Science & Technology HIGHLIGHTS

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Ensuring Robust, Reliable Power Transmission

On August 14, 2003, during the largest electricity blackout in U.S. history, communications were disrupted, traffic was snarled, elevators stopped, air conditioners quit, stores and businesses were forced to close, factories shut down, and hospitals went to emergency power.

"This blackout was largely preventable," said Secretary of Energy Spencer Abraham in his November 19 remarks announcing the U.S.-Canadian Power System Outage Task Force's *Interim Report* on causes of the blackout. However, "once the problem grew to a certain magnitude, nothing could have been done to prevent it from cascading out of control."

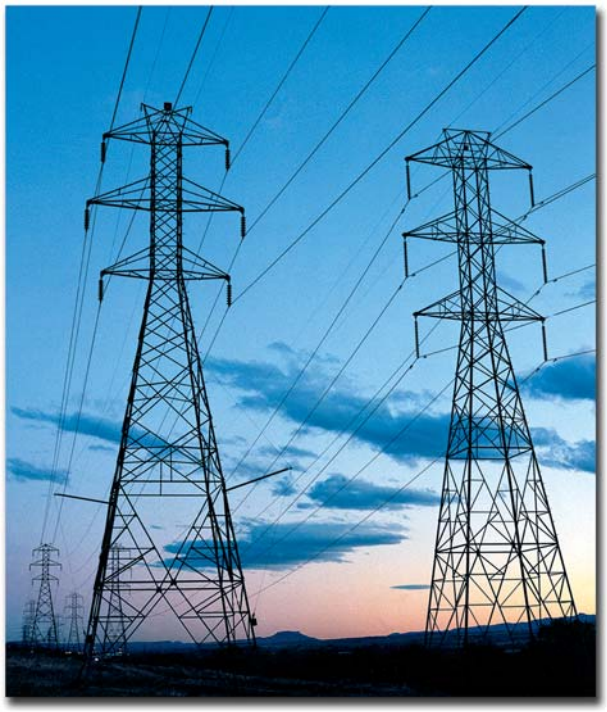
Two ORNL researchers—Brendan Kirby and John Kueck—served on the task force's Electric System Working Group. The task force concluded that the failure of power system operators to communicate that an alarm system had stopped functioning and the lack of emergency communication procedures contributed to the blackout. Multiple transmission lines failed, and the people who needed to know about these failures didn't find out until it was too late.

The investigation was managed by the newly created DOE Office of Electric Transmission and Distribution (OETD). The mission of this new office is to help ensure a robust and reliable U.S. transmission grid for the 21st century.

To support this effort, ORNL has established an Electric Transmission and Distribution Technologies Program, headed by Bob Hawsey. Researchers in this program have been evaluating new ways to reduce congestion on the nation's electric system infrastructure, improve its reliability, and prevent future blackouts. On hot days when air conditioning is in high demand, today's electric power lines can suddenly be forced to carry high current at temperatures higher than their normal operating level. Because of the properties of traditional steel-core-aluminum conductor cables, these overloaded lines can sag into trees, causing short circuits. "Utilities may be willing to replace their conventional power lines with advanced conductors if they see proof the conductors have significant advantages," says Bob Hawsey. "We can show them proof that advanced conductors carry more current without the same degree of sagging at the National Transmission Technology Research Center (NTTRC), operated by ORNL in partnership with the Tennessee Valley Authority."

At NTTRC's Powerline Conductor Accelerated Testing facility at ORNL, John Stovall and Tom Rizy have been subjecting advanced conductors to thermal, electrical, mechanical, and environmental "stress" tests while simulating 20 to 30 years of power transmission in several months of testing. They showed that 3M's composite-core conductor, which consists of ceramic fibers inside an aluminum-zirconium matrix, can carry 2.5 to 3 times the current of heavier conventional steel-core lines before sagging the same amount.

Other technologies being developed and evaluated at ORNL that could prevent future blackouts are superconducting underground power cables, real-time communication and control technologies, and power electronics to control reactive power. The communication technologies could have made the operators of the systems affected by the August blackout aware of the location and impact of transmission-line failures, enabling a quicker response to minimize voltage collapse.



The blackout in the Northeastern United States and Canada in summer 2003 has focused attention on power transmission.

In addition, energy efficiency, traditional load management, and price-responsive demand can improve electric reliability and curb electricity price spikes. ORNL is developing the concept of providing "spinning reserve" from responsive load instead of having generators standing by ready to provide reserve

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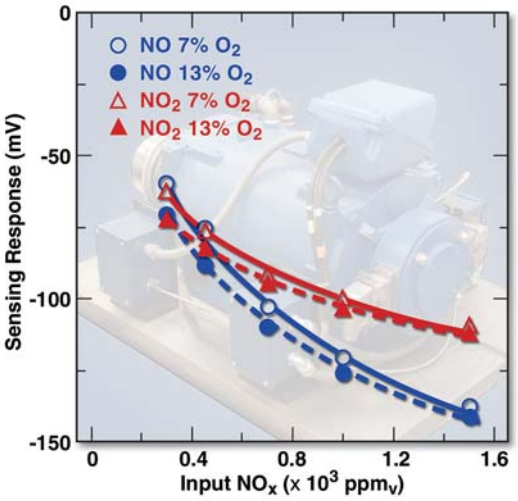
Diesel Engines Can Be Cleaner and Affordable

Envision a clean diesel engine, one with a closed-loop control system that can monitor emissions and rapidly adjust fuel injection, valve timing, and air-handling to ensure optimum engine operation and to keep emissions low. Such a vehicle is now becoming possible with the development of low-cost sensors to monitor NO and NO_2 in exhaust streams.



The response of ORNL's experimental sensor to NO_x, showing tolerance to changes in oxygen content.

ORNL and the Ford Motor Company want to improve emissions sensors so that heavy vehicles can run clean yet stay affordable. Through a cooperative research and development agreement, the two partners are developing a simple, low-cost electrochemical sensor that can effectively signal changes in NO or total NO_x ($NO + NO_2$) emissions within a second or less at an operating temperature of up to 600–700°C.

ORNL researchers have been experimenting with new materials and designs for a total NO_x sensor. As part of the project, they are screening catalysts that facilitate the decomposition of NO and NO_2 at high temperatures. Researchers are also studying the effects of oxygen and humidity, which can vary during normal operation and influence the output of electrochemical sensors.

So far, ORNL's experiments have led to a sensor with an improved output signal—three times stronger than the signals of sensors currently on the market. ORNL's bench-scale sensor is highly accurate, detecting total NO_x from 1 to >1500 ppm, and it is tolerant of O_2 fluctuations in the exhaust stream. In addition, ORNL has developed a sensor design and materials set that allow for direct NO sensing. The combination of NO and total NO_x sensing may eliminate the need for additional O_2 sensors. Ford is testing small numbers of the sensors to validate ORNL's bench scale results. For more detailed information, see www.ms.ornl.gov/programs/energyeff/HVPM/reports/qtrlyApril03.pdf.

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Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies

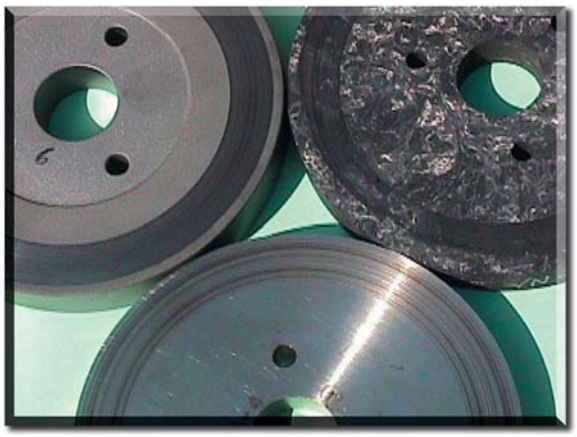
Lighter, Tougher Brakes for Heavy Vehicles

As trucks and vans have become more fuel-efficient through reductions in aerodynamic drag, engine friction, and tire rolling resistance, their brakes have come under increased stress. The next generation of fuel-efficient trucks will need lighter yet more durable brakes. ORNL researchers are working with industry to develop lighter brake materials that resist wear and corrosion.

Truck brakes typically consist of a metallic material for the disc or drum and a multi-component composite for the lining. Researchers want to reduce the weight of the drum or rotor, which traditionally is cast iron, and to find a suitable friction material to line new lightweight discs.

Researchers have screened a variety of experimental rotor materials, including aluminum matrix composites, an intermetallic alloy (Fe_3Al), ceramic composites (C/SiC), and titanium (Ti) alloys with and without coatings. A subscale brake testing apparatus developed at ORNL measured friction, temperature, wear, and vibration in the materials under both wet and dry conditions that simulate highway environments.

Screening revealed that Ti alloys are among the most promising materials to use. They are light in weight, resist corrosion from road deicers, and, with emerging technology, can be produced economically. With Ti brakes, truckers can potentially increase their payload, and fleet operators can save costs yet comply with future DOT regulations requiring shorter stopping distances for trucks. However, Ti alloys need surface treatments or coatings to control friction, wear, and heat conduction.



Potential brake disc materials: commercially coated Ti (upper left), experimental ceramic composite (upper right), and uncoated Ti alloy (bottom).

Researchers are now evaluating the best coatings and friction materials to use on the Ti rotors. In this effort, ORNL is collaborating with Titanium Metals Corporation, a major Ti alloy supplier, and with Red Devil Brakes, a manufacturer of racing-grade, coated Ti rotors. Future research will evaluate Ti discs on full-sized truck brakes.

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Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies

Microwaving Cooks Up Carbon Fibers at Lower Cost

Replacing metallic automobile parts with strong, lightweight materials such as carbon fiber composites could significantly reduce vehicle weight and increase fuel economy. Carbon composites offer excellent materials properties and simplified manufacturing techniques, but their cost—$6 to $16 per pound—is a problem. A cost of $3 per pound is believed to be the threshold for widespread automotive use.

Carbon fibers start out as long strands of precursor materials that are chemically treated and then heated to 1000–1500°F to form and carbonize fibers. ORNL is developing an approach to

ORNL's microwave-assisted processing line has attained a speed of 200 inches per minute.

manufacture the fibers inexpensively by using microwaves to heat and carbonize the precursor. Microwave-assisted processing (MAP) equipment is smaller, cheaper, and more energy-efficient than the huge ovens used in conventional processing. Cost models indicate that widespread adoption of MAP could reduce the price of finished carbon fiber by about 18%.

A new MAP line operating at ORNL has attained line speeds of more than 200 inches per minute operating with one tow (fiber bundle), exceeding most conventional line speeds. It can potentially be scaled to use 100 tows. To appeal to manufacturers, MAP must be able to operate at line speeds in the range of 120 inches per minute and bunch sizes of about 100 tows.

ORNL has also developed a method of producing an undulated surface on the carbon fibers that allows them to interlock mechanically with the resin matrix, resisting fiber pullout.

The carbon fibers produced on the line have favorable mechanical properties in comparison with commercial large-tow fibers. Their tensile strength exceeds the target values of the FreedomCAR Partnership.

Three patents have been awarded and others are pending on this technology. It has the support of the U.S. carbon fiber industry and has generated many inquiries from fiber and processing equipment manufacturers.

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Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies

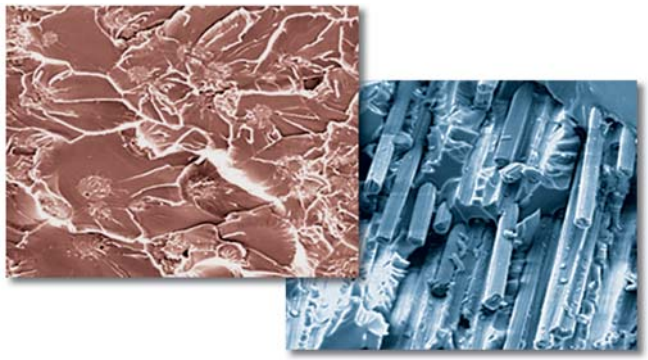
Carbon Composite Vehicles—A Matter of Recycling

First came recycled paper products. Then came recycled plastic decks and fences. If ORNL researchers have their way, cars too will incorporate recycled materials, namely composites of recycled plastics and lignin recovered from pulp processing. Working with universities and industry, ORNL is developing a blend of lightweight carbon fibers from these readily available low-cost sources to replace the ferrous metals in cars.

Small composite piece prepared from lignin-based carbon fiber.

Use of light carbon composites would decrease vehicle weight and thus decrease both fuel consumption and vehicle emissions. Furthermore, lignin-based fibers could cost less than conventional petrochemical-based fibers, result in fewer emissions during production, and reduce waste by supporting recycling.

The challenge has been to produce a multi-filament strand (or "tow") of even, dense, yet slender fibers that are suitable for composites. North Carolina State University and the University of Tennessee have been involved in developing the fibers. After evaluating a variety of fiber blends, ORNL researchers settled on a blend of pre-consumer recycled polyester and lignin. The University of Tennessee honed its fiber spinning technology to produce 28-filament fiber tows through a two-step melt-extrusion process. ORNL stabilized, carbonized, and graphitized the fibers and then modified their surface to improve adhesion to the resin in the composite.



The undulated surface of these carbon fibers produced at ORNL (left) prevents the shorter fibers from pulling loose from the resin matrix like the conventionally prepared commercial fibers on the right.

Working with Eastman Chemical Company of Kingsport, Tennessee, and Mead-Westvaco in Charleston, South Carolina, ORNL researchers have been able to use high-volume pre-consumer recycled polyesters along with hardwood lignin as the feedstocks for the carbon fibers. Future studies will focus on improving the feedstocks and refining fiber production, including die design, spinning conditions, and the development of winding, coating, and spooling technologies.

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Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies

First-Hand Learning from Research Apprenticeships

Eric Nafziger has had his engineering degree from the University of Tennessee for only a few months, but he already has 3 years of experience in research at ORNL. First he was a summer student and now he is a postgraduate through Oak Ridge Institute for Science and Education (ORISE).

The ORISE educational programs benefit students by giving them hands-on job experience and allowing them to see whether research careers are to their liking. It benefits DOE's research missions by helping recruit and train the next generation of researchers and by bringing the energy, enthusiasm, and new ideas of talented students and postgraduates into the national laboratories.

Eric Nafziger, an ORISE post-grad at the National Transportation Reseach Center, with an engine instrumented for analysis of diesel combustion regimes.

Nafziger is working with researchers in the Fuels, Engines, and Emissions Research Center at ORNL's National Transportation Research Center (www.ntrc.gov). His mentor at ORNL, Robert Wagner, researches advanced high-efficiency clean-combustion (HECC) regimes. The work is part of DOE's effort to help U.S. manufacturers develop cleaner, more-efficient diesel engines for automobiles and heavy vehicles.

Nafziger's most recent project was setting up and instrumenting a Mercedes diesel engine for studying novel diesel combustion regimes. The engine is being used to study the fuel properties of different diesel formulations during the transition into and out of HECC regimes. A wide range of fuels, including biodiesels, are being tested to determine how they affect emissions in advanced fuel cycles.

His group also is collaborating with a major diesel engine manufacturer to investigate HECC regimes in heavy-duty diesel engines. That work involves real-time engine controls for advanced combustion cycles.

Another project seeks to develop regeneration strategies for nitrogen oxide (NO_x) adsorbers—ways of operating engines so that the exhaust gases help regenerate on-board adsorbers that trap NO_x emissions, a primary pollutant of concern from diesel combustion.

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Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies

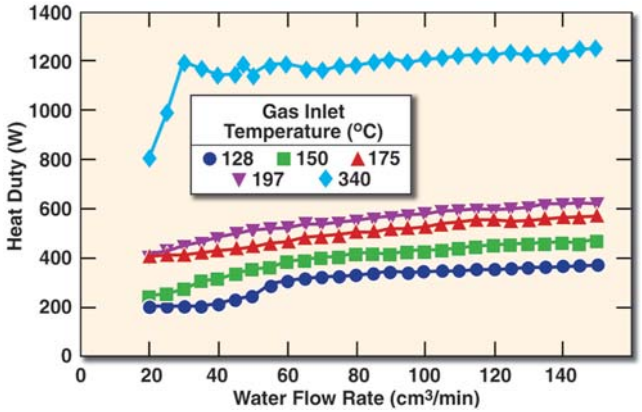
Moving the Heat Out of Fuel Cell Vehicles

Recent advances in fuel cell technology are moving hydrogen vehicles closer to reality. Working with private industry and other national laboratories, ORNL is advancing the technology associated with the vehicles. The idea is to build a fuel-cell–powered car with a fuel-reforming processor that can quickly convert gasoline to hydrogen. Such a device would provide a safe, convenient fuel supply, gasoline, eliminating the need for large quantities of hydrogen to be stored under high pressure.

Tier 1 and tier 2 graphite foam heat exchangers.

Until recently, regulating the heat and reducing the weight of the processor have been challenges. The fuel-reforming processor contains tiers of catalyst beds that operate at specific temperatures and pressures to break down the gasoline. Heat exchangers are needed to regulate the heat of the reactions taking place in the catalyst beds.

ORNL researchers have designed a heat exchanger that is lightweight yet can efficiently regulate the temperature of the gases. The core of the heat exchanger is composed of low-density graphite foam developed at ORNL. The near-perfect graphite structure of the foam gives it a thermal conductivity five to six times greater than that of aluminum or copper. Heat transfer in the carbon is enhanced by the addition of a water-cooled copper jacket around the graphite foam. Traditional thermal materials, such as aluminum or copper, would make the exchangers heavy and would require large amounts of cooling water.



Performance of tier 1 graphite foam heat exchanger in relation to water flow through the coolant jacket.

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Refining Lost Foam Casting to Preserve American Industry

The lost-foam-casting process used to make complex metal parts is one of the most environmentally friendly casting methods. Experience has shown that it can reduce energy use by as much as 27%, compared with conventional sand casting, and can greatly reduce metal scrap.

In lost foam casting, an expanded polystyrene (EPS) foam pattern is made as a mold for casting each part. The foam pattern is covered with a thin heat-resistant coating and embedded in sand. Molten metal is poured into the pattern, the EPS decomposes, and the metal replaces it, precisely duplicating its shape. The decomposition products diffuse through the coating and enter the sand, but the coating contains the metal. After the part has cooled, the coating flakes away.

Preparing to cast an aluminum part by lost-foam casting (left, top down): securing the EPS mold in sand, pouring molten metal into the mold. At right, Ralph Dinwiddie of ORNL with an EPS mold and Dennis Nolan of FOSECO-Morval with a cast aluminum part.

Expanding the use of lost foam casting could save energy and money for U.S. industry. One obstacle to its widespread adoption is that casting defects may result from foam residues trapped within the metal during the filling process. To clarify how the EPS and its residues are displaced as molten metal fills the mold, the casting industry is using the resources of ORNL's MPLUS Facility to analyze the process. ORNL is collaborating with three companies (FOSECO-Morval, Walford Technologies, and MCT) in using infrared (IR) imaging to measure and record thermal profile variations during casting. IR imaging provides unique spatial and thermal resolution of the different casting phases.

The most recent set of experiments at ORNL tested three different foam polymers and patterns made by three different tooling methods. IR images were made of the filling process as it occurred. The cast parts will be characterized and the data correlated with the IR data. The goal is refinement and improved control of the casting process.

Refinement of lost foam casting is of strategic interest to the casting industry because it would enable U.S./Canadian companies to make complex parts that foreign competitors cannot produce. As more low-end casting moves offshore, the strategic edge offered by the high-end capability could be a key to preserving the domestic industry.

For information about the MPLUS Facility, see www.ms.ornl.gov/programs/mplus/mplus.htm

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Sponsor: DOE/EERE Industrial Technologies

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Tests of ORNL's heat exchanger indicate that it meets or exceeds the specifications for temperature change and pressure drop for the compact fuel processor. Further tests are in progress to optimize the amount of water flow and system efficiency. Future goals of this work are to make the exchanger lighter, perhaps by changing the material in the coolant jacket or by reducing its size.

For more information, see http://www.ms.ornl.gov/researchgroups/cmt/foam/foams.htm.

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Sponsor: DOE/EERE Hydrogen Fuel Cells and Infrastructure Technologies

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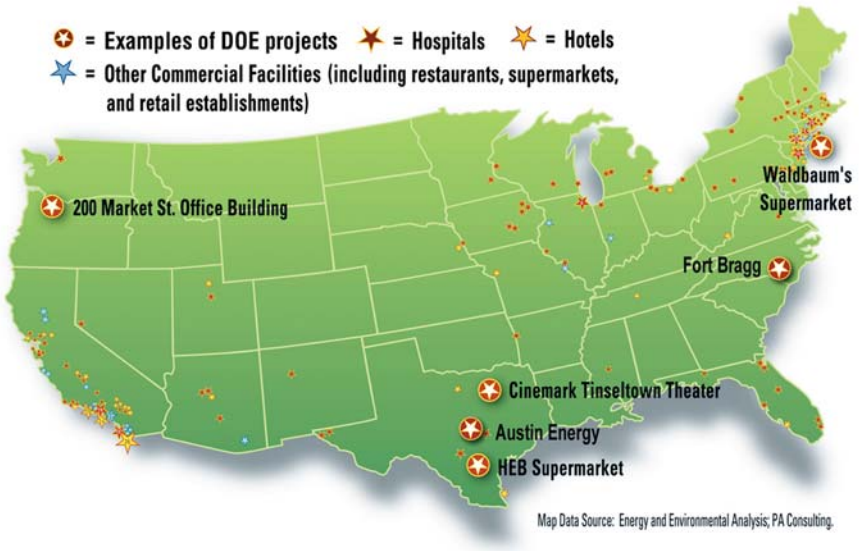
Integrated Energy Systems:
Combining Heat and Power to Recycle Energy

The massive power outages of the past year contrast with a little-known fact: the United States wastes almost 2/3 of the energy produced by central electricity generation because the heat released during fuel combustion is not recycled for heating or cooling. In support of DOE/EERE's Distributed Energy Program, ORNL's Combined Cooling, Heating, and Power (CHP) Group is developing and demonstrating integrated energy systems (IES), which make use of this wasted energy by coupling current technologies in energy supply and heat recovery packages that optimize building energy use. Sited at the point of use, these IES are beginning to solve energy reliability problems and to use energy more efficiently.



More than 1300 commercial and institutional buildings nationwide are benefiting from CHP technologies, which increase energy efficiency and reduce the load on the utility grid.

Today's Combined Heat and Power

Power outages are causing many building owners to re-evaluate their current power sources and their energy plans for the future. While increasing back-up generation may appear to be the quick fix, it is typically both inefficient and polluting. An alternative solution for energy reliability problems is CHP technology that is already on the market. Custom-designed CHP equipment captures and uses the waste heat produced during power generation in a nearby building to achieve high levels of efficiency and power reliability. These systems are installed in more than 1300 commercial and institutional facilities nationwide.

Custom CHP installations cannot achieve the technology's full potential. Packaged systems that integrate separate components into streamlined units are needed.

Tomorrow's Integrated Energy Systems

To date, CHP has recycled wasted energy on a case-by-case basis—each system has been custom designed and engineered. Such custom CHP installations cannot achieve the technology's full potential as a reliable, *off-grid* source of energy. What is needed are packaged systems that integrate separate components into streamlined units.

Along with private industry, the Distributed Energy Program sponsors ORNL's IES-CHP Laboratory that provides a test bed for improving the energy efficiency and utility load characteristics of CHP equipment and the integration of components into IES. The facility includes a thermal energy loop (consisting of heat recovery and thermally activated cooling and desiccant dehumidification technologies) coupled to electricity-generating equipment (e.g., microturbine, reciprocating engine, fuel cell). Unique capabilities are available to test integrated systems in various operating modes and equipment configurations. Data that are collected include a generating unit's electrical performance [voltage, current, real power (kW), power factor], emissions (nitrogen oxides), and a waste heat recovery unit's thermal performance.

To provide a framework for system performance, ORNL is developing the CHP System Mathematical Model. This predictive tool has used test results to optimize the design and performance of components and systems. Modeling and test results reduce CHP equipment manufacturing and operating risks while informing the development and deployment of IES.

First-generation IES are being deployed by manufacturer teams who are collaborating, through ORNL, to improve and standardize CHP equipment. DOE/ORNL-sponsored industry teams are moving from concept to reality: a pre-packaged power generation, heat recovery system controlled to optimize facility energy use (see the schematic). Six of these systems are described as follows.

- The United Technologies team developed a system that powers air-conditioning with waste heat from microturbines, maximizing fuel efficiency and energy cost savings. In December 2003, the team introduced PureComfort Solution™ that features four Capstone 60-kW microturbines coupled with a Carrier 110-ton double-effect absorption chiller. Carrier's distribution and maintenance network will support installations.

- NiSource Energy Technologies and Rahmat Shoureshi, Controls Consultant, are developing, integrating, and packaging an energy system that optimizes energy usage in a Chesterton, Indiana, hotel by combining multiple 60-kW microturbines with absorption chiller/heaters in packaged systems. The system uses continuous on-line learning through neural net modeling to optimize energy options for a facility's specific energy use patterns, including space heating, thermal load from hot water heating, and swimming pool and spa heating.

- Ingersoll-Rand (IR) Energy Systems and IR Hussman teamed with Energy Concepts Company and Advanced Mechanical Technology, Inc., to combine CHP components into an ideal package for supermarkets. The system, which can supply 70 to 100 kW, provides steady, grid-independent, microturbine-based power integrated with an ammonia-water absorption refrigeration system on a single skid serving applications to –20°F. The team is aggregating supermarkets' typically small, dispersed refrigeration loads to create a standard product suitable for varying store designs.

- The Gas Technology Institute, Waukesha, the Trane Company, Ballard Engineering, Inc., Charles Equipment Co., and the University of Illinois at Chicago have teamed to develop and demonstrate reciprocating engine generators ranging from 290 to 770 kW matched with absorption chillers [e.g., 90 refrigeration tons (RT)] to optimize performance. The resulting modularized "plug-and-play" IES are easily adaptable to various requirements for electricity, hot water, and chilled water. The team is using market analysis to guide development of this system to expedite commercialization.

- Burns & McDonnell has teamed with Broad USA, Solar Turbines, and Austin Energy, a municipal utility, to develop a modular system that integrates a 5-MW turbine generator with an advanced waste-heat–fired 2500-RT absorption cooling system to provide energy to serve a high-tech industrial park. Cost reductions result from chilled water being used for air-conditioning and from increasing the fuel-use efficiency from 33% to 70–80%. The modular design is adaptable to various capacity, space, and grid interconnection requirements.

- Honeywell Labs has teamed with Chelsea Group and I.C. Thomasson to develop reference designs to improve economics and simplify installation. Honeywell Energy Services is installing a prototype system at the Ft. Bragg Army Base. The prototype features a 5-MW turbine generator integrated with a 1000-ton Broad USA absorption chiller that is fired with waste heat or gas to supply air-conditioning or produce steam. The IES with supervisory controls will optimize the site's energy supply and maximize the cost-effectiveness of energy choices.

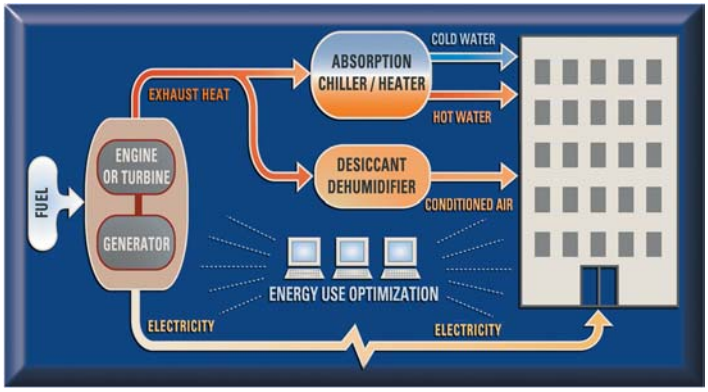
ORNL's IES-CHP Laboratory provides a test bed for improving the energy efficiency and utility load characteristics of CHP equipment and the integration of components into IES.

Integrated Energy System Benefits

These DOE-sponsored demonstrations—strengthened by testing at ORNL's IES-CHP Laboratory—provide a reliable, off-grid source of energy with several benefits including

- peak energy efficiencies double those of traditional power generation
- significant energy/operating cost savings that strengthen the bottom line
- reduced environmental impact because CHP uses less fossil fuel and reduces emissions

The benefits of power reliability can extend beyond the individual building. The IES of the future will contribute to grid stability during periods of peak demand because these systems will work in parallel with the grid, in essence freeing up valuable electric resources and alleviating stress on the grid. CHP-IES buildings can become community energy centers during power outages caused by catastrophic situations or utility failures, helping communities improve planning and response to emergencies. This potential for societal benefits makes CHP-IES systems a key remedy for U.S. electric power grid problems.



This schematic illustrates how power generation can be integrated with technologies that use recovered heat, such as desiccant dehumidification and absorption chillers.

To learn more about CHP, visit www.ornl.gov/eere/der or http://www.eere.energy.gov/deer.html

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Sponsor: DOE/EERE Distributed Energy

Helping Public Housing Authorities Stretch Energy Dollars

Public housing authorities spend over a billion dollars a year for energy and water, in addition to what residents spend on utilities. To help housing authorities take advantage of energy-efficiency opportunities, the U.S. Department of Housing and Urban Development (HUD) and DOE entered into an interagency agreement (IAA) under which DOE's Rebuild America provides training and technical assistance to housing authority personnel. ORNL coordinated the overall 2-year effort for Rebuild and assisted housing authorities with specific projects.

The IAA enabled Rebuild to establish partnerships with 51 housing authorities and initiate 77 energy-related projects. Rebuild provided assistance in several areas, including

- planning energy management and capital investments
- reviewing utility usage and metering options
- implementing energy incentives
- conducting design reviews and energy analyses
- developing energy projects and resident programs

One IAA strategy was to promote energy savings performance contracts (ESPCs) that enable housing authorities to finance energy-saving improvements with energy cost savings. ORNL helped conduct a series of workshops in performance contracting for HUD personnel and staff from 45 housing authorities. As a result of the workshops, 16 housing authorities have initiated performance contracts and others are investigating the possibility.

A partnership between DOE's Rebuild America and HUD is enabling public housing tenants and housing authorities to save energy and money.

Projects on which ORNL assisted individual housing authorities for the IAA include

- reviewing documentation for ESPCs implemented by the Albuquerque and Virgin Islands housing authorities
- participating in the design charrette co-sponsored by DOE for the Miami-Dade Housing Agency's Hope VI revitalization and bringing in lighting industry representatives to provide technical assistance on security lighting
- performing energy modeling for the Hagerstown, Maryland, Hope VI project and making design recommendations based on the modeling results
- assisting Rebuild Colorado's efforts to link housing authorities with the state's weatherization program and ESPC efforts
- performing computer simulation to ensure that retrofits being performed by the Boston Housing Authority would not result in wall system moisture problems
- working with an energy service company to develop and implement a resident energy education program for the Tallahassee Housing Authority

Nationwide, 31.3 million ft^2 of space in public housing has been improved through Rebuild partnerships, for an estimated savings of 403 trillion Btu and $23.2 million in energy costs.

Rebuild has recommended that HUD establish a public housing energy database to help manage energy programs. As a first step, ORNL and HUD are discussing creating an energy benchmarking tool similar to those ORNL has developed for other agencies. See www.rebuild.gov for a report on recent IAA activities and information on Rebuild's current efforts in public and multifamily housing.

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Sponsor: DOE/EERE Weatherization and Intergovernmental Program

Supermarkets Work to Trim Refrigeration Energy Costs

In 1999 the International Energy Agency (IEA) established Annex 26 (Advanced Supermarket Refrigeration/Heat Recovery Systems) to promote the development of supermarket refrigeration systems that use less energy, require less refrigerant, and produce lower refrigerant emissions, as well as to expand the knowledge base for energy-efficient supermarket technology.

The five participating countries (Canada, Denmark, Sweden, the United Kingdom, and the United States) met in 2000 to identify supermarket refrigeration and heating, ventilating, and air conditioning (HVAC) options that would help reduce the total equivalent warming impact of supermarkets by minimizing system energy use (increasing efficiency) and total refrigerant charge.

Supermarkets are among the most energy-intensive commercial buildings. Much energy is needed to keep food chilled and frozen in both product display cases and storage refrigerators. The refrigeration systems also produce large amounts of rejected heat that can be recovered and used by heat pumps or other equipment to provide space and water heating for the stores. The size of supermarkets varies widely among the Annex 26 countries. European stores range in size from about 500 to 3000 m^2. Stores are typically larger in Canada and the United States, ranging from about 1000 to 10,000 m^2. Annual energy use ranges from about 100,000 kWh/year for the smallest stores to 1.5 million kWh/year or more for the largest.

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Cold produce cases such as these make supermarkets among the most energy-intensive commercial buildings.

Refrigeration accounts for half or more of supermarket energy consumption, and compressors and condensers account for 60–70% of the energy used for refrigeration. The rest is consumed by display and storage cooler fans, display case lighting, evaporator defrosting, and anti-sweat heaters used to prevent condensate from forming on doors and outside surfaces of display cases.

The Annex 26 participants recently completed analytical and experimental investigation of several candidate refrigeration and HVAC system design approaches, including these:

- Distributed compressor systems—small parallel compressor racks are located close to the food display cases they serve, significantly shortening the connecting refrigerant line lengths.
- Secondary loop systems—one or more central chillers are used to refrigerate a secondary coolant (e.g., brine, ice slurry, or CO_2) that is pumped to the food display cases on the sales floor.
- Self-contained display cases—each food display case has its own refrigeration unit.
- Low-charge direct expansion systems—similar to conventional multiplex refrigeration systems, these use improved controls to limit charge.

Means to integrate supermarket HVAC and refrigeration systems have been investigated as well. One approach is to use heat pumps to recover refrigeration waste heat and raise it to a sufficient level to provide store heating. Another involves using combined heating and power (CHP) to integrate the refrigeration, HVAC, and power services in stores. Other methods, including direct recovery of heat rejected by refrigeration equipment for space and water heating, have also been examined.

The results of the Annex 26 work programs are available in a recently published report compiled by ORNL for IEA (see www.ornl.gov/sci/engineering_science_technology/Annex26/reports.htm/). Principal observations from the report include these:

- Several relatively new refrigeration systems offer total equivalent warming impact reductions of 60% or more.
- Traditional direct-heat-recovery approaches can cover 40–100% of store heating needs, depending primarily on climate and the relative size of coincident heating loads and heat rejection loads.
- Integrating heat pumps with the refrigeration heat rejection system can cover 100% of store heating needs.
- Integrating CHP systems with refrigeration systems has the potential to meet a store's heating needs and much of its electric power needs.

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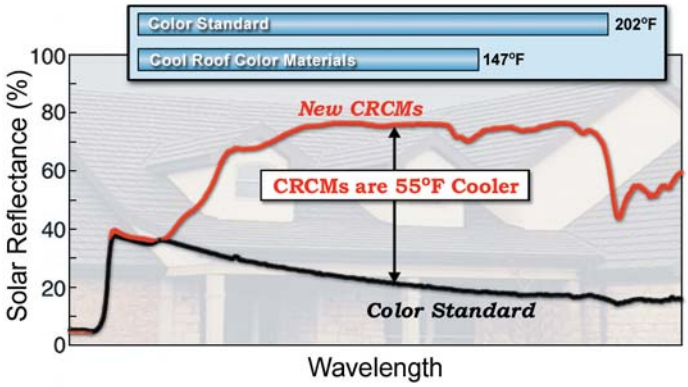
Sponsor: DOE/EERE Building Technologies Program

Color Your Roof Cool with Revolutionary Color Pigments

A new roofing product is about to revolutionize the building industry, bringing relief to homeowners and utilities alike. Cool roof color materials (CRCMs) made of complex inorganic color pigments will reduce the amount of energy needed to cool buildings, helping utilities reduce hot-weather strain on electrical grids by slashing summertime peak loads.

The California Energy Commission (CEC) has ORNL and Lawrence Berkeley National Laboratory (LBNL) working collaboratively on a 3-year, $2 million project with the roofing industry to develop and produce the new reflective, colored roofing products. Their aim is to make CRCMs a market reality in the homebuilding industry within 3 to 5 years. A roof covered with this special paint absorbs less solar energy and can reduce air-conditioning costs by 20%, which in turn will lead to national energy savings of about 0.5 to 2 quads per year by 2010. For tile, painted metal, and wood shake, the goal is products with over 45% reflectance. For residential shingles, the goal is a solar reflectance of at least 35% to 40%.



Comparative heat buildup and solar reflectance in cool roof color materials and standard roofing materials.

The new CRCMs contain mixtures of chromic oxide and ferric oxide. The materials look dark in color yet reflect most of the sun's energy. How can dark roofs reflect as much energy as white roofs, or even more? The trick is in the eye of the beholder. Solar radiation consists of ultraviolet, visible, and infrared

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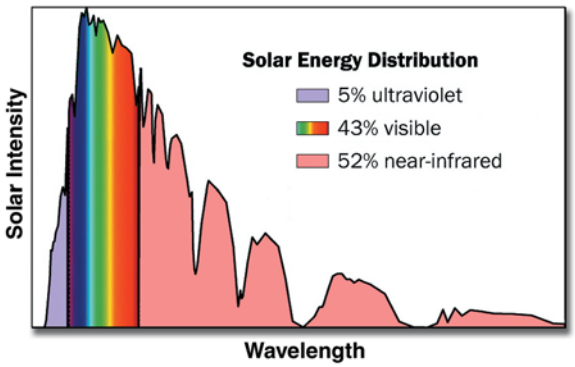
(IR) energy, but our eyes see only the visible portion. White roofs reflect most of the visible light spectrum, which mixes together to look white to our eyes, while dark roofs absorb most of the visible light, looking dark. Most solar energy, however, is in the IR region, which is not visible. CRCM roofs reflect more than 60% of the IR solar energy that strikes them.

Traditional roofing materials absorb or reflect IR light along with visible light. By reflecting the IR light independent of the visible light, the CRCMs reduce the total amount of solar energy absorbed without changing the amount of visible light reflected, hence retaining the roof color while cooling the roof. CRCMs offer other advantages over traditional roofing materials. They are available in a range of colors and resist fading better than standard materials.



Distribution of solar energy in the ultraviolet, visible, and near-infrared wavelengths.

Several metal roof manufacturers have successfully introduced CRCMs in their painted metal roof products. The additional cost of the CRCMs is only about 5¢ per square foot of finished product, which pays for itself within 3 years in energy savings. The architectural appeal, flexibility, and durability of CRCM-coated metal roofs are steadily increasing their market share. Historically metal roofs have held only about 3% of the residential market. From 2000 to 2002, the sales volume doubled to 6%, making metal roofs the fastest-growing residential roofing product.

ORNL and LBNL are collaborating with pigment manufacturers to reduce the sunlit temperatures of cedar shakes, clay and concrete tiles, and asphalt shingles, as well as metal roofing. ORNL is measuring the performance of CRCMs in the laboratory and in the field and will offer consumers information on the results. By showcasing the energy savings of CRCMs, they hope to accelerate the market penetration of these new products.

For more information, see http://coolcolors.lbl.gov/.

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Sponsor: California Energy Commission

Attic Handbook Offers Defense Against the Elements

Proper roof, attic and ceiling configurations are essential to good thermal, structural, and moisture performance, as well as energy efficiency, in homes. Many alternatives exist to configure these components, but some are unacceptable. ORNL researchers are preparing a *Residential Attic Handbook* that will provide practical information on designing and building the roof, attic, and ceiling to ensure the best possible approaches for protecting and enhancing residences, thus reducing energy consumption.

Attics need to be properly sealed and insulated against air exchange and heat exchange between indoors and outdoors. Attic ventilation protects against ice dams.

The *Residential Attic Handbook*, written by ORNL's Building Envelope Group (BEG), will help builders, contractors and homeowners ensure that every attic built is cost-effective and energy-efficient. Attics, ceilings, and roofs are key parts of the building. The ceiling is usually the location for much of the insulation that allows acceptable thermal performance. If the attic is sealed properly against air exchange between the indoors and outdoors, problems with moisture accumulation and wasted energy should be minimal.

Ice dams can form at the edges of roofs in cold, snowy climates if the attic is warm enough to melt the snow over it. The melt water flows to the edges, where it refreezes and forms dams. Additional melt water backs up under the roof covering and may leak into the attic. A way to avoid chronic ice dams is an attic ventilation system that keeps the roof over the attic as cold as the edges, preventing the formation of ice dams.

The thermal and moisture control configuration for attics in buildings along the Canadian border is not necessarily appropriate for areas such as the very hot, humid, hurricane-prone cooling zone of the southeastern coastal states, or even for moderate climates. Consequently, the *Residential Attic Handbook* features attic configurations for all three climate zones.

The roof is a building's main defense against the elements and the loss of heating and cooling energy. Structural integrity is a prerequisite for achieving long-term good thermal and moisture performance. Roof structures frequently fail in

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wind storms, often when the wind strips some of the covering off the roof and exposes joints in the decking. A failed roof allows water to penetrate the attic, damaging the building and contents. The most notorious wind damage occurs from category 1 hurricanes on the southeast and Gulf coasts and from tornadoes. Lessons learned from these catastrophic failures are incorporated in the *Handbook*.

The *Residential Attic Handbook*, to be published later in 2004, is one of at least a dozen tools produced by BEG research that offer relevant building envelope design information in a usable form. These tools reflect over 15 years of research and analysis dealing with the performance of building envelopes. They are highly regarded by the building industry because of their practicality and accuracy and the unbiased scientific method used to prepare them. They are available at www.ornl.gov/sci/roofs+walls; many are also available in print.

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Sponsor: DOE/EERE Building Technologies Program

Upgrading the Grid with Superconducting Transformers

The increased load demand and reduced investment in utility power transmission systems caused by deregulation uncertainties will result in a need for many new power transformers in the near future to replace aging units. Electricity can pass through three or more transformers as it flows from the generator to the transmission line and distribution system, resulting in power losses of 7–8%. High-temperature superconducting (HTS) transformers can reduce these losses, and they promise to be smaller and lighter with lower fire and environmental hazards than conventional units. Another advantage is greater tolerance for overloads without damage.

Under a DOE Superconductivity Partnership with Industry (SPI), ORNL is collaborating with Waukesha Electric Systems (WES), SuperPower, Inc. (SP), and the Energy East (EE) utility company to develop commercial HTS power transformers. The team has developed a unique design that is cooled by compact cryocoolers rather than piped-in liquid nitrogen. The design allows operation of the windings at temperatures as low as 30 K, which greatly improves the superconductor performance. A single-phase, 1-MVA unit was successfully tested in 1998, and a three-phase, 25-kV, 5/10-MVA prototype has now been built for testing on the grid system at the WES plant. This transformer is wound with the first-generation BSCCO-2223 HTS conductor that is now commercially available.

HTS transformers can reduce distribution losses and avoid overloads.

ORNL participated in many areas of the program. The 60-cycle ac losses in small test coils provided by SP were measured to predict the cryogenic cooling power needed for a full-size transformer. High-voltage breakdown and partial-discharge tests were carried out on many different insulating materials to qualify them for operation at cryogenic temperatures. Other materials tests investigated superconductor performance and insulation heat capacities. ORNL also designed and supervised fabrication of a drop-in cooling module for the 5-MVA transformer. This module contained the cryocoolers and the heat exchangers that couple them to

Moving the 5/10-MVA transformer to the Waukesha Electric Systems test area.

the superconducting coils. SP carried out design and fabrication of the HTS coils and their support system. WES was responsible for the conventional parts, including the tank, laminated steel core, and high-voltage leads and bushings; complete assembly of all components; ANSI standards electrical testing; and final installation in the WES substation.

In June 2003, the 5-MVA transformer was successfully cooled below 30 K. It took about 10 days to cool the 4-ton cold mass. Several low-voltage tests up to the full operating current were carried out. After some repairs and adjustments, it was moved on a truck while cold to the main WES plant test floor, where long-term high-voltage and high-current tests will be carried out in 2004.

Although the preliminary results for the transformer are encouraging, it has become clear that economically competitive HTS transformers will require a much less expensive conductor. The currently available conductor contains 65% silver, but second-generation conductors will use much cheaper materials and have higher current-carrying capability. Another area for further research is the development of better cryogenic dielectric materials that can operate at transmission-level voltages above 100 kV.

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Sponsor: DOE/Office of Electric Transmission and Distribution

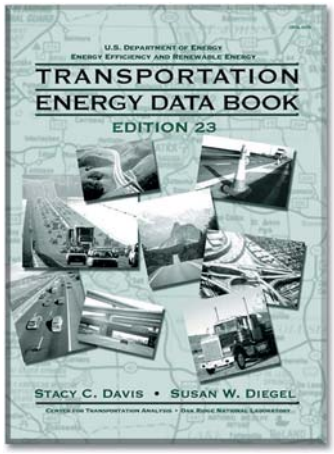
News Briefs

Babu Receives Award for Young Researchers

Sudarsanam Suresh Babu, a researcher in ORNL's Metals and Ceramics Division, has received an award for young researchers from The Welding Institute of the United Kingdom. The award is presented to a person under 40 years who is deemed to have made the most significant contribution to the advancement of welding technology during the preceding 5 years. Babu's research includes welding metallurgy, phase transformations in steel, aluminum alloys, and nickel-based superalloys.

Transportation Energy Data Book Available

The 23rd edition of the *Transportation Energy Data Book* is available from ORNL's Transportation Policy and Planning Group. The report is a statistical compendium of data and information on transportation with an emphasis on energy use. It is available online at www-cta.ornl.gov/data/. To obtain a printed copy, contact Stacy Davis, davissc@ornl.gov (phone: 865-946-1256, fax: 865-946-1314).



Becher Named to Advisory Board

Paul F. Becher of ORNL has been named to the National Materials Advisory Board of the National Research Council. The board is the principal source of objective, independent assessments of materials and processes used by industry, universities, and public agencies. Becher is a researcher and group leader in the Metals and Ceramics Division and an ORNL corporate fellow.

Liu Joins National Academy of Engineering

C. T. Liu of ORNL's Metals and Ceramics Division has been elected a member of the National Academy of Engineering. Liu is a Senior Corporate Fellow at ORNL. His work in high-temperature structural materials has resulted in 19 patents and three R&D 100 awards. The author of more than 270 publications, he has been recognized by the Institute for Scientific Information as one of the top five researchers worldwide in the number of citations to his papers in journals of materials science and engineering.

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power. Many of these efficiency and load management technologies have benefited from research in DOE's Office of Energy Efficiency and Renewable Energy (EERE).

DOE's Office of Energy Assurance (OEA) leads the federal government's effort to ensure a robust, secure, and reliable energy infrastructure in the new risk environment that includes malevolent threats and increasing complexity due to interdependencies. The nation has a variety of critical energy infrastructures (e.g., the electric grid, pipelines, power plants, and transformers) that are the backbone of commerce, transportation, communication, government, health care, and home life in the United States.

The combined focus of these three offices (EERE, OETD, and OEA) on energy efficiency, reliability, and security is the expanded scope of ORNL's *Science and Technology Highlights*.

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