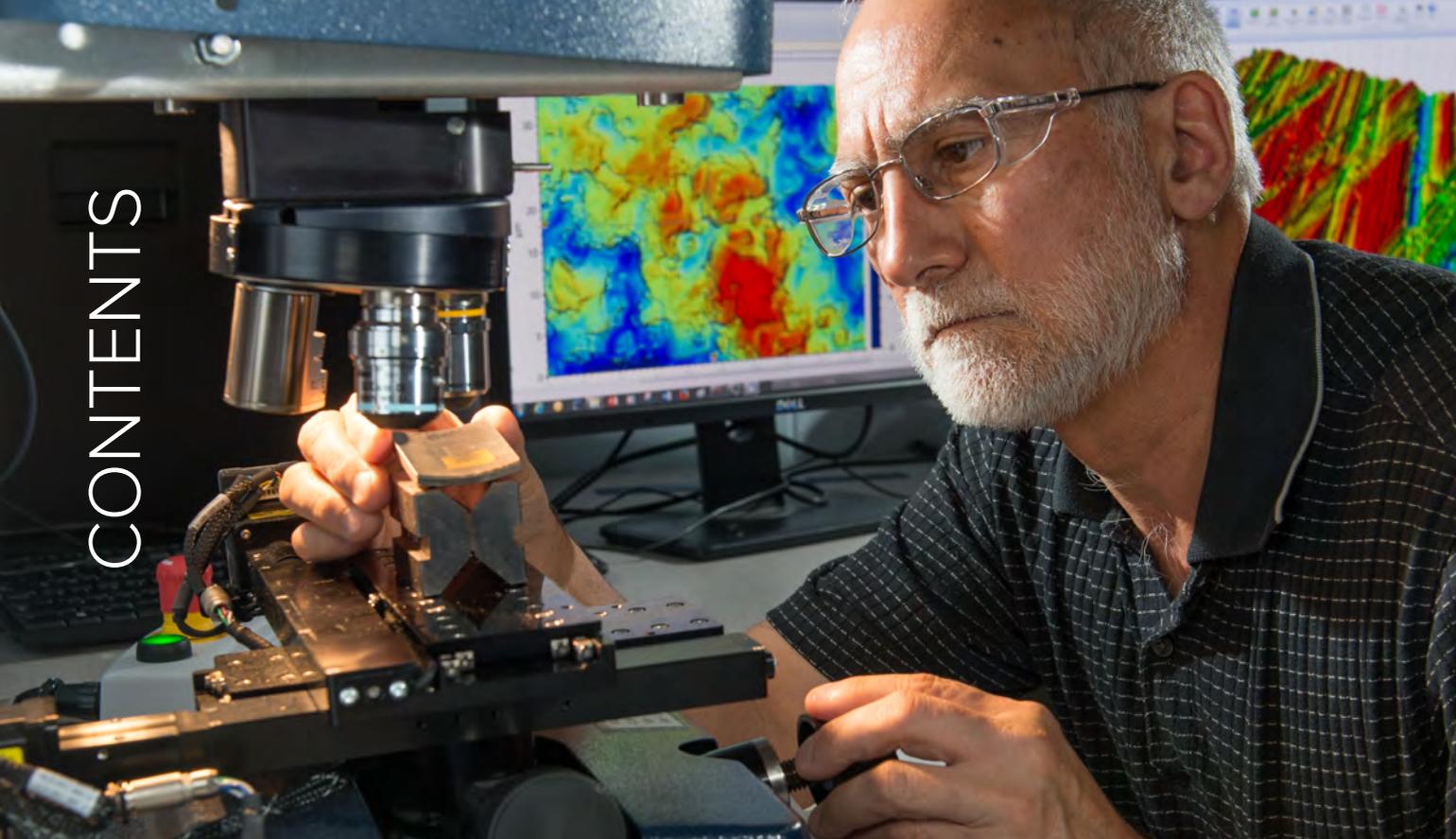


TRANSFORUM



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Transportation Research Program
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shown above

Metallurgist Robert Erck positions an engine part for examination using a white-light interferometric microscope. This optical instrument produces three-dimensional information on microscopic areas of the specimen, enabling measurement of wear.

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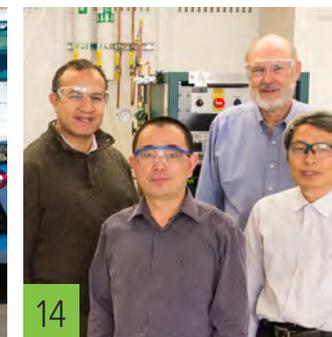
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SMOOTH MOVES

Argonne's SLIDE program seeks to reduce friction, increase efficiency

In their efforts to make America as energy-efficient as possible, researchers at Argonne National Laboratory leave no stone unturned. From internal combustion engines to wind turbines to next-generation power plants, Argonne's expertise spans the energy spectrum.

Unfortunately, so does friction—the force that restricts relative motion between surfaces and layers. This resistance to motion both slows things down and makes parts work harder, meaning poorer performance and limited component life. It's a challenging phenomenon for researchers to overcome, but one that also presents a great opportunity: by reducing friction it's possible to both increase energy efficiency and prolong the life of valuable components, a rare win-win in the arena of energy conservation.

The field concerned with this critical research is known as tribology, and Argonne is setting the standard with the launch of its Surfaces and Lubrication Interaction Discovery and Engineering (SLIDE) effort.

With an expert staff, and a suite of state-of-the-art analysis and validation tools, SLIDE builds on Argonne's rich history of tribological innovation by

partnering with industry and research institutions to develop solutions for today's most pressing problems in materials and friction reduction. Since its inception in 1983, Argonne's tribology program researchers have authored more than 300 peer-reviewed journal articles and won six *R&D 100* awards.

According to Section Manager George Fenske, "What sets SLIDE apart is the way we approach friction challenges. All the capabilities in the world won't help you fix something if you don't understand the underlying problem. Because our team has such a wide range of research and industrial backgrounds, we bring a unique set of perspectives to testing, characterization and development that enable us to look at things very differently than many others in the field."

SLIDE'S TESTING, CHARACTERIZATION AND DEVELOPMENT CAPABILITIES WORK IN CONCERT TO ACCELERATE INNOVATION.

To Fenske's point, when companies come to Argonne, they are looking for expertise and capabilities our SLIDE group can offer to not only replicate the conditions under which their products (materials, lubricants, additives) operate to provide data for optimizing their performance, but, more importantly, to investigate and understand how their systems behave on a microscopic/atomic level—how the additives, lubricants and materials respond to stress, speed and temperature to form ultrathin tribochemical films that control friction, wear and resist surface failure. While many organizations have the ability to test existing materials or develop new materials, they do not have Argonne's unique combination of multidisciplinary expertise and extremely sophisticated characterization tools (such as the Advanced Photon Source) to discover how additives, lubricants and materials interact and to engineer entirely new approaches to improve friction, wear and reliability.

In achieving those objectives, SLIDE pushes the tribological envelope via three core capabilities: lab-scale testing, to match real-world conditions as closely as possible and identify promising technologies; surface characterization, in which researchers observe and model the evolution of surface properties over time; and technology development, or the design of coatings and lubricants engineered to work in tandem with specific materials.

ENHANCED LAB-SCALE TESTING

In order to evaluate a wider range of technologies and bring



Principal Mechanical Engineer Nick Demas examines a steel specimen with a reciprocating tester.

innovation to the marketplace rapidly, tribologists often rely on lab-scale rigs that simulate engine conditions as closely as possible—from these initial experiments researchers can identify the most promising candidates for system-level validation.

And while lab-scale testing rigs and their operating conditions can offer a variety of testing conditions, differences between apparatuses can greatly affect research outcomes, making the prediction of system performance in the real world exceptionally difficult. Therefore, in order to extract meaningful data, researchers must select the most useful platform and the best conditions for each experiment and apply industry-standard methods to ensure reproducible outcomes.

SLIDE employs a comprehensive suite of customizable equipment, including 15 bench-top tribometers, for conducting tests in extreme environments to emulate real-world conditions, identify critical test

parameters and pair materials with lubricants and coatings for optimum performance.

SLIDE's assortment of lab-scale analysis tools can also quantify numerous phenomena including simple wear, abrasive wear, scuffing and contact fatigue across a range of controlled environments—including dry sliding (e.g., in vacuum, air or controlled gases), or, lubricated sliding with organic and inorganic fluids. Because tribological phenomena occur in a wide range of extreme environments, such as the heat inherent in the operation of internal combustion engines, SLIDE testing capabilities can replicate a broad spectrum of temperatures, from -20°C to 850°C, and stresses over six orders of magnitude.

The SLIDE program's test equipment also enables the rapid evaluation and validation of lubricants, coatings and materials across unique motions and geometries.



SLIDE researchers gather around some of the many components that their efforts protect and improve.

These evolving testing platforms, along with SLIDE expertise across the tribological spectrum—from transportation to energy production to medical devices—make Argonne the perfect setting in which to test different friction-reducing technologies.

SURFACE CHARACTERIZATION

As surfaces in motion come into contact, their properties—such as microstructure, chemistry, roughness and hardness—change. Understanding how these surface interactions alter a material's properties over time is critical for predicting performance across a range of technologies.

In their efforts to reduce friction and increase efficiency, SLIDE tribologists have developed unique methods for characterizing surfaces with predictive fidelity in

order to bring novel coatings and lubricants to market faster and more cheaply.

SLIDE researchers apply tailored scientific approaches to understand how lubricants interact with surfaces to form thin tribochemical films that reduce friction and protect components. They use analytical techniques to measure critical tribofilm properties such as film thickness, hardness, structure and chemical make-up and develop mechanistic models that predict tribological performance (friction, wear, and failure). The mechanistic models are in turn used in the development of advanced technologies that combine basefluids, additives, coatings and engineered/textured surfaces to reduce parasitic friction losses while maintaining or improving reliability, durability and compatibility with transformational technologies.

The unique combination of expertise and equipment in SLIDE enables the collection of data to predict and quantify both performance and failure, providing partners with a critical roadmap to optimization.

By quantifying the aging process and revealing how components change over time, SLIDE researchers enable their partners to control surface properties for both improved component performance and prolonged life, both of which are essential for increasing energy efficiency in numerous technologies.

TECHNOLOGY DEVELOPMENT

Novel lubricants and coatings have the ability, when paired with the right material, to increase efficiency and extend component life.

Through advanced testing and materials characterization techniques, SLIDE researchers optimize and validate next-generation lubricants and additive combinations, engineer custom coatings and integrate ideal lubricants and coatings with materials.

Because lubricants typically contain performance-enhancing additives that often compete with one another and react undesirably with other additives, materials and coatings, SLIDE researchers discover new approaches to achieving the desired properties of conventional additives with more environmentally friendly alternatives.

The discovery of new coatings for friction management lies at the core of the SLIDE mission—many

traditional coatings designed for manufacturing applications are not compatible with some of today's most common performance-enhancing additives, meaning SLIDE researchers must design novel coatings that complement newer additives under a wide range of conditions.

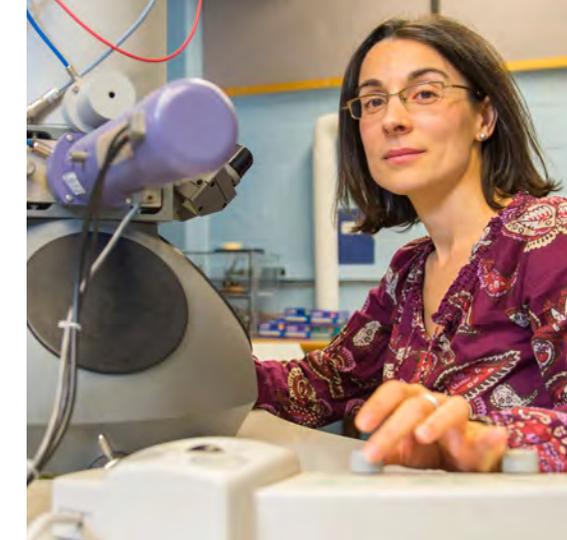
WINNING OUTCOMES

The combination of SLIDE's scientific expertise and methodologies produces unique, multi-dimensional approaches to truly understanding friction

and wear challenges, leading to insightful solutions that improve fuel economy, increase durability and reliability and enhance emissions performance.

Interested organizations can engage the SLIDE team through a variety of partnership and licensing arrangements described at <http://www.anl.gov/technology/partnerships>.

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Principal Materials Scientist Cinta Lorenzo Martin uses a transmission electron microscope to gain an enhanced understanding of structural and chemical characterizations of materials and surface interactions.

ARGONNE DISCOVERY YIELDS SELF-HEALING DIAMOND-LIKE CARBON

Argonne scientists recently discovered a revolutionary diamond-like film generated by the heat and pressure of an automotive engine. The discovery of this ultra-durable, self-lubricating, diamond-like carbon (DLC) tribofilm (a film that forms between moving surfaces) was reported recently in the journal *Nature*, and it could have profound implications for the efficiency and durability of future engines and machinery.

Citation

“Carbon-based Tribofilms from Lubricating Oils,” A. Erdemir, G. Ramirez, O. Eryilmaz, B. Narayanan, Y. Liao, G. Kamath and S.K.R.S. Sankaranarayanan, *Nature* **536**, 65–71 (2016). doi:10.1038/nature18948.

“This is a unique discovery, and one that was a little unexpected,” said Argonne Distinguished Fellow Ali Erdemir. “We have developed

many types of diamond-like carbon coatings, but we've never found one that generates itself by breaking down lubricating oil molecules and regenerating the tribofilm as it is worn away.”

The original discovery occurred when Erdemir and colleague Osman Eryilmaz coated a small steel ring with a catalytically active nanocoating—tiny molecules of metals that promote chemical reactions to break down other materials. They then subjected the ring to high pressure and heat using a base oil without the complex additives of modern lubricants. Examining the ring after the endurance test, they didn't see the expected rust and surface damage, but rather, an intact ring with an odd blackish deposit on the contact area.

Evaluation showed that the deposit was a tribofilm of diamond-like carbon, similar to several other

DLCs developed at Argonne. But it works even better—reducing friction by 25 to 40 percent and wear to unmeasurable values. Better yet, the new catalytic nanocoating allows the tribofilm to be renewed continually during operation. Further experiments revealed that multiple types of catalytic coatings can yield DLC tribofilms.

Because the new tribofilm develops in the presence of base oil, it could allow manufacturers to reduce or eliminate some of the modern anti-friction and anti-wear additives in oil—substances that can decrease the efficiency of catalytic converters and harm the environment due to their heavy metal content.

The research was funded by DOE's Office of Energy Efficiency & Renewable Energy.

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GIVING A BOOST TO BATTERY SAFETY

New diagnostic tools enable first and second responders to make smart decisions when dealing with damaged electric vehicles

Argonne researchers have developed a prototype tool to provide first and second responders with methods for the safe management and handling of high-voltage batteries in post-crash and non-operational environments.

The tool is the result of a two-year investigation into the dangers posed by stranded energy in batteries for the National Highway Traffic Safety Administration (NHTSA).

Unexpected events such as accidents, flooding and fire near an electric vehicle can damage or depower a battery's internal circuitry, making it difficult to access information on the battery's condition. Moreover, these situations can also lead to internal damage to the battery itself, resulting in a delayed thermal event or high-voltage exposure.

These dangers are a problem for responders who are tasked with investigating and clearing the scene, towing away the wreckage and storing and eventually scrapping a disabled vehicle.

Furthermore, the amount of energy stored in a vehicle's battery is often related to how severe a thermal incident may be in the rare case it does occur. In other words, both the battery's stored energy and general state, if not addressed appropriately, can pose a serious danger to workers or result in a battery fire even weeks after the accident.

"While these events are rare, they do happen," said project head and Argonne Principal Research Engineer Eric Rask, adding that these delayed fires are typically due to a vehicle's management systems being rendered inactive following an accident, making the state of the battery difficult to diagnose.

A TABLET-LIKE DEVICE ENABLES QUICK ANALYSIS OF BATTERY CONDITION.

Rask and his team developed the hardware and software for the prototype discharge and evaluation tool as well as a range of research findings and best practices that the NHTSA can use to better inform future decision making. A tablet computer-like device enables a quick analysis of the internal condition and charged state of the damaged battery (if information is available from the battery's various internal sensors), as well as procedures for the assessment of more severely damaged batteries and the safe discharge of stranded energy if warranted.

The tool can be easily used by second responders, such as tow truck drivers, and others to assess a battery's condition and provide guidance about follow-up procedures including discharging the "stranded" energy, although Rask points out it could possibly be used by first responders in certain circumstances as well. While it's not a product per se, it is proof of concept of one, and its creation leveraged the world-class vehicle communications, systems engineering capabilities and sensing expertise of Argonne researchers.

According to Rask, the project provided numerous lessons learned going forward, including the value of proactive tracking of parameters post-accident, investigating new systems that can predict the probability of thermal events occurring well in advance

and the need for expanded scenario testing and understanding regarding real-world conditions.

"While a lot of battery safety work rightly focuses on individual cells and materials, there are system-level aspects that are similarly important," said Rask. "When an entire battery and management system is integrated into a vehicle there are opportunities for issues to occur. But there are also new opportunities for assessment."

The project also included a demonstration for the NHTSA of the tool's capabilities on sample battery systems and is one of several system-level battery safety projects being conducted at Argonne for the NHTSA.

This research was funded by the National Highway Traffic Safety Administration.

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Uncertainty about a damaged electric vehicle's status can be a problem when removing, storing or scrapping the wreckage.



HIGH-ENERGY X-RAYS OFFER INDUSTRY AN AFFORDABLE WAY TO OPTIMIZE CAST IRON

Cast iron can be modified through the manufacturing process to optimize its mechanical and physical properties, such as strength and durability. This property makes it a material of choice for use in the transportation and machinery industries, which rely on cast iron's resistance to wear, deformation and rusting to design high-performance bridges, tools and engine parts.

In reality, the manufacturing process is as much art as science, producing good results yet not capturing cast iron's full potential. Controversy still exists over the correlation between manufacturing casting parameters and desirable properties. Limited by typical industrial 2-D imaging techniques or time-consuming 3-D laboratory studies, researchers have been unable to pinpoint the exact processing parameters needed to elicit the ideal properties for each cast iron application.

Finding an easier way to peer deep inside the alloy to get a definitive answer could be a boon for consumers and give American industry a competitive advantage. According to a study released in the journal *Scripta Materialia*, high-energy synchrotron X-rays can provide that insight.

Citation

"3D Quantitative Analysis of Graphite Morphology in High Strength Cast Iron by High-energy X-ray Tomography," C. Chuang, D. Singh, P. Kenesei, J. Almer, J. Hryn, and R. Huff, *Scripta Materialia* **106**, 5–8 (2015). doi:10.1016/j.scriptamat.2015.03.017.

"By understanding the structure, it will be possible to develop alloys with improved mechanical and thermal properties. This implies that for applications such as vehicle engine and engine components, one could use less material and reduce overall vehicle weight, which would translate

into fuel savings," said Dileep Singh, group leader of thermal-mechanical research at Argonne National Laboratory's Center for Transportation Research and technical lead of the study.

For the transportation industry, the ability to modify manufacturing processes to create high-performance materials could aid in the development of more fuel-efficient engines or engine parts that can withstand heat better to have longer lifespans.

"Researchers at Caterpillar are actively seeking to improve our understanding of cast iron alloys in order to provide innovative product solutions to our customers," said Richard Huff, a technical team leader with Caterpillar Inc., which supplied engine alloy castings for use in the proof-of-principle study.

The study results showed that high-energy X-ray tomography can reveal previously unknown behaviors of graphite in cast iron, such as the growth of nodules, as it undergoes various treatments. The X-rays can also unambiguously classify the particle type involved in the behavior, which is critical to identifying the structure-process relationship. These insights hold the key to manipulating the atomic structure of the graphite through manufacturing treatments such as changing the chemistry of the melt and altering the inoculants added to the liquid cast iron.

The research team included Huff from Caterpillar and Argonne researchers Singh, Chihpin Chuang, and John Hryn from the Energy Systems Division and Jon Almer and Peter Kenesei from the X-Ray Science Division. The Advanced Photon Source (APS), a U.S. Department of Energy (DOE)



Cast iron can be modified through the manufacturing process to optimize its mechanical and physical properties, such as strength and durability. This property makes it a material of choice for use in the transportation and machinery industries, which rely on cast iron's resistance to wear, deformation and rusting to design high-performance bridges, tools and engine parts.

Office of Science User Facility based at DOE's Argonne National Laboratory, was used as part of this research.

Synchrotron X-ray analysis has several advantages over the current techniques used to evaluate graphite microstructure.

Three-dimensional imaging of the structure of graphite, its spatial arrangement in the alloy and its phase connectivity are key factors that determine the properties of cast iron. These parameters cannot be attained reliably by the current industry standard 2-D test. Less frequently used, but more effective, is the use of focused ion beams (FIBs) and transmission electron microscopy (TEM), which can provide high-resolution 3-D images, but which is labor-intensive and time-consuming and destroys the sample. High-energy X-rays penetrate inhomogeneous samples up to a centimeter thick under real operating conditions. This avoids the challenges of FIB and TEM techniques while also providing a better statistical representation of parameters in bulk material.

The research team found that the synchrotron characterization methods enable new insight into why compacted graphite iron, used by Caterpillar in heavy-duty engine components, can conduct heat better than ductile iron while maintaining good ductile strength. The answer lay in the shape, size, and distribution of the graphite particles in the cast iron.

"The 3-D characterization of the material enables greater insight into the structure formation and structure-property relationships," Huff said.

The Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, supported the work, and the Office of Science supported the use of the APS.

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THE OHIO STATE UNIVERSITY DEFENDS TITLE, WINS SECOND YEAR OF ECOCAR 3 COMPETITION

The U.S. Department of Energy and General Motors Co. (GM) crowned The Ohio State University the Year Two winner of the EcoCAR 3—Advanced Vehicle Technology Competition (AVTC) during an awards ceremony at the Hotel del Coronado in San Diego. This is the second stage of an ongoing four-year competition that culminates in 2018. Ohio State took first place last year, and in the final year of EcoCAR 2, making this the third consecutive win for the team.

The Buckeyes returned to Columbus with an extra \$10,000, the coveted Year Two trophy and bragging rights as they started the third year of the competition. The team earned 880 out of 1,000 overall points, had an impressive 11 first-place category finishes and placed top 5 in 30 out of 36 categories. The team was also first to drive their vehicle at the competition.

EcoCAR 3 is the latest DOE AVTC series and challenges 16 North American university teams to redesign a 2016 Chevrolet Camaro to further reduce its environmental impact, while maintaining the performance expected from this iconic American car. Teams have four years (2014–2018) to harness those ideas into the ultimate energy-efficient, high-performance vehicle.

THIS IS THE THIRD CONSECUTIVE ECOCAR WIN FOR THE OHIO STATE BUCKEYES.

“The second year of the four-year competition added a level of complexity that definitely tested each of the 16 EcoCAR 3 teams in reworking the propulsion system of the 2016 Camaro,” said Al Oppenhesier, Chevrolet Camaro Vehicle Chief Engineer. “Even with these new challenges, the students from Ohio State displayed an exceptional ability to integrate their Series Parallel Plug-in Hybrid Electric Vehicle (PHEV) system, transforming this high-performance vehicle into a uniquely eco-friendly alternative.”

In the second year, the teams worked with EcoCAR 3 organizers to secure the hardware, software and industry mentors needed to help them integrate their hybrid-electric designs into the Camaro, with the end goal of making the vehicle even more energy efficient without losing the high-performance and safety features Camaro buyers expect.

“This year’s overall winner, Ohio State, demonstrated all-around excellence by using the research and data gathered in the previous year and successfully applying it during Year Two of the vehicle development process for their Series Parallel PHEV 2016 Chevrolet Camaro,” said Kristen Wahl, director of the Advanced Vehicle Technology Competitions at Argonne National Laboratory.

Virginia Tech and Embry-Riddle Aeronautical University took second and third place, respectively.

EcoCAR 3 sponsors include Headline Sponsors — the U.S. Department of Energy and General Motors; Visionary sponsors — MathWorks, California Air Resources Board, Freescale and Clean Cities; Leadership Sponsors — AVL Powertrain

Engineering, BOSCH, ETAS and dSPACE; Sustaining sponsors — Snap-on Tools, Siemens, GKN Driveline and Transportation Research Center; Supporters — Enerdel, Proterra and Ricardo; and Contributors — EcoMotors and A123 Systems.

FOR MORE INFORMATION ABOUT ECOCAR 3
www.ecocar3.org

EcoCAR 3 challenges 16 North American university teams to redesign a 2016 Chevrolet Camaro to further reduce its environmental impact while maintaining its performance.





STABLE “SUPEROXIDE” SHOWS PROMISE IN BATTERIES

While lithium-ion batteries have transformed our everyday lives, researchers are currently trying to find new chemistries that could offer even better energy possibilities. One of these chemistries, lithium-air, could promise greater energy density but has certain drawbacks as well.

Now, thanks to research at Argonne, one of those drawbacks may have been overcome.

All previous work on lithium-air batteries showed the same phenomenon: the formation of lithium peroxide (Li_2O_2), a solid precipitate that clogged the pores of the electrode.

In a recent experiment, however, Argonne battery scientists Jun Lu, Larry Curtiss and Khalil Amine, along with American and Korean collaborators, were able to produce stable crystallized lithium superoxide (LiO_2) instead of lithium peroxide during battery discharging. Unlike lithium peroxide, lithium superoxide can easily dissociate into lithium and oxygen, leading to high efficiency and good cycle life.

“This discovery really opens a pathway for the potential development of a new kind of battery,” Curtiss said. “Although a lot more research is needed, the cycle life of the battery is what we were looking for.”

**OPEN SYSTEMS
REQUIRE THE
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FROM THE
ENVIRONMENT,
WHILE CLOSED
SYSTEMS DO
NOT—MAKING
THEM SAFER AND
MORE EFFICIENT.**

The major advantage of a battery based on lithium superoxide, Curtiss and Amine explained, is that it allows, at least in theory, for the creation of a lithium-air battery that consists of what chemists call a “closed system.” “The stabilization of the superoxide phase could lead to developing a new closed battery system based on lithium superoxide, which has the potential of offering truly five times the energy density of lithium ion,” Amine said.

Curtiss and Lu attributed the growth of the lithium superoxide to the spacing of iridium atoms in the electrode used in the experiment. “It looks like iridium will serve as a good template for the growth of superoxide,” Curtiss said.

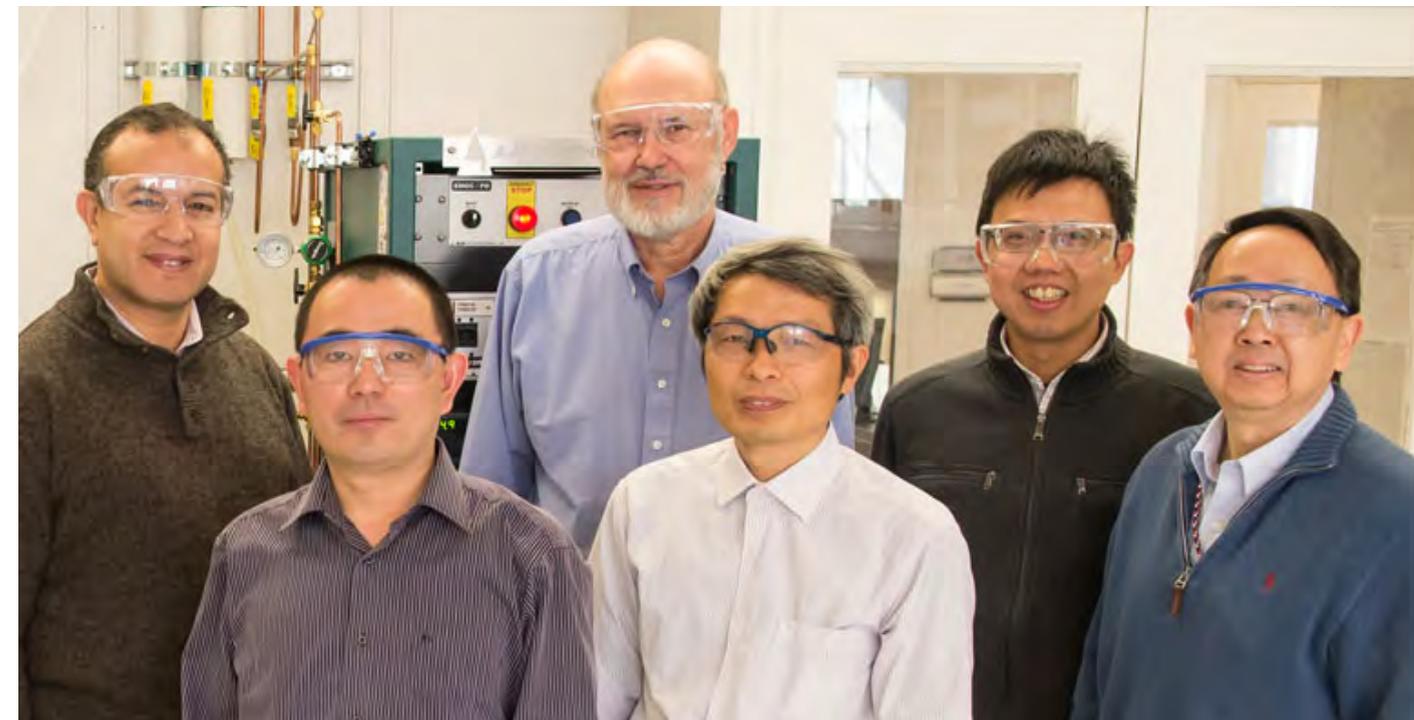
“However, this is just an intermediate step,” Lu added. “We have to learn how to design catalysts to understand exactly what’s involved in lithium-air batteries.”

A study based on the research appeared in the January 11, 2016 issue of *Nature*.

The work was funded by the DOE’s Office of Energy Efficiency and Renewable Energy and Office of Science.

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A team of Argonne researchers (from left, Khalil Amine, Jun Lu, Larry Curtiss, Zonghai Chen, Kah Chun Lau and Hsien-Hau Wang) have developed a way to create stable lithium superoxide in a lithium-air battery system.



SILVER IS GOLD FOR BATTERY MATERIAL PERFORMANCE

Argonne researchers are working to create an electric car battery that is smaller, cheaper and allows drivers to go farther on a charge.

Materials scientist Larry Curtiss is part of an Argonne team working on a new battery architecture that uses lithium-oxygen bonds as it stores and releases energy, and silver as the metal catalyst that makes this possible.

When you charge contemporary electric vehicles, lithium ions migrate from the positive electrode to the negative electrode where they are stored in a higher energy state. When you start the car, these stored ions release their energy in the form of electrons, and the lithium ion migrates back to the positive electrode. Today's electrode materials provide good charge-discharge cycles with the migration of lithium ions between electrodes, but they need to take advantage of other chemical processes to store more energy.

In the new scenario, oxygen and lithium atoms combine to create chemical bonds, releasing more energy in the same amount of

space (that is, they have a higher energy density), but a metal catalyst is required to help form the bonds.

After experimentation with a variety of precious metals, the researchers found that tailored clusters of silver atoms seem to provide the surface texture required to create these lithium-oxygen bonds in abundance.

"In previous studies, we've had metal catalysts that helped the formation of these bonds, but we never knew what size these catalysts were—they could be from thousands to a couple of atoms in size," said Curtiss. "Now we're actually able to put down specific size clusters of silver and see what effect it has on the formation of these lithium-oxygen bonds."

According to Argonne Materials Scientist Stefan Vajda, using the ultra-small clusters as catalysts for electric battery electrodes is new. It was proposed because multiple studies showed that the small clusters can easily activate, or break apart, oxygen to boost chemical reactions and release more energy.



"Once we understand how the process works and determine what size clusters perform the best, then we can design catalysts that work well, perhaps using lower-cost metals," said Vajda.

Funding for this project was provided by the U.S. Department of Energy's Office of Energy Efficiency & Renewable Energy and Office of Science, Basic Energy Sciences.

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ARGONNE'S NEW BATTERY ARCHITECTURE COULD STORE UP TO 10 TIMES MORE ENERGY THAN CURRENT LITHIUM-ION BATTERIES AND OFFER ELECTRIC VEHICLE DRIVERS A CRUISING RANGE UPWARDS OF 400–500 MILES BEFORE IT'S TIME FOR THE NEXT CHARGE.

ARGONNE NAMED AS U.S. LEADER FOR TWO UNITED STATES-CHINA RESEARCH INITIATIVES



Argonne National Laboratory was recently designated as the U.S. lead institution for the Clean Energy Research Center-Clean Vehicle Consortium (CERC-CVC), which aims to be the leading United States-China effort in the clean vehicle arena by performing both long-range transformational and translational research to bring discoveries and technologies to market.

The CERC-CVC brings together academia, national laboratories, and industry into a consortium of exceptional intellectual strength and expertise in key engineering, natural science and social science areas. Recognizing that energy use in vehicles represents both challenges and opportunities for our two countries, the United States and the People's Republic of China have chosen Argonne National Laboratory and Tsinghua University to lead a consortium of experts to collaborate in the field of clean vehicles research for phase two of the CERC-CVC that got underway in 2016. This second five-year program of research, from 2016 through 2020, will build on the outstanding accomplishments of the first five-year program, which ran from 2011 through 2015.

In a related development, The U.S. Department of Energy (DOE) selected Argonne to lead a consortium of university, private sector and national laboratory partners for a new medium- and heavy-duty truck technical track under the U.S.-China CERC Truck Research Utilizing Collaborative



Officials from the United States and China signed the working plan for the U.S-China Clean Energy Research Center-Clean Vehicles Consortium (CERC-CVC) 2.0 at the 8th U.S.-China Clean Energy Research Center Steering Committee Meeting in Beijing on Friday, July 1, 2016. Signing for Argonne National Laboratory, at left, is Don Hillebrand, director of Argonne's Energy Systems Division and the U.S. director of the CERC-CVC, along with Professor Ouyang Minggao, right, Chinese director of the CERC-CVC. Observing the signing are U.S. Energy Secretary Ernest Moniz, left center and Chinese Minister of Science and Technology Wan Gang, right center.

Knowledge (TRUCK) program. The multidisciplinary consortium includes Cummins Inc., Freightliner Custom Chassis Corporation, The Ohio State University, Oak Ridge National Laboratory, Purdue University and the University of Michigan. The program will address cost-effective measures to improve the on-road freight efficiency of medium- and heavy-duty trucks by greater than 50 percent compared to today's vehicles. In the United States, freight hauling by truck accounts for more than 15 percent of our oil use, and for nearly 60 percent in China. The U.S. consortium will work with counterparts in China to leverage the technological research capabilities of both countries.

The CERC-TRUCK team's work will focus on advanced internal combustion engines and powertrain systems; energy management (such as system-level efficiency improvements); hybrid electric powertrains; key truck technologies such as light weighting and aerodynamics; and applied research, testing and evaluation to better explore and improve the operating efficiency of medium- and heavy-duty

trucks. The consortium and its Chinese counterparts will bolster collaborative efforts in pursuit of state-of-the-art technologies to improve freight efficiency that will reduce carbon emissions and lower fuel costs for companies and drivers.

The CERC-TRUCK program addresses cost-effective measures to improve on-road freight efficiency of medium- and heavy-duty trucks by greater than 50 percent compared to today's vehicles.



ROUNDUP

TRIFECTA PROBES DUAL FUELS

It's not as challenging as mixing oil and water, but Argonne scientists are partnering with industry to study a tricky fuel mixing problem that could lead to more efficient engines.

The pre-competitive research is focused on exploring technical concepts and development of engine technology that simultaneously uses natural gas and traditional gasoline to maximize the best characteristics of both fuels, while reducing oil consumption and making the most of the recent boom in natural gas supplies in the United States. The project partners Argonne with Ford Motor Company and FCA US LLC, under a cooperative research and development agreement (CRADA).

"The fact that two major players in the auto industry are partnering with Argonne on this project really shows the promise of this approach," said project director Thomas Wallner. "The assumption here is that if you blend the fuels properly, you can make substantial gains in efficiency."

Wallner said vehicles that use both gasoline and natural gas have been around for some time, but what most people think of as a dual-fuel vehicle is actually more of a bi-fuel vehicle. Bi-fuel vehicles have both compressed natural gas and gasoline on board, but typically use only one fuel at a time. A bi-fuel vehicle may use all its natural gas, then switch over to gasoline. The research concept being studied

Argonne researcher Jim Sevik tightens the fuel rail on a natural gas direct-injection system at the lab. The engine is an automotive-size single-cylinder research engine that operates with gasoline as well as natural gas.



under the project will use both fuels at the same time, which will maximize the efficiency of an engine that uses this approach.

Natural gas has much higher resistance to knocking, which is caused when the fuel/air mixture in an engine's cylinder auto-ignites. Mixing natural gas with gasoline would allow the engine to run without fuel enrichment and with optimal spark timing, thereby enabling higher engine efficiency and minimizing conditions that might otherwise cause knocking and potential engine damage. The team plans to explore technical opportunities to adjust ratios of the two fuels "on the fly" based on the load of the engine. For example, the engine under heavy load could run more efficiently with more natural gas, whereas under lower load it could use a blend heavier in gasoline.

The project's objective is to understand potential benefits and demonstrate targeted blending of gasoline and natural gas in an engine that uses half as much gasoline and shows a 10 percent increase in overall efficiency and a 10 percent improvement in power density.

The project is funded by DOE's Vehicle Technologies Office within the Office of Energy Efficiency & Renewable Energy.

FOR MORE INFORMATION
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ARGONNE, ACHATES AIM TO REVOLUTIONIZE INTERNAL COMBUSTION ENGINES

Argonne researchers have teamed up with Achates Power, Inc., and Delphi Automotive to develop an innovative new engine that could yield efficiency gains of up to 50 percent over a comparable conventional engine.

The research is part of a three-year project funded by a \$9 million award from the U.S. Department of Energy's (DOE's) Advanced Research Projects Agency-Energy (ARPA-E) and an additional \$4 million of cost share from the team members.

The new engine combines two promising technologies—gasoline compression ignition and opposed pistons—to create a "super engine" that could fundamentally change the way internal combustion engines work in the light-duty transportation market.

"Conventional spark-ignited engines have improved so dramatically over the past few decades that there is little room to make big efficiency gains," said Steve Ciatti, who is the experimental lead for Argonne. "You need a game-changer to get into large double-digit efficiency gains, and we believe this engine is capable of doing that."

The new engine will meld the best characteristics of gasoline and compression ignition engines with an innovative piston architecture refined by Achates Power that sets two pistons moving in opposition in one cylinder. As the crowns of the pistons slide toward each other, they compress a mixture of air and gasoline to such extreme pressures that the mixture auto-ignites without the need for spark plugs in a process known as compression ignition.

As the pistons reverse course and slide to opposite ends of the cylinder, ports machined into the cylinder allow exhaust gases to escape while fresh air is taken in, then the pistons move together again to compress and ignite in a two-stroke cycle. The design eliminates cylinder heads—which are a major cause of heat loss and inefficiency in conventional engines—and allows the engine to run with diesel-like efficiency and power, while maintaining gasoline's emissions benefits.

An analysis by Achates Power indicates the new engine will yield fuel efficiency gains of more than 50 percent compared with a downsized, turbo-charged, direct-injection gasoline engine, while reducing the overall cost of the powertrain system.

ROUNDUP

Creating such a novel engine will require the expertise of all the team members, who bring together decades of experience in various aspects of engine design and production.

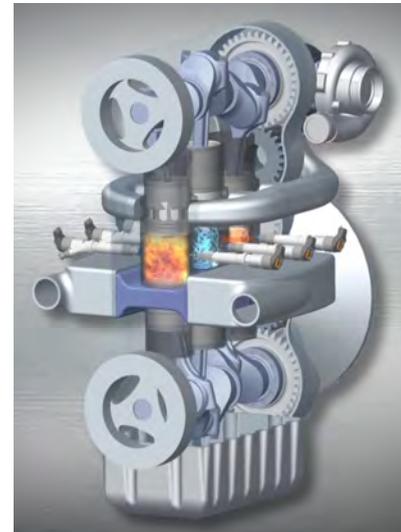
“The dynamics of this team are really perfect to make this project work,” said Doug Longman, the project manager for Argonne. “Combining Argonne’s scientific and engineering experience with Achates Power’s engine architecture and Delphi’s expertise in fuel injection and gasoline direct-injection compression ignition will give us the tools to develop an engine we think is going to show very large efficiency gains.”

Another key to the success of the project will be the modeling and simulation of the complex fluid dynamics and combustion inside the engine, which will be conducted through Argonne’s Virtual Engine Research Institute and Fuels Initiative (VERIFI). By using high-performance computing to model and predict the movement of fuel and air in the cylinders, the VERIFI

team will be able to optimize the design of the engine and fuel injectors using computing rather than prototyping, which will enable accelerated development.

“Modeling and simulation have become ever more important to engine designers in recent years,” said Sibendu Som, Argonne’s computational lead for the project. “Using VERIFI to optimize combustion technologies for industry has significantly shortened development times and helped lead to more efficient engines.”

Shorter development time through computational modeling and efficiency gains developed through experimental research will be critical to the creation of an engine that can be widely adopted commercially. Many engines have been proposed over the years that show benefits over conventional spark-ignited gasoline engines, but the efficiency gains have not been dramatic enough to convince auto manufacturers to retool production lines and car designs to incorporate the new approaches. This novel



Argonne is working with Achates Power and Delphi Automotive to develop an advanced engine that could yield efficiency gains of up to 50 percent. This illustration shows how such an engine operates, with opposed pistons moving toward each other, compressing gasoline until it auto-ignites. Illustration courtesy of Achates Power.

research team is poised to break that barrier and create an engine that could transform the automotive market.

This research was supported by DOE’s Advanced Research Projects Agency-Energy (ARPA-E), Achates Power, Inc., and Delphi Automotive.

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Argonne is partnering with Marathon Petroleum Corporation (MPC) to support an ongoing effort by DOE to explore fuels and engines holistically in search of greater efficiency. By advancing on both fronts simultaneously, the researchers hope to make substantial gains that would not be possible by working on engines and fuels individually.

ARGONNE AND MARATHON JOIN FORCES TO OPTIMIZE FUELS AND ENGINES

The modern internal combustion engine is a complex and finely tuned system where small changes in one area can have important ramifications on the whole. Decades of dedicated work to

maximize efficiency have refined engines to the point where major improvements require innovative approaches that look at the entire system.

“This is an exciting area of exploration that we think can yield significant benefits in overall efficiency,” said Thomas Wallner, manager for Fuels, Engine and Aftertreatment Research at Argonne’s Center for Transportation Research. “Co-optimization of fuels and engines has been identified as an area that is ripe for improvement.”

The collaboration between Argonne and MPC is designed to support the “Co-Optimization of Fuels and Engines” initiative, which was recently launched jointly by the DOE’s Vehicle Technologies Office and Bioenergy Technologies Office. The new collaboration leverages MPC’s and Argonne’s complementary capabilities in fuel design, analysis and production, as well as advanced engine combustion and emissions formation.

MPC and Argonne will collaborate on research projects, as well as exchanging knowledge and expertise in fuel characterization and fuel characterization equipment. The collaborators will also share information on efficiency, performance and emissions assessments of advanced combustion concepts using current and potential future fuels. This agreement builds on existing joint efforts, including MPC’s support of Argonne’s experimental research activities, by supplying samples of test fuel and refinery streams for research and testing at Argonne.

MPC also provided Argonne’s Center for Transportation Research with a cooperative fuel research (CFR) engine, a test platform extensively used throughout the industry for testing related to the performance of fuels for internal combustion engines. Argonne’s engineers will work alongside MPC experts to ensure efficient knowledge transfer and comprehensive assessment of potential improvements to the test setup and methods.

Argonne and MPC will use this project to advance the state-of-the-art of research in the area of

fuel-engine interactions and jointly disseminate research findings in the form of peer-reviewed publications, presentations and reports.

This research was supported by the U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office and Bioenergy Technologies Office and the Marathon Petroleum Corporation.

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Don Hillebrand, left, director of Argonne’s Energy Systems Division, shakes hands with Fred Walas, Fuels Technology Manager at Marathon Petroleum Corporation.



ROUNDUP

NEW PLATINUM-FREE CATALYST MAY ADVANCE FUEL CELL COMMERCIALIZATION

For improving fuel utilization efficiency and reducing greenhouse gas emissions, fuel cells provide tantalizing technology options. First developed in the nineteenth century, fuel cells generate electricity using hydrogen from a fuel tank and oxygen in the air, emitting only water. Because an electrochemical reaction generates the power instead of combustion, fuel cells offer very high energy conversion efficiency.

While fuel cells represent a cleaner way to produce power compared to traditional combustion methods, until now, they have also had a significant drawback—their need for expensive platinum group metals (PGMs) to catalyze essential electrode chemical reactions.

Argonne researchers recently announced the development of a new nanofibrous fuel cell catalyst that uses low-cost, earth-abundant

materials and offers performance comparable to that of platinum-containing catalysts in laboratory tests. This new catalyst could be commercially viable as the replacement for platinum, greatly reducing the price of fuel cell-powered electric cars.

According to Principal Investigator Di-Jia Liu of Argonne's Chemical Sciences and Engineering Division, "Platinum represents about

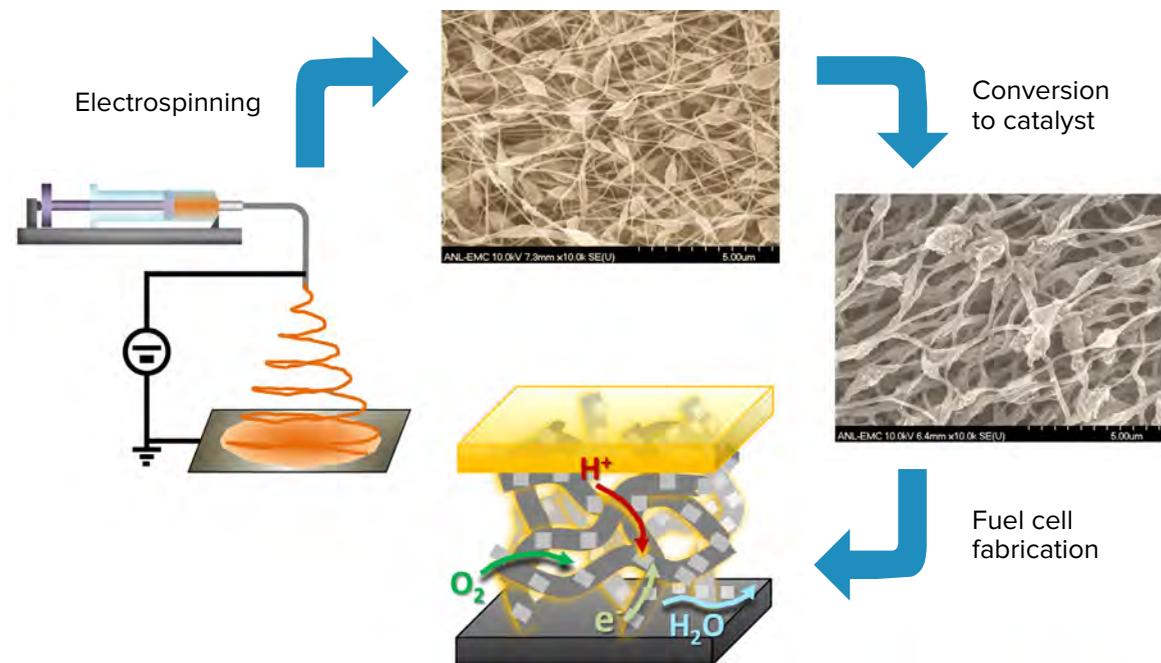
50 percent of the cost of a fuel cell stack, so replacing or reducing platinum is essential to lowering the price of fuel cell vehicles."

Not only does the new Argonne catalyst replace the platinum used in the fuel cell's cathode, the new catalyst design also optimizes the air flow and proton/electron transfer within the electrode and facilitates the removal of water.

"In order for a platinum-free catalyst to work well in a fuel cell," Liu explained, "the catalyst must have densely packed active sites that are uniformly distributed throughout the electrode and connected directly to the passages for protons and electrons, while maintaining easy access to oxygen. The catalyst should also have an architecture that can readily channel away the product water." The platinum-free nanofibrous network catalyst developed at Argonne offers a new morphology that can meet all these criteria, Liu added.

The research was supported by the U.S. Department of Energy's Office of Science and the Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office.

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This figure shows the process to make fuel cells with the catalyst. The fibers are generated via electrospinning and are heat-treated. Then the catalysts are fabricated into the fuel cell; the bottom image illustrates the interior of the fuel cell. "High-efficiency Non-precious Metal Catalyst Containing Metal-organic Framework Precursor in a Continuous Carbon Nanofibrous Network," J. Shui, C. Chen, L.R. Grabstanowicz, D. Zhao and D.-J. Liu, *Proceedings of National Academy of Sciences* **112**(34), 10629–10634 (2015). doi:10.1073/pnas.150715911

NATIONAL LABORATORIES TEAM TO DEVELOP BETTER, CHEAPER FUEL CELLS

The cost and durability of current polymer electrolyte membrane fuel cells (PEMFCs) are major impediments to their commercial use for stationary or transportation power generation.

The U.S. Department of Energy Fuel Cell Technologies Office (FCTO) has established a consortium of national laboratories, including Argonne, to tackle these barriers. The consortium, named "Fuel Cell Performance and Durability or FC-PAD" (www.fcpad.org), brings together proven expertise in the core national laboratories, building on existing capabilities to achieve world-class improvements in fuel cell

performance and durability while also reducing the platinum group metal loading to exceed the 2020 cost, performance and lifetime targets set by FCTO.

Argonne will coordinate FC-PAD's efforts and perform research toward improving the performance and durability of the fuel cell electrocatalyst and electrocatalyst support and also in the modeling and validation of fuel cell performance and degradation. The Argonne team is led by scientist

Debbie Myers of the Chemical Sciences and Engineering division and engineer Rajesh Ahluwalia of the Nuclear Engineering division.

Other consortium members include Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, the National Renewable Energy Laboratory, and Oak Ridge National Laboratory.

FOR MORE INFORMATION
www.electrocat.org



FASTRAX

ES Engineers Receive USCAR 2015 Team Award

On May 26, 2016, four Energy Systems division engineers were honored with a 2015 Team Award from the U.S. Council for Automotive Research (USCAR).

Section Manager **Thomas Wallner** and Principal Mechanical Engineers **Steve Ciatti**, **Scott Goldsborough** and **Andrew Ickes** are members of USCAR's Advanced Combustion & Emissions Control Tech Team, whose mission is to reduce petroleum dependence by removing critical technical barriers to the mass commercialization of high-efficiency, emissions-compliant internal combustion engine powertrains.

The team was selected for the award based on its development of the Fuels Research Roadmap.



STEVE CIATTI



SCOTT GOLDSBOROUGH



THOMAS WALLNER



ANDREW ICKES

Argonne Employees Honored by U.S. DOE

Three Argonne transportation researchers were honored for their research and deployment expertise supporting the U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) during VTO's June 2016 Annual Merit Review.



MARCY ROOD

Marcy Rood received a Special Recognition Award for her 20-year history with the Clean Cities program both at DOE and Argonne. She has spearheaded numerous innovations for the National Clean Cities Program as co-leader of the program for 13 years and has led program efforts at Argonne for eight years. Under her leadership, Argonne developed innovative fleet tools, such as AFLEET and the IdleBox toolkit, and established a successful workforce development program and groundbreaking electric vehicle analysis and modeling efforts.

Amgad Elgowainy and **Jeongwoo Han** were a part of the team award of the Cradle-to-Grave (C2G) Working Group of the US DRIVE program. On June 1, 2016, this team published the results of its multi-

year effort in a report titled "Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025–2030) Technologies." This work takes a deep dive into the opportunities for low-carbon vehicles and fuels, providing a comprehensive lifecycle analysis of the cost and greenhouse gas (GHG) emissions of a variety of vehicle-fuel pathways, as well as the levelized cost of driving GHG emissions and avoided GHG emissions. DOE, its partners and the clean energy community will be able to cite this valuable work innumerable times.



AMGAD ELGOWAINY



JEONGWOO HAN



MICHAEL WANG

Wang Named Distinguished Fellow

Michael Wang of the Energy Systems division has been named an Argonne Distinguished Fellow. Wang is a senior scientist and the manager of the Systems Assessment Group of the Energy Systems Division, an associate editor for the Biotechnology for Biofuels journal and a member of the Transportation Energy Committee of the Transportation Research Board and the Society of Automotive Engineers.

In his research, Wang assesses the impact of vehicle technologies and fuels. His life cycle analysis results have been used worldwide in evaluating energy and environmental effects of vehicle technologies and energy systems. He studies transportation development in emerging economies such as China.

RESEARCH RESULTS

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FOR MORE INFORMATION

Argonne’s Technology
Development and
Commercialization Office
800.627.2596

RESEARCH RESULTS

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PARTING SHOTS

Upper right: A visitor to Argonne's May 21 Open House discovers how magnets and radio-frequency power systems move the Advanced Photon Source's X-ray beam to nearly the speed of light.



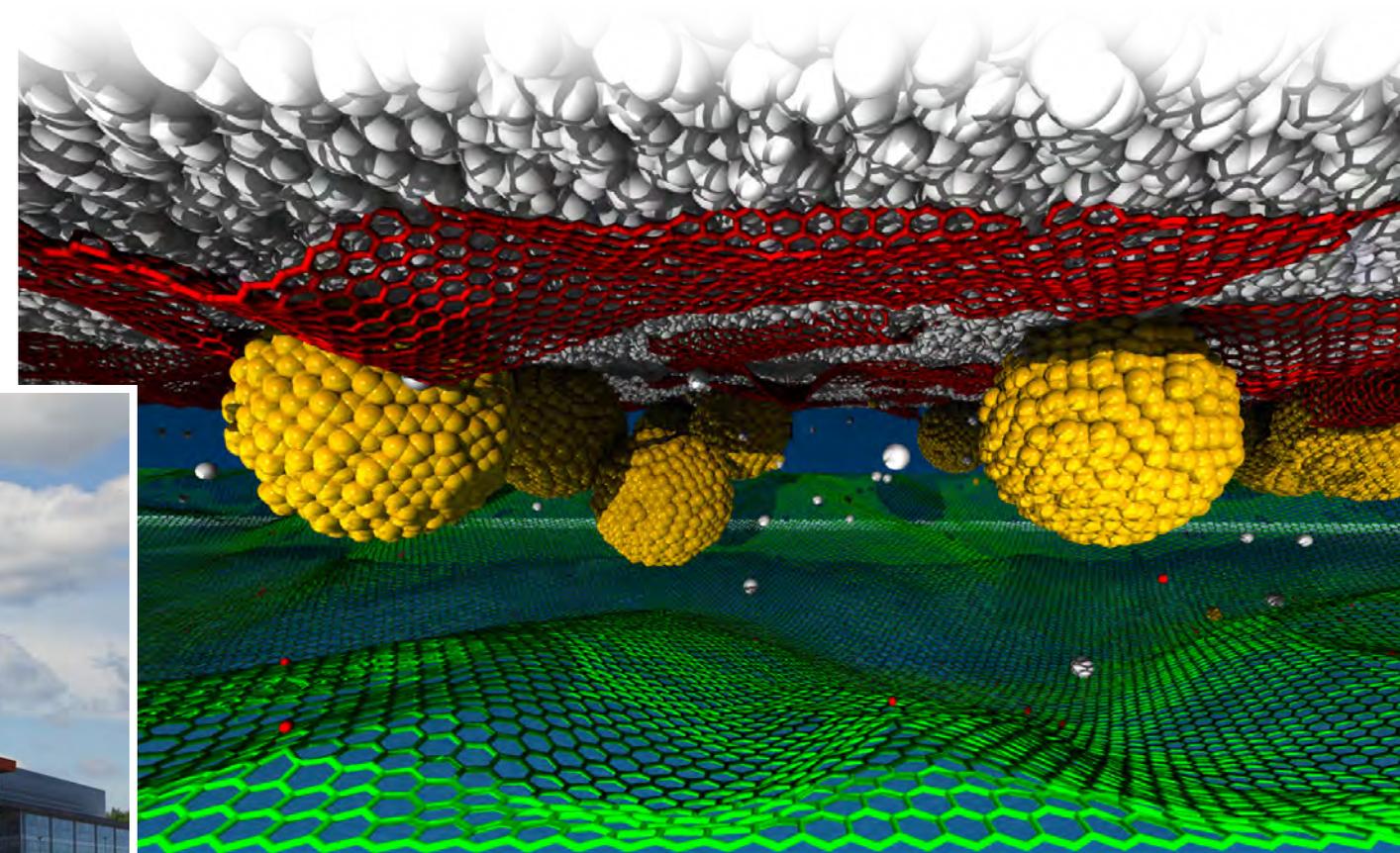
Lower right: The new Materials Design Laboratory at Argonne will be the final building to complete Argonne's Energy Quad, a group of four adjoining buildings designed to maximize collaboration between energy and materials scientists at the laboratory. A September 2 groundbreaking ceremony marked the official project start.



Below: Henning Lohse-Busch of Argonne's Advanced Powertrain Research Facility discusses energy efficiency and vehicles with Maroš Šefčovič, Vice President of the European Commission (EC), during a June 4 visit to the laboratory.



BEAUTY IN SCIENCE AND ENGINEERING



Graphene nanoscrolls enable slick surfaces

The above simulation of an Argonne-developed superlubricity system shows formation of graphene-encapsulated nanodiamond. The gold represents nanodiamond particles; red is a graphene nanoscroll; green shows underlying graphene on silicon dioxide and the white material at the top is a diamond-like carbon interface. Image credit: Sanket Deshmukh, Joseph A. Insley and Subramanian Sankaranarayanan, Argonne National Laboratory.

FOR MORE INFORMATION

www.anl.gov/cnm/articles/slip-sliding-away-graphene-nanoscrolls-enable-slick-surfaces



Left: The Joint Center for Energy Storage Research (JCESR) at Argonne hosted 80 Chicago-area students and seven teachers at Argonne National Laboratory in August for a full-day outreach event entitled "Building a Better Battery." Students used JCESR's Sprint model to solve scientific challenges more efficiently. They collected voltage and current data to determine the best electrolyte and other battery materials to use in their battery, which needed to store enough energy to power a remote-control car.

WORKING WITH ARGONNE

Industrial technology development is an important way for the national laboratories to transfer the benefits of publicly funded research to industry to help strengthen the nation's technology base. The stories highlighted in this issue of **TRANSFORUM** represent some of the ways Argonne works with the transportation industry to improve processes, create products and markets and lead the way to cost-effective transportation solutions, which in turn lead to a healthier economic future.

By working with Argonne through various types of cost-sharing arrangements, companies can jump-start their efforts to develop the next generation of transportation technologies without shouldering the often prohibitive costs of initial R&D alone. Argonne has participated in dozens of these partnerships and has even been involved in helping to launch start-up companies based on the products and technologies developed here.

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