SOUTHWEST RESEARCH INSTITUTE®

FALL 2022

TECHNOLOGY TODAY®

Southwest Research Institute not only designs, prototypes and evaluates antenna technology for military clients, but also produces and supports limited numbers of these highly specialized items. SwRI maintains the facilities needed to support the fabrication of this equipment including capabilities to custom machine aluminum structures, such as this unique cylindrical continuous-slot antenna array substrate.

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TECHNOLOGY TODAY

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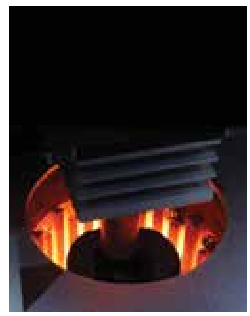
ON THE COVER



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SwRI tribologists conduct pin-on-disc tests to determine the friction coefficients and wear mechanisms of materials at 1,200 degrees Celsius.

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IN THIS ISSUE

This issue of Technology Today wraps up our 75th anniversary celebration by offering a page showing some significant or unusual projects undertaken throughout those seven-and-a-half decades. An aluminum submarine. Fleets of automobiles for over-the-road fuels and lubricants testing. A robotic paint stripper for fighter jets. Direction-finding antennas designed to home in on the source of radio signals.

One might ask why a research organization so focused on the future should look backward at all. The short answer is it shows the importance of the work we've done in the past. But it also demonstrates that our current work, built on those past foundations, remains on the frontier of new knowledge.

There's a link between the know-how that produced an aluminum submarine, the Aluminaut, in the 1960s and the titanium crew capsule we recently built for the latest version of Alvin, one of the world's deepest diving research submarines.

Our antenna research that began in the early 1950s has led to shipboard antennas — still being designed and built by SwRI — sailing on Allied warships today.

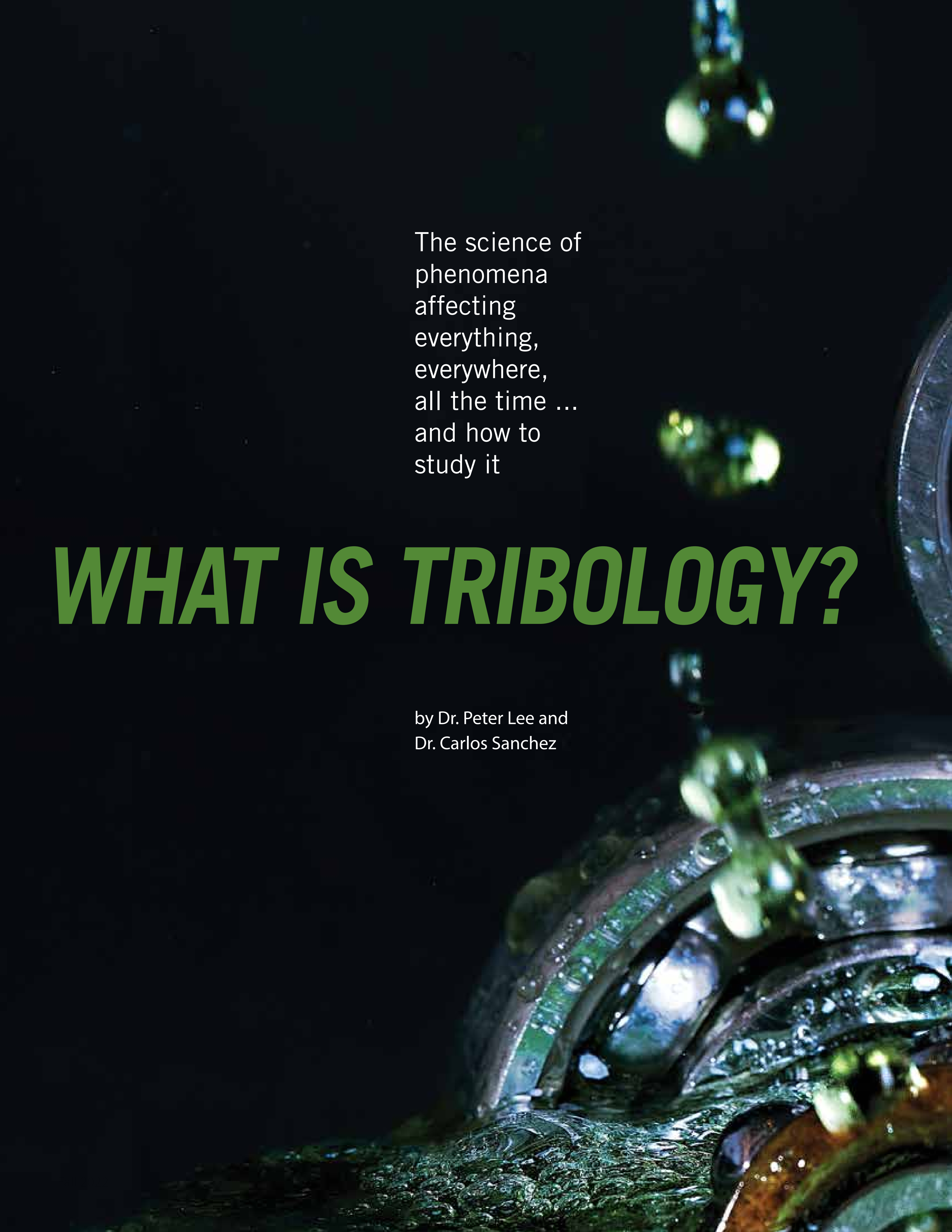
Our early research in robotics and autonomous systems continues to lead in the design of robotic assembly plants and driverless vehicles — including an autonomous shuttle van operating around our campus today.

Check out the other stories in this edition: Collaborative research with leading universities, research that wins awards for innovation, and initiatives to help send astronauts back to the Moon and on to Mars.

There's a saying that you're only as good as your latest movie or your last at-bat or touchdown. But we have to say that over the years, we've had a string of blockbusters ... an incredible batting record ... and more than a few visits to the endzone. While we know that there are no points for past performance, our focus on knocking it out of the park for our clients is what has kept us in the starting lineup — for 75 years now — for industry- and government-sponsored research from Deep Sea to Deep Space, and Everywhere in Between.

Sincerely,

Walter D. Downing, P.E.
Executive Vice President/COO



The science of phenomena affecting everything, everywhere, all the time ... and how to study it

WHAT IS TRIBOLOGY?

by Dr. Peter Lee and Dr. Carlos Sanchez

Tribology is the science and engineering of interacting surfaces in relative motion, or more simply, the study of lubrication, friction and wear.

It may sound like hyperbole, but tribology is ubiquitous, affecting everything, all the time. Whether you are reading a paper copy of this magazine or a digital version on a tablet, you are using friction to hold it. Whether you are sitting or standing, you are using the perfect balance of friction to stay where you are and not fall over or slip off your chair. Consider how you adjust your gait when navigating a slippery surface. Tribology affects the clothing you wear and how it feels against your skin. Tribology determines how food feels in your mouth and how toothpaste behaves on the brush and your teeth. Think about how your joints work and how your eyelids glide imperceptibly over your eyes when you blink. Tribology affects how cosmetics feel during application and over the course of the day. And tribology allows a car with regular maintenance to work like a well-oiled machine without wearing out.

Now that we have established how tribology plays into every aspect of daily life, it is easy to see its role in almost every program area at Southwest Research Institute. Because tribology is so universal, it follows that it affects products and processes from deep sea to deep space and everywhere in between.

A key component of tribology is friction, or the resistance to motion, which can cause huge energy losses. In cars, this translates to reduced fuel economy or range, whether they are powered by conventional fuel or batteries. Lubrication provided by a liquid or coating is the primary method of reducing friction. SwRI established the Tribology Research and Evaluations group 11 years ago in the engine and drivetrain field, helping engine and lubricant manufacturers reduce their frictional losses and improve their lubricants and coatings. SwRI now has more than 3,200 square feet of laboratory space at its San Antonio campus dedicated to tribology research, development and

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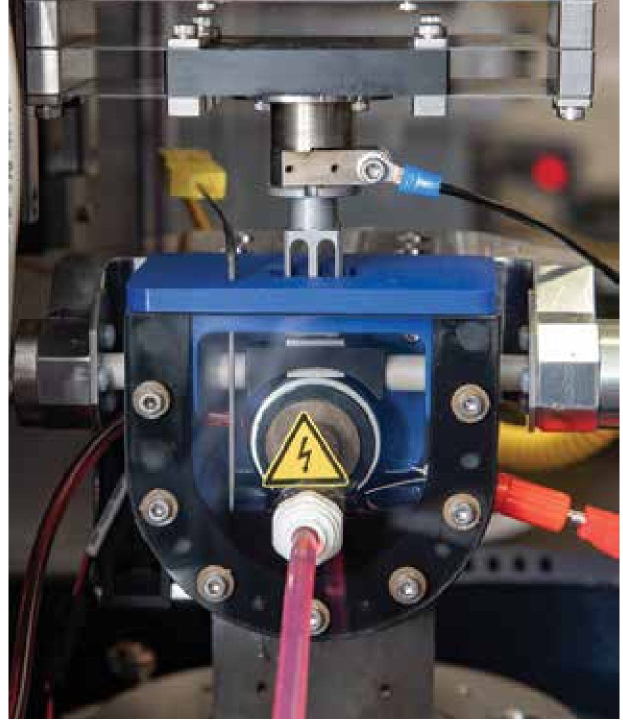
SwRI's tribology team specializes in creating novel test fixtures, such as this unique high-pressure, high-frequency reciprocating rig to evaluate fuel lubricity of various conventional, alternative, volatile and gaseous fuels.

SwRI adapted this block-on-ring test system to supply electrical current across the test parts to replicate electric vehicle drivelines and test fluids, materials and coatings.



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DETAIL

The term tribology, which comes from the Greek for "the study of rubbing," was first used in 1966 in a report about the costs of friction, wear and corrosion in the United Kingdom.

testing. The facility is equipped for standard — and many novel — tribology test methods and houses several state-of-the-art tribometers and other equipment. Due to the multidisciplinary nature of tribology, over time, SwRI's tribology team has expanded to work collaboratively with many clients outside of the automotive industry.

Although much of the work is still vehicle-based, cosmetics, contact lens solutions, weed trimmers, rocket parts and downhole drilling devices are often scattered around the labs. We've tested and helped develop many strange and unexpected items and often wonder what weird and wonderful request will come in next.

COST-SAVING BENCH TESTS

Tribometers replicate relative motion, forces, operating temperature and environment, all important in replicating exact conditions. These bench-top rigs are designed to rub parts together in different ways. Because tribology is interactive in nature, the tribology team attempts to use sections of real parts to accurately replicate the conditions under study. This ensures the correct material properties and surface finishes are being tested. The test rig reproduces reciprocating, oscillating, rotating, sliding and slipping movements, measuring friction and wear as well as temperatures and controlled parameters throughout the test. To meet the needs of SwRI's diverse clients, tribometers must be modified or new test rigs need to be developed. For example, using internal funding, we are currently adapting tribometers to run driveline fluids in an electrified environment to understand potential effects on friction and wear for electric vehicles.

One of the tribology team's first projects was designing a new test rig to screen diesel engine lubricants for valvetrain and tappet wear. A valvetrain controls the intake and exhaust valves in an internal combustion engine, and a tappet converts the rotating motion of the camshaft into the linear motion of the valves.

DETAIL

A tribometer is a laboratory bench instrument that measures tribological properties between two surfaces in contact, such as coefficients of friction, frictional heating and wear.

Components in SwRI's single-cam test rig include a section of the camshaft and a tappet, which convert rotating motion into linear motion.

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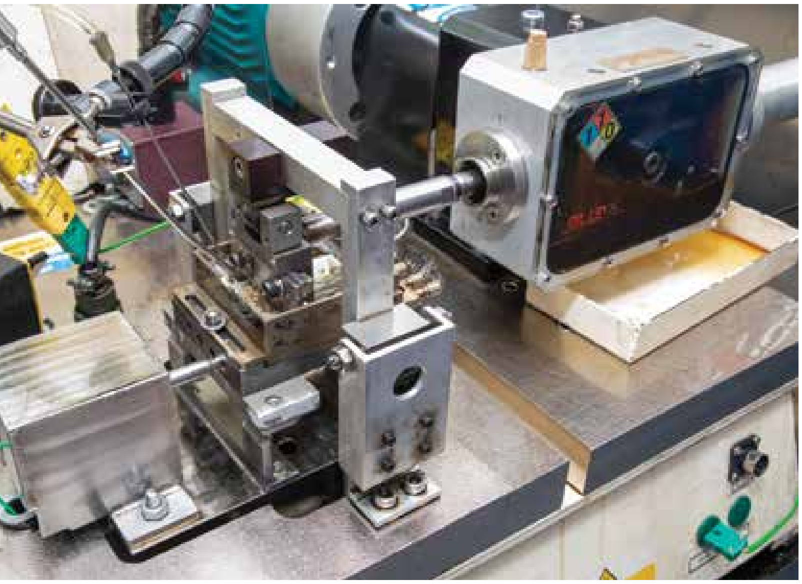

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This bench reciprocating rig tests oils by quantifying wear and friction of a piston ring and cylinder liner contact.

The tribology team developed this single-cam rig as a cost-saving screening tool prior to conducting the lubricant test in large engines.

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DETAIL

A vehicle's driveline is the powertrain minus the engine and the transmission, including the driveshaft, differentials, axle shafts, and universal and constant-velocity joints.

Lubricant manufacturers must license their products with the American Petroleum Institute before lubricants can be put on the market. These products must pass numerous ASTM standard engine tests on a dynamometer to certify that the lubricant meets minimum performance specifications for valvetrain wear, cylinder bore protection, fuel economy, sludge and several other parameters. These engine tests are costly and time-consuming, often running for hundreds of hours. The tribology team designed a lubricant screening test to evaluate lubricants before putting them through the more comprehensive and expensive Cummins ISB diesel engine dynamometer test. Developing this bench test began with a question: If you close your eyes and imagine you are on the valvetrain in the engine, what do you see, feel and smell? Through this process, the team noted all the different conditions that needed to be replicated in the test rig.

The single-cam valvetrain fixture has a pushrod operating the inlet and exhaust valves. The test rig includes a cutaway engine head, a section of the camshaft, the original camshaft bearings and an aluminum facsimile of the engine block as well as the valves, springs and levers, which can affect system wear. Drilled pathways deliver the test lubricant at accurate pressures, and temperatures replicate the inlet and exhaust sides of the engine, with the exhaust side running hotter. The team created a machined sleeve for the camshaft tappet to allow rotation to be measured, resulting in the group's first patent. The rig is fitted with the same inline torque meter, motor and operating system used for the engine test.

The tribology team then conducted a matrix of tests to ensure bench results correlated with engine tests. Once that was achieved, SwRI used the test rig to screen candidate oils at approximately one tenth the cost of the full engine test, eventually adding a second rig to meet customer demands. Prescreening lubricants in the bench rig has reduced wear in engine tests, allowing more candidate oils to be tested for the same budget, while saving thousands of gallons of diesel fuel and allowing corresponding emission reductions.

TRIBO-CORROSION

Recently, SwRI adapted a standard reciprocating bench rig to study friction and wear in downhole oil and gas drilling applications. This harsh environment accelerates wear and corrosion in drilling equipment. The corrosion on steel piping was of particular concern to the client, so SwRI's industry experts on staff proved an invaluable resource. The tribology team consulted with SwRI corrosion specialists to set up a closed-loop flow system for the test fluid, gas and chamber.

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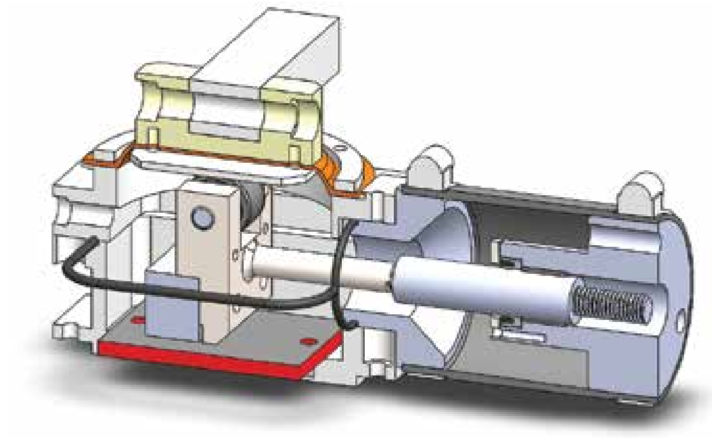
Dr. Carlos Sanchez demonstrates one of the key aspects of rheology using a popular children's toy. When the putty is pulled slowly, the material stretches out, but when yanked hard, it snaps apart.



This schematic shows how engineers enclosed a reciprocating rig to simulate downhole drilling conditions.

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The testing had to replicate hot, high-pressure, oxygen-deprived downhole environments while incorporating drilling fluids consisting of salt water, lubricants and other additives. The team modified the reciprocating rig to create a sealed, pressurized chamber to simulate the downhole conditions. The test setup had to control the introduction of test fluids and gases and measure dissolved oxygen levels in the fluid to parts per billion. This "tribo-corrosion" test can control the corrosive environment for the duration of the wear test.

Typically, these tests are performed in open test cells, exposed to ambient lab conditions. Excess salt build-up from heated test fluids, coupled with exposure to air, creates unrealistic corrosion of parts because air and oxygen are not present in actual downhole environments. The SwRI-developed tribo-corrosion test created realistic corrosion seen in the real drilling system, allowing the effects of different drilling fluids to be better understood.

RHEOLOGY

Rheology, which complements tribology, deals with the deformation and flow of "soft" solid and liquid materials, particularly fluids that change viscosity and other properties under strain. For example, ketchup becomes less viscous when shaken because it's a shear-thinning material. Viscosity refers to a fluid's resistance to flow and corresponds to the informal notion of "thickness."

While rheology is a universal science important in a range of industries, it's not very well known. Rheology examines the behavior of fluids and materials under different stresses — like pressures and temperatures — to understand the internal behavior of a fluid. Understanding flow properties can help solve problems in a variety of applications.

Rheology provides insight into the "lubrication" side of tribology. Rheology explains why materials behave the way they do. Why do

SwRI adapted a standard reciprocating bench rig to study wear in downhole oil and gas drilling applications under more realistic conditions.

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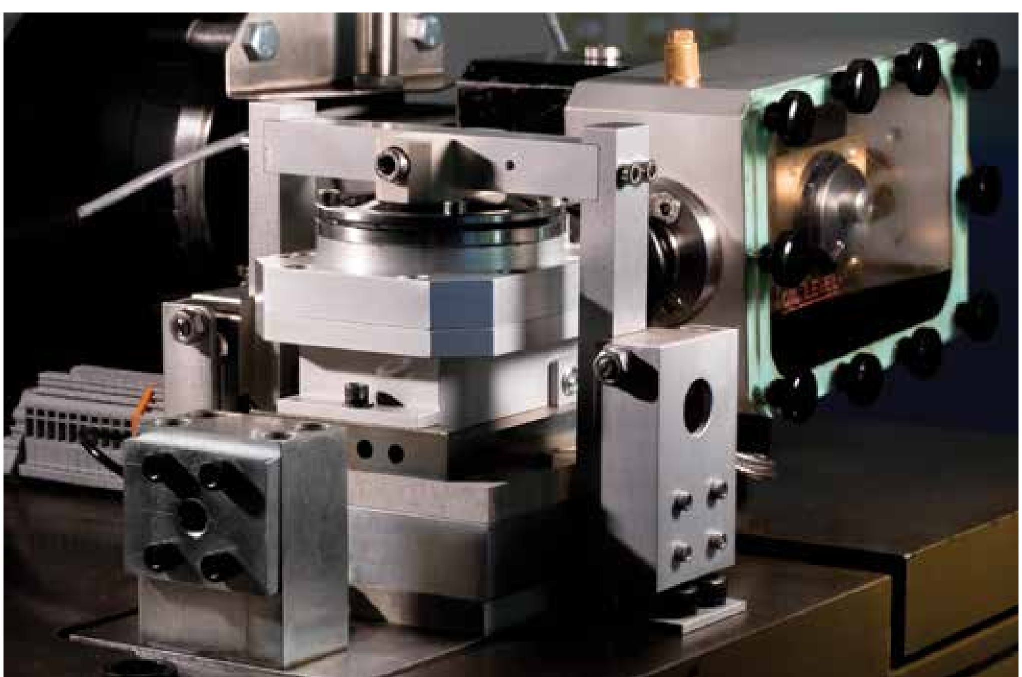

DETAIL

The term rheology was inspired by Greek words for the observation that "everything flows" and applies to substances that have complex microstructures, such as muds, sludges, biological materials and soft matter such as food.

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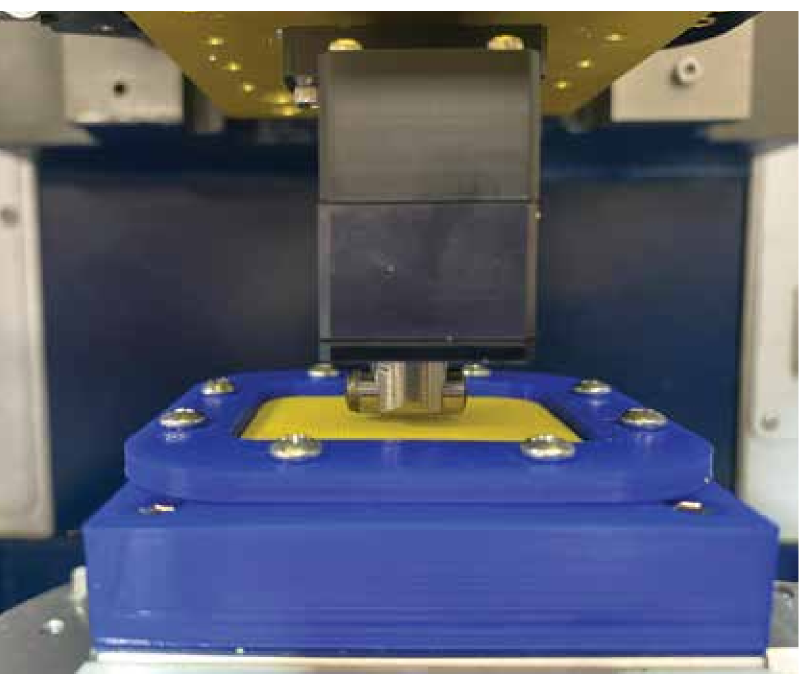
To solve the cookie cream conundrum, scientists applied cookie filling to the bottom plate of the rheometer. Then the top plate covers the cream and oscillates, allowing the instrument to measure the flow behavior of the filling to optimize the production of a new sandwich cookie cream flavor.

certain paints leave streaks, and others don't? Why do cosmetics tend to cake over time? If you cook, you've likely used rheology without even realizing it, adding more flour to thicken a sauce or adjusting the amount of dry ingredients to get the perfect cookie.

Using 3D-printed test fixtures, SwRI tribologists studied wear in belts used in a food factory to assist with quality control of potato chip packing operations.



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COOKIE CONNECTION

Speaking of cookies, rheology affects the assembly of sandwich cookies with cream fillings. At the factory, a nozzle deposits a controlled amount of cream onto one cookie before the other is pressed on top of it. A food manufacturer came to SwRI when a new cream flavor was overfilling the cookie and stalling production. The client delivered tubs of chocolate and vanilla creams, as well as a mystery-flavored cream, to the lab. Because the chocolate and vanilla behaved as expected in the factory, they were used as controls in the analysis. The SwRI team developed a rheology profile to map the optimum flow conditions for the mystery flavor. Then they adjusted the pumping speed, temperature and nozzle size so the mystery flavor would fill the cookies without issues.

CHIP PACKAGING

In another food application, the tribology group developed a method to study the friction and wear for belts used in potato chip production, working with SwRI manufacturing specialists to help optimize the assembly line. When potato chips are packaged, they are fed through a hopper, deposited into bags and sealed. The bags are on a large roller, pulled into place with rubber belts. Unfortunately, these belts tend to wear like an eraser, and the rubber shavings could contaminate bags of chips. To address the problem, the team looked at various types of belts in a bench-top tribometer.

Rheologists support drug delivery applications at SwRI, studying the materials used to encapsulate active ingredients for targeted release.

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These belts are backed with "teeth" that attach to the drive pulleys, much like a timing belt on an engine. To study these belts in a tribometer, the team 3D-printed a plate with matching grooves. The test involved rubbing a metal pin against the belt over time at a set speed, measuring the belt wear and the pin friction to determine performance. To make it more realistic, potato chips were crushed onto the belt to add oil. With the potato chip oil acting as a lubricant, the friction and wear changed slightly but the belts had the same ranked performance.

DRUG DELIVERY

To further illustrate the breadth of the field, the team collaborated with SwRI's chemists to study drug delivery systems. For more than 60 years, SwRI has used encapsulation technologies at micro- and nanoscales to find solutions in food, pharmaceutical, cosmetic, consumer product, veterinary medicine, industrial chemical, biomedical and sensor applications. For much of that time, SwRI has specialized in microencapsulation of various drugs for controlled release.

Typically, active ingredients are encased in small capsules of waxy substances. These compounds are designed to melt or dissolve under certain conditions, releasing the drug. For a specific effort, rheologists measured the viscous behavior of capsule materials at various temperatures to determine the "flow point," when the solid wax melts and starts to flow like a liquid. Then they measured the viscosity under increasing stress, looking to lower the viscosity and allow the medication to travel easily through the body.

Drug delivery, cookie filling, chip packaging, pipeline corrosion and engine lubrication are just a few of the eclectic problems SwRI has solved in its specialized tribology lab. This facility is recognized as one of the premier tribology research and evaluation laboratories in the world, with a specialized staff able to address challenges in a wide range of industries and arenas.

Questions about this story? Contact Lee at peter.lee@swri.org or (210) 522-5545.

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ABOUT THE AUTHORS: Dr. Peter Lee (right) leads the internationally recognized SwRI Tribology Research and Evaluations Group, which he helped establish within the Fuels and Lubricants Research Division in 2011. He received his doctorate in Engine Tribology from the University of Leeds in the United Kingdom. Dr. Carlos Sanchez is a senior research engineer specializing in both tribology and the related science of rheology, developing and adapting test rigs and fluid characterization techniques. He has a doctorate in mechanical engineering from Texas A&M University.

SwRI, UT AUSTIN LAUNCH ENERGIZE INITIATIVES

SwRI and The University of Texas at Austin have funded five research projects through the Energize Program, a new opportunity for enhanced scientific collaboration between the two institutions.

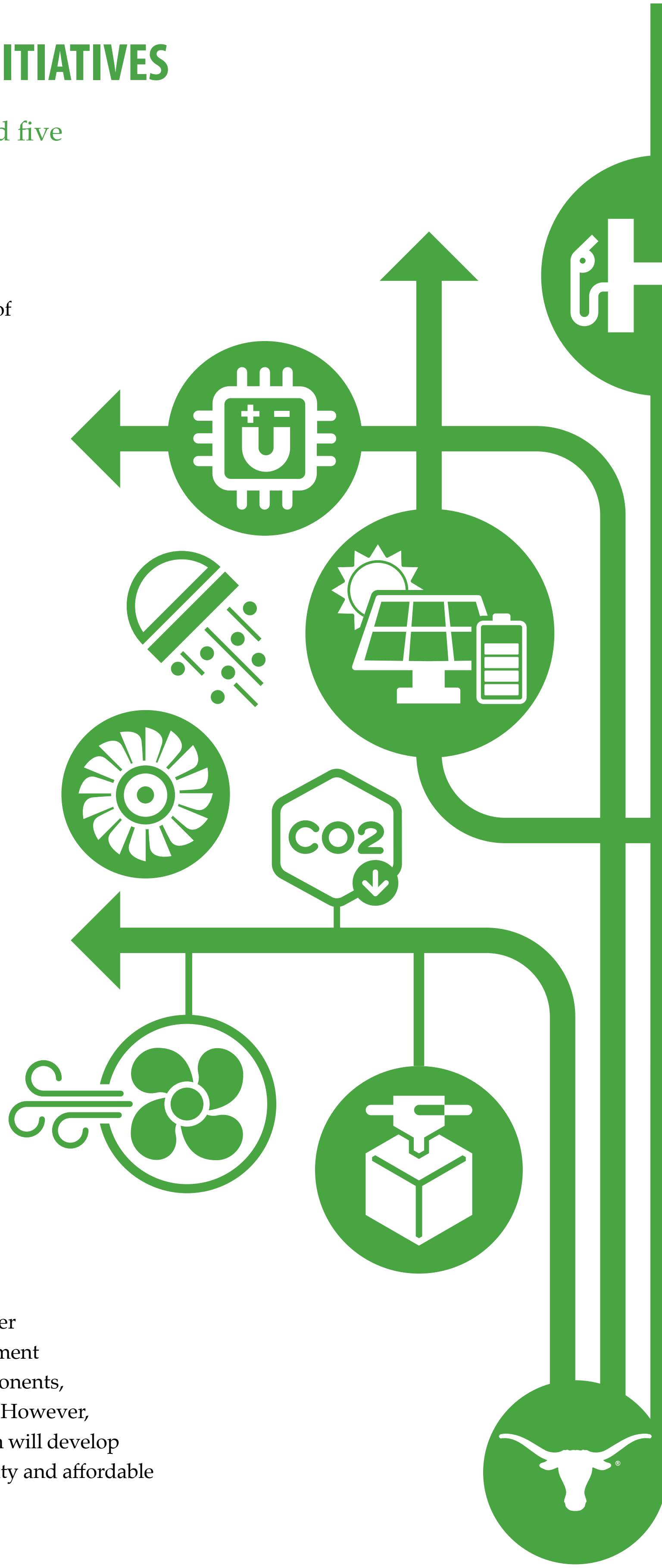
"I have no doubt that with the combined capabilities and expertise of SwRI and UT Austin, these projects will have a strong, positive impact on some of our greatest challenges in the energy sector," said SwRI Executive Vice President and COO Walt Downing.

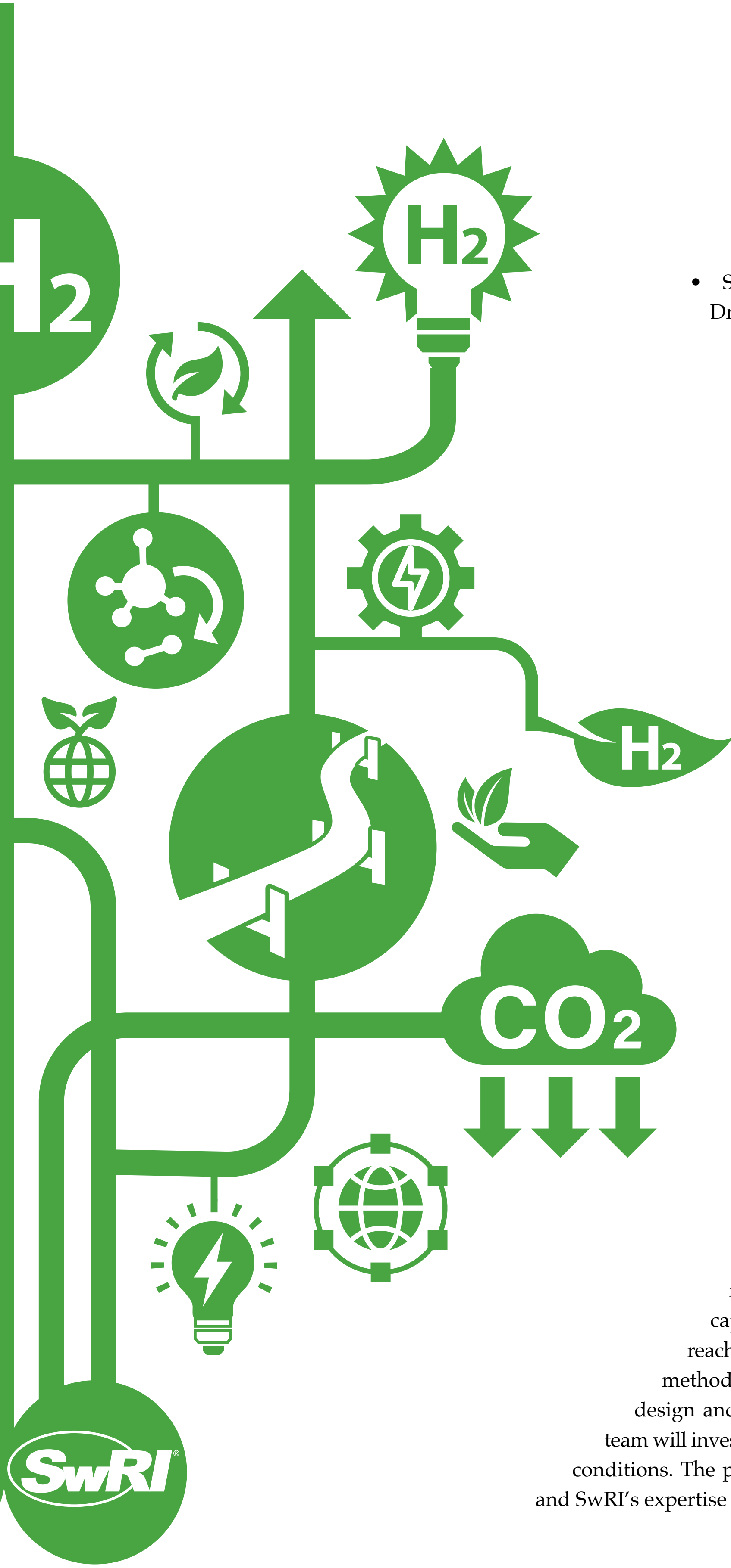
The Energize Program includes two funding opportunities. The first, overseen by UT's Energy Institute, funds projects in any energy field with a focus on decarbonization. The second, run by UT's Hildebrand Department of Petroleum and Geosystems Engineering, funds projects in any field of energy-related research, including oil and gas, renewable resources, hydrogen, carbon storage and geothermal energy. All projects include at least one principal investigator from each institution.

The Energy Institute has selected three projects. Each will receive $75,000 per year for two years from SwRI and a total of $60,000 from UT Austin.

- In the first project, SwRI Senior Research Engineer Ellen Smith and UT Austin's Dr. David Bogard seek to develop and evaluate an enhanced turbine cooling method to facilitate cleaner hydrogen-fueled engine applications. Hydrogen fuel exhaust is free from carbon byproducts. However, hydrogen combustion requires higher temperatures, resulting in higher heat transfer. Smith and Bogard will use additive manufacturing to design and build a turbine strut with advanced cooling technologies to enable high-temperature operations. The design will incorporate film cooling configurations recently developed at UT Austin and will be tested in the hydrogen burning combustor facility at SwRI.

- SwRI Principal Scientist Dr. Jianliang Lin is collaborating with Dr. Alex Hanson and Dr. Jean Anne Incorvia, both of UT Austin's Cockrell School of Engineering, to create reliable and affordable magnetized chip technology for next-generation energy technologies. Many climate-relevant next-generation technologies — data center power delivery, grid-scale smart transformers, advanced solar and battery management systems and internet-of-things applications — require expensive components, impeding large-scale adoption. Magnetic chips are very energy-efficient. However, integrating the magnetic components can be challenging and costly. The team will develop a large-scale rapid coating deposition technology for synthesizing high-quality and affordable magnetic materials for wide application.





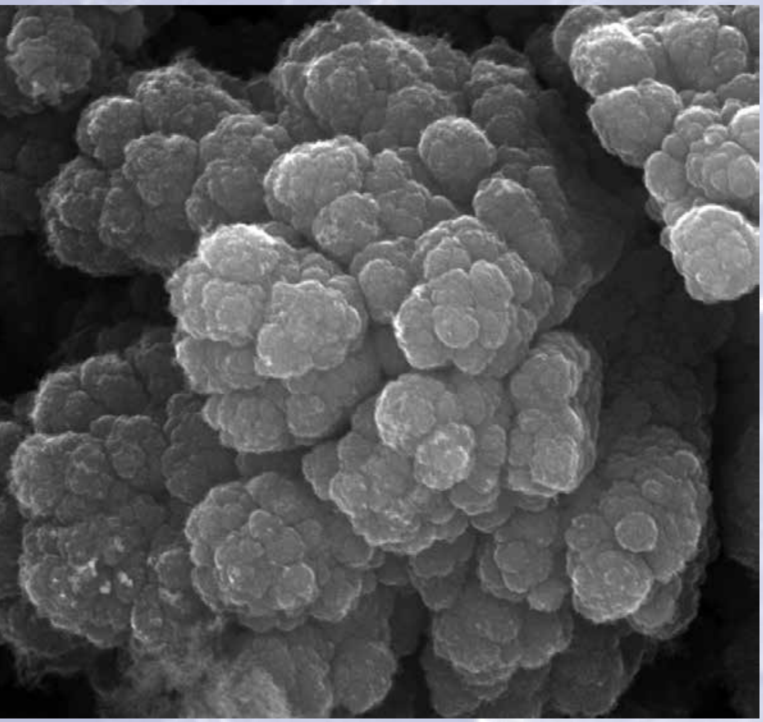
- SwRI's Dr. Michael Miller will work with UT Austin professors Dr. Thomas C. Underwood, Dr. Fabrizio Bisetti, Dr. Graeme Henkelman, and Dr. Charles Mullins to create a cost-effective and environmentally friendly method for producing hydrogen fuel. Although hydrogen could help decarbonize transportation, power generation and manufacturing, conventional industrial hydrogen production from natural gas creates significant greenhouse gas emissions. The team is investigating a plasma-enabled catalytic process to eliminate carbon monoxide and carbon dioxide emissions, converting methane directly into hydrogen and solid carbon at near-ambient temperatures and atmospheric pressures. The project will build on current and previous studies of plasma-enabled chemical processes and catalysis at both SwRI and UT Austin.

The Hildebrand Department of Petroleum and Geosystems Engineering has selected two projects, each to be supported by $75,000 from UT Austin and $75,000 from SwRI.

- SwRI's Angel Wileman and Sarah Stuart are collaborating with UT Austin professors Dr. David DiCarlo and Dr. Masa Prodanovic to study using CO_2 foams to improve long-term carbon storage. Capturing carbon emissions and storing them in depleted oil and gas wells is a viable method for reducing atmospheric carbon. The challenge is making sure stored CO_2 does not leach out of the reservoir into the air. The researchers will leverage traditional CO_2-enhanced oil recovery methods to investigate the stability and behavior of foam-entrapped CO_2 in high-temperature and high-pressure reservoir conditions.

- SwRI's Kevin Supak, Dr. Jordan Nielson and Kelsi Katcher will work with UT Austin's Dr. Yingda Lu to study CO_2 pipeline flow behaviors as part of a larger effort to facilitate large-scale carbon capture utilization and storage (CCUS). Before CCUS technology can reach its potential for reducing harmful CO_2 emissions, a cost-effective method for transporting large quantities of CO_2 is needed. To facilitate the design and operation of large-scale CCUS transportation systems, the project team will investigate the flow behaviors of CO_2 under typical pipeline transportation conditions. The project utilizes UT-Austin's expertise in multiphase flow modeling and SwRI's expertise in large-scale multiphase flow research.

ADVANCING HYDROGEN FUEL STORAGE TECHNIQUES



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In addition to the new collaborative program with the University of Texas at Austin described on page 10, SwRI is continuing its long support for a similar program with The University of Texas at San Antonio. The Connecting through Research Partnerships Program, known as “Connect,” recently funded a program to improve storage materials for hydrogen fuels with a hybrid metal-carbon microstructure that combines both chemical and physical hydrogen storage mechanisms. Supported by a $125,000 Connect grant, Dr. Josh Mangum of SwRI’s Mechanical Engineering Division, UTSA Associate Professor of Physics and Astronomy Dr. Kathryn Mayer, and UTSA Assistant Professor of Chemistry Dr. Fang Xu are leading the project.

Hydrogen fuel is an attractive alternative to fossil fuels because its emissions are free from carbon byproducts. SwRI is leading several multidisciplinary efforts evaluating hydrogen as a potential fuel for automobiles, power generation and even as a replacement for natural gas in homes.

“While hydrogen energy is very promising, several hurdles must be overcome,” Mangum said. “Some of the chief challenges are transportation and storage.”

Currently, hydrogen gas is compressed and liquefied for transport and storage in cryogenic and high-pressure fuel tanks, which is an expensive process. Because hydrogen is highly flammable, transporting these tanks is inherently dangerous.

To address these challenges, SwRI and UTSA will create high surface area carbon (HiSAC) microstructure particles to physically and chemically absorb the hydrogen for safe, cost-effective transport.

“Instead of a highly pressurized tank, we plan to store hydrogen in a low-cost powder material,” Mangum explained. “The hydrogen will be chemically and physically absorbed and desorbed. One of our project goals is evaluating how much hydrogen can be stored in the powder as this will dictate the overall storage cost.”

The researchers will fabricate the HiSAC microstructures using SwRI-developed High Power Impulse Plasma Source (HiPIPS) technology, which efficiently generates coatings using high-density, high-flux plasmas at low temperatures and atmospheric pressures. R&D Magazine recognized SwRI’s HiPIPS technology as one of the 100 most significant innovations of 2017.

UTSA will perform the analytical characterization of the microparticle structures. Mayer’s research team will perform a detailed structural characterization of the materials using state-of-the-art instrumentation in the Kleberg Advanced Microscopy Center. Xu’s team will modify HiSAC particles using magnesium deposition and test the materials’ hydrogen storage capacity.

“Previous research has demonstrated HiSAC microstructures at high temperatures and low pressures, but HiPIPS allows us to form these materials at room temperature in a simple, scalable process,” Mangum said. “The process uses less energy than it takes to power an incandescent light bulb.”

SwRI’s Executive Office and UTSA’s Office of the Vice President for Research, Economic Development and Knowledge Enterprise sponsor the Connect program, which offers grant opportunities to enhance greater scientific collaboration between the two institutions.

SwRI Synthesizes Anti-Nausea Compound

SwRI has developed an efficient, fully synthetic method to produce scopolamine, a plant-derived compound used to prevent nausea and vomiting from motion sickness and anesthesia. The accomplishment marks the first time SwRI has fully synthesized a drug compound that is derived from plants.

The antinausea medication is made from plants in the nightshade family and from the corkwood tree native to Australia. Although these plants are toxic, extracts have been used for centuries in herbal medicine. Scopolamine is typically delivered using transdermal patches placed on the skin and intravenously during surgery to prevent nausea.

"Half of all drugs are derived from natural compounds," said Dr. Shawn Blumberg, a senior research scientist in SwRI's Chemistry and Chemical Engineering Division. "Wildfires, inclement weather, pests, plant diseases and even climate change can significantly decrease crop yields, affecting the availability and price of plant-based medicines. Developing a fully synthetic version of scopolamine decreases our reliance on medicinal crops and will increase availability, allowing us to investigate other uses."

SwRI used internal research funding to develop a novel synthetic pathway for scopolamine production using inexpensive materials. Although the process for synthesizing compounds is typically lengthy and complex, the SwRI technique achieved the highest yield to date using a short number of steps in a process that can be scaled up indefinitely.

In addition to their current uses, scopolamine, atropine and other derivatives from nightshades may be useful countermeasures for nerve agent exposure. However, the current

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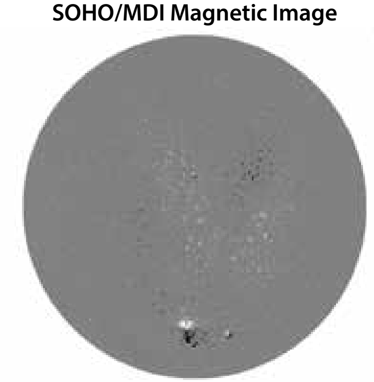
high demand for scopolamine coupled with limited agriculture-based production rates has made it difficult to explore other uses for the compound. SwRI will pursue other therapeutics based on these compounds and novel derivatives.

"Developing the technology to create synthetic alternatives to natural drugs will help bring prices down and make us less vulnerable to geopolitical and environmental disruption of the supply chain," Blumberg said.

SOHO/MDI Magnetic Image



SOHO/EIT Lower Coronal Image

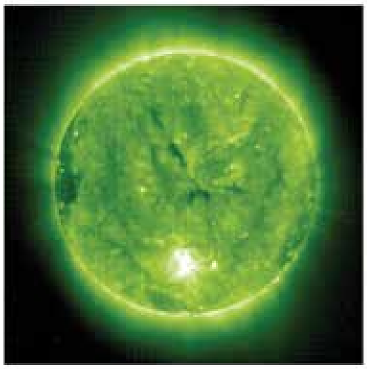


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IMAGE COURTESY NASA/ESA

Using Solar and Heliospheric Observatory data, SwRI developed a tool to efficiently label large, complex datasets, such as the magnetogram shown at top, to allow a machine learning application to identify potentially hazardous solar events illustrated by the ultraviolet image above.

SMART SOLAR DATA PROCESSING

Big data has become a big challenge for space scientists analyzing vast datasets from increasingly powerful space instrumentation. To address this, an SwRI team has developed a machine learning tool to efficiently label large, complex datasets to allow deep learning models to sift through and identify potentially hazardous solar events. The new labeling tool can be applied or adapted to address other challenges involving vast datasets.

As space instrument packages collect increasingly complex data in ever-increasing volumes, it is becoming more challenging for scientists to process and analyze relevant trends. Machine learning (ML) is becoming a critical tool for processing large complex datasets, where algorithms learn from existing data to make decisions or predictions that can factor more information simultaneously than humans can. However, to take advantage of ML techniques, humans need to label all the data first — often a monumental endeavor.

"Labeling data with meaningful annotations is a crucial step of supervised ML. However, labeling datasets is tedious and time-consuming," said Dr. Subhamoy Chatterjee, a postdoctoral researcher at SwRI. "New research shows how convolutional neural networks (CNNs), trained on crudely labeled astronomical videos, can be leveraged to improve the quality and breadth of data labeling and reduce the need for human intervention."

Deep learning techniques can automate processing and interpret large amounts of complex data by extracting and learning complex patterns. The SwRI team used videos of the solar magnetic field to identify areas where strong complex magnetic fields, the main precursor of space weather events, emerge on the solar surface.

"We trained CNNs using crude labels, manually verifying only our disagreements with the machine," said co-author Dr. Andrés Muñoz-Jaramillo, an SwRI solar physicist with expertise in machine learning. "We then retrained the algorithm with the corrected data and repeated this process until we were all in agreement. While flux emergence labeling is typically done manually, this iterative interaction between the human and ML algorithm reduces manual verification by 50%."

TESTING VALVES FOR HYDROGEN FUEL TANKS

SwRI developed a new test stand to evaluate the durability of fuel tank valves for hydrogen-powered vehicles. The work is part of a National Highway Traffic Safety Administration (NHTSA) initiative to evaluate current testing standards for pressurized hydrogen tank valves.

In recent years, demands for hydrogen research have increased as industry searches for alternatives to burning fossil fuels, which contributes to climate change. SwRI is leading several multidisciplinary efforts to evaluate hydrogen as a potential fuel source for automobiles and power generation and to replace natural gas in homes.

"Advances in hydrogen-powered vehicles have led to an increased need for evaluating fuel tank components pressurized with hydrogen gas," said SwRI Research Engineer Jacqueline Manders. "The transportation industry must ensure that tanks and associated components are safe and reliable prior to use on the road."

Manders led the development of a test stand to perform pressure integrity testing on valves and flow components with hydrogen gas, while meeting safety requirements. The test stand is designed to achieve pressures as high as 20,000 psi, with temperature control capabilities ranging from -40 to 240 degrees Fahrenheit.

The current test program is evaluating and providing feedback on a series of tests for primary closure components on compressed hydrogen storage systems, as specified in a worldwide standard.

"The test stand could eventually support future integrity testing of components for the hydrogen industry, improving component reliability," Manders said. "With increased demand for hydrogen research, it's imperative that we evaluate current test procedures and ensure that these products are qualified to an acceptable standard."

The temperature and pressure extremes are meant to exceed the recommended operating range of the hydrogen valves, conservatively qualifying them for global climate conditions. The test stand is now in operation, allowing the Institute to test hydrogen valves for NHTSA as well as other clients.

The surface of Jupiter's fourth largest moon Europa (immediately above in this composite image) was imaged at ultraviolet wavelengths, mapping concentrations of sulfur dioxide on its surface that likely came from Io (top), Jupiter's ultra-volcanic moon.

MAPPING SULFUR RESIDUE ON EUROPA

An SwRI-led team used the Hubble Space Telescope to observe Jupiter's moon Europa at ultraviolet wavelengths. The team's near-global UV maps show concentrations of sulfur dioxide on Europa's trailing side and filled a gap in the various wavelengths used to observe this icy water world.

SwRI will further these studies using the Europa Ultraviolet Spectrograph (Europa-UVS), which will observe Jupiter's fourth largest moon from aboard NASA's Europa Clipper, scheduled to launch in 2024. Hidden beneath Europa's icy surface is a saltwater ocean containing nearly twice as much water as in all of Earth's oceans, making it one of the promising places in our solar system suitable for some form of life beyond Earth.

"Europa's relatively young surface is primarily composed of water ice, although other materials have been detected across its surface," said Dr. Tracy Becker, lead author of a paper describing these UV observations. "Determining whether these other materials are native to Europa is important for understanding Europa's formation and subsequent evolution."

Assessing the surface material can provide insights into the composition of the subsurface ocean. SwRI's dataset is the first to produce a near-global map of sulfur dioxide that correlates with large-scale darker regions in both the visible and UV wavelengths.

"The results were not very surprising, but we did get much better coverage and resolution than previous observations," said SwRI's Dr. Philippa Molyneux, a co-author of the paper. "Most of the sulfur dioxide is seen on the 'trailing' hemisphere of Europa. It's likely concentrated there because Jupiter's co-rotating magnetic field traps sulfur particles spewing from Io's volcanoes and slams them against the backside of Europa."

Io is another of Jupiter's largest moons but, in contrast, is considered the most volcanic body in the solar system. The intense radiation environment created by Jupiter's powerful magnetic field can cause chemical reactions between the water ice and the sulfur, creating sulfur dioxide on Europa's surface.

IMAGE COURTESY NASA

SwRI DEPLOYS AUTOMATED SHUTTLE

As a leader in software and systems integration development for automated vehicles and robotics, SwRI has deployed an automated shuttle at its 1,500-acre campus.

Capable of ferrying up to 14 passengers, the shuttle uses algorithms, sensors, cameras and software that SwRI developed through internal research into automated driving. During operations, a human driver sits behind a steering wheel as an additional safety measure.

"It is rewarding for our engineers to take the very best technology that SwRI has developed to serve our clients and then embed it into a showcase vehicle that has a practical purpose in our backyard," said Ryan Lamm, director of SwRI's Applied Sensing Department.

Using SwRI's Ranger system, the vehicle autonomously drives unique routes around the grounds. Ranger is a localization tool that uses a ground-facing camera and automation software to precisely maintain its position to within two centimeters on a given route.

"Fully automated driverless vehicles are still several years away, but this shuttle proves that we are well on our way to such a future," said Dr. Steve Dellenback, vice president of SwRI's Intelligent Systems Division.

The shuttle's core functionality lies in SwRI's autonomy stack, a suite of tools utilizing proprietary machine learning algorithms, software and processing tools as well as cameras and sensors. SwRI has been developing the shuttle technology for over a year.

Classified as a low-speed vehicle (LSV) operating at less than 50 mph, the shuttle is ideal for closed campuses, such as the SwRI headquarters, or roads with lower speed limits. The Ranger system creates maps of the unique characteristics of the asphalt and recognizes features such as intersections, lanes and crosswalks. The operator can select from various mapped routes.

It uses sensor systems and artificial intelligence to classify roadway signs, pedestrians, vehicles and other objects. SwRI has programmed the shuttle for various driving scenarios such as sharing the road with other vehicles, detecting dynamic objects such as cyclists, and determining right of way at intersections.

"The shuttle collects data every time it is on the road, allowing us to continually refine its algorithms to improve reactions in various situations," said Alexander Youngs, an SwRI senior research engineer who led development of the shuttle.

Additional capabilities include the ability to integrate and share data with intelligent transportation systems and other connected and automated vehicles. The shuttle can be deployed in a convoy of similar vehicles, taking traffic and congestion into consideration for improved mobility.

"This mid-size passenger vehicle presents future opportunities to improve mobility and access to transportation in neighborhoods where large buses cannot travel," said SwRI's Dan Rossiter. "We are thrilled to be able to say San Antonio not only has this capability at SwRI, but that we are helping to develop and deploy similar systems around the globe."

The shuttle is a working research platform, allowing SwRI to create and upgrade the vehicle with new automation capabilities and innovations. In addition to serving as a functional tour shuttle, it continues to serve as a test bed for other pilot programs for government and industry clients seeking to deploy similar shuttles on both closed campuses and open roads.

Watch a video of the shuttle at https://youtu.be/hoCwBnqQSx0.

Alex Youngs demonstrates the self-driving capability of the SwRI automated shuttle, a 14-passenter, self-driving transport vehicle equipped with lidar, camera sensors and machine vision algorithms that enable automated driving. The shuttle autonomously navigates campus tours on pre-programmed routes, but a human driver is always behind the steering wheel for added safety.

EARTH & SPACE

DEEP SEA TO DEEP SPACE

D025621

1950

Engines, fuels and lubricants research has been a major endeavor at the Institute since it was founded. SwRI developed new techniques using stationary automotive engines and automotive fleet tests as research tools for evaluating fuels and lubricants.

1958

Although far from an ocean, the Institute quickly became known for its deep sea design and development work. Engineers conceived, designed and tested a scale model of the world's first deep diving submarine built out of aluminum, the Aluminaut.

D003247

CHEMISTRY & MATERIALS

MANUFACTURING & CONSTRUCTION

1957

One of SwRI's first internal research programs studied direction finding using this shielded loop antenna and carefully calibrated instrumentation. The signals intelligence program area persists today.

DC5778

D025620

AUTOMOTIVE & TRANSPORTATION

1971

The Institute pioneered and remains internationally recognized for its engine exhaust measurement and analysis research, which contributes to national emissions standards.

DE74230

CELEBRATING SEVENTY-FIVE YEARS OF ADV

G EVERYWHERE IN BETWEEN

ENERGY & ENVIRONMENT

D025650

BIOMEDICAL & HEALTH

2021

In addition to developing space instruments, avionics and small satellites, SwRI is home to the principal investigators for five NASA space missions, with research ranging from the Sun to the outer reaches of our solar system, including the Lucy mission to Jupiter's Trojan asteroids, which launched in 2021.

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...EST RESEARCH INSTITUTE

DEFENSE & SECURITY

D016501_4285

2000

SwRI conducts vacuum distillation tests and develops new processes to help industry develop methods to create quality fuels and useful chemicals from renewable feedstocks.

1989

SwRI developed a two-robot system to strip paint from military fighters using a plastic bead blasting technique.

D019737_3814

2014

To support the U.S. Department of Defense, SwRI develops both unmanned aerial systems and ground vehicles, connecting them to provide more global information about the surrounding environment. This technology can help remove military personnel from particularly hazardous duties.

DE64659

1996

Institute engineers solve problems and develop new technology to improve the safety, reliability and efficiency of large industrial engines, turbomachinery and gas transmission technology.

ELECTRONICS & AUTOMATION

IMAGES COURTESY NASA/SwRI/JPL-

ANCED SCIENCE AND APPLIED TECHNOLOGY

PAVING THE WAY TO THE MOON AND BEYOND

Seven SwRI projects to help understand our nearest neighbor

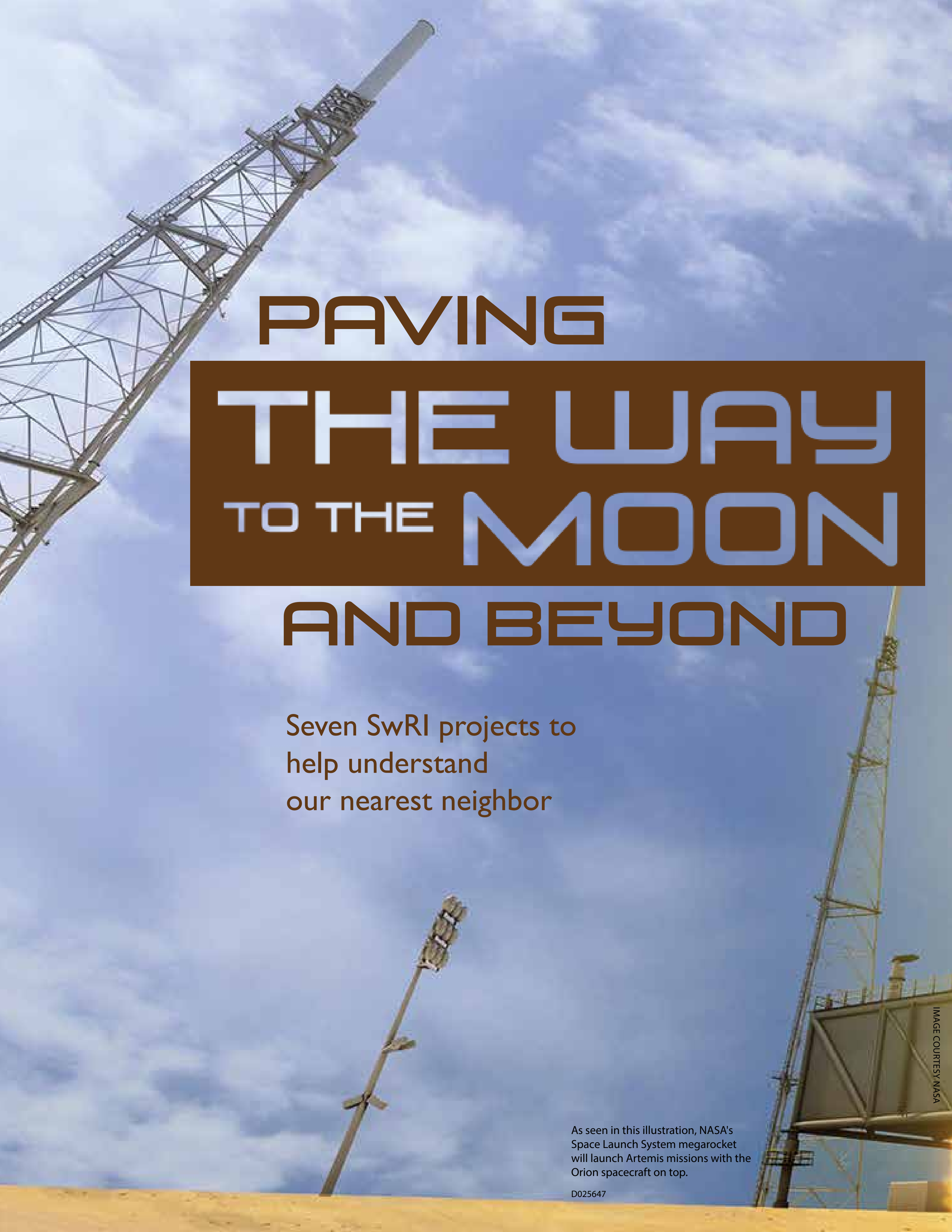


IMAGE COURTESY NASA

As seen in this illustration, NASA's Space Launch System megarocket will launch Artemis missions with the Orion spacecraft on top.

D025647

While humanity looks to Mars as the next goal for human exploration, many in the space community believe revisiting and creating a long-term presence at the Moon is the next crucial step to get there.

By studying the Moon up close, humanity will learn more about the origin and history of the Earth, the Moon and our solar system while developing the technologies, capabilities, and business approaches needed for the future.

Goals of the next generation of Moon exploration include extending commercial and international partnerships while inspiring a new generation to reach beyond our home planet.

In addition to providing experience in living off-planet, the Moon is rich in resources that can support a human outpost. The abundant water ice discovered by NASA's Lunar CRater Observation and Sensing Satellite (LCROSS) mission can be split into oxygen and hydrogen to power fuel cells and make liquid rocket fuel. To get to Mars or anywhere else, transporting these resources from the surface of Earth is prohibitively expensive. Launching these missions from the Moon with one-sixth the gravity of Earth would be much more efficient.

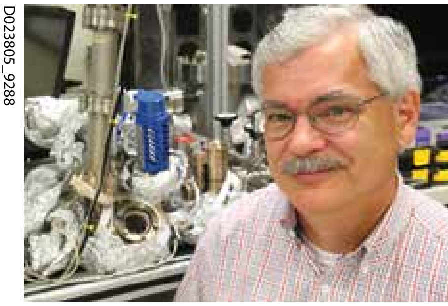
Six countries and seven missions are targeting the Moon in just the next year. Notably, NASA is scheduled to fly its first uncrewed test flight in its Artemis program in late 2022, launching its massive SLS rocket carrying the Orion spacecraft as well as 10 CubeSats deployed as secondary payloads. Fifty years after the last Apollo mission to the Moon, Artemis represents the next generation of exploration, with plans to place a Gateway space station in lunar orbit to support a permanent Moon base. What the space community will learn at the Moon will help humanity send the first astronauts to Mars.

To support NASA's ability to establish a presence on the Moon and ultimately get to Mars, Southwest Research Institute is conducting a number of projects ranging from laboratory studies to zero-gravity experiments and orbital research as well as developing new lunar instruments. These include three NASA Commercial Lunar Payload Services (CLPS) projects that use American companies to deliver science and technology to the Moon's surface.

ENABLE Mass Spectrometer

Ed Patrick

D023805_9288



Ed Patrick, who oversees SwRI's space environment simulation lab, leads the ENABLE project, adapting a commercial off-the-shelf mass spectrometer to identify materials present on the Moon.

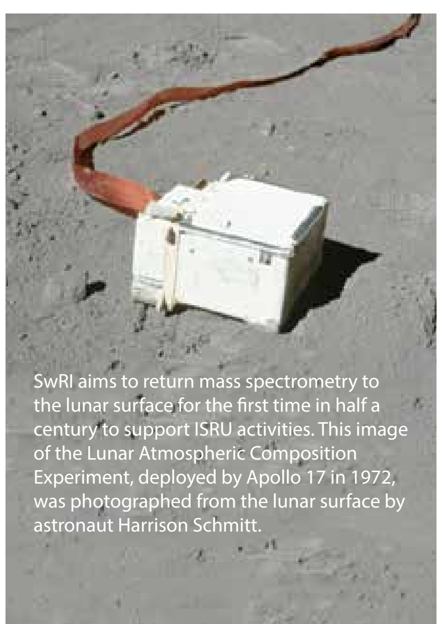
SwRI scientists are developing a new mass spectrometer to operate in the Moon's close-to-zero atmospheric pressure. The instrument will measure the chemical components present at the Moon to support *in situ* resource utilization (ISRU) for future lunar missions. Being able to "live off the land" — capturing and processing local lunar resources for rocket fuel, breathable air, engineered materials and structural components — could support a permanent human presence on the Moon and serve as a springboard for missions to Mars and beyond.

While lunar missions have found increasingly unambiguous evidence for water and other volatiles trapped beneath the lunar subsurface, Apollo and laboratory investigations have also shown that spacecraft, equipment and astronauts can locally overwhelm the lunar extreme high vacuum (XHV) environment. Equipment for prospecting and processing lunar resources could mask the native lunar background chemical signal as well as those signals arising when volatiles trapped within the lunar subsurface are disturbed. For these reasons, analytical chemistry by mass spectrometry will be essential for analyzing the native lunar background, probing for volatiles known to be present and monitoring the impact of spacecraft, equipment and processes soon to be deployed by the coming armada of international spacecraft.

Anticipating the needed instrumentation capabilities for this coming global renaissance in lunar exploration, NASA implemented the Development and Advancement of Lunar Instrumentation Program (DALI). The DALI program has funded the development of the Environmental Analysis of the Bounded Lunar Exosphere (ENABLE) project. SwRI is adapting a commercial off-the-shelf quadrupole mass spectrometer (QMS) into a space-qualified prototype instrument that could serve aboard multiple mission platforms to monitor environmental conditions under multiple lunar mission scenarios.

The goal for the QMS prototype is to analyze atmospheres from Earth pressures to the extreme high vacuums found on the Moon, providing mass-spec composition measurements over the entire lower half of this range. This range would allow the delivered ENABLE instrument to handle unanticipated pressure spikes associated with spacecraft engine plumes and nearby surface impacts while also producing partial pressure composition measurements targeting and identifying specific volatile species. As a handheld device, astronauts could use ENABLE to detect sources of leaks in spacecraft or habitation modules arising from equipment defects or the occasional perforation caused by micrometeoroid impacts.

D025651



SwRI aims to return mass spectrometry to the lunar surface for the first time in half a century to support ISRU activities. This image of the Lunar Atmospheric Composition Experiment, deployed by Apollo 17 in 1972, was photographed from the lunar surface by astronaut Harrison Schmitt.

IMAGE COURTESY NASA/SCHMITT/AS17-134-20499

D025641

Dr. Akbar Whizin has conducted a variety of experiments in the zero-gravity portion of parabolic flights.

Regolith Resources

Dr. Akbar Whizin

The surface of the Moon is covered by regolith, a loose collection of dust and other detritus produced over billions of years by meteor impacts and charged particles bombarding the lunar surface rock. SwRI scientists are conducting low-gravity laboratory and flight studies to assess how regolith resources could help sustain longer-term human habitation on the Moon.

From aboard a 727 aircraft modified to simulate weightlessness through parabolic maneuvers, scientists studied the regolith's properties and usefulness by developing and deploying surface penetrometers for reduced-gravity applications. Penetrometer devices are forced into soil to measure its resistance to vertical penetration. The experiment used lunar gravity to test sensor performance in a relevant environment.

Other microgravity experiments include an internally funded study of bubbles and boiling in zero gravity and a NASA SSERVI-funded investigation of low-speed impacts into analog asteroid surfaces using a gasless projectile launcher within a vacuum chamber on parabolic flights.

Another project is creating a lattice of small experiment chambers within a vacuum chamber to efficiently test science and engineering concepts simultaneously. The team proposed to further develop this test chamber through NASA's Space Technology Mission Directorate, which funds transformative space technologies to enable NASA's future missions.

To support ISRU initiatives, SwRI is studying additive construction and other techniques to make "regolith bricks" to build a future lunar base. The team is exploring using magnetic induction to heat the regolith into construction materials. Because the technique uses induction instead of radiated heat to sinter the regolith, it works in a vacuum. The team is addressing some technical challenges and will propose further development through a NASA Innovative Advanced Concepts (NIAC) study.

D025633

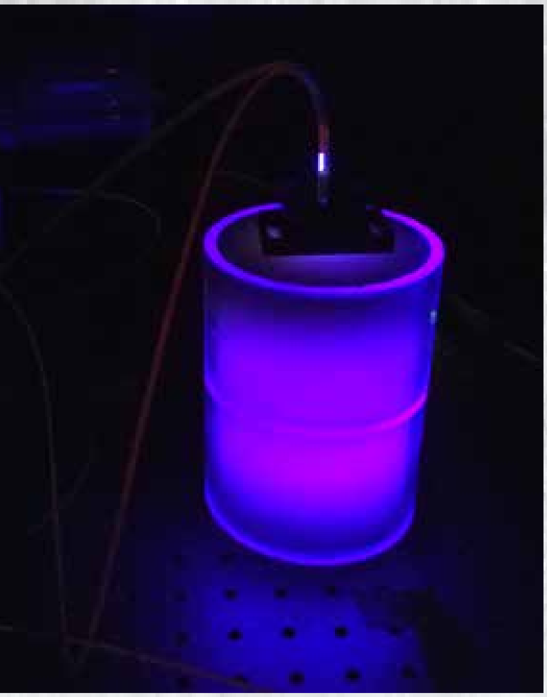
SwRI flew an experiment payload to characterize sensor-regolith interactions in microgravity aboard a parabolic flight in December 2021.

D025632

SwRI scientists used internal funding to demonstrate induction coil heating (~1,000 C) of lunar regolith simulant to investigate use as building materials.

3 Prospecting on the Moon

Dr. Philippa Molyneux



SwRI is using internal funding to develop an instrument for a future lunar lander. The Integrating CAvity enhanced Raman Ultraviolet Spectrograph or ICARUS instrument includes a sample collection chamber designed to thoroughly investigate compounds.

To better understand lunar resources that can push the boundaries of human exploration, SwRI is developing the Integrating CAvity enhanced Raman Ultraviolet Spectrograph (ICARUS) instrument for a future lunar lander. It includes arm-based sensors to identify materials of interest, as well as a sample collection chamber designed to thoroughly investigate compounds.

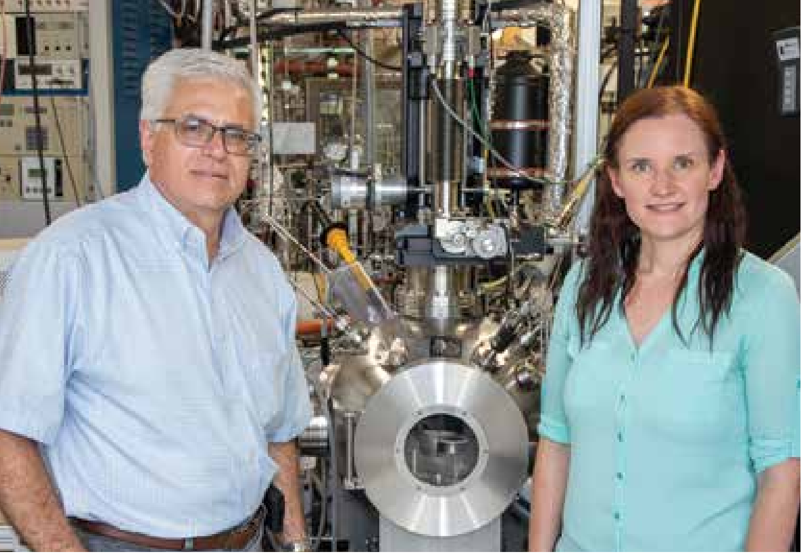
Raman spectroscopy is an incredibly powerful nondestructive optical technique that helps scientists identify and quantify molecules in liquid, solid and gas compounds on both the lunar surface and the shallow subsurface. Raman spectroscopy uses scattered light to measure the vibrational energy of materials, providing both chemical and structural information to identify substances through their characteristic Raman “fingerprint.”

ICARUS provides the ability to identify major and trace mineral and volatile phases at the lunar surface and in the shallow subsurface without sample preparation or destruction. The technique can be coupled with sample collection and / or measurements from other instruments during a landed mission.

The ICARUS instrument uses two laser light sources, covering the deep ultraviolet and visible ranges. The visible laser targets minerals. The ultraviolet laser is particularly sensitive to organic compounds, by minimizing fluorescence that can swamp the Raman scattered light. ICARUS is designed with a front-end sensor that can be deployed on a lander arm to analyze lunar material *in situ*. If this analysis detects materials of interest, the lander arm can scoop up a sample and deposit it into an SwRI-patented, highly reflective, integrating cavity.

The integrating cavity increases the number of laser-light interactions with the sample, maximizing the number of Raman-scattered photons to analyze materials at nanomolar detection limits. This precision may be essential for detecting volatiles such as water ice, carbon monoxide, ammonia and organics present in very low concentrations. These volatiles are particularly important for *in situ* resource utilization and for expanding human exploration on the Moon and eventually Mars.

Dr. Philippa Molyneux develops and tests UV instrumentation for planetary science and heliophysics, with a particular interest in UV studies of planetary atmospheres and surfaces. She is contributing to the development of the ICARUS instrument for a future lunar lander mission.



D025568_6691

Dr. Michael Miller and Dr. Amy McCleney are integrating several systems to create an instrument to characterize the lunar surface to support habitation.

VAPORR Verification

Dr. Michael Miller and Dr. Amy McCleney

SwRI is developing the Volatiles Analyzer and Prospector of Regolith Resources (VAPORR) to support near-term NASA and commercial missions to the Moon as well as future missions to Mars and beyond. To prepare for a long-term lunar presence, VAPORR would characterize the lunar surface to inform how future chemical plants on the Moon could process the available resources to sustain life and synthesize materials to support habitation — a fundamental goal of ISRU. While satellites orbiting the Moon have collected remote spectroscopy data about surface materials, the instrument would collect ground-truth data about the composition of the regolith in the context of what volatile species can be extracted from the surface.

The VAPORR instrument works by inserting its spear-like probe into the lunar regolith and shining a laser below the surface to heat it. Careful control of laser power extracts volatile molecules of different chemical structures over distinct temperature ranges through thermal desorption, allowing the instrument to characterize their abundancies and potential uses. VAPORR integrates two different analysis principles in one instrument: optical emission spectroscopy (OES) and mass spectrometry to analyze the various volatile species entering the spear and assess the chemical reactions a chemical plant can use to synthesize useful products.

While the design of VAPORR is relatively straightforward, ensuring that the instrument's many integrated systems function properly in concert requires extensive testing. SwRI scaled down several pre-existing technologies and integrated them to perform as a single instrument to support either mobile rover research or stationary resource utilization efforts.

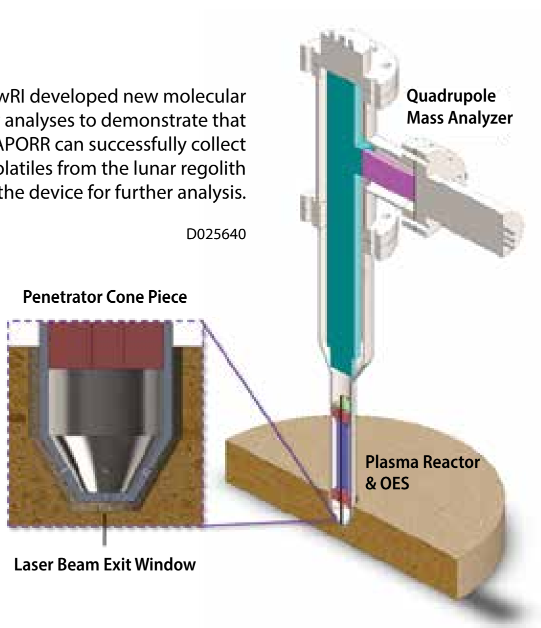
The team used computational molecular flow analyses to determine VAPORR's critical gas flow pathways and flow patterns in interaction with the lunar regolith. The challenge was modeling the erratic movements of individual molecules. Traditional computational methods would not work, so the team created new coding to understand how molecules behave, particularly in the reduced-gravity environments found on the Moon and Mars.

Using the novel molecular flow computational analysis method, SwRI analyzed how lunar regolith would behave using a 3D solid model of VAPORR and its interior pathways. These simulations assessed how well VAPORR captures gas emitted from moondust, serving as a benchmark for future probe design tradeoff studies.

SwRI has been actively pursuing external funding to advance the state of development of VAPORR through NASA's DALI program and commercial opportunities.

SwRI developed new molecular flow analyses to demonstrate that VAPORR can successfully collect volatiles from the lunar regolith into the device for further analysis.

D025640



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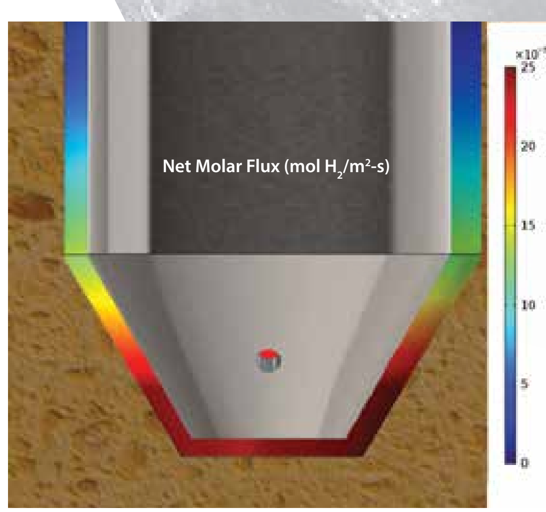
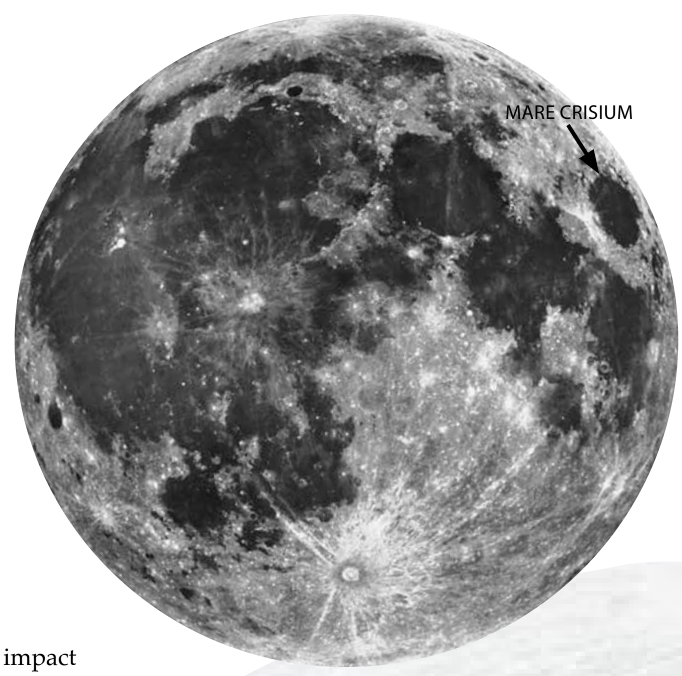


5 Nearside Sounder

Dr. Robert Grimm



LMS will land in Mare Crisium, a 350-mile-diameter lava-filled circular basin at three o'clock in this image. This basin — which stands apart from the anomalous large, connected areas of dark lava where most of the Apollo missions landed — could be more representative of most of the Moon.

D025657

IMAGE COURTESY LICK OBSERVATORY

Through NASA's Commercial Lunar Payload Services (CLPS) program, SwRI is developing the Lunar Magnetotelluric Sounder (LMS) to determine the electrical conductivity of the interior of the Moon by measuring low-frequency electric and magnetic fields. For more than 50 years, scientists have used the magnetotelluric technique, which uses natural time variations of the Earth's electromagnetic fields to determine the electrical conductivity of the subsurface for research and resource exploration. LMS will be the first extraterrestrial application of magnetotellurics.

Electromagnetic fields penetrate to greater depths with decreasing frequency, probing the interior of the Moon to depths up to 700 miles or two-thirds of the lunar radius. The electrical conductivity depends on the temperature and composition of the materials traveling through the field. The measurements will shed light on the differentiation and thermal history of our Moon, a cornerstone to understanding the evolution of solid worlds.

LMS is a payload on a CLPS lander mission, scheduled to land in Mare Crisium in early 2024. Firefly Aerospace of Austin, Texas, is providing the lander. Mare Crisium is an ancient, 350-mile-diameter impact basin that subsequently filled with lava. It is a dark circular spot to the northeast that stands apart from the large, connected areas of dark lava to the west where most of the Apollo missions landed. These vast, linked lava plains are now thought to be compositionally and structurally anomalous with respect to the rest of the Moon. From this separate vantage point, Mare Crisium may provide the first geophysical measurements representative of most of the Moon.

Texas Tech University's Lunar Instrumentation for Thermal Exploration with Rapidity (LISTER) — another geophysical instrument selected along with LMS — determines lunar heat flow using a pneumatic drill to measure temperatures up to 10 feet into the subsurface. Because heat flow and electromagnetics are complementary, combining data from the instruments will improve temperature and composition profiles. When the SwRI and Texas Tech teams discovered that both instruments had been selected, they immediately requested that the instruments fly on the same mission and successfully advocated for a geophysically relevant landing site.

DETAIL

The large dark spots visible to the naked eye on the Moon's surface were dubbed lunar maria, Latin for "seas," by early astronomers who mistook them for actual seas.

SwRI is leading a team to develop the LMS instrument for the Mare Crisium lander mission, which includes four spring-launched electrodes (one shown at right), a magnetometer (next page, bottom left), and a central electronics box (next page, bottom right).

D025649

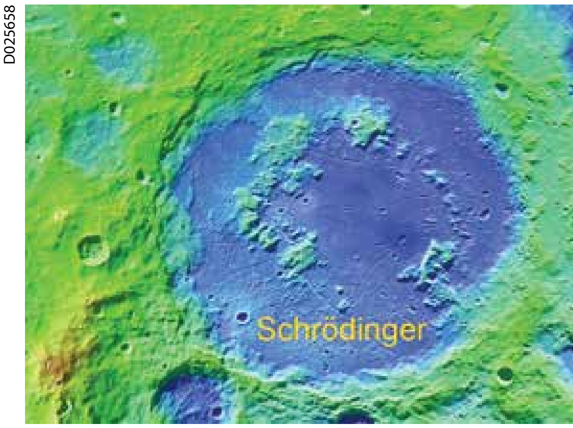
IMAGE COURTESY HELIOSPACE

D025628

Bob Grimm shows part of a conventional magnetotelluric system used for subsurface sounding on Earth.

Far Side Foray

Dr. Robert Grimm



D025658

The Lunar Interior Temperature and Materials Suite (LITMS) will land on the far side of the Moon — a NASA first — in Schrödinger basin to study the thermal evolution, differentiation and asymmetry of Earth's closest neighbor. In this topographic image, the elevation difference between blue (low) and brown (high) is over 30,000 ft. The landing site is in the upper-right portion of the basin.

IMAGE COURTESY NASA/LPI/USRA

When another round of CLPS payload opportunities was announced, LMS and LISTER teamed up from the start to respond. This time, the call was for instrument suites to go to Schrödinger Basin on the far side of the Moon, a first for NASA. The SwRI-led Lunar Interior Temperature and Materials Suite (LITMS) will study the thermal evolution, differentiation and asymmetry of Earth's closest neighbor.

The lander payload also includes the Jet Propulsion Laboratory's Farside Seismic Suite (FSS). The combination of seismology, electromagnetics, and heat flow provides a near-ideal geophysical package that could be a model for a future Lunar Geophysical Network.

The 200-mile-diameter Schrödinger Basin has an inner ring characteristic of craters this size. LITMS was able to negotiate a landing site outside of this ring, where the crust is thicker and likely more representative of the majority of the Moon. A third instrument suite, the Lunar Surface Electromagnetic Explorer (LuSEE) led by the University of California, Berkeley, will also fly on the Schrödinger mission and will cooperate closely with the SwRI-led suite. LITMS will use data from LuSEE's magnetometers, which provide greater bandwidth than the original LMS implementation. This mission is slated to launch in early 2025. The Draper Laboratory of Cambridge, Massachusetts, will provide the lander.

The hardware teams include SwRI (electronics), Heliospace Corp. (electrometer), Goddard Space Flight Center (magnetometer) and Honeybee Robotics (LISTER). Science teams span several institutions in the U.S. and the United Kingdom. Although CLPS instruments are low-cost, LMS and LITMS aim to make fundamental contributions to our understanding of the Moon.

IMAGE COURTESY GSFC/HELIOSPACE

D025618

D025619

Magnetic Mystery Mapping

Dr. Jörg-Micha Jahn

D025569_6704

SwRI's Dr. Jörg-Micha Jahn is developing a lander instrument to study the influx of solar wind and how it interacts with localized lunar magnetic fields.

SwRI scientists are developing a plasma spectrometer to study magnetic mysteries on the Moon's surface as part of NASA's Lunar Vertex lander-rover mission.

The SwRI-developed Magnetic Anomaly Particle Spectrometer (MAPS) will study the interaction of the solar wind with surface materials on the Moon, aiming to understand the origin of swirling patterns of bright and dark soil that coincide with localized swaths of magnetic fields.

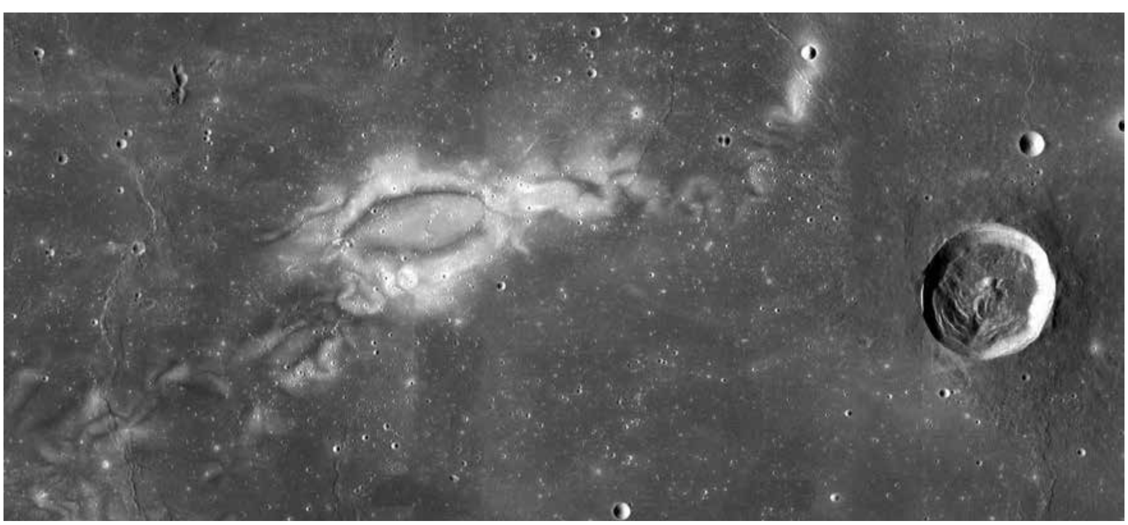
MAPS will remain on the Lunar Vertex lander to investigate how the influx of the solar wind interacts with the Moon's localized magnetic fields and how it could affect features on the lunar surface. The spectrometer will help determine how many charged particles delivered by the solar wind even make it to the surface of the Moon.

Unlike the Earth, the Moon does not have a global magnetic field that protects it from the supersonic solar wind. As these streams of energetic particles hit the lunar surface, magnetic patches bend the trajectories of the solar particles, acting like an umbrella. The Johns Hopkins University Applied Physics Laboratory (JHUAPL) is leading this investigation to Reiner Gamma, one of the most prominent local pockets of magnetized crust, to understand conditions on the Moon and other airless worlds throughout the solar system.

MAPS will gather sensitive, high-resolution insights not possible with spacecraft orbiting around the Moon. It offers more than four times higher resolution than instruments typically orbiting around Earth or the Moon, yet it weighs only eleven pounds (five kilograms) and draws less than eleven watts of power. Just as a spectrometer separates light into its constituent wavelengths, a particle spectrometer separates particles according to their energy and direction of travel. This three-dimensional "picture" of the charged particles reveals how the solar wind has been altered by the magnetic fields at Reiner Gamma.

MAPS will help scientists understand space weathering, the continuous surface erosion of objects ranging from rocky planets to moons, asteroids and comets. The space weathering process is the combined accumulation of micrometeor impacts, energetic radiation and the constant stream of particles from the solar wind.

The Lunar Vertex mission is funded through NASA's CLPS initiative.



The SwRI-led MAPS instruments will study mysterious swirls on the Moon's surface thought to be associated with localized lunar magnetic fields.

D025652

IMAGE COURTESY NASA

R&D World Magazine recognized SwRI and Hanwha Power Systems' Integrally Geared Supercritical CO_2 Compander as being among the 100 most significant innovations for 2022. The compander converts thermal energy from a heat generation source, such as CSP, to electrical energy.

D025627

Integrally Geared Supercritical CO_2 Compander Wins R&D 100 Award

An SwRI-developed technology has won a prestigious R&D 100 Award. R&D World Magazine recognized SwRI and Hanwha Power Systems' Integrally Geared Supercritical CO_2 "Compander" as being among the 100 most significant innovations for 2022.

"Southwest Research Institute is committed to exploring energy solutions that will benefit humankind," said SwRI President and CEO Adam Hamilton, P.E. "I'm very proud that this work has been recognized as one of the most important innovations of the year."

SwRI worked with Hanwha to create the compander for a 10 MW-scale concentrated solar power (CSP) supercritical carbon dioxide (sCO_2) plant application. It converts thermal energy from a heat generation source, such as CSP, to electrical energy. SwRI's Dr. Jason Wilkes and Dr. Tim Allison and Hanwha's Dr. Karl Wygant, Rob Pelton and Jon Bygrave led the development with support from the U.S. Department of Energy Office of Energy Efficiency and Renewable Efficiency.

The new compander operates in a high-efficiency power cycle that aims to make diverse, non-hydrocarbon-based power sources widely available and affordable. Closed-loop sCO_2 power cycles are more cost-effective and efficient and use equipment that is a fraction of the size of conventional turbomachinery. These cycles can utilize heat from CSP, nuclear power, stored energy and waste heat recovery to generate electricity.

Using a low-cost, low-speed driver, the compander's multiple pinion shafts interact through a single bull gear to create a compact package. In addition, the integrally geared architecture allows each pinion to operate at different rotational speeds to optimize performance and easily allow for interstage cooling and turbine reheating to enhance both stage and cycle efficiency. The close integration of all turbomachinery elements into a single integrally geared design lends itself to power-block modularization, which makes it suitable for a variety of applications such as CSP, waste heat recovery and carbon-neutral fossil fuel power plants.

The compander operates in the first functional MW-scale sCO_2-compressor-driven turbine power cycle loop, operating at temperatures up to 720 C, which has already achieved several noteworthy records for turbomachinery, including the highest-pressure sCO_2 dry-gas seal, integrally geared expander and integrally geared compressor in the world. It also features the highest-density integrally geared expander, radial expander and integrally geared compressor, as well as the highest temperature radial expander at pressures above 100 bar.

The R&D 100 Awards are among the most prestigious innovation awards programs, honoring the top 100 revolutionary technologies each year since 1963. Recipients hail from research institutions, academic and government laboratories, Fortune 500 companies and smaller organizations. Since 1971, SwRI has won 51 R&D 100 Awards.

SwRI MODELS TEXAS GROUNDWATER RESOURCES

D025614

Nearly a third of the planet's population relies on groundwater as its primary water supply. Because of global population growth and economic development, groundwater and surface water resources are coming under increasing stress in terms of quantity and quality.

"So many people in Texas rely on groundwater to meet their water needs. Sustainable groundwater management is the future of Texas water, especially with increasing demands on these resources and possible changes in climate and weather patterns expected to occur in the near future," said SwRI Research Scientist Rebecca Nunu. "To ensure viability of these resources for generations to come, we need to understand the science and communicate findings to water resource managers and policy makers."

SwRI Lead Scientist Dr. Dimitrios Stampoulis proposes modeling a fusion of hydrologic simulations and satellite observations to improve estimates of depth changes in the water table. Implementing a four-layer version of the Variable Infiltration Capacity (VIC-4L) hydrologic model across the state of Texas could improve understanding of the whole system. This innovative approach would provide a comprehensive view of water resources, which would be particularly valuable to authorities in water-stressed regions of Texas. The valuable, high-resolution data provide a more reliable estimation of fluctuations in groundwater levels, which are vital to long-term management of these resources for the future.

"SwRI is expanding its capabilities and capacity to support the objectives of sustainable groundwater management for water resource managers in Texas," Nunu said.

ASTEROID BENNU'S SHIFTY SURFACE

When NASA's OSIRIS-REx spacecraft collected samples from asteroid Bennu's surface in 2020, forces measured during the interaction provided scientists with a direct test of the poorly understood near-subsurface physical properties of rubble-pile asteroids. Now, an SwRI-led study has characterized the layer just below the asteroid's surface as composed of weakly bound rock fragments containing twice the void space as the overall asteroid.

"The low gravity of rubble-pile asteroids such as Bennu weakens its near-subsurface by not compressing the upper layers, minimizing the influence of particle cohesion," said SwRI's Dr. Kevin Walsh, lead author of a paper about this research published in the journal Science Advances. "We conclude that a low-density, weakly bound subsurface layer should be a global property of Bennu, not just localized to the contact point."

Fitting its designation as a "rubble-pile asteroid," Bennu is a spheroidal collection of rock fragments and debris 1,700 feet in diameter and held together by gravity. It is thought to have been formed after a collision involving a larger main-asteroid-belt object. Rocks are scattered across its heavily cratered surface, indicating that it has had a rough-and-tumble existence since being liberated from its much larger parent asteroid some millions or billions of years ago.

Before, during and after the sampling event, the Sample Acquisition Verification Camera (SamCam) of the OSIRIS-REx Camera Suite captured images looking at the Touch-and-Go Sample Acquisition Mechanism (TAGSAM) robotic arm.

These SamCam images showed the downward force as TAGSAM lifted a nearly 16-inch rock. Though strong enough to withstand breaking, the rock was re-oriented and small debris lofted off its surface. The mobility of these millimeter-scale particles under relatively weak forces suggests minimal cohesive bonding with the surface of the larger rock.

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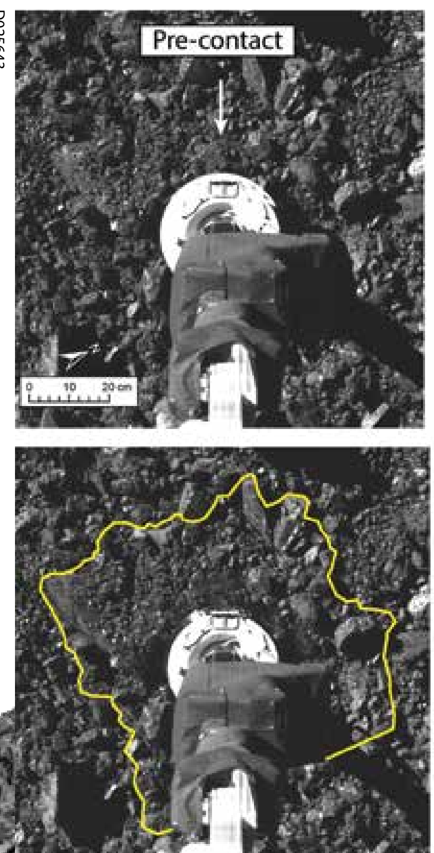


IMAGE COURTESY NASA/GODDARD/UNIVERSITY OF ARIZONA

SwRI Demonstrates Novel Energy Storage System

SwRI has completed assembly and commissioning of the first-of-its-kind pumped thermal energy storage (PTES) demonstration facility. Long-duration, large-scale storage capabilities, like PTES, can help balance energy volatility and reliability issues allowing high market penetration of variable renewable energy resources such as solar and wind energy, creating solutions to help fulfill worldwide carbon reduction goals.

"One of the big problems that we face with renewable energy is balancing supply and demand," said SwRI Group Leader Dr. Natalie Smith, the project's lead investigator. "As the Sun goes down in the evening, many people are returning home from work, turning on lights and using other electronics. This mismatch between high power demand and solar availability creates grid volatility. We want new technologies to store solar and wind power so that it can be used when the Sun isn't shining and the wind isn't blowing."

A PTES system stores energy thermally in hot and cold tanks for later use. When excess wind or solar energy is being produced, the PTES runs a heat pump to make the hot storage tank hotter and the cold storage tank colder. Then, when energy demands exceed production, PTES runs as a heat engine converting the large temperature difference between the hot and cold stored energy into electricity.

"The full-scale PTES system offers high potential system performance up to 60% round-trip efficiency and can store energy for more than 10 hours," Smith said. "PTES is a promising, versatile technology that can be applied to many different energy sources without geological or geographical restrictions."

Under Department of Energy funding, SwRI developed a small-scale PTES demonstration system in collaboration with Malta Inc. that uses simple recuperated cycles for both modes of operation with air as the main working fluid. The facility design is similar in basic architecture and operation to full-scale technology and is intended to demonstrate system operability and controls strategies. Malta is developing a full-scale commercial system.

D025646

IMAGE COURTESY NASA / JOHNS HOPKINS APL / SwRI

Identifying the Source of Charon's Red Cap

SwRI scientists combined data from NASA's New Horizons mission with novel laboratory experiments and exospheric modeling to reveal the likely composition of the red cap on Pluto's moon Charon and how it may have formed. This first-ever description of Charon's dynamic methane atmosphere, its cold trapping and concurrent photodecomposition provide a fascinating glimpse into the origins of the moon's red spot.

Soon after the 2015 encounter, New Horizons scientists proposed that a reddish "tholin-like" material at Charon's pole could be synthesized by ultraviolet light breaking down methane molecules. These are captured after escaping from Pluto and then frozen onto the moon's polar regions during its long winter nights. Tholins are sticky organic residues formed by chemical reactions induced by light, in this case the Lyman-alpha glow scattered by interplanetary hydrogen atoms.

The team realistically replicated Charon's surface conditions at SwRI's new Center for Laboratory Astrophysics and Space Science Experiments (CLASSE) to measure the composition and color of hydrocarbons produced on Charon's winter hemisphere as methane freezes beneath the Lyman-alpha glow. A team led by SwRI's Dr. Benjamin Teolis fed the measurements into a new atmospheric model of Charon to show methane accruing, breaking down and forming more complex hydrocarbons on Charon's polar zone.

"Our findings indicate that drastic seasonal surges in Charon's thin atmosphere as well as light breaking down the condensing methane frost are key to understanding the origins of Charon's red polar zone," said SwRI's Dr. Ujjwal Raut, lead author of a paper titled "Charon's Refractory Factory" in the journal Science Advances. However, Charon's color mystery remains as the model has polar zones primarily generating ethane, a colorless material.

"The solar wind may further process the Lyman-alpha-cooked polar frost to synthesize increasingly complex, redder materials responsible for the unique albedo on this enigmatic moon," Raut said.

AUTOMATING AEROSPACE SURFACE PREP

SwRI is introducing new automation technology that allows industrial robots to visually classify work and autonomously perform tasks.

Using this new technology, robots autonomously sand and prepare surfaces on aircraft and other machinery. The automation tool can be applied to grinding, painting, polishing, cleaning, welding, sealing and other industrial processes such as paint or coating removal or application.

"Our solutions increase process repeatability while improving part quality and decreasing rework," said Matt Robinson, a robotics manager at SwRI. "They also reduce human exposure to dangerous environments."

The system uses SwRI-developed machine learning algorithms and classification software that work in conjunction with open-source tools such as Scan-N-Plan™ and ROS 2, the latest version of an open-source robot operating system. Traditional robot programming can be slow and tedious.

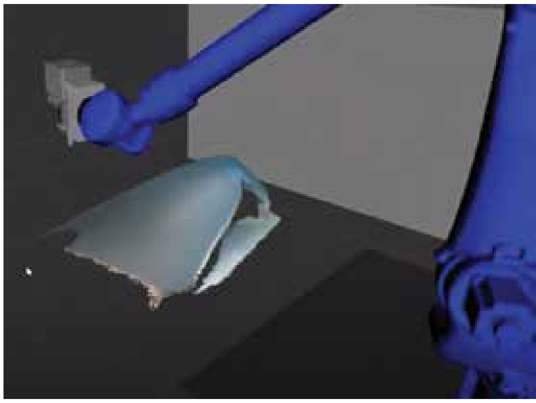
Scan-N-Plan, a ROS-Industrial technology, uses machine vision to scan parts, creating 3D mesh data that robots use to plan tool paths and process trajectories while performing real-time process monitoring. SwRI works closely with the ROS-I project to maintain its software repository and expand open-source automation solutions.

"By leveraging these open-source tools with our custom software, we have developed a solution that intelligently classifies regions and textures of part surfaces in various stages of work," Robinson said.

The solution includes custom machine vision algorithms that enable robots to apply various media with varying pressure based on the amount of surface work needed. Feature-based processing is also enabled through additions that leverage semantic segmentation approaches to apply the right tool to the right feature, cutting versus sanding for instance.

"These are breakthroughs that will help prevent robots from over-sanding or over-grinding metal surfaces," said Paul Evans, director of SwRI's Manufacturing Technologies Department. "It is exciting to leverage the open-source community with our custom robotics engineering."

In this image, a robotic arm uses a 3D camera and machine vision software to scan and dynamically reconstruct contoured surfaces on aircraft parts. The robot uses 3D data to plan trajectories for surface preparation with sanders, grinders and other power tools.



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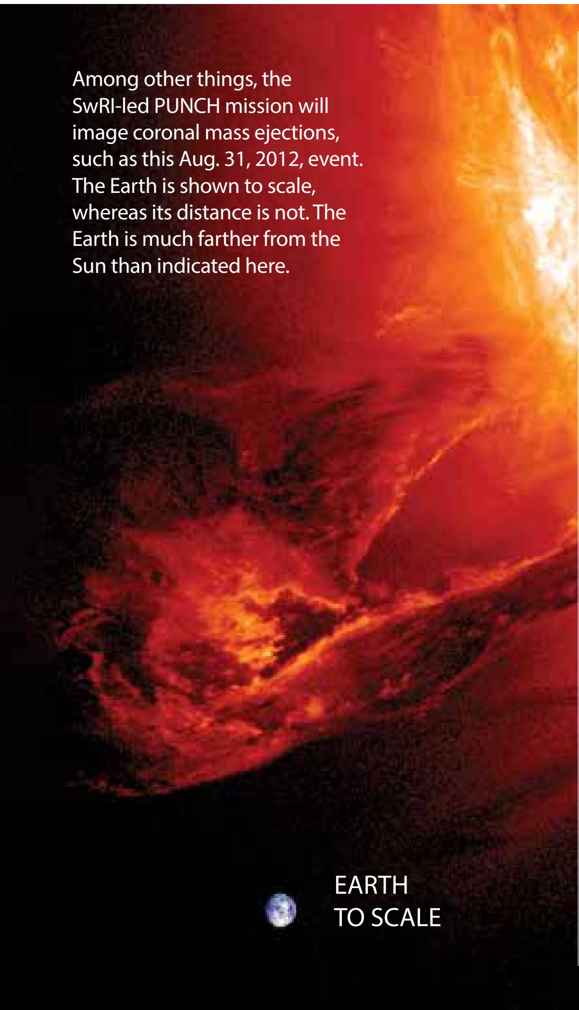


Among other things, the SwRI-led PUNCH mission will image coronal mass ejections, such as this Aug. 31, 2012, event. The Earth is shown to scale, whereas its distance is not. The Earth is much farther from the Sun than indicated here.

IMAGE COURTESY NASA GODDARD SPACE FLIGHT CENTER

D025648

PUNCH Launch Preparations

More than 60 engineers and scientists gathered at SwRI in August to kick off the launch vehicle collaboration for NASA's Polarimeter to Unify the Corona and Heliosphere (PUNCH) mission. PUNCH, which will study the inception of the solar wind, has secured its ride into Earth orbit aboard a SpaceX Falcon 9 rocket, sharing a ride into space with NASA's Spectro-Photometer for the History of the Universe, Epoch of Re-ionization, and Ices Explorer (SPHEREx) mission.

PUNCH consists of four suitcase-sized satellites designed to study the Sun's outer atmosphere, the corona, and how it generates the solar wind. This continuous supersonic stream of charged particles fills the solar system, forming the bubble-like region of space known as our heliosphere. The spacecraft will also track coronal mass ejections — large eruptions of solar material that can drive significant space weather events near Earth — to better understand their evolution and develop new techniques for predicting such eruptions.

"It's great to have a definite launch date and vehicle, and we're looking forward to working with the SPHEREx team as we 'carpool' to orbit," said Craig DeForest, PUNCH principal investigator at Southwest Research Institute. "Rideshares are a great way to save money by taking advantage of each rocket's capability."

The PUNCH team can now finalize its schedule to meet the new launch date of no earlier than April 2025. This extended schedule will also mitigate post-pandemic supply chain challenges.

Following launch, the PUNCH satellites will spread out around Earth along the day-night line to create a continuous, complete view of the Sun's corona and the inner solar system. Three of the PUNCH satellites will carry identical Wide Field Imagers, which cover a significant portion of the sky around the Sun. The fourth PUNCH satellite carries a Narrow Field Imager coronagraph, which will study regions closest to the Sun.

Studying Oxidation in sCO_2 Environments

SwRI and Sandia National Laboratories collaborated to examine the differences in oxide film growth on additively manufactured (AM) metals and wrought stainless steel in a supercritical carbon dioxide (sCO_2) environment. More research is needed, but initial experiments showed the AM materials performed better, experiencing less oxidation than the wrought metal.

Most thermal power stations currently use water as a thermal medium in steam turbines, but supercritical fluids are attractive alternatives. Carbon dioxide becomes supercritical when held above a critical temperature and pressure, which causes it to exhibit the properties of both gas and liquid. SwRI's Machinery Department is a worldwide leader in developing new power cycles that replace water with sCO_2 to increase efficiency by upwards of 10 percent, while requiring smaller equipment and supporting decarbonization.

"The high temperatures and pressures of the sCO_2 environment can make oxidation a concern for metal components," said SwRI Senior Research Engineer Dr. Florent Bocher.

Additive manufacturing uses 3D printing or rapid prototyping technology to build an item by layering plastic, metal and other materials following a computer-generated design. Because AM can create sturdy components with complex geometries, it is an attractive option to improve machinery, such as turbine blades or heat exchangers.

The team tested the durability of AM metals and traditional wrought stainless steel, exposing samples to a simulated sCO_2 power cycle environment at 450 degrees Celsius and 76 bar, for two weeks. Sandia built and analyzed the AM materials.

While both types of metals experienced oxide growth, 72% of the wrought stainless steel surface oxidized compared to 54% of the AM material. The grain size and thickness of the oxide layer was also statistically larger and thicker for the wrought material. This research suggests that optimizing AM processes to create more durable articles for sCO_2 applications should be explored.

SwRI simulated sCO_2 conditions to evaluate the corrosion performance of these stainless steel samples produced by Sandia National Laboratories using additive manufacturing techniques.

D025659

D025635

IMAGE COURTESY SANDIA NATIONAL LABORATORIES

NEW EVIDENCE FOR HABITABILITY IN ENCELADUS'S OCEAN

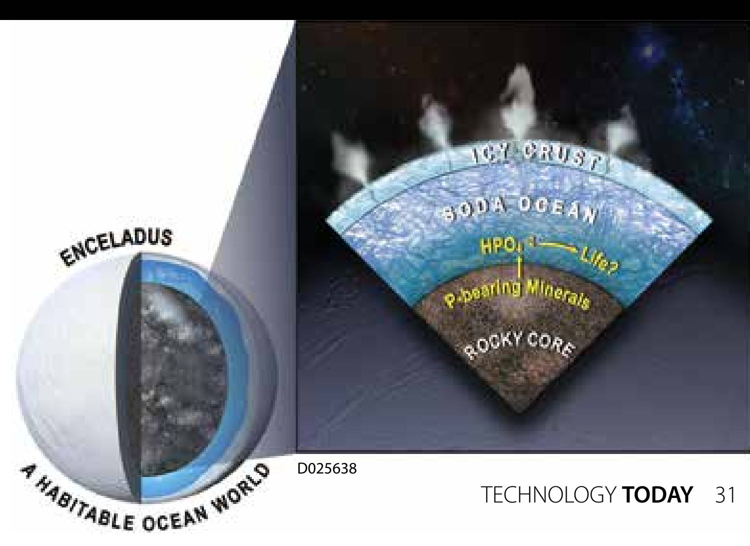
The search for extraterrestrial life just got more interesting as a team of scientists including SwRI's Dr. Christopher Glein discovered new evidence for a key building block for life in the subsurface ocean of Saturn's moon Enceladus. New modeling indicates that Enceladus's ocean should be relatively rich in dissolved phosphorus, an essential ingredient for life.

The Cassini spacecraft discovered Enceladus's subsurface liquid water and analyzed samples as plumes of ice grains and water vapor erupted into space from cracks in the moon's icy surface.

"What we have learned is that the plume contains almost all the basic requirements of life as we know it," Glein said. "While the bioessential element phosphorus has yet to be identified directly, our team discovered evidence for its availability in the ocean beneath the moon's icy crust."

Phosphorus in the form of phosphates is vital for all life on Earth. It is essential for the creation of DNA and RNA, energy-carrying molecules, cell membranes, bones and teeth in people and animals, and even the sea's microbiome of plankton. Team members performed thermodynamic and kinetic modeling that simulates the geochemistry of phosphorus based on insights from Cassini about the ocean-seafloor system on Enceladus.

"The underlying geochemistry has an elegant simplicity that makes the presence of dissolved phosphorus inevitable, reaching levels close to or even higher than those in modern Earth seawater," Glein said. "What this means for astrobiology is that we can be more confident than before that the ocean of Enceladus is habitable. Now we need to get back to Enceladus to see if a habitable ocean is actually inhabited."



D025638

UPCOMING

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

Thermal Stress Analysis: Balancing Vibration, Thermal Growth, and Flange Loads, October 26, 2022. Free virtual webinar.

Gas Turbine & Compressors, November 14, 2022, San Antonio. Short course.

Launch Vehicle Propulsion, March 1, 2023. Virtual training course.

Introduction to Microencapsulation, March 27, 2023. Workshop.

Oil & Gas Machinery Lecture Series: Emissions Reduction, April 18, 2023. Short course.

Pulsations & Vibrations: Analysis and Testing, April 19, 2023. Training course.

NPSS Annual Training, May 1, 2023. Training course.

CONFERENCES/MEETINGS:

Opportunity Crudes Conference, Houston, October 24, 2022.

Weapons and Tactics Conference (WEPTAC), Tucson, AZ, October 24, 2022, Booth No. B25.

Automotive Testing Expo, Novi, MI, October 25, 2022, Booth No. 3046.

ASNT Annual Conference, Nashville, October 31, 2022. Booth No. 1219.

SupplySide West, Las Vegas, November 2, 2022, Booth No. 2919.

AAAA Cribbins Army Aviation Readiness Conference, Huntsville, AL, November 14, 2022, Booth No. 401.

Advanced Materials for Defense Summit, Alexandria, VA, November 16, 2022.

Aircraft Structural Integrity Program (ASIP) Conference, Phoenix, November 28, 2022, Booth No. 15.

Defense Manufacturing Conference (DMC), Tampa, FL, December 13, 2022.

Feedwater and Secondary Systems Reliability Users Group (FSRUG) Conference, San Antonio, January 16, 2023.

Conference on Composites, Materials, and Structures, St. Augustine, FL, January 23, 2023, Booth No. 7.

Waste Management Symposia, Phoenix, February 26, 2023, Booth No. 623.

AIChE Spring Meeting & Global Congress on Process Safety, Houston, March 12, 2023.


D025624

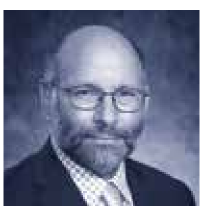
Dr. William Bottke, director of Southwest Research Institute's Department of Space Studies, has been named a Fellow of the American Geophysical Union (AGU). Bottke specializes in planet formation studies and the origin and evolution of small-body populations throughout the solar system. He also studies how asteroids and comets have bombarded the Earth, the Moon and other worlds throughout their histories, among other topics.


D025487

James L. Burch, vice president of the Space Science and Engineering Division, will become Senior Vice President leading SwRI's new Space Sector organization. Space Science and Engineering, with 465 employees in three states, has been restructured to add two new technical divisions, all within the Space Sector. He will lead the Space Science Division.


D022449

Dr. Robin Canup has been named vice president leading SwRI's new Solar System Science Division, based in Boulder, Colorado. The division will focus on planetary physics, atmospheres and surfaces as well as solar physics and lunar studies. The division will also address related research in solar system dynamics, astronomy, computer systems, and space and mission operations.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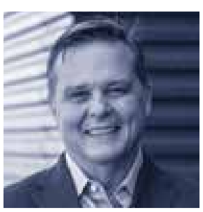
Dr. Stephen Fuselier, executive director of the Space Science Directorate at Southwest Research Institute, has been named co-chair of the National Academies Solar and Space Physics Decadal Survey. The Decadal Survey is an independent activity undertaken by the National Academies to describe the highest priority science goals, develop a comprehensive ranked research strategy for the 2024–2033 timeframe and assess the state of the profession.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Michael McLelland has been named vice president and will lead SwRI's new Space Systems Division, located at the Institute's headquarters in San Antonio. The division will focus on developing next-generation space observation missions and enabling technology to support fundamental space science research, national security and commercial applications. A new, state-of-the-art, 74,000-square-foot facility will house the new division.


D025547_6066

Dr. Joe McDonough has been named vice president of SwRI's Chemistry and Chemical Engineering Division. The division is one of the oldest, continuous technical disciplines at SwRI since it was founded in 1947. He will oversee a staff of more than 200, working in five research departments: Analytical and Environmental Chemistry, Chemical Engineering, Fire Technology, Geosciences and Engineering, and Pharmaceuticals and Bioengineering.

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TECHNOLOGY **TODAY**

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Technology Today® (ISSN 1528-431X) is published three times each year and distributed free of charge. The publication discusses some of the more than 4,000 research and development projects under way at SwRI.

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Southwest Research Institute's staff of more than 2,700 employees provides client services in the areas of communication systems, modeling and simulation, software development, electronic design, vehicle and engine systems, automotive fuels and lubricants, avionics, geosciences, polymer and materials engineering, mechanical design, chemical analyses, environmental sciences, space science, training systems, industrial engineering and more.

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