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INDUSTRY NEWS

LG ELECTRONICS GROWS ITS ADVANCED MATERIALS BUSINESS

LG Electronics' advanced materials business is now using an in-house developed antimicrobial glass powder and marine glass, which the company says will help grow its new advanced materials business. The company's antimicrobial glass powder is made at LG Smart Park in Changwon, Republic of Korea, which produces 4,500 tons of the material annually.

The antimicrobial glass powder was initially applied to LG ovens launched in North America in 2013.

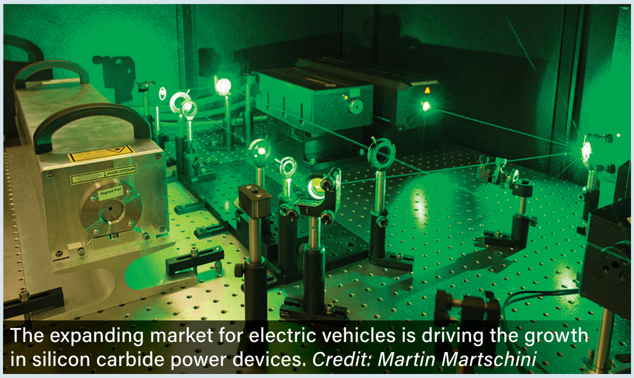
CORNING CREATES JOINT VENTURE IN INDIA

Manufacturing of Velocity Vials at SGD Pharma's facility in Vemula, India, is expected to begin in 2024.

Corning and SGD Pharma announced a joint venture to open a glass tubing facility in Telangana, India, to expand access to Corning's Velocity Vial technology in India. The agreement combines SGD Pharma's vial-converting expertise with Corning's proprietary glass-coating technology. "The joint venture supports our continued global expansion as we localize manufacturing for our customers," says Ron Verkleeren, senior vice president and general manager of Corning's Life Sciences Market Access Platform.

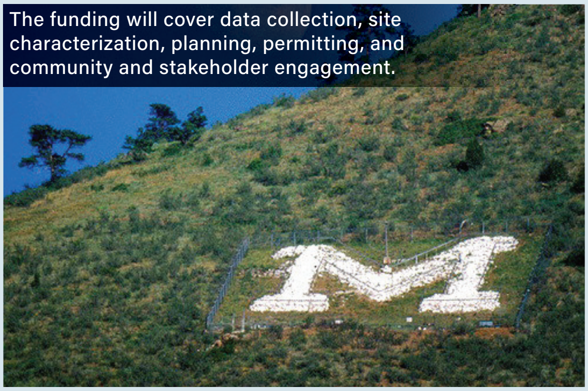
COHERENT CORP. TO DEVELOP SIC DEVICES FOR MITSUBISHI ELECTRIC

Pittsburgh-based Coherent Corp. signed a memorandum of understanding with Mitsubishi Electric to collaborate on a program to scale manufacturing of silicon carbide power electronics. Mitsubishi Electric announced an investment of 260 billion yen in the five-year period ending March 2026, with about 100 billion yen for the construction of a new plant for SiC power devices. Under the MOU, Coherent will develop a supply of 200-mm *n*-type 4H SiC substrates for Mitsubishi's future SiC power devices manufactured at the new facility.



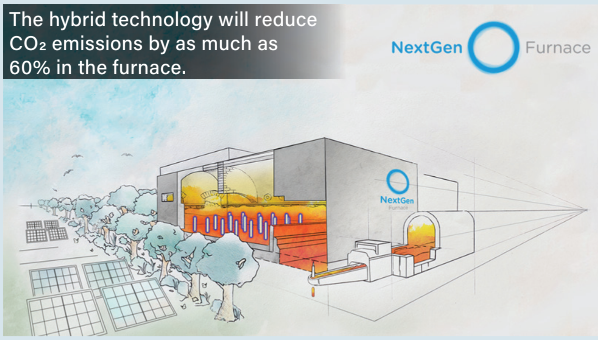
The expanding market for electric vehicles is driving the growth in silicon carbide power devices. *Credit: Martin Martschini*

MINES CARBON STORAGE PROJECT AWARDED DOE FUNDING



The funding will cover data collection, site characterization, planning, permitting, and community and stakeholder engagement.

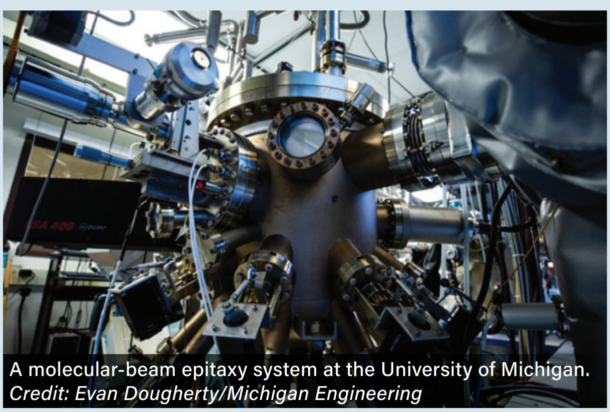
Colorado School of Mines, Carbon America, and Los Alamos National Laboratory were awarded $32.6 million from the U.S. Department of Energy's Carbon Storage Assurance Facility Enterprise initiative to advance the development of a carbon storage hub for the Pueblo, Colo., area. It was one of nine projects selected by DOE as part of a $242-million nationwide investment to accelerate the development of large-scale, commercial carbon storage projects with capacities to securely store carbon dioxide deep underground.



The hybrid technology will reduce CO_2 emissions by as much as 60% in the furnace.

ARDAGH GLASS BUILDS LARGE-SCALE HYBRID FURNACE

Ardagh Glass GmbH is constructing a hybrid furnace to enable a switch to renewable electricity at its glass production facility in Obernkirchen, Germany. The large-scale hybrid electric furnace will run predominantly on renewable electricity and a small amount of gas. It will use high levels of recycled glass cullet to produce up to 350 tonnes of glass bottles per day.


A molecular-beam epitaxy system at the University of Michigan. *Credit: Evan Dougherty/Michigan Engineering*

NSF INVESTS IN NINE MATERIALS RESEARCH CENTERS

The U.S. National Science Foundation will invest $162 million in nine Materials Research Science and Engineering Centers to transform scientific breakthroughs into benefits for multiple sectors of the U.S. economy. The centers are Illinois Materials Research Science and Engineering Center at the University of Illinois at Urbana-Champaign; Center for Dynamics and Control of Materials at the University of Texas; University of Washington Molecular Engineering Materials Center; Northwestern University Materials Research Science and Engineering Center; Laboratory for Research on the Structure of Matter at the University of Pennsylvania; Materials Research Laboratory at the University of California, Santa Barbara; Wisconsin Materials Research Science and Engineering Center at the University of Wisconsin; Center for Advanced Materials & Manufacturing at the University of Tennessee; and Center for Materials Innovations at the University of Michigan. Each center will receive $18 million over six years.

HYDRO AND SAINT-GOBAIN GLASS PARTNER TO DECARBONIZE BUILDING FACADES

Hydro Building Systems entered into an agreement with Saint-Gobain Glass to reduce the carbon footprint of building facades in half by integrating the low-carbon solutions offered by both companies. Hydro Building Systems uses a high percentage of recycled post-consumer scrap in its aluminum facades, while Saint-Gobain Glass produces low-carbon glass products using renewable electricity and recycled content.

Bruno Mauvernay, left, managing director of the glass facades unit at Saint-Gobain, and Henri Gomez, vice president at Hydro Building Systems.

RESEARCH PARTNERSHIP EXAMINES HYDROGEN FUEL FOR REFRACTORIES

The U.K.-based Materials Processing Institute announced a research partnership with Trent Refractories and Swedish industrial heating technology company Kanthal to examine the impact on industrial processes of using hydrogen as an alternative fuel source. The three-year agreement will focus on the effect of hydrogen on refractories and will also test a range of electrical elements for use in high-temperature applications in a hydrogen environment.


The research will examine the effect of hydrogen on heat-resistant materials that form the linings of furnaces, crucibles, kilns, and ladles.

CERAMIC MATRIX COMPOSITES: IS THE FUTURE HERE YET?

By David Holthaus

Ceramic matrix composite (CMC) technology has long held the promise of solving some of the most fundamental yet perplexing challenges in the materials industries.

CMCs are created by embedding coated fibers about the width of a human hair into a ceramic matrix. Coating the fibers alters the bond between fiber and matrix, permitting the material to be more durable. Cracks from the surrounding material do not propagate into the fibers, so the material holds together in service environments and avoids catastrophic failures.

CMC technology has been the subject of decades of research and testing at leading manufacturers, national laboratories, and universities. The sustained interest in CMCs stems from the fact they are typically one-third the density of metal alloys and one-third the weight. They are also more heat resistant than metals and can be very durable in extreme environments.

The decades of CMC research have led to application of the technology in aerospace, power generation, transportation, and defense—and subsequent gains in competitiveness, efficiency, and

GE's LEAP engine at the assembly plant in Durham, N.C. *Credit: GE Aerospace*

Global market for CMCs

The lighter weight, durability, and heat resistance of CMCs has made this technology a subject of investment, research, and application in the aerospace, automotive, and energy industries. Unsurprisingly, all this investment is causing the global market for CMCs to expand.

An informal survey of market forecasts showed global market growth of CMCs is estimated to range from a 9.6% consolidated annual growth rate to 11% over the next five to seven years. Estimates vary, but three market research firms forecast the global market will grow to at least $21.5 billion in five years.

Driving that growth will be increases in demand in the automotive sector, which is seeing a surge in demand for lightweight and electrified automobiles, and the aerospace sector, where the airlines and engine makers are searching for more powerful yet lighter weight engines and aircraft.

sustainability in these industries. But though CMC technology has been tested, adopted, and put into commercial use in many areas, the technology is still considered to be in an early stage of development. Promising research is underway that is expected to lead to broader application in a range of industries.

THE EARLY DAYS OF CMCS

Research into CMCs goes back at least three decades, but it was advanced in the early 1990s when the Department of Energy funded its Continuous Fiber Ceramic Composite (CFCC) program, which supported research and development that was going on at private corporations, including Dow Chemical, Dow Corning, DuPont, and GE. The program funded companies to make composites, which were then characterized at national labs and universities. The researchers were working toward a common goal of getting CMCs into industrial applications, including high-pressure heat exchangers, land-based turbines, heat-treating furnaces, and radiant burners.

The efforts at that time were coordinated and funded through Oak Ridge National Laboratory (ORNL), where researchers studied different fibers, coatings, and matrices, as well as how the materials degraded and performed, and cost-effective techniques for preparing them.

GE researchers have worked with CMCs since the '70s. They initially studied the technology's application in gas turbines, which then found its way into industrial power plants. Researchers at the industrial conglomerate then turned their attention to the company's jet engine manufacturing and the possibility of using CMC technology in flight.

They were undeterred by a 2001 study done by the Institute of Defense Analyses for the Defense Advanced Research Projects Agency. The study assessed the potential use of CMCs in the development of military supersonic aircraft, which would require a lightweight, efficient engine that could operate at high pressure. The study, titled "Will pigs fly before ceramics do?," ultimately concluded that "What is needed is a more radical, unconventional approach toward designing turbine engines that will take better advantage of ceramic materials properties … if the present mindset in technology development continues, there may be more pigs flying than ceramics in the future."

Two decades later, GE has invested more than $1.5 billion in CMC research and development. The company's CMC technology has found its way into the LEAP engine, the first widely deployed CMC-containing product. CMCs are used in the hottest section of the LEAP engine, which is made by CFM International, a joint venture between GE and Paris-based Safran Aircraft Engines.

CMC DEVELOPMENT AT GE: LEAPING INTO COMMERCIAL DEPLOYMENT

Jon Blank, an engineer and manager at GE Aerospace who has worked with CMCs for years, explained the technology's evolution at the jet engine maker.

Components of the ceramic matrix composite turbine shroud in the LEAP engine. *Credit: GE Aerospace*

"We know temperatures are always going to go up, and engine pressures are going to go up," he says, describing the competitive drive to make more powerful yet efficient engines. "On the material side, we said we need the next-generation material."

Nickel-based superalloys were running out of the capability to achieve higher operating temperatures, he says.

"We needed that next step. And that's where ceramic matrix composites came in."

GE researchers began developing the material and testing it on a small scale. Fast forward to today, and ceramics are not only flying but have been successfully put into the field in one of the best-selling engines for single-aisle aircraft in the world.

The LEAP engine features a CMC turbine shroud, i.e., the component which directs airflow into the hottest part of the engine. The component is much lighter than its metal counterpart and can withstand hotter temperatures, increasing the potential for greater thrust and better efficiency.

"If you need more thrust, more power, this allows you to get that," Blank says. "It also is an environmental play, a sustainability play, because now you can change how you run the engine … you can change the amount of emissions that come off. It's a real game changer from a materials standpoint in our end product."

The LEAP engine has been embraced by the world's airlines. At the Paris Air Show in June 2023, GE announced orders for 70 LEAP-1A engines and for 80 LEAP-1B engines to power Boeing and Airbus aircraft.

Following the success of LEAP, GE has incorporated CMCs into its GE9X engine. This engine, which GE says is the largest and most powerful aircraft engine ever built, is designed to power the next-generation Boeing 777X aircraft. In contrast to the single CMC component in LEAP engine, the GE9x features five CMC components: two combustor liners, two nozzles, and one shroud.

"And the level of complexity of those components has gone up significantly," Blank says. They will help make that engine one-third the weight of conventional jet engine but twice as durable, and able to use 59% less cooling air.

In an engineering test in 2017 at GE's outdoor test facility outside Cincinnati, Ohio, the GE9X achieved 134,300 pounds of thrust, a world record.

CMCs have also been incorporated into GE's military engines, specifically its XA100 adaptive cycle engine, which has completed testing and is planned for the Air Force's F-35 combat aircraft. Its engineering innovations, including the use of CMCs, have contributed to a 10% increase in thrust and a 25% improvement in fuel efficiency.

CMCs are also a key part of the engineering behind the RISE program that GE initiated with its joint venture partner Safran. RISE, which stands for Revolutionary Innovation for Sustainable Engines, aims to reduce fuel consumption and carbon dioxide emissions by more than 20% compared with today's most efficient aircraft engines, a key to helping the aviation industry achieve a larger target: net-zero CO_2 emissions by 2050.

"So, we see a very bright future for CMCs," Blank says. "It's why we've invested now close to $2 billion in it."

In addition to leading the charge to commercialize CMCs, GE's research and investment led to its decade-long effort to establish an integrated CMC supply chain.

In 2017 in Huntsville, Ala., GE opened what it says is the first center to mass produce silicon carbide, the raw material used to manufacture CMCs. Two adjacent factories on 100 acres produce silicon carbide ceramic fiber, the material used to make the unidirectional CMC tape produced in the neighboring factory. The tape, which is used to fabricate CMC components, is then shipped to Asheville, N.C., where another plant condenses it, machines it, and then ships the final part to engine assembly shops in Durham, N.C., or Lafayette, Ind.

Control over the supply chain allows the company to focus on boosting production rates, refining manufacturing processes, and lowering costs, GE says.

Researchers working with CMCs at GE's complex in Evendale, Ohio. *Credit: GE Aerospace*

CMC DEVELOPMENT THROUGHOUT THE AEROSPACE INDUSTRY

GE's competitors in the aircraft engine space are also investing in CMC technology research and development.

In 2013, Rolls-Royce purchased Hyper-Therm High-Temperature Composites, a privately held company based in Huntington Beach, Calif. Then in 2016, it announced a $30 million expansion and new facility in southern California as its CMC technology hub.

"The development of lighter, stronger, composite fiber components is just part of our commitment to continuously improve the performance of our products by focusing on lowering fuel consumption, emissions, and noise," former CEO Marion Blakey said at the time.

Tubes made of nuclear-grade continuous silicon carbide, fiber-reinforced, silicon carbide-matrix composite. These tubes will be used in the development of accident-tolerant fuel cladding for light-water reactors. *Credit: ORNL*

In 2021, Pratt & Whitney opened a CMC facility in Carlsbad, Calif. This 60,000-square-foot facility focuses on the engineering, development, and production of CMCs for aerospace applications.

"Some of our best and brightest minds are innovating within this facility and they will ensure that we continue to operate on the cutting edge of aviation technology for decades to come," says Frank Preli, vice president of Propulsion and Materials Technology at Pratt & Whitney.

NEXT-GENERATION CMCS: ESTABLISHING NEW APPLICATIONS AND FABRICATION METHODS

The promise of lightweight durability in high-stress environments has scientists looking for new applications and new manufacturing methods for CMCs.

Oak Ridge National Laboratory researchers recently demonstrated the feasibility of additively manufacturing fiber-reinforced ceramic matrix composites, an advancement that will open new possibilities in the design space for these materials, says Edgar Lara-Curzio, a distinguished scientist at the national laboratory.

Researchers there are also initiating a project to test new techniques, including additive manufacturing, to fabricate furnace heating elements and components. The successful completion of that project could enable a leap in CMC capabilities by improving matrix densification, Lara-Curzio says. Another ORNL team is working to further develop CMCs for applications in nuclear energy.

Westinghouse, in partnership with San Diego-based General Atomics and the Department of Energy, has developed "accident-tolerant" nuclear fuel rods that use CMC cladding to replace the metal cladding that it typically used. The companies say the silicon carbide-based cladding allows the fuel rods to withstand temperatures of more than twice what can be sustained by metal cladding.

At GE, researchers are developing rotating engine parts using CMCs and have conducted engine tests using the material, Blank says.

Researchers at Boeing, the University of Southern California, and 3M are working on a project to ensure the affordability of CMC components for hypersonic platforms, and to use 3D vision-based sensors to reduce the cost and variability for high-rate production of CMC structures. The project recently received funding from the Advanced Robotics for Manufacturing Institute.

Clearly, the future for CMCs is attractive, as corporations, universities, and governments continue to invest in research and development for new applications. This collaborative atmosphere supports the recommendation that faculty in the Sustainable Manufacturing Systems Centre in the School of Aerospace, Transport, and Manufacturing at Cranfield University (U.K.) noted in a paper published in February 2023.

"Advanced ceramics have a tremendous amount of innovation potential, but to fully realize this potential along the entire value-added chain, significant efforts from both the academic and industrial sectors are needed," they write.

They continue, "Despite already having a plethora of uses, CMCs have not yet reached their full potential. The obstacles in the medium and long term, particularly in aeronautics and aerospace applications, will be such that the use of custom materials will necessitate a significant R&D investment."

That situation appears to be in the cards, as successes to date in critical applications of the material are leading to stepped-up investments and broader research.

OAK RIDGE NATIONAL LABORATORY-LED PROGRAM SUPPORTED R&D OF FIRST WIDELY DEPLOYED CMC PRODUCT

By Dawn Levy, senior science writer at Oak Ridge National Laboratory

This article is an edited and trimmed version from Oak Ridge National Laboratory. It is reprinted with permission. Read the original article at https://www.ornl.gov/news/ceramic-matrix-composites-take-flight-leap-jet-engine. The LEAP engine, introduced in 2016, has more than 25 million aircraft hours of service. The story of the researchers and discoveries that led to its development is still compelling.

Ceramic matrix composite (CMC) materials are made of coated ceramic fibers surrounded by a ceramic matrix. They are tough, lightweight, and capable of withstanding temperatures 300–400 degrees Fahrenheit hotter than metal alloys can endure. If certain components were made with CMCs instead of metal alloys, the turbine engines of aircraft and power plants could operate more efficiently at higher temperatures, combusting fuel more completely, and emitting fewer pollutants.

More than a quarter-century ago, the U.S. Department of Energy began a program, led by DOE's Oak Ridge National Laboratory (ORNL), to support U.S. development of CMC materials. In 2016, LEAP, a new aircraft engine, became the first widely deployed CMC-containing product. CFM International, a 50/50 joint venture of Safran and GE, manufactures LEAP.

The engine has one CMC component, a turbine shroud lining its hottest zone, so it can operate at up to 2,400°F. The CMC needs less cooling air than nickel-based super-alloys and is part of a suite of technologies that contributes to 15% fuel savings for LEAP over its predecessor, the CFM 56 engine.

"The materials developed in the DOE program became the foundation for the material now going into aircraft engines," says Krishan Luthra, who led GE Global Research's development of CMCs for 25 years.

GE's CMC is made of silicon carbide (SiC) ceramic fibers (containing silicon and carbon in equal amounts) coated with a proprietary material containing boron nitride. The coated fibers are shaped into a "preform" that is embedded in SiC containing 10–15% silicon.

ORNL's Rick Lowden did foundational work in the 1980s that paved the way for DOE programs. The key was coating the ceramic fibers.

"A ceramic matrix composite is different than almost all other composites because the matrix is ceramic and the fiber is ceramic," Lowden says.

Combining two brittle materials typically yields a brittle material, he says. But altering the bond between fiber and matrix allows the material to act more like a piece of wood. Cracks do not propagate into the fibers from the matrix around them. The fibers hold the material together and carry the load while slowly pulling from the matrix, adding toughness.

FIRING UP RESEARCH ON CERAMIC COMPOSITES

DOE's Continuous Fiber Ceramic Composite (CFCC) program ran from 1992 to 2002 and supported industrial development of CMCs by AlliedSignal, Alzeta, Amercom, Babcock and Wilcox, Dow Chemical, Dow Corning, DuPont-Lanxide Composites, GE, and Textron. Its budget averaged $10 million per year, and industry shared costs.

CFCC funded companies to make composites and national labs and universities to characterize the properties of the materials. Efforts were coordinated and funded through ORNL. Lowden wrote the program plan with Scott Richland of DOE and Mike Karnitz of ORNL and co-led support to companies with ORNL's Karren More, Pete Tortorelli, and Edgar Lara-Curzio and Argonne National Laboratory's Bill Ellingson.

"We were looking at different fibers and different interfacial coatings and different matrices," More says of ORNL's role. "We were involved in understanding the degradation mechanisms and down-selection of the more promising composites and cost-effective techniques for preparing them.

Long before ceramic fibers reinforced ceramic composites, ORNL researchers coated nuclear fuel with carbon and SiC to confine radioactivity inside tristructural-isotropic (TRISO) fuel particles. During experiments in the '70s, ORNL's Jack Lackey realized the process could be modified to manufacture ceramic composites more rapidly. With support from DOE's Fossil Energy Materials Program, his group pioneered a process to do just that.

"You take a fibrous preform, place it in a furnace, and vapor-deposit solids on and around the fibers," explains Lowden, who was Lackey's technician. To coat the whole object uniformly, the deposition process must be extremely slow—a half-inch part might take six months to process.

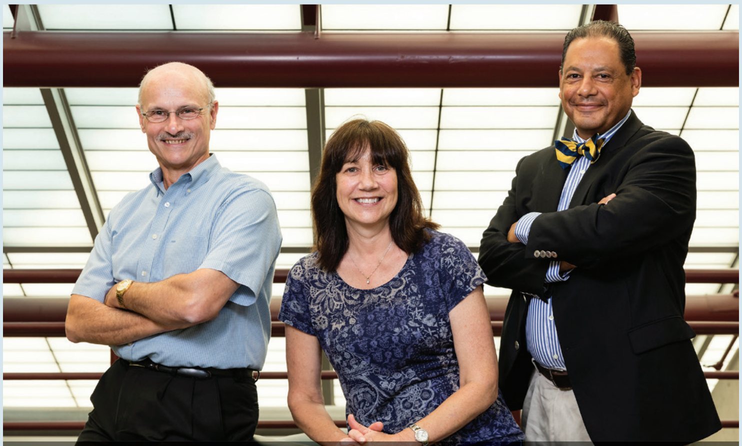
However, the ORNL team found that placing a fibrous mat on a cold plate, heating the top, and forcing gases through the mat sped up the process from months to hours.

"That's where we got involved in ceramic matrix composites," Lowden says. ORNL supplied CMCs for years to researchers evaluating CMCs for various applications.

Since CFCC, GE has tested CMCs for more than 2 million hours, including 40,000 hours in industrial gas turbines. Jim Vartuli of GE's CMC program says DOE support on large industrial gas turbines to get those first demonstrators gave GE confidence that the ceramics could survive high temperatures and stresses in turbines for long periods.

HOW DOE AND ITS NATIONAL LABS HELPED INDUSTRY

CFCC companies brought materials they had made to DOE national laboratories at Argonne for nondestructive evaluation and at Oak Ridge for microstructural characterization and stress and oxidation tests.



From left, Oak Ridge National Laboratory researchers Pete Tortorelli, Karren More, and Edgar Lara-Curzio were instrumental in advancing CMC technology. *Credit: ORNL*

"This partnership highlights the value of the national labs," More says. "We do work that is fundamental and broad to understand materials' behaviors. We provide necessary information to help the community make decisions about where to go, how to proceed." New knowledge about how materials degraded helped industry accelerate improvements and optimize manufacturing processes.

Research at ORNL ranged from development by Allen Haynes of environmental barrier coatings that could extend the lives of underlying materials five-fold to nondestructive imaging of materials with thermal cameras by Ralph Dinwiddie.

At Argonne National Laboratory, Bill Ellingson led development of broader nondestructive testing methods to ensure safe continued use of components by monitoring material degradation after intervals of usage. Without damaging the components, the inspections revealed how materials responded in an environment over time.

With ORNL researchers, Argonne scientists developed several nondestructive inspection technologies that were instrumental in determining component performance.

ORNL's Pete Tortorelli and H. T. Lin stressed materials in environmental exposure chambers to learn their points of failure. Lab colleagues Jim Keiser and Irv Federer exposed samples to corrosive gases, temperatures up to 2,550°F and pressures up to 500 psi in "Keiser rigs" that simulated conditions in turbines. These methods were also used by More, Tortorelli, and Keiser to screen protective coatings needed in combustion environments.

Meanwhile, More characterized structures of stressed materials.

"Karren More entered the picture as our microscopist, and that changed our world," Lowden recalls. "To be able to see what was happening with transmission electron microscopy, and understand what was happening at that level, was incredible."

GE had access to some techniques in-house because of its large infrastructure.

"But we got invaluable help from Karren on the fiber coatings," Luthra says. "It helped us develop the fiber coatings faster."

ORNL's early findings encouraged industry to abandon carbon as a fiber coating. Carbon oxidized, turning into carbon monoxide and carbon dioxide, and volatilized, thinning the coating. ORNL engineers recommended oxidation-resistant boron nitride instead.

Moreover, Edgar Lara-Curzio modeled and tested the mechanical performance of CMC materials under different loading conditions and their resistance to fatigue, creep, and rupture in ORNL's High Temperature Materials Laboratory. In collaboration with Matt Ferber and Chun-Hway Hsueh, he implemented experimental and analytical methods to characterize the micromechanics of fiber–matrix interfaces.

"These measurements were essential to quantify chemical bonding between fibers and matrix, residual stresses experienced by the fibers, and friction between the fibers and the matrix during fiber sliding," says Lara-Curzio, noting CMCs are tough mainly because interfacial coatings let fibers slide and bridge matrix cracks.

He and Hsueh provided key information about how a single fiber slides in a ceramic matrix. Lara-Curzio, Ferber, and Lowden then quantified the effect of the thickness of fiber coatings on sliding and discovered a value that optimized mechanical properties. Companies widely adopted this correlation to optimize their composites.

DOE's Advanced Manufacturing Office (AMO), formerly known as the Industrial Technologies Program, supports applied research, development, and demonstration of new materials, information, and processes that improve U.S. manufacturing's energy efficiency, as well as platform technologies for manufacturing clean energy products. AMO helped fund this research.

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December 2023	Furnaces, dryers, and thermal processing equipment

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WELCOMING NEW FACULTY

Dr. Collin Wilkinson

Alfred University would like to introduce you to our latest faculty member Dr. Collin Wilkinson has been hired as Assistant Professor of Glass Science. Collin earned a Bachelor's in Physics at Coe College followed by a Ph.D. in Material Science at the Pennsylvania State University. He served as director of research and development and CTO of small startups focusing on next-generation recycling technology through material informatics. Collin is the inventor or co-inventor of several new glass compositions for green applications ranging from reducing greenhouse gases to improved glasses for renewable energy applications. Collin joined the faculty at Alfred University in 2022 and his current research revolves around building computational tools for simulations of extreme conditions, understanding the fundamental physics of glassy materials, and engineering better solutions for sustainable glass technology. Collin is the author of over 50 peer-reviewed publications and 4 patents. He is additionally the chair of the undergraduate research committee at Alfred University where he has created a research program for undergraduates from around the world in glass and ceramics.

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