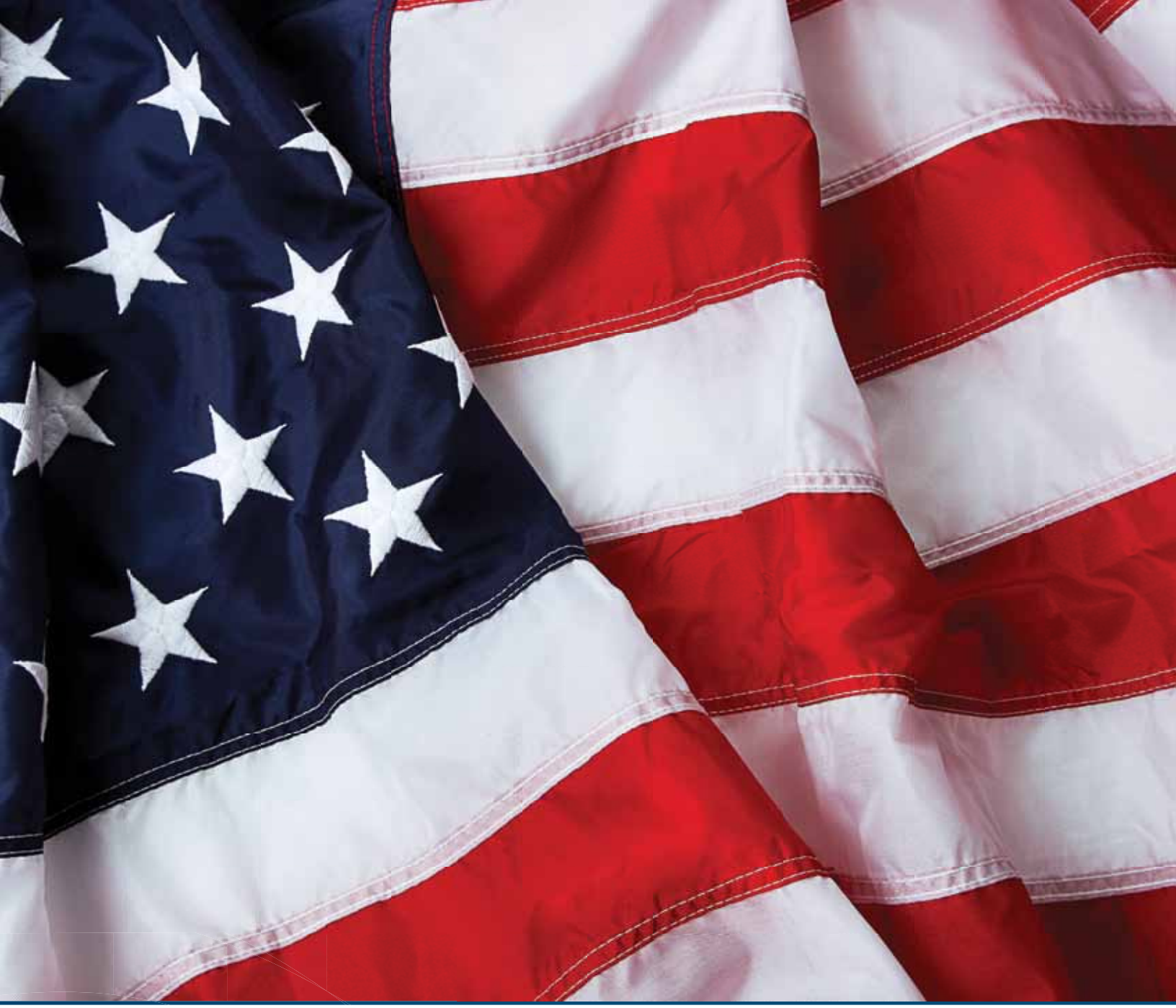
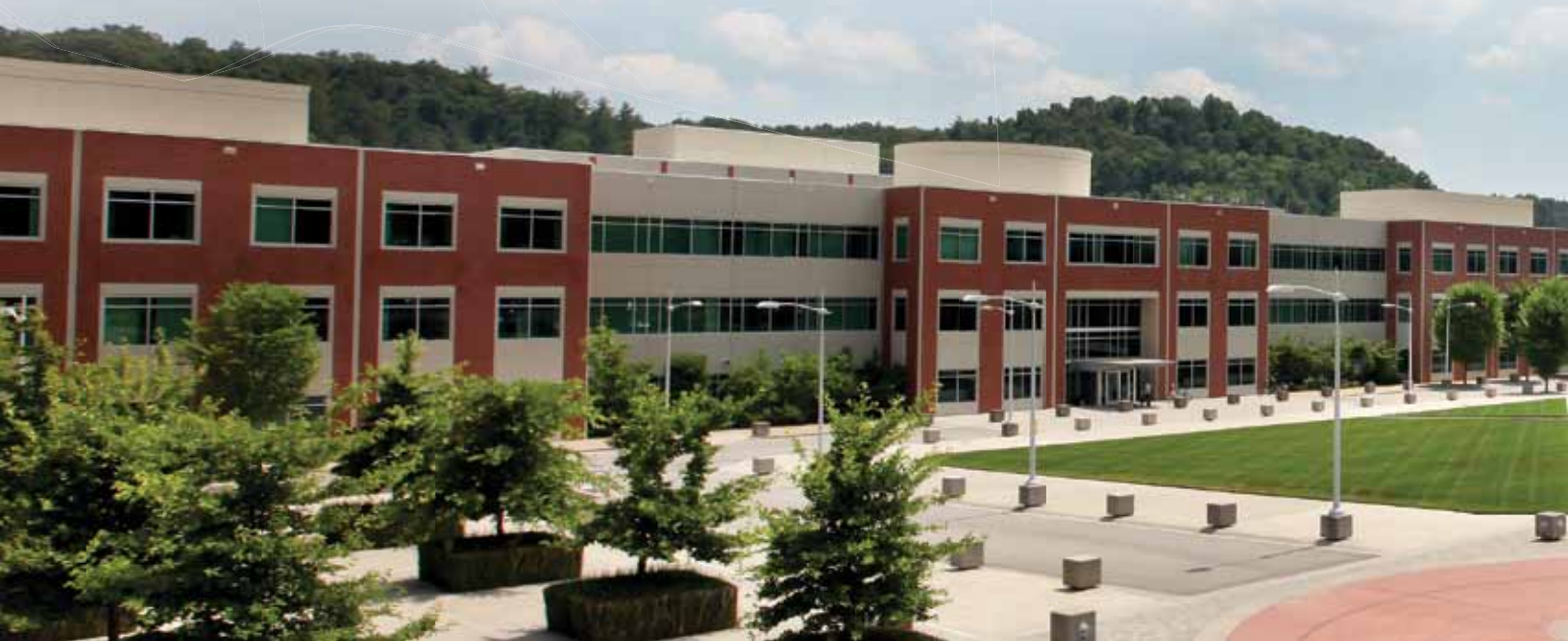


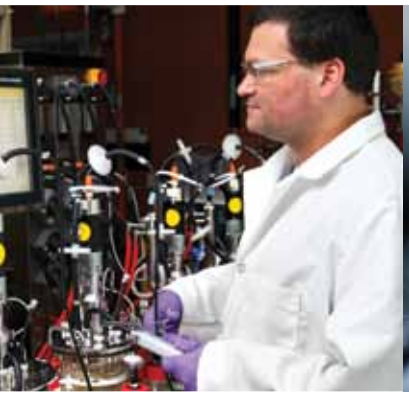
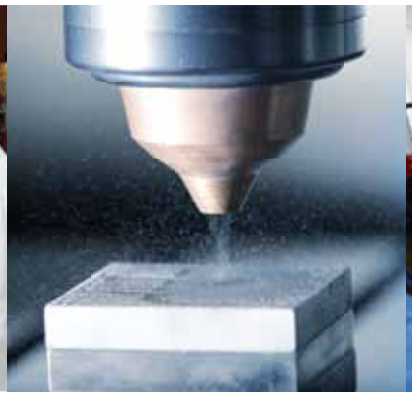
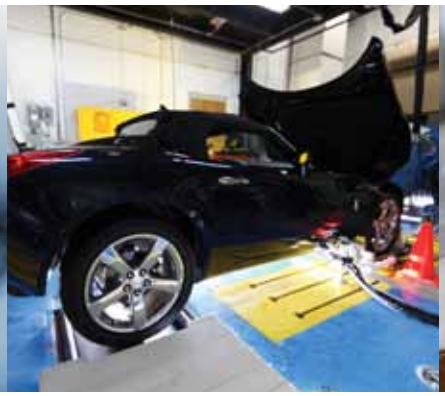
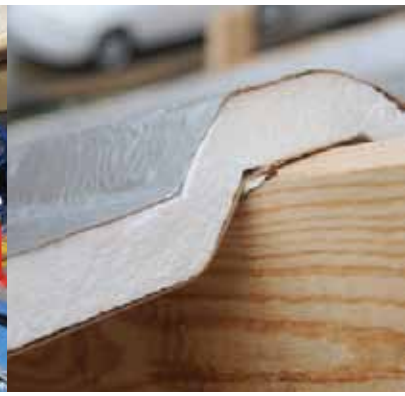
Impacting US Industry Today

A Snapshot of Innovative Solutions at Work for You

OAK RIDGE
National Laboratory

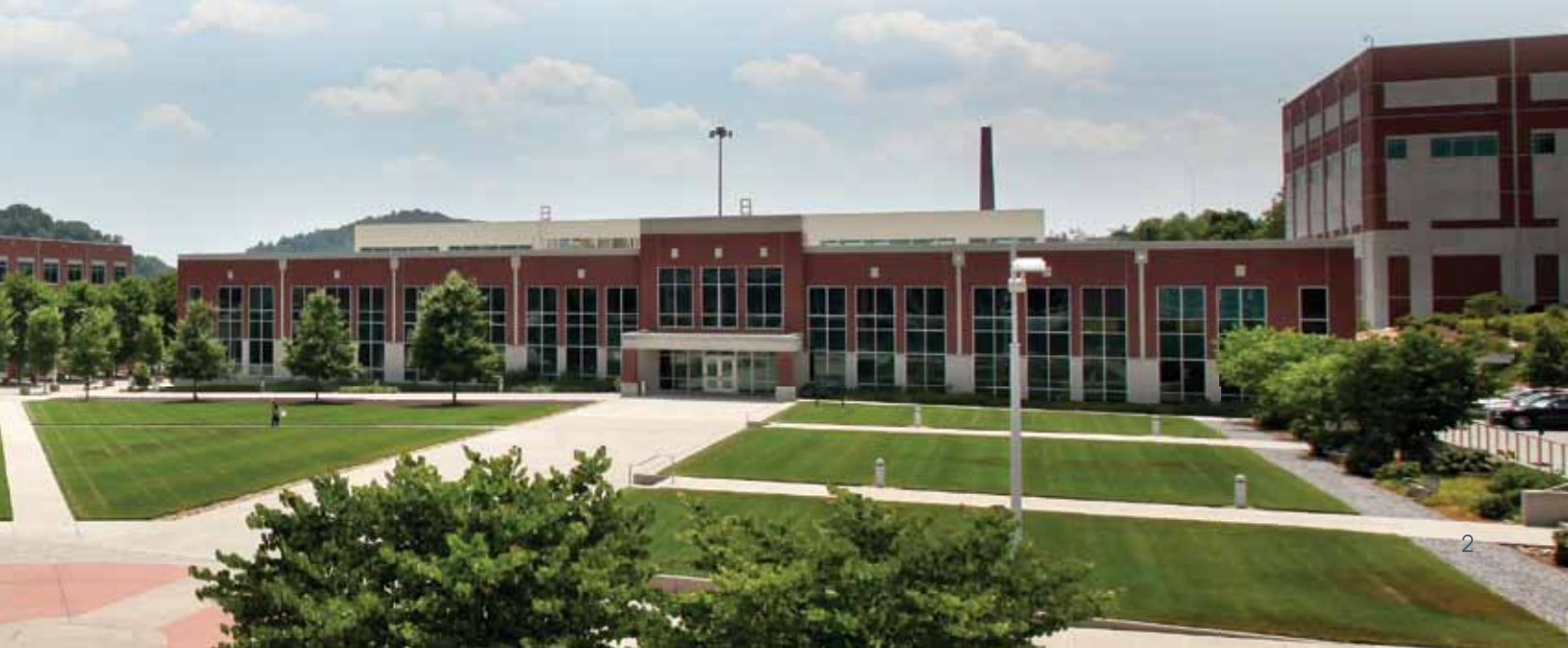
Where Innovation Happens



Industry is the cornerstone of the American economy and the engine that drives innovation, job creation, prosperity, and investment across the nation. An income source for millions of families providing three indirect jobs for each manufacturing job, it has enabled the United States to be the dominant market leader since the early 20th century. During the last decade, however, the country has experienced a steady decline in manufacturing jobs and output due to increased global competition as well as rising energy costs and environmental regulations.

As the Department of Energy's largest energy laboratory, Oak Ridge National Laboratory is addressing the scientific needs of US industry and making an impact – at home, at work, and on the road. With facilities and expertise beyond the reach of most private industry and educational institutions, ORNL is enabling economic vitality through innovations in manufacturing, buildings, and transportation that support an energy-independent and environmentally-sustainable future.



Advanced Manufacturing

1 Ford-Dow Partnership Linked to Carbon Fiber Research at ORNL

Growing Companies

Carbon fiber is a strong, stiff, lightweight enabling material with high chemical resistance, high temperature tolerance, and low thermal expansion strategically used in aerospace, civil engineering, military, and competitive sports applications. However, its use in cost-sensitive, high-volume industrial applications such as transportation, wind energy, infrastructure, and oil drilling is limited because of its relatively high price when compared to other reinforcing fibers, such as glass fibers, for composite structures.

ORNL is home to DOE's Carbon Fiber Technology Facility for process scale-up and sourcing low-cost carbon fibers for use with industry in development programs including, for example, lightweight structures and thermal management. Through its industrial partnerships, ORNL is enabling a carbon fiber commodity industry by combining more economical precursors to obtain carbonized fibers that are technically and economically viable.

IMPACT

- A greater than $10 million research agreement between Dow, ORNL (funded by DOE), and the state of Michigan catalyzes Dow's entry into carbon fiber.
- Oak Ridge establishes the Carbon Fiber Composites Consortium, a public–private partnership with more than 40 companies to accelerate the development, demonstration, and commercial application of new low-cost carbon fiber and composites materials.
- Roane State Community College, with ORNL's assistance, receives $5.6 million towards developing emerging carbon fiber workforce. Carbon Fiber Technology Facility technicians will be hired from Roane State's program.
- Dow partners with Aksa, the world's largest producer of acrylic fiber, to develop and globally market a broad range of products and support carbon fiber-based composites industry.
- Ford and Dow team up to bring low-cost, high-volume carbon fiber composites to next-generation vehicles.

2 Driving Costs Down by Three-Fold in American Automotive Batteries

Changing Ahead

Lithium-ion secondary battery technology enables full electrification of automotive drive trains and provide stationary storage solutions that enable the effective use of fluctuating renewable energy sources. Currently most batteries are imported.

Enabling the domestic energy storage industry in the US, research under way at ORNL encompasses formulation chemistry, materials processing, manufacturing, and component engineering. Use of novel cathode materials is expected to yield a twofold improvement in automotive cycle life and understanding of degradation mechanisms could extend automotive battery pack lifetime to beyond 10 years. By addressing these challenges and opportunities in energy storage, US industry will surpass nondomestic secondary battery manufacturers that dominate today's market.

IMPACT

- $6.2 million in manufacturing research collaborations with A123 Systems, Dow Kokam, LLC, Porous Power Technologies, and Planar Energy tackles some of the most critical challenges facing lithium-ion battery production.
- Michigan Economic Development Corporation provides refundable tax credits for A123 Systems and Dow Kokam, LLC to construct battery manufacturing facilities in Michigan and cost-shares ORNL 's battery research with Michigan companies.
- Dow Kokam's 1200 MWh/yr NANO production line is implementing research findings and assisting manufacturers in satisfying the demand for hybrid electric and electric vehicles that are safe, affordable, and go the extra mile.
- New low cost raw materials with more than 1000°C reduction in heat treatment temperatures outperforms commercial benchmarks and is considered for scaling by A123 Systems
- Several companies are interested in ORNL's new proprietary water based processing of electrodes which reduces electrode manufacturing cost by up to 75%.

3 Powering More than 1,000,000 Diesel Engines

Pioneering Innovations

Impellers designed for diesel engines are typically machined from titanium due to the harsh engine environment. Replacing titanium with aluminum offers a significant cost savings because both material cost and machining speed for titanium are 10 times greater than that for aluminum. However, traditional methods of heating aluminum fail to provide the necessary mechanical properties for product performance.

Using ORNL's patented process for rapid infrared heating of aluminum forgings, the physical properties of aluminum show improved fatigue life through refined structure. In addition, rapid infrared heating provides a faster, cheaper, and less energy-intensive alternative to traditional gas-fired convection ovens.

IMPACT

- Queen City Forging, a 120-year-old company that originally produced metal component parts for horse-drawn carriages, installed an innovative full-scale production infrared furnace to enhance the physical properties and forging tolerances of aluminum components. Now a state-of-the art supplier of metal components, the company's manufacturing costs decreased by an order of magnitude, energy consumption decreased by more than 70%, and downtime decreased to less than 5%, while production increased fourfold.
- Over 300,000 aluminum impellers are sold annually.
- Over 1 million aluminum impellers produced for Cummins diesel engine turbochargers are on the road today.

4 Printing Low-Cost Electronics in Less Than 1 Millisecond

Emerging Markets

Printed circuit boards are the backbone of America's high tech environment, with the average household using over 100 such devices for controlling everything from the television, to the refrigerator, to the bedside alarm clock. Unfortunately, the majority are made by expensive, outdated processes on rigid, flat surfaces. Tomorrow's technology will require flexible printed circuits using low-cost, high-throughput printing approaches for affordable high-performance applications such as photovoltaics, solid state lighting, and flexible displays.

Pulse thermal processing, PTP, is an ORNL-developed technology capable of heating thin film materials by up to 600,000°C per second on low-temperature substrates such as plastics. Such large-area processing not only speeds manufacturing by increasing the throughput but also provides for more uniform microstructures and leads to more consistent electrical and optical properties. PTP offers a low thermal budget, increased throughput, higher heating rates, the ability to process on lower temperature substrates, and the ability to control diffusion on the nanometer scale.

IMPACT

- NovaCentrix, a leader in printed electronics manufacturing technologies based in Austin, Texas, commercially licensed ORNL's Pulse Thermal Processing technology to develop the next generation of PulseForge tools for thin film and other applications.
- Showa Denko K. K. and NovaCentrix cooperate in printed electronics for the development, manufacture, and sale of conductive inks.
- DuPont Microcircuit Materials expands development of functional inks for the printed electronics industry using NovaCentrix PulseForge® tools.

Building Technologies

5 Partners Create Energy-Efficient Equipment Products and Jobs

Enabling Jobs

Buildings consume 41% of the nation's primary energy, of which equipment uses 57% to provide comfortable indoor temperature and humidity levels, healthy air quality, heated water, and refrigeration. Increasing concerns over rising costs, resource scarcity, and climate change are driving interests in improving equipment efficiency.

ORNL collaborations with industry have led to game-changing advancements that are helping overcome these concerns, clearing the way to more energy-efficient equipment, greater market acceptance, and job creation.

IMPACT

- GE Appliances launched its GeoSpring™ electric heat pump water heater 20 months after initiating research collaboration with ORNL. Compared with a standard model, GeoSpring saves 62% on energy use and pays for itself in less than 2.5 years. In 2012, the initiative created 100 GE manufacturing jobs in Louisville, KY with over 1,000 US jobs estimated.
- After a research collaboration with ORNL, in 2012 ClimateMaster launched the Trilogy™ 40 Q-Mode™, a variable-speed geothermal (ground-source) integrated heat pump that reduces annual energy use for space conditioning and water heating in residential applications by up to 65% compared with conventional systems. The product is manufactured in Oklahoma City.
- Southwest Gas has entered into a series of research collaborations with ORNL to bring to market new commercial and residential products for space conditioning, water heating, backup power, and/or micro-cooling, -heating, and -power. The first product, launched in 2011 under the NextAire™ brand, is an engine-driven rooftop unit with heat recovery for space conditioning.
- Appliance Research Consortium (including Maytag, Amana, Frigidaire, General Electric, and Whirlpool), which in the 1990s controlled 95% of the domestic refrigerator-freezer (RF) market, entered into a research collaboration with ORNL and developed technologies enabling 1 kWh/day RFs that consumed 50% less energy than the minimum efficiency standard at the time.

6 Vapor Compression Cycle Model Spurs Advances in Equipment Efficiency

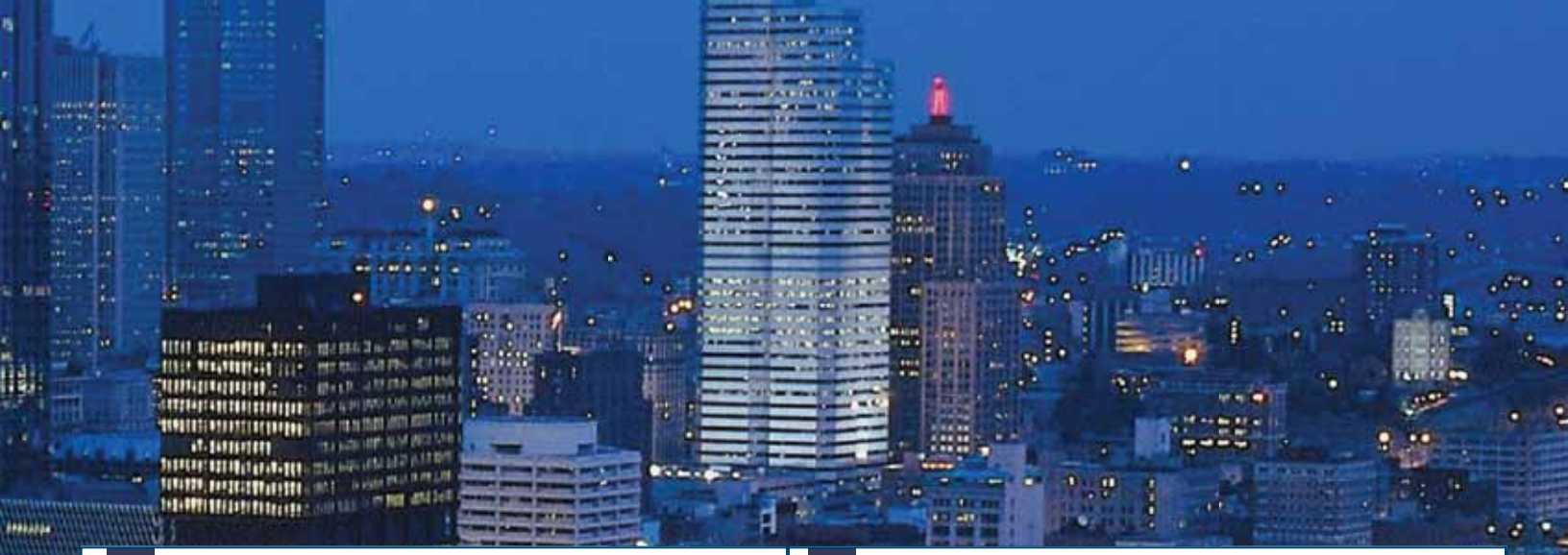
Guiding Investments

Electric equipment providing space conditioning, water heating, and refrigeration consumes 12.5% of the nation's primary energy. Most of this electricity is used to drive vapor compression cycles, which are the heart of air conditioners, heat pumps, chillers, supermarket refrigeration systems, and more. Global use of electricity to drive such devices will have to increase dramatically if living standards including food preservation and comfort are to rise in the developing world.

Over the past 30 years vapor compression equipment has advanced dramatically in efficiency while successfully transitioning to more environmentally-acceptable refrigerants. Industry continues to face many large investment decisions, however, with severe consequences for wrong choices. Whether involving design of specific new products or refrigerants to which the entire industry should migrate, ORNL's Heat Pump Design Model (HPDM) is a world-class hardware-based vapor compression model for research and product design at the decision-making core for much of the industry.

IMPACT

- NORDYNE, using HPDM, developed the iQ Drive® inverter-driven rotary compressor air conditioner, the highest-efficiency product on the market when introduced in 2006.
- Emerson Climate Technologies, Inc., a business unit of Emerson Electric Co. and the nation's largest manufacturer with Copeland Scroll™ compressors, is using HPDM as the engine for its system design tool.
- The National Appliance Energy Conservation Act minimum efficiency standards for some product categories are based on analysis using HPDM.
- Under the Montreal Protocol and US Clean Air Act, replacement refrigerants for chlorofluorocarbons and hydrochlorofluorocarbons were selected in part based on analysis using HPDM to verify equipment redesigned for the new refrigerants could have increased efficiency.
- HPDM is actively used by companies and research collaborations between ORNL and firms designing equipment to achieve industry-leading efficiency levels.



7 Ensuring Affordable, Efficient, Moisture-Durable Buildings

Managing Moisture

Faced with rising fuel costs, building and home owners are looking for energy-efficient solutions. Improving the building envelope (roof or attic system, walls, foundation) is an obvious choice as heating, ventilating, and air-conditioning (HVAC) accounts for 17% of the nation's primary energy consumption, with envelope quality dictating the magnitude of HVAC loads. However, improvements making building envelopes for residential and commercial buildings more airtight and highly insulated must be done properly to avoid moisture durability issues.

ORNL, in collaboration with the Fraunhofer Institute of Building Physics (Federal Republic of Germany), has developed the world's most respected hygrothermal models for understanding the flow of heat, air, and moisture through envelope assemblies, storage of heat and moisture in the assemblies, and thresholds for onset of failure modes. Known as WUFI (Wärme Und Feuchte Instationär), the model has been validated with data from natural exposure field test facilities in Germany and North America. Scaling envelope improvements in the market is now feasible without fear of unintended consequences (mold, rot, freeze damage).

IMPACT

- WUFI enables codes and standards writers to prescribe, or practitioners to design, new envelope assemblies or retrofits that are airtight, highly insulated, affordable, and moisture-durable.
- ORNL established test facilities to measure essential property values needed by WUFI, enabling better understanding of product performance by the entire construction materials industry.
- ORNL participated in the development of the first moisture-control envelope design standard (ASHRAE 160), adopted by the General Services Administration (GSA P100).
- Hygrothermal expertise has enabled multiple ORNL research collaborations with industry (cool roofs, air barriers, insulation systems) resulting in affordable, moisture-durable products to increase energy efficiency.

8 Dramatically Reducing Risk Using Entire "Test Buildings"

Maximizing Efficiency

Evaluating preproduction prototypes of new energy-efficiency products in realistic test beds is an essential, challenging step before market introduction. Environmental chambers and other lab apparatus cannot reliably impose every operating condition encountered in a real building, while occupied buildings (the living lab approach) is intrusive, risky for industry, and expensive.

ORNL has developed a risk-reducing approach to realistic residential test beds through innovative partnerships. Utility and private partners provide the land, building materials, and labor cost-share to build research houses that are leased for research purposes over extended periods. Each house supports R&D on one envelope strategy and several generations of equipment, appliances, and controls before the house is sold. Competitively awarded American Recovery and Reinvestment Act funds were used to establish realistic light commercial building test beds at ORNL, with research scheduled to begin in FY 2013. In the test beds, an average occupant effect on energy use is imposed using process control, so realistic loads, operating conditions, and interactive effects are provided for physical validation of models.

IMPACT

- ORNL has access to seven research houses: three from the Tennessee Valley Authority and four from Schaad Companies. So far these houses have supported the launch of the General Electric GeoSpring™ heat pump water heater and ClimateMaster Trilogy™ 40 Q-Mode™ geothermal (ground-source) integrated heat pump.
- The first test buildings will be installed on the new light commercial building flexible research platforms by the end of calendar year 2012. More than a dozen industry partners are cost-sharing the first cycle of research.
- ORNL is currently developing an automated building energy model tuning (to measured data) methodology, enabling more cost-effective determination of energy-saving opportunities and ongoing verification of operational efficiency.

Vehicle Technologies

9 Reducing the Heat in over 35,000 Heavy-Duty Highway Diesel Engines

Solving Problems

Today's advanced diesel engines have improved fuel efficiency and lower emissions, yet their components must be durable, reliable, and endure extreme temperature fluctuations that exceed 750°C. Commercial cast stainless steels such as CF8C have certain desired properties for such applications but lack others, including the ability to withstand temperatures above 600–650°C.

CF8C-Plus, a low-cost cast stainless steel developed at ORNL, is an alternative to conventional cast steels that can meet the extreme temperature demands of diesel engines, gas turbines, and nuclear reactors. Approved by the American Society for Testing and Materials, this heat-resistant alloy operates within 650–900°C with creep properties similar to nickel-based alloys, but at the cost of stainless steel, and is resistant to mechanical and thermal fatigue as well as age-induced failure. CF8C-Plus is also more castable than standard steel, an ideal property for casting thin- or thick-wall components.

IMPACT

- Caterpillar's Regeneration System employs the technology in more than 35,000 heavy-duty highway diesel engines, using 500 tons of CF8C-Plus for a net savings of nearly $23 million from the overall manufacturing process.
- Honeywell Turbo Technologies is testing the technology in both diesel and automotive engine turbocharger applications.
- Solar Turbines, Inc. deployed the technology in a 4.5 MW Mercury 50 gas turbine engine at the 29 Palms US Marine Corps Base in California showcasing clean energy applications.
- Trial licenses have been established with companies including General Electric and Stainless Foundry & Engineering, which obtained the first commercial license in May 2008.

10 Extending the Life and Reliability of Vehicle Components

Measuring Stress

"Residual" internal stresses can develop in structural materials used to manufacture components for automotive and diesel engines. Materials used to make components, such as alloys, ceramics, and composites, are subjected to rapid changes in temperature and other forces that may cause deformation and stress formation during both the manufacturing process and while on the road. Residual stress is a problem waiting to happen that eventually leads to degraded mechanical performance, stress corrosion cracking, shortened lifetime, and even catastrophic failure.

ORNL's Residual Stress User Center, a joint effort of the High Temperature Materials Laboratory (HTML) and High Flux Isotope Reactor (HFIR) Facility, conducts nondestructive testing of engine components using neutron and X-ray technology to help industry determine (1) which manufacturing processes minimize the generation of residual stresses, (2) whether an object can tolerate certain demanding applications, and (3) whether heat treatment (annealing) of an object that contained residual stresses successfully eliminated or reduced them. Such testing helps developers of computer models more accurately predict when various types of residual stresses combined with externally applied stresses will cause cracking and failure.

IMPACT

- Honeywell Turbo Technologies worked with ORNL's HTML to collect residual stress measurements on the shaft wheel assembly weld joints of vehicle turbochargers used in both automobiles and trucks. By quantifying the role that residual stresses play in the lifetime of the shaft wheel assembly and turbocharger housings, Honeywell will be better able to design the highest quality shaft wheel assemblies and monitor manufacturing processes.
- Future collaborations with Honeywell include the evaluation of cost-effective ways to mitigate residual stress and thereby extend component life and ensure reliability of both the shaft wheel assembly and turbine housing in the company's turbochargers.

11 Meeting Emissions Control Standards 3 Years Ahead of Schedule

Analyzing Within

Accounting for about 70% of US oil demand, the transportation sector presents vast opportunities and challenges for reducing oil consumption and managing the environmental impact. Clean diesels and other advanced engines can contribute to these challenges, yet require highly effective exhaust treatment technologies to meet increasingly stringent emissions regulations.

SpaciMS, or spatially resolved mass capillary input mass spectrometry, is a diagnostic tool developed through ORNL collaborations with Cummins Inc. that has provided unprecedented insights into catalysts devices, aftertreatment systems, and engine performance. SpaciMS measures fast changes in gaseous chemical composition within confined-space chemical reactors, such as the catalytic converters of diesel or other engines. Using gas sampling capillaries positioned inside the catalyst, the instrument pinpoints, measures, and maps concentrations of diverse gaseous pollutants, such as nitrogen oxide, carbon monoxide, and carbon dioxide. The method is widely used in catalyst research now and, with its ability to "look inside" chemical reactors, has been applied to fuel cells and fuel reformers.

IMPACT

- "With the advent of diesel aftertreatment systems, the speciation of exhaust gases became critical to the function of the engine/aftertreatment system. The SpaciMS allowed us to quantify speciation in a way that previous instrumentation did not and now is a mainstay of our aftertreatment system development." – John C. Wall, Vice President/Chief Technical Officer, Cummins Inc.
- Hiden Analytical commercialized SpaciMS technology for determination of intra-catalyst reactor chemistry and is the first commercially available instrument of its kind.
- With Cummins utilizing this specialized tool in the engine development and calibration process, Chrysler brought their Cummins-powered 2007 Dodge Ram pickup truck to market, fully compliant with 2010 environmental standards.

12 Materials Expertise Helps Solve Manufacturing Challenge

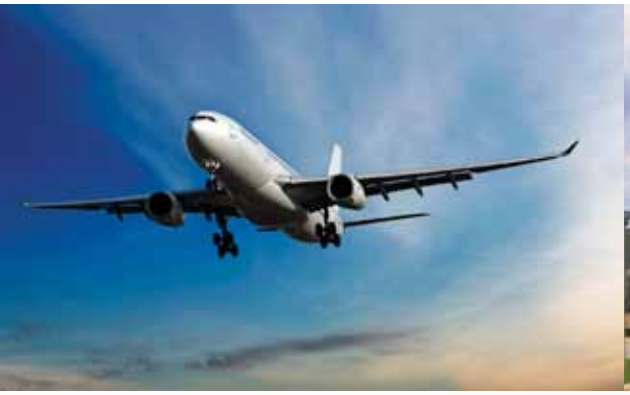
Restarting Production

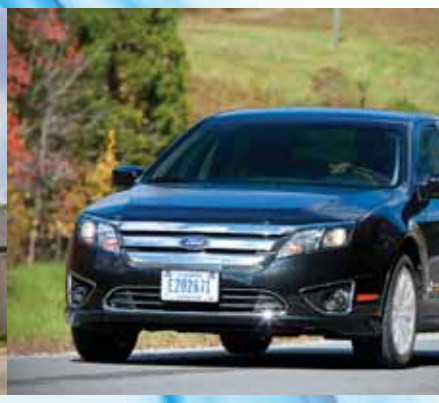
Due to the demand for reduced vehicle weight, improved safety, and crashworthiness qualities, the need to manufacture automobile structural components from ultra-high-strength steels is apparent. Since 2000, the use of hot stamped parts in the automotive industry for chassis components, like A-pillar, B-pillar, bumper, roof rail, rocker rail and tunnel cars, has significantly increased from 3 million to over 107 million parts/year since 1987. However, problems that occur during the manufacturing process are often costly and difficult to resolve, involving lost production time.

ORNL is home to a number of highly sophisticated experimental user facilities that offer unique and specialized technology, instrumentation, and expertise. ORNL's High Temperature Materials Laboratory (HTML) specializes in the characterization of advanced materials, such as structural ceramics, metal-, ceramic-, and polymer matrix composites, lightweight and lightweighting materials such as aluminum and magnesium alloys and high-strength steels, as well as non-structural functional materials. HTML has a strong track record of working with industry to solve materials problems that limit the efficiency and reliability of systems for power generation and energy conversion, distribution, storage, and use.

IMPACT

- Using world-class tools at HTML, ORNL assembled a rapid-response team to assist Cosma International, a global automotive parts supplier, in solving a problem that had interrupted the production of automotive components and their assembly in vehicular structures at an OEM's plant.
- ORNL's quick response enabled Cosma's 334,000 ft^2 facility with over 800 employees and the OEM to rapidly resume production, thus saving time, money, and jobs.

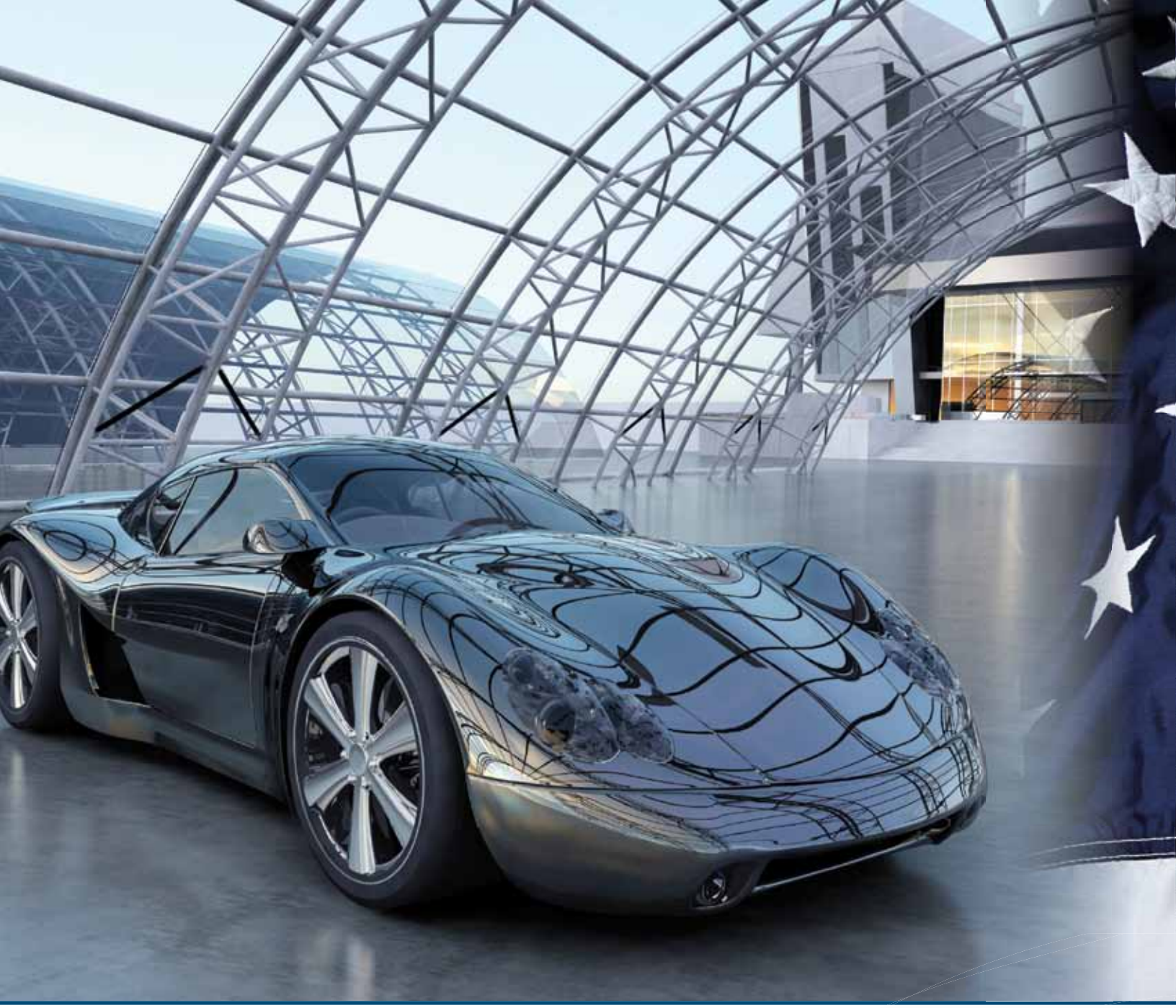




Addressing the Challenges of Tomorrow, Making a Difference Today

The development and commercial deployment of next-generation technologies remain essential to America's long-term economic competitiveness and energy independence. With real-world applications, new cutting-edge technologies can both revitalize existing industries and support emerging ones. Today's advances have resulted in a host of innovative products, ranging from jet aircraft, computers, building technologies, advanced instruments, and vehicles to sophisticated materials and processing methods to improve existing systems.

ORNL, through its ongoing collaborative relationships with more than 800 companies and distinction as the Department of Energy's leading recipient of R&D 100 Awards among the national laboratories, has demonstrated the ability to work with US manufacturers to transition technologies that will drive innovations in the coming decades. From concept to commercialization, ORNL's world-leading facilities and expertise enable research focused on reducing energy demands, developing new products, and strengthening our nation's clean-energy economy to meet the commercial and national security needs of tomorrow.



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Energy Efficiency &
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