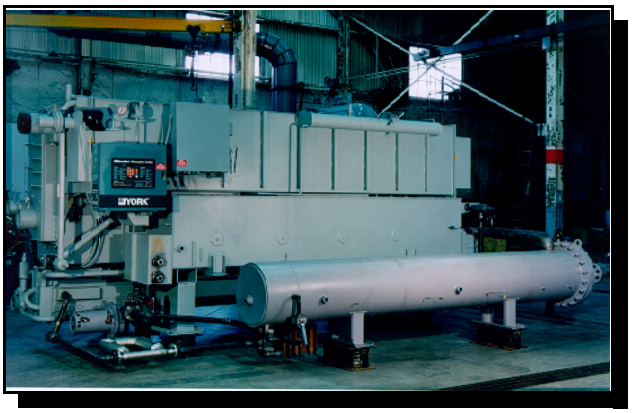
Building Systems Technology



Opportunity

The development of new "onsite and near-site" distributed power generation technologies, such as advanced natural gas turbines and reciprocating engines, microturbines, and fuel cells, will open up new possibilities for buildings. The next important efficiency opportunity for buildings will come from integrating whole building thermal/electrical energy needs with distributed generation. Buildings cooling, heating and power (BCHP) has the potential to increase energy efficiency by as much as 30 percent, reduce carbon emissions by 45 percent or more and improve indoor air quality through humidity management. BCHP equipment systems produce both electric or shaft power and useable thermal energy onsite or near site, converting as much as 80% of the fuel into useable energy.

Current Research

The goal of the ongoing thermally-activated equipment program is to accelerate the development and facilitate the commercialization of a new class of highly efficient cooling, dehumidification, and heat pump equipment for buildings that use natural gas. The focus is on absorption heat pump and chiller technology and on desiccant-based ventilation technology for improved indoor air quality. An advanced

Current Research (continued)

"triple-effect" chiller for large commercial building applications will be demonstrated in 2000-2001. Combined desiccant-based energy recovery and second-generation dehumidification product prototypes were installed at field sites in late 1999 and are currently being evaluated. Thermally-activated cooling and desiccant regeneration are essential technology elements that establish the principle of energy recovery and BCHP as widely applicable in the buildings sector. Immediate research needs include assessing and evaluating the current and advanced equipment and its ability to utilize waste heat from the various prime movers (turbines, microturbines, fuel cells, etc.). Additionally, we need to develop BCHP metrics and begin laboratory and field performance evaluation tests of various integrated configurations.

Successful Partnerships

Natural-gas fired triple-effect chiller units have been developed in partnership with two U.S. manufacturers. These chillers deliver up to 40% more cooling efficiency in laboratory tests than double-effect units now on the market. A 450-ton prototype has been undergoing tests at York International's Developmental Test Facility since 1998. Trane is conducting laboratory tests of a prototype triple-effect unit that uses a technology licensed from ORNL.

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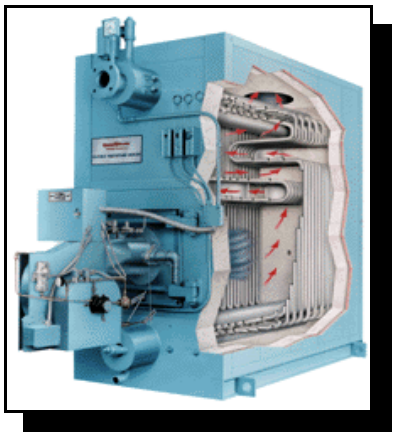
Steam - Best Practices



Opportunity

One of the chief attractions of distributed generation is the potential for cogenerating both electrical power and thermal energy, at a much greater efficiency than when serving these energy needs independently. Often the thermal energy is output from the distributed generation system in the form of steam. However, many industrial facilities lose valuable resources because of poorly operated steam systems.

The overall goal of the Best Practice efforts is to assist steam users in adopting a systems approach to designing, installing and operating boilers, distribution systems, and steam applications.

Current Research

Steam Best Practice efforts to support industrial steam use improvements include: (1) Performing a Steam System Market Assessment to establish parameters describing the industrial market for steam efficiency improvements; (2) Developing a Steam Systems Sourcebook to increase awareness of energy efficiency opportunities among plant engineers, facility managers, and system operators; and (3) Developing Steam System Assessment Tools to assist users in grading their steam system operations and identifying additional steam system improvement opportunities.

Successful Partnerships

Steam BestPractices is led by the DOE Office of Industrial Technology and the Alliance to Save Energy, and is supported by a Steering Committee of steam system users, steam system service providers, and relevant trade associations. Steam Best Practices has collaborated with the following organizations to document their recent steam system improvement efforts in the form of case study writeups:

- Chemical Manufacturer's Association (CMA), 1997 Energy Efficiency Award Winners;
- ExxonMobil;
- Bethlehem Steel;
- Georgia Pacific;
- Babcock and Wilcox; and
- Texas Instruments.

These case studies have documented steam system energy savings ranging from $42,000 to $3,300,000 annually, with simple paybacks ranging from minimal to up to 1.5 years.

During the past year, Steam Best Practices has published nine "Energy Tips" - one-page writeups describing steam energy savings opportunities.

Steam Best Practices has sponsored more than a dozen Steam Awareness Workshops designed to make steam users aware of the opportunities available to improve their steam systems.

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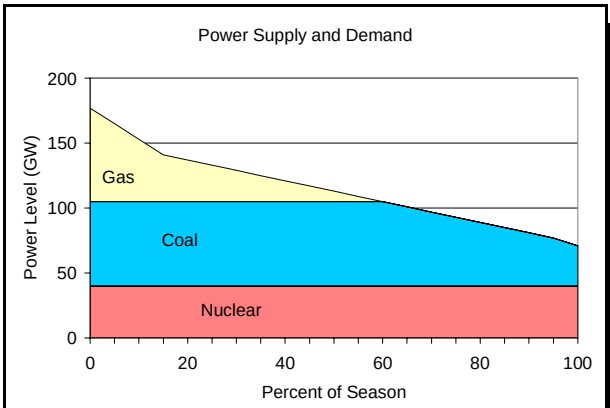
Electricity Generation Emissions Impacts



Opportunity

Most electricity generation technologies, including those used for distributed generation, emit the byproducts of combustion, but the amount and type of emissions vary widely depending on the fuel, combustion technology, and cleaning processes. At the same time, the cost of the electricity, and consequent use, is a function of these same factors. Since the electric system contains a mix of facilities with different emissions factors and costs, the total emissions will depend on how the costs and performance of these facilities interact to meet the varying demands for a region.

Current Research

Understanding the emissions impacts of various demand and supply policies requires an understanding of the system mix of plants and their operations. ORNL has developed flexible models that integrate a region's supply and demand, including both the financial and emissions aspects of electricity generation. This, plus experience with nationally recognized energy models, provides ORNL the opportunity to analyze the effects of various distributed generation projects on emissions reductions.

Current Research (continued)

Oak Ridge National Laboratory is one of the lead laboratories in the *Clean Energy Futures* study, looking at the impact of potential policies on reducing greenhouse gas and other emissions from the electricity generation and other sectors. The Oak Ridge Competitive Electricity Dispatch (ORCED) model is being used to study the impact of hydropower facility relicensing for the Federal Energy Regulatory Commission. ORNL is also providing technical support to other groups using the model to study the cost impact of multi-emission regulations versus emission by emission regulation.

Another model developed at ORNL is ORFIN (which models an individual utility either regulated or in a restructured market). We have also used outputs from the EIA's NEMS model (or its variation, the CEF-NEMS model).

Successful Partnerships

ORNL, working with four other national laboratories, used the ORCED model to analyze the potential for greenhouse gas emission reductions through energy efficiency and renewable energy programs. The model has also been used in studies of the effects of carbon charges on electricity generation in the Midwest, the electricity price impact from electric industry restructuring in the Pacific Northwest, the potential for biomass cofiring in various regions, and the emissions impact of industrial motor efficiency programs.

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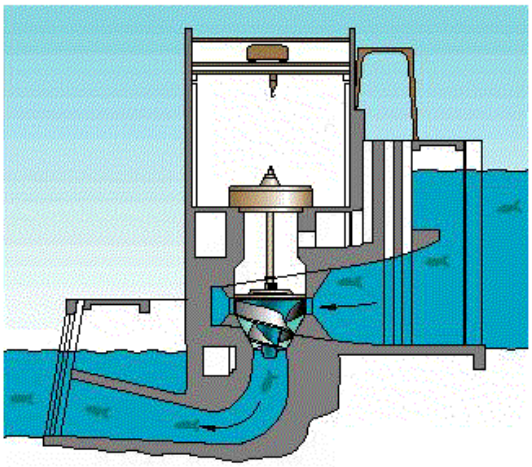
Advanced Hydropower Technology



Opportunity

Hydropower is one of the oldest technologies used for distributed generation. Advanced hydropower technology improves on available techniques for producing hydroelectricity by reducing adverse environmental impacts and increasing generation and other operational efficiencies. By developing more environmentally friendly ways to use water for hydroelectric generation, hydropower production can be maintained and even increased. These types of improvements are needed in the design and operation of dam structures and turbines.

Current Research

R&D on advanced hydropower technology is designed to improve the environmental performance of hydropower projects by developing and demonstrating new ways to reduce or eliminate adverse environmental effects while still producing hydroelectricity efficiently. The highest priority environmental problems are: 1) injury and mortality to fish as they pass through hydropower turbines, 2) low dissolved oxygen in water released downstream of the dams, and 3) altered stream flows and associated habitat for aquatic organisms in the vicinity of hydropower projects.

Successful Partnerships

ORNL has been working with a diverse set of sponsors over more than 20 years to develop and demonstrate advanced hydropower technologies of many types. The most important sponsor is DOE's Office of Power Technologies, which supports the Advanced Hydropower Turbine Systems Program (AHTSP). That program is developing and testing new turbine designs that will substantially reduce the number of fish that are killed or injured during passage through a hydropower project. Through the AHTSP and partners such as Georgia Institute of Technology and Voith Hydro, computational fluid dynamics models are being applied to predict the passage pathways and physical stresses to fish inside turbines. Virtual fish simulation models are also being developed to better understand internal stresses. Field and laboratory research is also being conducted to better understand fish survival and responses to stress in real turbines. For other sponsors, ORNL researchers have developed simulation models of fish populations affected by hydropower operations and are applying these as assessment tools in regulatory proceedings, such as the licensing of nonfederal projects. A 1/3-scale prototype, new-generation hydropower turbine is being constructed for the DOE program by Alden Labs. ORNL staff are playing a leadership role in the testing of this new Alden turbine in 2000 and 2001.

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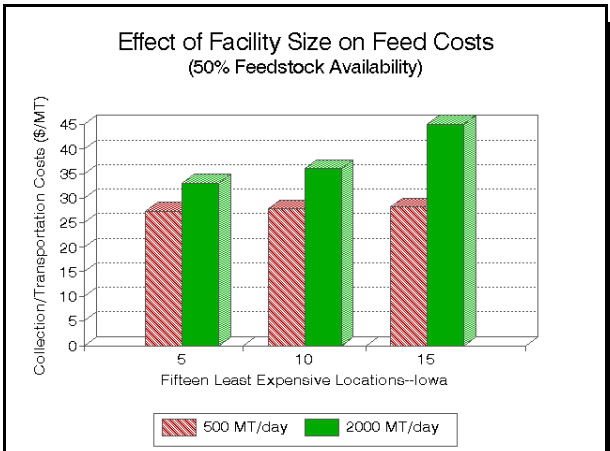
Biomass Resource Analysis



Opportunity

Distributed generation systems that utilize numerous, small plants with wider geographic dispersion than the existing electricity infrastructure provide significant opportunities to utilize biomass resources. The bulkiness of biomass and the more dispersed nature of its availability increase the cost of using biomass in large, distant facilities. Location of smaller plants near feedstock sources can reduce feedstock costs. If located in rural areas where many biomass resources are available, distributed generation systems using biomass resources offer substantial potential to enhance rural development and increase agricultural income.

Current Research

The Bioenergy Feedstock Development Program at ORNL was established to develop energy crops (switchgrass, hybrid poplar, willow) that could be used to produce power, fuels, and chemicals. The program conducts a full range of research that includes genetics, physiology, agronomy, silviculture and environmental assessments. Additionally, the program supports economic and policy modeling activities and has expanded these analyses to include other biomass feedstocks (forest, mill, and agricultural residues; urban wood wastes) in addition to energy crops.

Successful Partnerships

ORNL constructed a biomass database that is widely used in many models, including the NEMS model used by the Energy Information Administration to prepare the Annual Energy Outlook.

ORNL led a joint effort between the US Department of Agriculture and DOE to modify an existing agricultural sector economic model to include energy crops. The model evaluates the economic potential of energy crops under alternative price and policy scenarios, and estimates the impacts of energy crop production on agricultural commodity prices and farm income. Results from the model have been used to support two bills introduced in the US Senate (and passed by Congress) and to support new bioenergy initiatives within USDA and DOE. The model is being extended to evaluate the potential implications of hybrid poplar production on the fiber sector in a joint effort with the USDA Forest Service.

A GIS-based transportation model has been developed to estimate biomass transport costs, and when combined with the resource database, used to identify locations with minimum delivered feedstock costs, given the facility's feedstock demand. Under development is a logistics model to evaluate optimal combinations of biomass collection, transport, storage, and handling technologies to meet the demand needs of a facility, given the geographic availability of biomass feedstocks. Analyses to evaluate the macroeconomic impacts of biomass energy use are also on-going. New efforts involve linking economic models with environmental models to evaluate the joint economic and environmental implications of producing energy crops and collecting agricultural and forest residues.

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Superconductivity for Electric Power Systems

Opportunity

Superconducting wires can carry as much as 100 times the current as ordinary conductors. The current interest is due to the development of electric wires that become superconducting when cooled to the affordable operating-temperature realm of liquid nitrogen.

Cables - Superconducting cables cooled to 77 K are being demonstrated and will soon be carrying at least 3 to 5 times more current than conventional cables. Network designers have traditionally increased voltage to transmit more power efficiently, entailing large investments in high-voltage transformers and related equipment, as well as large electric losses. Superconducting cables may make it possible to lay out grids in innovative ways, to position generators closer to customers without having to step voltage up and down as frequently as is done today. The economic savings would be formidable.

Transformers - Use of superconducting windings will turn power transformers into compact, environmentally friendly and highly efficient performers that will help deliver high quality power cost effectively. These transformers have potential advantages over conventional transformers in the following areas: about 30% reduction in total losses, about 45% lower weight, and about 20% reduction in total cost of ownership. Superconducting transformers also eliminate oil cooling, thus reducing fire and environmental hazards.

Motors - Big outputs come in small packages due to revolutionary electric motors that use superconducting technology to max-imize efficiency while reducing size and weight.

Current Research

A 5-m prototype cable was constructed and tested at ORNL at the Cable Test Facility. These tests showed the cable was able to exceed the rated current-carrying ability. A 1-kW cryogenic system was constructed to cool this prototype and provided design guidance for the full-scale cooling system later constructed at the Southwire installation. Cryogenic dielectric materials were tested in a specially designed facility to determine the performance of these electrical insulating materials used in the superconducting cable system.

Successful Partnerships

ORNL helped the Southwire Company of Carrollton, Ga., set technological history on Friday, Feb. 18, 2000 when the cable manufacturing company energized an electrical power cable utilizing superconductivity. Three facilities at the 2000-employee plant now receive electricity through a high-temperature superconductor (HTS) power system that was built and tested with the assistance of ORNL.'s Superconductivity for Electric Systems program.

ORNL, Waukesha Electric Systems, Intermagnetics General Corporation, and Rochester Gas and Electric Company designed and built a 1-MVA prototype high-temperature superconducting transformer which was then tested at Waukesha's laboratory.

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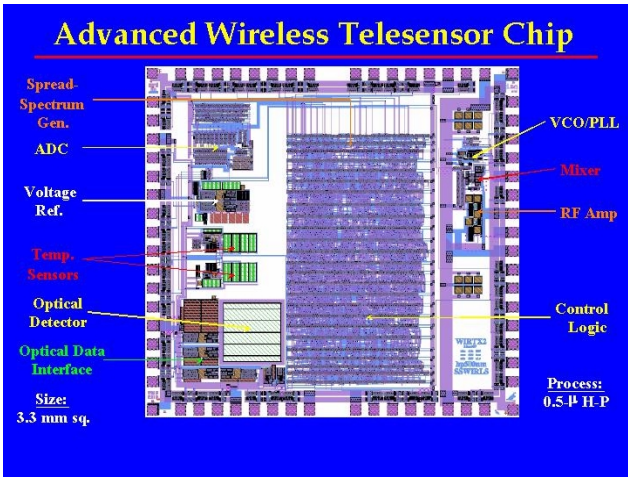
Intelligent Wireless Sensors



Opportunity

To meet process needs, or to efficiently tie into thermal energy loads, distributed generation systems may be located remote from central control rooms. Such remote locations can pose a significant challenge to traditional control and sensor systems. Innovations in commercially available wireless components have opened new opportunities in such environments. With wiring costs soaring to $2000 per foot for some installations, users are pursuing alternatives. Integrating sensors, intelligence, and telemetry into new compact, low power packages provides new options for the deployment of low cost sensors into more remote systems. Ultimately, the deployment of "peel-and-stick" sensors for industrial measurements can be used to improve processes and verify compliance with environmental restrictions. Success will hinge on the integration of these functions into low cost, easily deployable, rugged packages.

Current Research

Researchers at ORNL built the first fully integrated, single chip, wireless temperature sensor in 1997. Since then, a new generation chip has been fabricated

Current Research (continued)

tested. The graphic illustrates the on-chip components that provide the functions of filtering, digitizing, converting to engineering units, and transmitting to the host.

The successful integration of an infrared sensitive region on the chip allows the gain and other critical set-up parameters to be programmed by remote control. Besides the research on building silicon devices, ORNL is also active in architecture development, modulation schemes, encryption, and stealthy communications. Using advanced techniques promises robust wireless connectivity in remote power generation environments.

Successful Partnerships

ORNL and Aeptec, Incorporated demonstrated the feasibility of wireless sensors in a harsh environment in 1998 when the research device fabricated the year before was installed and successfully transmitted over three decks in the engine room on board the USS Sullivans. The device was also demonstrated in the ship's control room where an existing wireless Ethernet LAN posed some concerns.

The Department of Energy's OIT program is currently sponsoring the development of a testbed at ORNL to demonstrate the implementation of wireless sensors and intelligent architectures for deploying wireless systems. The final implementation will include devices deployed in plants that are flexible, scalable, and robust.

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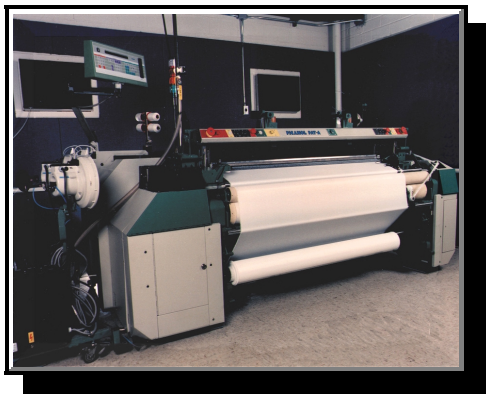
Predictive Diagnostics and Machine Health Assessment



Opportunity

Predictive diagnostics and machine health assessment will provide the machine condition and cost information required for optimal selection of generation resources. Selection can be based on the current resource condition, the projected time the resource will be needed, the probability of successful operation, and the estimated operating cost. This information allows both the resource aggregator and the resource owner to make the best possible decisions.

Current Research

Current prognostics and health assessment research at ORNL involves developing and applying advanced signal processing methods for extracting information from measured signals, developing methods for evaluating the economic impact of machine maintenance decisions, and investigating the use of anticipatory systems for prognostics. Techniques employed in this research include higher order spectral analysis, wavelet analysis, nonlinear time series analysis, Bayesian parameter estimation, and model-based techniques for both condition assessment and economic analysis.

Successful Partnerships

ORNL has been involved in a number of research projects aimed at developing practical applications of machinery health assessment and diagnostics for industry.

ORNL was a key player in the Department of Energy's AMTEX Computer-Aided Fabric Evaluation Project. Health assessment and economic models were developed to predict impending loom failures and evaluate the economic impact of various maintenance and R&D decisions.

A practical anticipatory system employing Bayesian parameter estimation to detect impending cavitation in pumps was developed as part of a joint research effort with APTEC Microsystems. Signal characteristics indicative of impending cavitation were identified and a practical method was developed for extracting these characteristics from pressure signals by applying Bayesian methods.

Detection of motor arcing was the focus of research performed for the Aluminum Company of America through ORNL's partnership with the Maintenance and Reliability Center at The University of Tennessee. Two model-based methods were developed to detect arcing; the first detected arcing based on overall characteristics of a measured RF signal while the second technique used a matched filter approach to identify individual arcing events.

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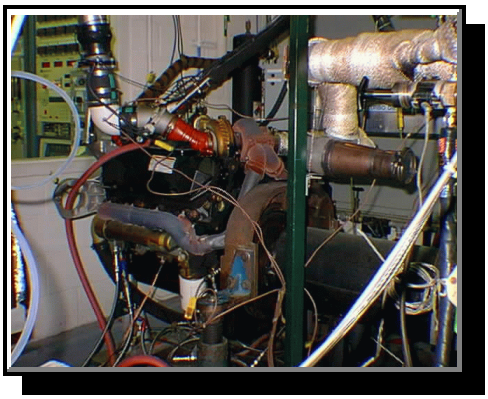
Advanced Propulsion Technology Center



Opportunity

Internal combustion engines have been and will continue to be a mainstay of distributed generation technology. However, carbon management and other air quality issues will have to be addressed up front in order to realize the full benefits of these engines. This requires system optimization and emissions measurements and control.

Current Research

The Advanced Propulsion Technology Center is a research, development, and evaluation laboratory for new technologies for internal combustion engines and emission controls. Focus areas include: alternative fuels, NOx and particulate control devices, new materials, diagnostics and controls, and efficiency-enhancing techniques. Designated as a DOE National User Facility in 1999, the lab can apply a number of unique or extraordinary diagnostic and analytical tools for engine/emission control R&D. Nearby world-class facilities for advanced materials, analytical chemistry, and sensors/controls can be engaged as needed in projects conducted in the propulsion lab.

Current research capabilities include: multi-fuel expertise including diesel fuel, gasoline, and natural gas; ignition system diagnostics and development, including natural gas ignition; four fully-instrumented multi-cylinder engine test cells; state-of-the-art emissions measurement equipment for regulated and unregulated emissions, with certain instruments not available elsewhere; optical diagnostics; and a bench flow reactor for evaluations of catalysts.

Successful Partnerships

ORNL is currently prototyping advanced generator sets for the military in a size range consistent with DG systems. The focus on system improvements in efficiency, emissions, and electrical output are applicable to distributed generation. Specifically, variable speed system operation allows the engine to be run under optimum conditions while generating high quality electrical power. The control system will allow the optimization of multiple parameters (efficiency, emissions, noise, etc) and system simulation and diagnostics are also being explored.

There are also seven active CRADAs with auto and engine industry partners. Some of these agreements address improved catalyst development, experimental and analytical study of engine cyclic dispersion, characterization of NOx-control catalysts for lean-burn engines, in-cylinder oil film and surface temperature diagnostics, development of high-speed, mass spec-based emissions instrumentation, diesel exhaust speciation for NOx catalyst, NOx sensor R&D, and ignition modeling and diagnostics. With the Massachusetts Institute of Technology, the effects of fuel reforming on engine efficiency and emissions are under evaluation.

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Building Technology Center

Opportunity

Proper equipment sizing is crucial for a successful distributed generation application. Appropriate energy conservation measures should therefore be made before selection and installation of any distributed generation resource. Buildings are responsible for 37 percent of the energy consumption in the U.S. and approximately 40 percent of that energy is used to heat, cool, and ventilate buildings.

Current Research

The Building Materials and Structures Program has the goal of accelerating the use of energy efficient and sustainable thermal insulation materials and systems by identifying and developing new or improved building materials and envelope systems and providing the methods and procedures for their accurate evaluation. Areas of recent extensive activity include determining the energy savings potential of using light colors on the exterior surfaces of buildings, developing experimental and computational capabilities for assessing the impact of moisture on materials and building envelopes, developing foam insulation materials that are energy efficient and environmentally sound, and improving the methodologies that are employed to select energy efficient materials and building envelope components.

Successful Partnerships

Over the past five years, the program has performed cooperative research with over 350 industrial partners.

The Program teamed with the Poly-isocyanurate Insulation Manufacturers Asso., the National Roofing Contractors Asso., the Environmental Protection Agency, and the Society for the Plastics Industry to develop and demonstrate CFC-free foam insulation products that satisfy the requirements on the Montreal Protocol. This collaboration guaranteed that foam insulations having the highest level of thermal efficiency would continue to be available to the buildings and appliance industries.

Urban heat islands (temperature buildup in cities due to dark heat-absorbing surfaces and the lack of vegetation) have recently been identified as a source of significant energy use. The program has initiated three industry-cosponsored research projects to quantify the energy savings potential of light-colored or “cool” roofing systems. With nearly 80 percent of the roofing industry participating, we are conducting systematic side-by-side exposure studies of roofing systems to assess their long-term performance and will use this experimental database to develop and validate computer models to estimate the energy savings.

New energy-efficient envelope systems that are attempting to gain market share are hampered due to the lack of adequate metrics. To level the playing field, the “Whole Wall Labeling Program” was developed using all of these variables in assessing the system’s energy efficiency. Over fifty wall systems, many sponsored by industry partners, have been analyzed.

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